We thank the reviewer for the helpful comments which we think have helped to improve the manuscript significantly. Especially, by removing the grammatical errors and misleading statements the revised manuscript will be easier to understand for the reader. The detailed replies on the reviewer comments are given below and structured as follows. Reviewer comments have bold letters, are labeled with the page number and line from the discussion paper, and are listed always in the beginning of each answer. The reviewer comments are followed by the author's comments with an explanation if necessary and revised parts of the paper. The revised parts of the paper are written in quotation marks and italic letters.

Sequential comments:

P1423, L4: The quoted reference, Bennartz et al. (2013) is a poor choice for substantiating the statement that clouds play a major role in projections of the future Arctic climate because it is observations-based and do not include climate model runs in any way.

➔ The reviewer is right. Bennartz et al. (2013) only state that clouds may play a major role in projections of the future Arctic climate, but not prove this by climate model runs. Therefore, we exchanged the reference Vavrus (2004), what is more suited for the given statement.

"Among others, Vavrus (2004) identified clouds as a major source of uncertainty in model predictions of the future Arctic climate."

L11: "In this regard, surface albedo: : :" since this follows after statement about the dominating influence of IR, one should perhaps clarify that this is for the solar wavelength range again - how about "For the solar wavelength range, surface albedo: : :"

➔ We agree that the wording in the original manuscript might confuse the reader. We adopted your suggestion and revised the section by:

"Depending on the time of year and their altitude, Arctic clouds may exert either a net warming or cooling effect. However, the low Sun in summer combined with a usually high surface albedo lead to a dominance of the terrestrial (infrared) radiative warming of low clouds (Intrieri et al., 2002b; Wendisch et al., 2013). For the solar wavelength range, surface albedo (sea ice coverage) is a major parameter determining whether a change of cloud amount in future climate is associated with a warming or cooling effect."

L14: ": : :Arctic stratus is nearly homogeneous: : :" This is an unsubstantiated claim if no reference is provided. Also, "from a microphysical point of view" is ambiguous. Does this mean in terms of droplet radius, thermodynamic phase, LWC/IWC? Wouldn't stratus be homogeneous in the macroscopic rather than microphysical sense?

➔ Thanks for pointing at this not properly discussed section. We now include references and clarified it more in detail, which parameters are described as homogeneous.

"While Arctic stratus often shows a horizontally homogeneous structure, both in macropyhsical (cloud base and top altitude) and microphysical properties, sea ice is often characterized by a

more heterogeneous horizontal distribution. Tsay and Jayaweera (1984) showed that Arctic stratus has a considerable horizontal homogeneity of cloud morphology, droplet diameter, concentration, and liquid water content, except for the cloud top layer. Here, mixing results in small-scale inhomogeneities identified by Lawson et al. (2001) and Klingebiel et al. (2015): bi-modal cloud particle size distributions at cloud top, while mono-modal distributions dominate the lower cloud layers representative for the adiabatic and homogeneous character of the clouds. In contrast, sea ice has irregular top and bottom surfaces and is broken into distinct pieces, called floes (Rothrock and Thorndike, 1984). …"

P1424, L4: Krijer et al. (2011) cannot be used to support the statement that "retrievals of Arctic cloud properties over bright surfaces [is] impossible". In fact, the opposite is true: Krijer et al. do state that with visible channels alone, this is not possible, but in their paper, they specifically mention that they overcome this limitation by introducing near-infrared channel(s) from SCIAMACHY.

➔ We totally agree with the reviewer. This is changed in the revised version. In particular, based on the comments by the reviewers, it is clear that we overemphasized the difficulties of cloud retrievals over bright surfaces and were wrong with the statement that cloud retrievals are not possible over ice surfaces. The reason for our misleading statement was that we focused only on the measurements with the imaging spectrometer AisaEAGLE, which covers only wavelength in the range from 400 nm to 1000 nm. For this spectral range, cloud retrievals over ice surfaces in fact are not possible without additional information (as it is stated by Krijger et al., 2011). But of course it has to be mentioned that this is only valid for the visible wavelength range and can be overcome by introducing near-infrared wavelength channels. We thank the reviewer for highlighting this lack of information, which necessarily must confuse the reader. We revised the relevant parts in the manuscript (also with respect to your later comments on MODIS) and introduced a series of new references including Platnick et al. (2001, 2004), Platnick and King (2003), and Krijger et al. (2011).

> *"A highly variable Arctic surface albedo as observed during the VERDI campaign complicates the cloud retrieval introduced by Bierwirth et al. (2013). In fact, retrievals of cloud microphysical and optical properties using only visible wavelengths are strongly biased by a bright surface (Platnick et al., 2001, 2004; Platnick and King, 2003; Krijger et al., 2011). To overcome this limitation, near-infrared channels are introduced in the retrieval algorithms instead of the visible channel used over dark surfaces. E.g., for MODIS the 1.6 µm band reflectance is applied as a surrogate for the traditional non-absorbing band in conjunction with a stronger absorbing 2.1 or 3.7 µm band (Platnick et al., 2001, 2004; Platnick and King, 2003). However, an accurate separation between sea ice and open water needs to be performed before the retrieval algorithms are applied. Operational algorithms such as that for MODIS use NOAA's (**N**ational **O**ceanic and **A**tmospheric **A**dministration) microwave-derived daily 0.25° **N**ear Real-Time **I**ce and **S**now **E**xtent (NISE) dataset (Armstrong and Brodzik, 2001; Platnick and King, 2003) to identify snow- or ice-covered scenes."*

P1425, L16-L17: "Variations: : :will characterize: : :" unclear wording. Is the intention to say that changes in cloud altitude etc. will affect the transition? Or is the intention to describe what will be done in the paper?

➔ The wording in fact was unclear. We changed the relevant part to the following:

> *"Variations in cloud altitude, cloud geometrical thickness, r_{eff}, and surface albedo are investigated to characterize how strong these parameters influence the magnitude and distance of the γ_λ transition from high to low values."*

P1426: This is an insufficient description of the instruments; while references can be used to "outsource" specific information, each paper needs to stand on its own, and at least the information that are crucial for understanding this paper need to be provided - for example the accuracy etc. of the instrumentation. For example, a google search reveals that AisaEAGLE covers wavelengths up to 1000 nm only - but later on in the paper, near-infrared wavelengths are used for applying the retrieval method by Werner et al. (2013).

➔ Thanks for showing that crucial information were missing. In the revised version we included those missing information (measured quantity, wavelength range, spectral resolution) to the description of the single instruments, which were used in this study. In order to do so, we decided to revise the order of paragraphs in this chapter as well to concentrate the instrument description to one section.

"The aircraft was equipped with an active and several passive remote-sensing systems. The active system was the Airborne Mobile Aerosol Lidar (AMALi; Stachlewska et al., 2010). It was operated in nadir viewing direction at 532 nm wavelength. Passive radiation measurements were carried out with the imaging spectrometer AisaEAGLE (manufactured by Specim Ltd. in Oulu, Finland; Schäfer et al., 2013). To analyze the 3-D radiative effects of ice edges in a cloudy atmosphere, we focus on measurements by this instrument. With 1024 spatial pixels, the single-line sensor provides a sufficiently high horizontal resolution to observe ice edges in detail. The flight altitude during the remote sensing legs was about 3 km above ground which is about 2 km above cloud top for typical boundary layer clouds with cloud top altitudes at about 1 km. For this geometry, the width of one AisaEAGLE pixel at cloud top is 3.5 m and the length is 4.2 m at an exposure time of 10 ms and a flight speed of 65 ms^{-1}. Each spatial pixel consists of 488 spectral pixels to detect spectra of radiance in the wavelength range from 400 to 970 nm with 1.25 nm full width at half maximum (FWHM). AisaEAGLE converts the detected photon counts into digitalized 12-bit numbers. By applying a spectral radiometric calibration, those numbers are transformed into radiances. The calibration, data handling, and necessary corrections are described by Schäfer et al. (2013). For radiance measurements, Schäfer et al. (2013) estimated an uncertainty of ±6 %. Assuming a fixed r_{eff}, those detected spectra of radiance can then be used to retrieve τ.
Further passive radiation measurements were carried out with the Spectral Modular Airborne Radiation measurement system (SMART-Albedometer; Wendisch et al., 2001), initially designed for albedo measurements, and a Sun tracking photometer. The SMART-Albedometer is horizontally stabilized and measures up-/downwelling spectral radiance I_λ and irradiance F_λ (λ = 350 – 2100 nm, 2-16 nm FWHM), while the Sun photometer covers aerosol optical thickness between λ = 367 – 1026 nm. The configuration was similar to that during the aircraft campaign SoRPIC described by Bierwirth et al. (2013). Additionally, dropsondes were used at selected waypoints to sample profiles of meteorological parameters (air pressure, air temperature, relative humidity) over the whole distance between the ground and the aircraft. For a more detailed description of the airborne instruments installed on Polar 5, see Bierwirth et al. (2013), Klingebiel et al. (2015) and Wendisch and Brenguier (2013).
In this study, the data from the AMALi and the dropsondes were used to determine the cloud-top altitude and geometrical thickness, whereas the data from the SMART-Albedometer were used to verify and validate the $I_\lambda^\uparrow$ measurements of AisaEAGLE. Furthermore, the SMART-Albedometer measurements of the downwelling irradiance $F_\lambda^\downarrow$ are used to transform the AisaEAGLE radiance $I_\lambda^\uparrow$ into the nadir reflectivity γ_λ, which is derived by: …"

➔ This comment by the reviewer may have evolved from a misunderstanding due to an insufficient introduction of this section. The reviewer is right that AisaEAGLE only covers the visible wavelength range of up to almost 1000 nm. However, in Section 5 no measurements were applied at all. The whole study is based on radiative transfer simulations as our measurements do not cover the wavelength needed to apply the retrieval method by Werner et al. (2013). We still have done this study as outlook with regard to future studies, when a near-infrared imaging

spectrometer (AisaHAWK, 1000-2500 nm wavelength) might be available. Intelligible, this is a legitimate question, since this information was not included in the manuscript yet. We have revised the manuscript and added a few more words at the point in the manuscript where we introduce the retrieval method by Werner et al. (2013).

> *"To quantify the magnitude of this overestimation, a synthetic cloud retrieval is investigated. The retrieval is based on simulations only in order to investigate also the uncertainties of retrieved r_{eff}, which cannot be derived from the current setup of AisaEAGLE measurements during VERDI. The limitation of AisaEAGLE to visible wavelengths restricts the retrieval to τ (Bierwirth et al., 2013). However, near-infrared measurements might be available by use of additional imaging spectrometers such as the AisaHAWK. Therefore, this study addresses both quantities τ and r_{eff}. To do so, the retrieval based on forward simulations is applied to the $γ_λ$ field of a 3-D simulation where the cloud optical properties are known exactly."*

Figure 1: What do the labels (1) and (2) mean (probably open ocean vs. ice, but it needs to be stated).

➔ Your assumption on label (1) and (2) is correct. We revised Figure 1 caption to more clearly point out the meaning of the labels.

> *"**Figure 1.** VERDI flight track and true-colour MODIS image (Aqua; 250m resolution) from 17 May 2012. Numbers (1) and (2) label open ocean and sea ice, respectively."*

Figure 2: The authors may consider showing reflectance rather than radiance because the effects of SZA would then be removed, and the effect of optical thickness/surface albedo be isolated.

➔ Thanks for this helpful suggestion which we did follow in the revised manuscript. To do so, we transformed all radiance values appearing in the manuscript into reflectivities and introduced the definition.

$γ_λ = π \cdot I_{Up} / F_{down}$

For the calculation we used measured downwelling irradiance from the collocated SMART-Albedometer. For the transformation of the simulated radiance we additionally used simulated values for the downwelling irradiance.

To avoid any confusion by making use of the word reflectivity instead of reflectance (like it is used in your review), we like to justify our choice of "reflectivity". In our view all quantities with suffix "-ance" are radiometric quantities and have a dimension of, e.g., radiance (W m^{-2} sr^{-1}) or irradiance (W m^{-2}). Quantities which are the ratio of two radiometric quantities are dimensionless and own the suffix "..ivity" like transmissivity, emissivity. Contrarily, transmittance and emittance have the unit (W m^{-2} sr^{-1}). This nomenclature follows the discussion by Bohren and Clothiaux (2006). Following your suggestion, we revised all figures (Fig. 2, 3, 4, 5, 6, 7, 8, 12, 13, 14 following the numbering of the old manuscript) that showed measurements or simulations of the radiance. The use of the reflectivity clearly improved the interpretation of the graphs. As an example, the revised Figure 2 (see below Reply-Fig. 1) is shown here.
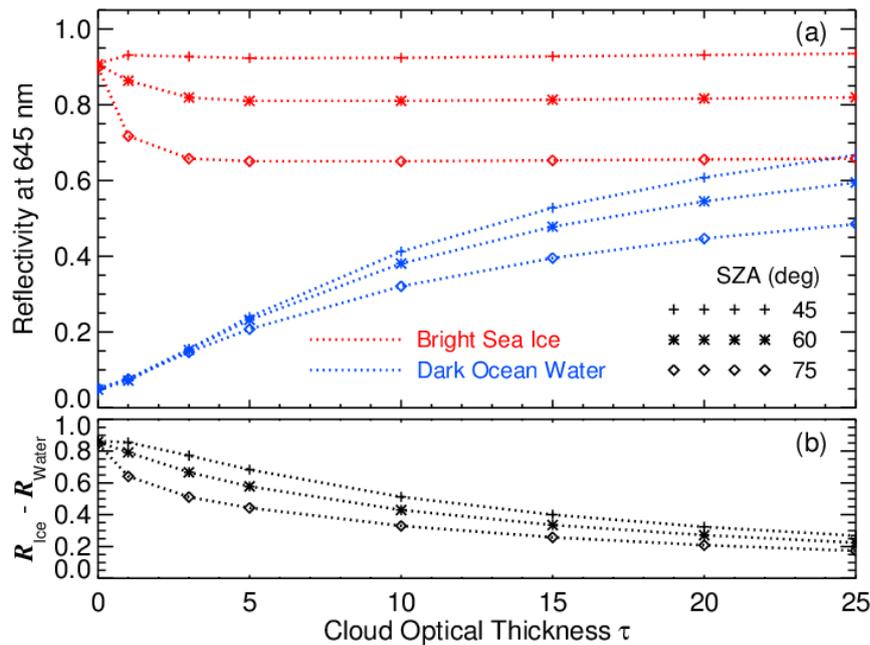
Reply-Figure 1: Revised Fig. 2.

Using the reflectivity instead of the radiance, the single simulations for different solar zenith angles (Θ) are much better separated from each other than before. However, the dependency on the Θ is not fully eliminated, what results from the non-lambertian scattering at cloud particles and the surface. Therefore, we keep the simulations for different Θ in this Figure.

P1427, L23: Unclear what this statement means. In fact, MODIS uses 860 nm, not 650 nm, for cloud retrievals over open ocean; 650 nm is used over land (when snow-free). MODIS retrievals over land (sea) ice and snow are a different story (see comment below).

➔ It is correct that MODIS retrieval over water uses the wavelength λ = 860 nm and not λ = 645 nm like we have done. However, our introduction into this section was quite misleading when we used a MODIS image to discuss the limitations of the Eagle measurements. Therefore, we revised the first part of this section to avoid any confusion. We also kept the choice of 645 nm as it was not our intention to relate the simulations to MODIS retrievals but to introduce a simple method to differentiate between ice and open water using the AisaEAGLE sensor. However, the statement at this point is not related to MODIS. In fact, we want to explain that we used the wavelength of λ = 645 nm because of its sensitivity to the cloud optical thickness. In addition, the use of the citation of Nakajima and King (1990) might be confusing, since they have used λ = 745 nm as their non-absorbing retrieval wavelength. We have revised this part and replaced the citation of Nakajima and King (1990) by Werner et al. (2013), who used the wavelength λ = 645 nm.

"The γ_λ presented in this paper are calculated at a wavelength of λ = 645 nm, where scattering is dominant and shows a strong sensitivity to τ (Werner et al., 2013)."

P1427, L18-19; P1428,L1-2: Statements of this kind are all over this manuscript and need to be carefully removed everywhere because the retrieval of cloud microphysics is, in fact, possible, and is done operationally by MODIS. Rather than Nakajima-King, it is based on near-infrared bands (1.6 and 2.1 microns) where snow is dark. This is discussed by King et al. (2004), among a few other papers. Why this is not mentioned anywhere in the manuscript is unclear. It appears that the authors are unaware of it, which seems impossible given the publication and research record of this group. Have they checked whether MODIS retrievals are, in fact, available, in addition to just looking at RGB images (Figure 1)? Attached as a supplement is a description of MODIS products, which demonstrates that MODIS does have skill to provide retrievals over snow and ice. Many more documents are publicly available. The question is what direction the manuscript would have taken, had the authors known of the existence of the MODIS algorithm. Since section 5 only refers to retrievals over the dark ocean in the vicinity of ice floes, but not over snow/ice itself, this paper is actually pertinent to the "classical" MODIS retrieval above dark surfaces. Back to the statement "A retrieval of cloud : : : properties : : : is not possible." and others of this kind: Please remove because they are incorrect.

➔ As mentioned above, the reviewer is absolutely correct with this criticism. Unfortunately we did overemphasis to motivate our study using the MODIS retrieval and did not refer to the current version of MODIS retrievals over sea ice. However, we think that our study on the 3D-effects does not necessarily needs to be motivated with satellite retrieval but is worthwhile to be presented as it is without strong link to satellite observations. Therefore, we carefully revised the whole manuscript for statements of this kind and clarified that cloud retrievals, in fact, are possible over ice surface. Only if sensors like the AisaEAGLE are used alone which do only cover visible wavelength, cloud retrieval are almost impossible over sea ice. Additionally to the before mentioned changes, the revised parts are the following:

"However, for 86 % of the cloud observations a cloud retrieval as described by Bierwirth et al. (2013) could not be applied as the surface albedo did not fulfill the constraint of being relatively dark. Either snow-covered ice almost eliminated the contrast between cloud and surface, or a mixture of ice and open water made a cloud retrieval following the strategy from Bierwirth et al. (2013) impossible."

"Using only the visible wavelength channels of the image, no visible contrast between sea ice and cloud remains. This is why near-infrared channels are applied in MODIS cloud retrievals over sea ice. However, with AisaEAGLE the observations are limited to wavelength below 1000 nm, where the contrast is weak (compare Fig. 4) and a retrieval of τ is not possible in those areas; it can only be performed above water surfaces.."

"Using those methods to estimate the threshold, ice masks were created to identify measurements of clouds above sea ice for which the cloud retrieval by Bierwirth et al. (2013) cannot be applied."

P1428, L24: "We estimate the cloud optical thickness: : :" What does this mean? Did the authors look at the level-2 MODIS products and got the number from there? Or did they visually estimate 5 from the RGB image? Why estimate if a retrieval is, in fact, available? Also, why did the authors not do their own retrieval of tau and reff, based on data from the instrumentation?

➔ We understand the confusion of the reviewer. "Estimate" is indeed a misleading word. We had a look at the closest level-2 MODIS product for cloud optical thickness (see Reply-Fig. 2). In the area of interest (red circle), the image shows values from 0 to 10 in cloud optical thickness. From this point of view we decided to use an areal average of the observation area which leads to a cloud optical thickness of 5. To point that out more clearly, we changes the sentence to:

> "τ was obtained from AisaEAGLE measurements above open water far from any ice edge using the retrieval method presented by Bierwirth et al. (2013). An average value of τ = 5.3 ± 0.5 was derived, which agrees with the MODIS level-2 product showing values for τ between 0.02 and 15.5 (τ = 3.6 ± 2.5) in the investigated area."
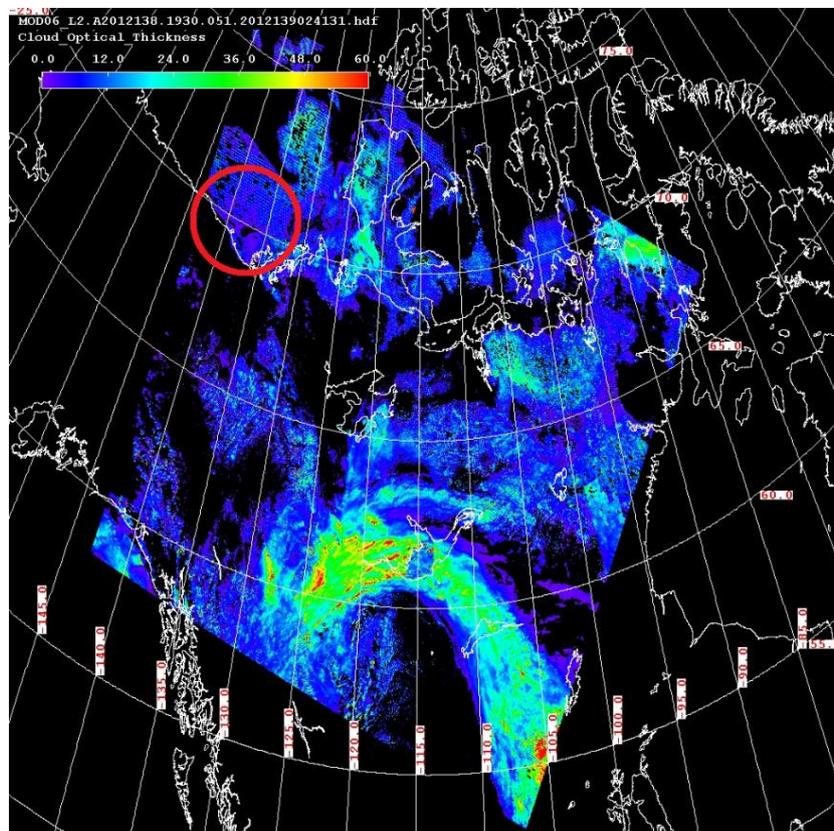
Reply-Figure 2: Level-2 MODIS product. Cloud optical thickness.

P1430, L20: One cannot see the effect of enhanced reflected radiance close to the sea ice from Figure 4b and d (mask results); better use Figure 6, which shows quantitative radiances.

➔ We agree, that the effect of enhanced reflected radiance close to the sea-ice edges was difficult to identify from Figure 4b and d. Therefore, we revised this Figure (see below Reply-Fig. 3) and color-coded the images. Due to the use of reflectivities instead of radiances, the span between extreme values became closer, which supports the use of the same legend for each image. The enhancement in the narrow bright bands around the sea-ice edges should now be easier to identify. However, we followed your suggestion to rather highlight the effect of enhanced reflected radiance close to the sea-ice edge in the text using Fig. 6 (now 7) than Fig. 4.
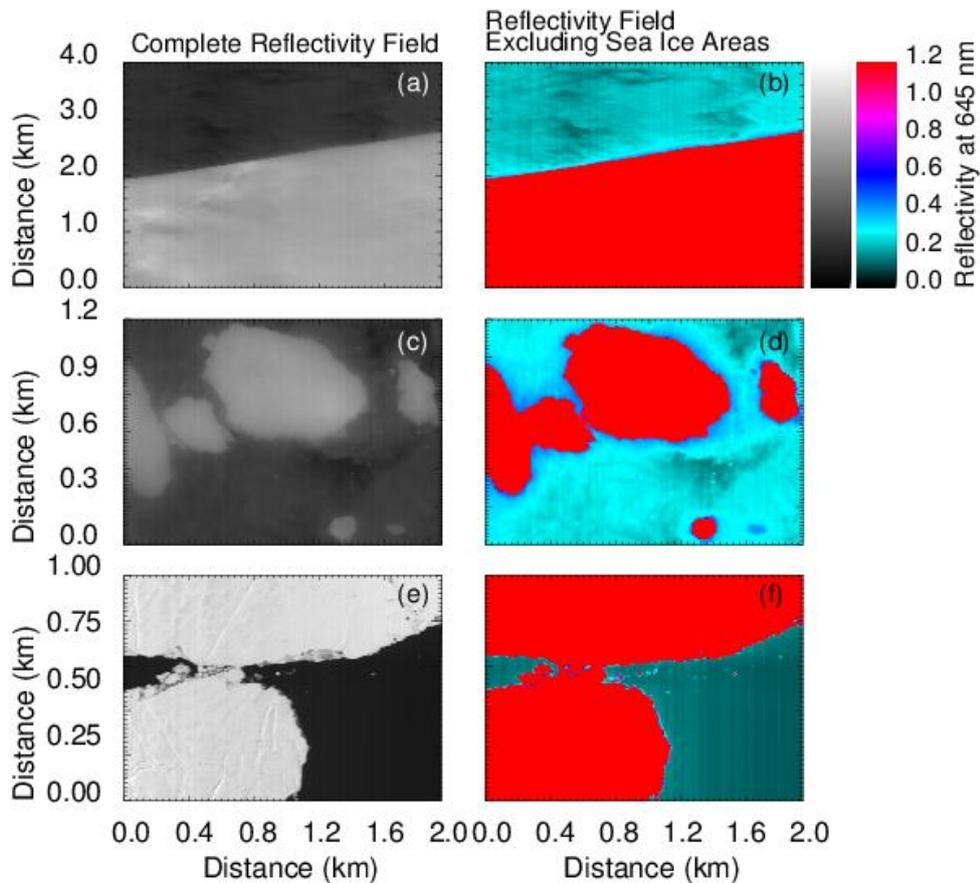
Reply-Figure 3: Revised Figure 4.

> "Figure 7 shows the measured nadir radiance as function of the distance to the ice edge for the three scenes in Fig. 4. It shows that for the cases presented in Fig. 4b and d (red and blue in Fig. 7) close to the detected sea ice areas enhanced reflected radiance, i. e. narrow bright bands, are observed, which are most likely related to 3-D effects in clouds and the interaction between cloud and surface."

Figure 6, Question 1: The question about Figure 6 that needs to be discussed is the significance of the local maximum of radiance at -50m.

➔ This is a justified question, which also arose to us, when we have seen this graph in the first time. However, the visibility of the local maximum of radiance at -50 m results only from the way we presented the measurements. Each gray line in the original figure represented one section across the ice edge out 488 total cross sections. The majority of the cross sections ranges close to the mean values and are superpose so that the few outlier weighted to strong by human eye. Those higher radiances are related to the small bright spot at x = 0.8 km and y = 2.0 km in Fig. 4a. In total, the number of data points that contribute to this enhanced radiance spot is less than 5 % of the total amount of data points. Nevertheless, we have revised this figure and show the standard deviation for each distance instead of all data points. Due to the small contribution of the bright spot to the standard deviation, the local maximum of radiance at -50 m does not appear anymore in the graph.
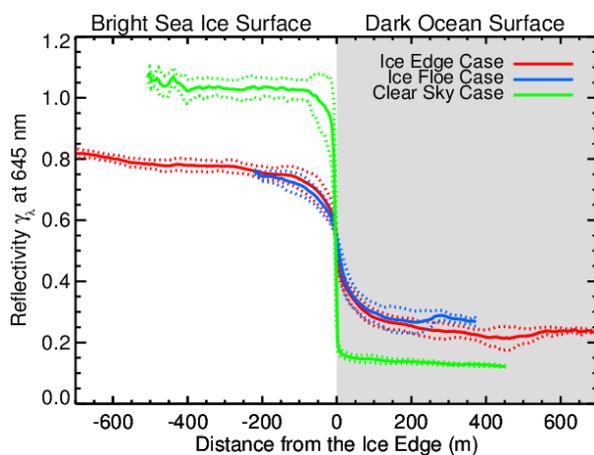
Reply-Figure 4: Revised Figure 6.

Figure 6, Question 2: The different cases shown are probably observed at different solar zenith angles. Could this be shown as reflectance instead to normalize with respect to mu?

➔ The reviewer is right. The different cases shown are observed at different solar zenith angles. In case of the same cloud properties, the reflectivity should be similar. Following one of your comments above, we have also exchanged the radiance values from this figure by reflectivities. Please see Reply-Fig. 4. The results for the first (red) and second (blue) measurement case (cloudy), which were measured almost during the same time with nearly equal Θ, are now approximately congruent. The results from the third (cloud-free) case (green) shows still different maximum and minimum values over the bright sea-ice and dark ocean water, compared to the two cloudy cases. The remaining differences result from the missing clouds in the clear sky case.

P1433, L12: No, The MODIS retrieval over water does not use this wavelength (see comment above).

➔ As replied to an earlier comment, we corrected the manuscript with regard to our choice of wavelength and the incorrect statements about MODIS.

"The input to the radiative transfer model (RTM) contains the optical properties of the atmosphere (e.g., extinction coefficients, single-scattering albedos, phase functions) and the 2-D surface albedo."

P1435, L7-8: Unclear statement

➔ With this part we wanted to address that the radiation, which is reflected by the sea ice, will travel into the direction in which it was scattered by the sea ice. On its way, the efficiency that it is scattered again into the nadir observation direction of the sensor is much lower for a clear atmosphere than for a cloudy atmosphere. We revised this part to point this out more clearly what is meant by this statement. Additionally, we included a schematic illustration of the 3-D effect in the revised version.

> *"…This indicates that the 3-D effect is dominated by horizontal photon transport between sea ice and clouds and the scattering processes by the cloud particles into the nadir observation direction. Without clouds, the horizontal photon transport above the isotropically reflecting surface is of similar magnitude to the cloudy case. However, due to the weak scattering in the clear atmosphere compared to the scattering by cloud particles, this effect is only significant for cloudy cases."*

P1435, L18: The purpose of Delta L and Delta L critical is misleading - why was Delta L critical (in addition to Delta L) introduced? Judging from Figures 9 and 10, it appears that the horizontal extent of the "vicinity zone" around ice floes decreases with cloud optical thickness, increases with cloud base/top height, (and geometrical thickness? - please add a table or Figure that shows this), as well as with the radius of the ice floe. It does not appear that Delta L critical is necessary because Delta L alone gives a clear picture.

➔ We chose the two different definitions, ΔL_{crit} (now ΔL_{HPT}) and ΔL, to address the influence on the horizontal photon transport on the one hand side and the influence of the 3-D effects on the cloud retrieval on other hand side. The first distance, ΔL_{HPT}, is a measure for the horizontal photon transport. This distance is increasing with increasing τ. Contrary, the second distance, ΔL, is a measure for the horizontal extent of the 3-D effects, within which cloud retrievals in the visible wavelength range above water are biased by the bright sea ice. We agree with the reviewer that this was not properly discussed in the original manuscript. In the resubmitted manuscript, we have revised the following parts:

> *"Over the water-covered area, an enhancement of γ_λ was measured close to the ice edge; while over the ice-covered area, γ_λ is reduced near the ice edge. We define two distances measured from the ice edge to quantify the enhancement effect. The first distance ΔL_{HPT} is introduced to quantify the range of horizontal photon transport. It characterizes the distance at which the transition from high $\gamma_{\lambda,ice}$ to low $\gamma_{\lambda,water}$ is $1/e^3$ of the initial difference between the mean γ_λ above ice ($\gamma_{\lambda,ice}$) and the mean γ_λ above open water ($\gamma_{\lambda,water}$):*
>
> $$\gamma_{\lambda,water}(\Delta L_{HPT}) = \gamma_{\lambda,water} + 1/e^3 \cdot \Delta IPA, \qquad (3)$$
>
> *with $\Delta IPA = \gamma_{\lambda,ice} - \gamma_{\lambda,water}$. By including ΔIPA, ΔL_{HPT} quantifies the range of horizontal photon transport independent on the difference of the surface albedo contrast. For the scene from Fig. 4a, ΔL_{HPT} indicated by the enhancement of γ_λ over the water surface extends to a distance of 200 m from the ice edge.*
> *Furthermore, a second distance to the ice edge ΔL is defined for which $\gamma_{\lambda,water}$ is enhanced by 6 % of the average γ_λ above open water.*
>
> $$\gamma_{\lambda,water}(\Delta L) = \gamma_{\lambda,water} + 0.06 \cdot \gamma_{\lambda,water}. \qquad (4)$$

The choice of the threshold results from the radiance measurement uncertainty (± 6 %) of the imaging spectrometer AisaEAGLE. Using this definition, ΔL is independent of γ_λ measured above the ice surface. It only accounts for the significance of the enhancement with respect to the measurement uncertainty. If the enhancement is higher than the measurement uncertainty, a cloud retrieval might be significantly biased when using the contaminated measurements. Therefore, ΔL is a measure for the horizontal extent within which the 3-D effects bias the cloud retrieval in the vicinity of an ice edge. For the special case of the measured γ_λ in Fig. 6, the ΔL = 300 m. Above open water, all measurements within that transition zone cannot be used for the cloud retrieval as the enhanced γ_λ will positively bias the retrieved τ."

"To compare the results with the measurement example in Fig. 6, the distance ΔL_{HPT} defined by Eq. (3) is analyzed. $\gamma_{\lambda,water}$ is set to the IPA values above water. For the cases presented in Fig. 8, ΔL_{HPT} increases with increasing τ from 100 m at τ = 1 to 250 m at τ = 5 and to 300 m at τ = 10. This shows that the horizontal photon transport increases with τ due to increased scattering inside the cloud layer. In contrast to ΔL_{HPT}, the distance ΔL defined by Eq. (4) decreases from 600 m (at τ = 1.0) to 400 m (at τ = 5.0) and to 250 m (at τ = 10.0). The decrease of ΔL suggests that the area in which γ_λ is enhanced and a cloud retrieval might be biased is smaller for optically thick clouds. This is related to the decrease in contrast between cloud covered sea ice and cloud covered ocean if τ increases. The difference Δ(IPA) between $\gamma_{\lambda,ice}$ and $\gamma_{\lambda,water}$ decreases from $\gamma_\lambda = 0.87$ for the clear-sky case to $\gamma_\lambda = 0.44$ for τ = 10, mainly due to the increasing reflection of incoming radiation by the cloud. If τ increases, $\gamma_{\lambda,water}$ increases which results in a higher uncertainty range exceeding the γ_λ enhancement also in areas closer to the ice edge. Therefore, the γ_λ enhancement becomes less significant for a cloud retrieval compared to the measurement uncertainties. Since we aim to retrieve τ above water areas enclosed by ice floes, in the following ΔL is used to quantify the 3-D effects."

➔ The information that Δ**L** is increasing with an increase of the geometrical thickness, as it is written in the manuscript, is an artifact of a former version of the paper and actually not provable by Figure 9. Figure 9 only confirms that Δ**L** is increasing with increasing cloud base altitude. We revised Figure 9 (now Figure 10 in the resubmitted manuscript) to also include the information that Δ**L** is increasing with the geometrical thickness of the cloud. Furthermore, we corrected the labeling, which was the wrong way round in the former manuscript. Please see Reply-Fig. 6.
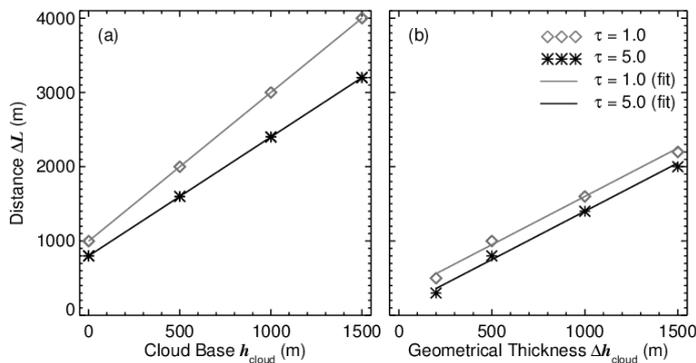
Reply-Figure 6: Revised Figure 9 (now Figure 10): *"(a) Distance Δ**L** as a function of the cloud base altitude h_{cloud} for a cloud with a geometrical thickness of Δh_{cloud} = 500 m and different τ. (b) Distance Δ**L** as a function of the cloud geometrical thickness Δh_{cloud} for a low-level cloud with cloud base at h_{cloud} = 0 m and different τ."*

"For two model clouds with a geometrical thickness of 500 m and values of $\tau = 1$ and $\tau = 5$, Fig. 10a shows ΔL as a function of the cloud base altitude h_{cloud}. Similarly, Fig. 10b shows ΔL as a function of the cloud geometrical thickness Δh_{cloud} for low-level clouds with $\tau = 1$ and $\tau = 5$ and cloud base at 0 m. The increase of ΔL with increasing altitude of the cloud base (Fig. 10a) follows an almost linear function and can be parameterized by

$$\Delta L(h_{cloud}, \tau) = A(\tau) \cdot h_{cloud} + B(\tau). \quad (5)$$

For the parameters $A(\tau)$ and $B(\tau)$, the linear regression yields $A(\tau) = 2.00/1.6$ and $B(\tau) = 1000\ m/800\ m$ for clouds with $\tau = 1/5$. This shows that the influence on ΔL is much larger for clouds at higher altitudes and lower τ. Comparing the results for $\tau = 1$ and $\tau = 5$ indicates that the slope A decreases with increasing τ. This proves that the influence of cloud geometry on ΔL is decreasing with increasing τ.
Similarly, ΔL increases almost linearly with increasing cloud geometrical thickness Δh_{cloud}. This relation can be parameterized by

$$\Delta L(\Delta h_{cloud}, \tau) = A(\tau) \cdot \Delta h_{cloud} + B(\tau). \quad (6)$$

The regression of the increase of ΔL with increasing cloud geometrical thickness yield $A(\tau) = 1.3/1.3$ and $B(\tau) = 300\ m/100\ m$ for clouds with $\tau = 1/5$."

Section 4.2.3: This section is too long, and there are many problems with repetition, language/grammar. Rather than listing the issues in detail, the authors are encouraged to shorten this section AND have this proof-read by the co-authors (something that should always be done). I would like to point out that the finding on P1442,L22-24 seems important, but would "shine more" if presented in a considerably shorter section 4.2.3.

➔ We have revised this section and significantly shortened it, especially by removing most of the repetitions or summarizing them in Section 4.2 (repetition of input parameters such as τ, cloud altitude or geometrical thickness) and 4.2.1 (general findings such as the description of the enhanced or reduced reflectivity in the vicinity of ice edges). Furthermore, we have resorted single paragraphs, which makes this section even shorter and avoids unnecessary back and forth switching between the single parameters. In the revised version, we try to separate the investigations of single parameters, before discussing the next one (ice edge length, sea-ice area,...). Due to the length of the changes we decide not to copy all new sections here. Please use the revised manuscript.

P1443, L21-23: Unclear what justifies the statement that cloud and surface heterogeneity effects "are in the same range". If that is true, please make this a quantitative statement and provide the respective ranges.

➔ We agree with the reviewer that the reason for the broader frequency distributions of the observations compared to the simulations cannot be substantiated by the last sentence of the corresponding paragraph – "Compared to the observations, this indicates that cloud heterogeneity effects and surface heterogeneity effects are in the same range". We have revised this sentence. However, we think that the broadening is due to differences in the cloud base altitude and due to cloud-inhomogeneity effects. While the cloud top is well defined by measurements with the AMALi, it cannot see the cloud base. Therefore, we performed some

tests with a different altitude of the cloud base. Additionally, we slightly varied the surface albedo. Doing so, we could achieve a better agreement between simulation and observation. Furthermore, in the revised manuscript we changed the normalization of the distributions in Fig. 13 (now Fig. 14) to a total value of one. This makes the comparison more meaningful and highlights the different radiative effects. A broadening of the dark ocean water and sea-ice peak may result from both sea ice edge effect and cloud heterogeneities. However, while surface effects will fill up the gap between the two peaks only, clouds inhomogeneities can also result in values smaller (over water) and higher (over sea ice) then the IPA simulations. This is clearly obvious, comparing simulations and measurements, what gives us reason to address the broadening partly to cloud inhomogeneities. The revised version of this part is the following:

> *"The albedo map was used in the simulations implementing a cloud of τ = 5 and a fixed r_{eff} = 15 μm, as derived from in situ measurements. With regard to the AMALi measurements, the cloud top altitude was set to $h_{cloud,\ top}$ = 200 m. Compared to the simulations shown before, the best agreement between measurement and simulation is derived for this specific case for a cloud base altitude of $h_{cloud,\ base}$ = 100 m and a slightly adjusted surface albedo (α_{water} = 0.09, α_{ice} = 0.83). Fig. 14 shows the frequency distributions of simulated and observed γ_λ. Comparing observation and simulation, the maximum of the ocean-water and sea-ice peak are found at equal γ_λ. In regions over dark ocean water as well as in regions over bright sea ice, the γ_λ of the observation show a broader distribution than the γ_λ of the simulation. Indeed, the magnitude of the simulated γ_λ peak above the sea-ice surface agrees well with the peak from the observation, while the difference above the dark ocean water is significantly larger. The different magnitude and the broader distribution of the observed single peaks compared to the simulation result most likely from simplifications in the simulations where a horizontally homogeneous cloud is assumed. Thus, variations of γ_λ due to cloud 3-D effects are not included here. Only the surface 3-D effects cause a broadening of the frequency distribution. However, while surface effects will fill up the gap between the two peaks only, cloud inhomogeneities can also result in values smaller (over water) and higher (over sea ice) than the IPA simulations."*

Section 5: I recommend removal of this section. In general, sections 5, 4.2.3, and 4.2.4 are of much lower quality than the rest of the paper. But regarding content, the applied retrieval technique actually does not replicate what MODIS is doing (if the goal is to improve/validate satellite retrievals). If this were the purpose of the study, the correct pairing of bands (860 nm + 2150 nm), should be used. It is unclear why Werner et al. (2013) is used here instead - why is Nakajima-King ambiguous (with respect to which retrieval parameters)? In addition, if the overestimation zone for cloud optical thickness is only 2 km, this would hardly be seen by MODIS anyway because its grid size is 1km. If anything, this will affect ONE pixel in the vicinity of an ice floe. This would be relevant for sub-grid-resolution ice floes though, which MAY bias the MODIS cloud retrievals high if they go undetected. But this does not seem to be the intent of the current study.

➔ The main focus and we hope that we could clarify this by the revisions discussed before is not to connect the observed 3-D effects to satellite observations. Still this is part of our motivation, but in this study the application of airborne measurements of imaging spectrometers is the main driver. Here the observed scales are much smaller and the 3-D effect might affect cloud retrievals. Therefore, in Section 5 a sensitivity study for such cloud retrieval is presented where we apply wavelengths and retrieval methods developed for airborne observation (Bierwirth et al. 2013, Werner et al., 2013) The motivation is to show how strong airborne derived cloud microphysical and optical properties with a high spatial resolution are affected by the 3-D effects.

Due to the missing near infrared wavelength in the measurements which are needed for retrieval of cloud particle effective radius, we decided to base this study purely on simulations. This is justified by the fact that in near future an imaging spectrometer for near infrared wavelength is available and will be used in future projects continuing the investigations of VERDI. From that point of view, we would like to keep this section and revised it throughout to avoid further misunderstandings. Additionally, we changed the title of the manuscript to clearly point out the focus on airborne measurements and avoid any confusion by the reader.

"Airborne observations and simulations of three-dimensional radiative interactions between Arctic boundary-layer clouds and ice floes"

➔ We also added an extra paragraph to the introduction, which shell clarify that the investigations are related to airborne measurements.

> *"As demonstrated by Bierwirth et al. (2013), airborne remote sensing using spectral imaging sensors is one promising method to characterize small scale inhomogeneities of clouds in the spatial range below 5 m. For airborne imaging spectrometer measurements over dark ocean surfaces, Bierwirth et al. (2013) introduced a novel five-wavelength cloud retrieval procedure that is based on the classic two-wavelength cloud retrieval by Nakajima and King (1990) and follows the multi-wavelength approach by Coddington et al. (2012) and King and Vaughan (2012). For airborne measurements performed during the international field campaign SoRPIC (Solar Radiation and Phase discrimination of ArctIc Clouds), Bierwirth et al. (2013) showed that accurate retrieval results can be obtained for the cloud optical thickness τ. However, due to the limitation of the instrument to wavelengths below 1000 nm a retrieval of r_{eff} was not feasible. Also, the application of the retrieval was restricted to areas of open water."*

> *"Within the present study, the focus lies on those 3-D radiative effects that are related to the horizontal photon transport between cloud and surface due to isotropic reflection of the incident radiation on the bright sea ice. The goal is to quantify the magnitude and horizontal extent of those 3-D effects as well as their influence on cloud retrievals from the visible wavelength range with a high spatial resolution. In reality, such surface 3-D radiative effects will be combined with cloud 3-D radiative effects due to cloud inhomogeneities. ..."*

➔ The choice of the method by Werner et al. (2013) is justified by the following points. We refer to Werner et al (2013), because the general approach using ratios instead of absolute radiances was applied here as well. Second, the method is not restricted to cases when cirrus is above the aircraft (we have chosen data with clear sky conditions above the aircraft) but also improves retrieval uncertainties in this cases. It further improves the retrieval technique from Bierwirth et al. (2013) by using ratios of radiances instead of total radiance only. In comparison to the retrieval grid, derived by the two-wavelength retrieval from Bierwirth et al. (2013), the ratio method further results in a better orthogonality of the τ and r_{eff} solution space (please notice Reply-Figure 7). This leads to a better separation of the τ and r_{eff} solution space ("More unambiguous" was the wrong wording at this point. We revised it by the words "better separation"). For airborne investigations of τ and r_{eff} with large spatial coverage and high spatial resolution (as we want to perform it in future studies), this will result in a better accuracy of the retrieved values. To make our decision using the ratio method by Werner et al. (2013) more clear, we included the following part in the revised manuscript:

> *"The retrieval grid is constructed from the simulated γ_λ at 645 nm wavelength on the abscissa and the ratio of γ_λ at 1525 and 579 nm wavelength on the ordinate. This wavelength and the wavelength ratio was chosen in order to improve the retrieval method by Bierwirth et al. (2013). The choice of wavelength follows the method presented by Werner et al. (2013). This*

method creates a retrieval grid with a more separated solution space for τ and r_{eff} than the classic two-wavelength method by Nakajima and King (1990) or Bierwirth et al. (2013). Furthermore, it effectively corrects the retrieval results for the influence of overlying cirrus and reduces the retrieval error for τ and r_{eff} caused by calibration uncertainties (Werner et al., 2013). For airborne investigations of τ and r_{eff} with large spatial coverage and high spatial resolution, this will result in a higher accuracy of the retrieved cloud properties."
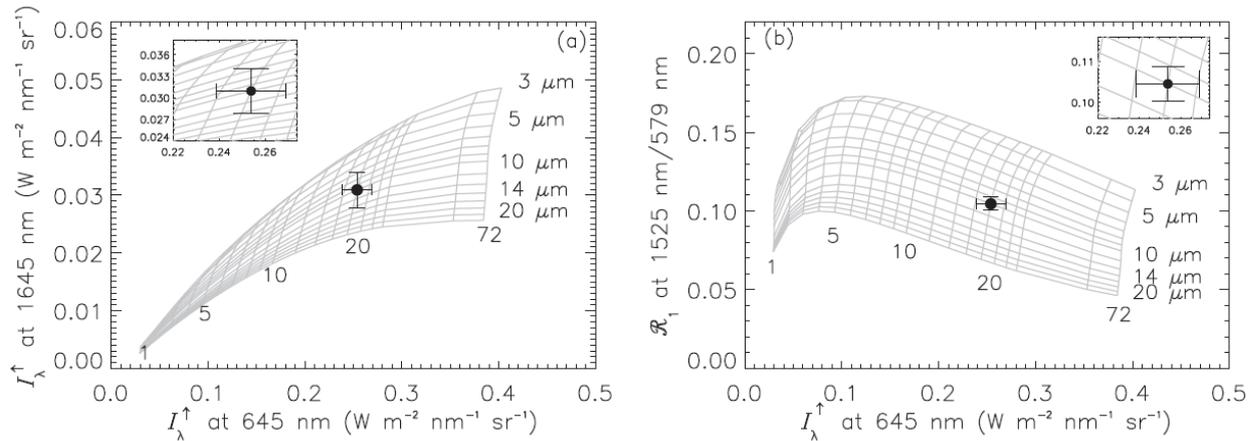
Reply-Figure 7: Comparison of classical two-wavelength retrial method by Nakajima and King (1990) and ratio method by Werner et al. (2013). Graphs adapted from Werner et al. (2013), not included in the manuscript.

P1445, L22-23: ": : :different patterns of : : : 3D effects can be larger at absorbing wavelengths". This statement needs to be substantiated. How do the different patterns suggest this?

➔ The reviewers confusion is justified. The statement as it is, is misleading. It is the wrong way around and contradicts the statements given before. Accordingly, we revised this part and also spend a few more words for the explanation.

"Furthermore, Fig. 16 shows that the overestimation of τ increases approximately exponentially starting at about 1.5 km distance, while the overestimation of r_{eff} increases more slowly and only extends up to a distance of 1.0 km. This indicates that the magnitude of the 3-D effects depends on the wavelengths. In all simulations shown in Sect. 4.2, a wavelength of 645 nm was used for the retrieval of τ. However, the retrieval of r_{eff} also requires simulations at 1 525 nm in the absorption band of liquid water. Therefore, the smaller magnitude and horizontal extent of the overestimation of r_{eff} compared to the magnitude and horizontal extent of the overestimation of τ suggest that the 3-D effects will be smaller at absorbing wavelengths."

P1446, L11-13: See comments above. Retrievals are possible over snow surfaces. Please review the literature.

➔ As stated before, we revised the whole article with respect to those justified comments. Here at this point, we removed this statement.

Conclusions: This section should be significantly shortened; after all, the purpose of this section should be to summarize the most important results.

➔ We agree with the reviewer that the summary in many instances was not written efficiently. We tried to follow the suggestions by the reviewer, revised this section and shortened it by almost the half summarizing only the most important results from the main part.

P1449, L14-L26: Remove (see comment above), or frame this differently, after having reviewed the cloud retrieval literature.

➔ As discussed above, we kept this section, clearly pointing out that it is representative only for the airborne measurements presented in the manuscript. We have revised the particular sentence by:

> *"The results from the simulations suggest that applying a 1-D cloud retrieval to airborne measurements over ocean areas located close to sea ice edges, τ and r_{eff} will be further overestimated the closer the pixel is located to the ice edge. …"*

Language/Spelling comments:

I am sure I did not capture all the language issues (especially in punctuation), the ones given below are representative. The manuscript needs to be revised by a native speaker and undergo ACP copy-editing.

➔ We thank the reviewer for the detailed list of language issues.

P1422, L2: add comma after "observations"
➔ inserted

L7: "instantaneously" –> "instantaneous"
➔ changed

L10: "with help" –> "with the help"
➔ changed

L13: "ground overlaying" sounds a bit awkward, can it be replaced with some other term or at least be hyphenated?

➔ The reviewer is right. "Ground overlaying" is a bad choice to characterize low-level clouds, which are touching the ground. However, we could not find an appropriate word, so we decided to replace "ground overlaying" by "low-level" and to add the altitude in quantitative numbers, from which it should become clear that the cloud is touching the ground. We changed it at each point where it occurred in the manuscript.

*"For a low-level cloud at 0–200 m altitude, as observed during the Arctic field campaign **VER**tical **D**istribution of **I**ce in Arctic clouds (VERDI) in 2012, an increase of the cloud optical thickness τ from 1 to 10 leads to a decrease of ΔL from 600 to 250 m."*

"From the two measurement cases presented here (τ = 5, h_{cloud} = 0–200 m), a distance ΔL of 400 m was observed."

*"**Figure 8.** Simulated mean γ_λ across an ice edge for clear-sky conditions as well as for low-level clouds between 0 and 200 m altitude, τ = 1/5/10, and r_{eff} = 15 μm. …"*

*"**Figure 10.** (a) Distance ΔL as a function of the cloud base altitude h_{cloud} for a cloud with a geometrical thickness of Δh_{cloud} = 500 m and different τ. (b) Distance ΔL as a function of the cloud geometrical thickness Δh_{cloud} for a low-level cloud with cloud base at h_{cloud} = 0 m and different τ."*

L13: "in 0-200m altitude" –> "at 0-200m altitude" (multiple occurrences throughout manuscript)
➔ We have changed this (see above) and revised the whole manuscript for similar mistakes.

L13: "on both, cloud and sea" - remove comma
➔ Removed

L21: "infinite" –> "infinitely"
➔ We have changed it and revised the whole manuscript for similar occurrences.

P1424, L19: "superposed" – use a more suitable word such as "combined"
➔ We changed it to the reviewers suggestion "combined".

P1425, L12: add comma after "(2013)"
➔ inserted

L13: add comma after "simulations"
➔ inserted

L23 and L27: add comma after "(VERDI)"
➔ inserted

P1426, L3: "aimed at" –> "was aimed at"
➔ changed

P1426, L22: "obverse" –> "observe"

➔ corrected

P1434, L11: "effects affect" - improve language

➔ We have replaced "affect" with "influence".

L16: "will be simulated" – please fix the usage of tense throughout the paper. The simulations have already been performed, so future tense is inappropriate.

L21: "have been" –> "were"?

➔ Changed to were

P1435, L1: add comma after "observations"

➔ inserted

L2: add comma after "ice"

➔ inserted

L9: add comma after "general"

➔ inserted

L16: add comma after "7"

➔ inserted

L20: "That" –> "This"

➔ corrected

P1437, L5: "That proofs" –> "This proves"

➔ corrected

P1439, P1443: R_(3-D-IPA) is misleading, this should be relabeled R_(3D)/R_(IPA) (Currently, this looks like a difference, but it's a ratio).

➔ The reviewer is right that this was misleading in the old manuscript and could confuse the reader. We have changed and R_(3-D-IPA) to R_(3D)/R_(IPA) at each point where it occurred in the manuscript.

P1444, L8: "roll" –> "role"

➔ corrected

P1445, L17: Replace "kind of" - this is slang

➔ changed to "approximately"

P1446, L19: "This causes horizontal photon transport, which : : : is scattered" It is not the transport that is scattered but the radiation (fix structure).

> *"This reflection causes horizontal photon transport, before the radiation is scattered by cloud particles into the direction of observation."*

References cited in this reply:

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