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 reviewers 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:

Page 1424, Lines 20-25: I don't quite agree with this point. The fact that the Zinner et al. (2010) paper found weak 3D effects for stratocumulus clouds does not rule out strong 3D effects for many observations of Arctic stratus clouds. This is because while the Zinner et al. (2010) simulations used a 45_ solar zenith angle, numerous studies pointed to much stronger 3D effects for the lower solar elevations that are quite frequent for Arctic clouds (see, for example, Loeb and Davies 1997, Loeb and Coakley 1998, Horvath et al. 2014, Grosvenor and Wood 2014).

➔ The reviewer comment is right. We did not adequately discuss the study by Zinner et al. (2010) and missed referring to results of other studies. We revised this part and included also the reference to Loeb and Davis (1996) and Grosvenor and Wood (2014).

> *"For a solar zenith angle (Θ) of 45°, Zinner et al. (2010) found that the remote sensing of stratocumulus was not biased by 3-D effects, while that of scattered cumulus was sensitive to horizontal heterogeneities. This leads to the assumption that retrievals of cloud microphysical and optical properties can be treated by 1-D simulations if the distance to ice-open water boundaries is sufficiently large. However, measurements in Arctic regions are often performed for solar zenith angles larger than 45°. In such cases, 3-D radiative effects generated by the cloud structures become important. Using plane-parallel 1-D simulations of clouds, Loeb and Davis (1996) stated that the cloud optical thickness shows a systematic shift towards larger values with increasing solar zenith angle. This dependence is still weak (≤ 10 %) for thin clouds (τ ≤ 6) and Θ ≤ 63°. Grosvenor and Wood (2014) confirmed this statement. They investigated MODIS satellite retrieval biases of τ and stated that τ is fairly constant between Θ = 50° and ≈ 65–70°, but then increases rapidly with an increase of over 70 % between the lowest and highest Θ."*

Page 1428, Lines 1-5: I recommend adding some qualifying words here, as the results only show that retrievals are not possible using the wavelengths used in this paper. However, using other wavelengths such as 1.2 micron can enable retrievals for some water clouds over frozen surfaces (Platnick et al. 2001) even if the retrieval accuracy is lower.

➔ We agree with the reviewer. Of course it has to be mentioned that our statement is only valid for the visible wavelength range and can be overcome by introducing near-infrared wavelength channels. We revised the relevant parts in the manuscript and introduced methods, which are using the near-infrared channels to retrieve cloud optical properties above ice surfaces.

> *"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."*

➔ Furthermore, at each time when we are talking about the fact that retrievals are not possible over bright sea ice surfaces, we included "for the visible wavelength range".

Page 1435 lines 9-13, and Page 1447 lines 13-15: I recommend mentioning that having stronger 3D effects for larger optical thicknesses is similar to the behaviors discussed earlier in the context of aerosol measurements near bright clouds. For example Marshak et al. (2008) found stronger "bluing" (3D enhancement near clouds) at shorter wavelengths, where the Rayleigh optical thickness is larger.

➔ This is a good suggestion. The dependence of the radiance enhancement to cloud optical thickness enhancement due to the ice floes in our study is comparable to the enhancement of the AOD due to the clouds in the study from Marshak et al. (2008), although the geometry differs and additional reasons for the bluing are discussed in literature. And the reviewer is right. There are more comparable studies (Kobayashi et al. (2000), Koren et al. (2007), …) , which are dealing with the "twilight zone" around clouds. Out of them, following the reviewers suggestion, we included a reference to Marshak et al. (2008).

> ***"****Similar investigations are presented by Marshak et al. (2008) with respect to aerosol-cloud interactions. In the vicinity of clouds, they found that the radiance in cloud-free columns is increased due to a cloud-induced enhancement of the Rayleigh scattering.****"***

Page 1435, lines 21-27: I recommend mentioning the additional consideration that, because of the nonlinearity of the optical thickness vs. reflectance curve, the same 5% relative change in reflectance implies a larger relative change in retrieved optical thickness for thicker clouds than for thinner clouds. In other words, it may help to determine Delta_l using a lower threshold for thick clouds than for thin clouds. For example, depending on solar elevation and other conditions, a 5% reflectance-difference threshold could be optimal for cloud optical depths around 1, but a 3.5% reflectance-difference threshold may be optimal for CODs around 5 and a 2% reflectance-difference threshold may work best for CODs around 10. It may even be worth including some results based on such dynamic thresholds into the paper.

➔ This is in fact a good suggestion. According to your idea, we have also tested the results of Figure 7 (now Figure 8) with different thresholds of 5 % (at $\tau = 1$), 3.5 % (at $\tau = 5$), and 2 % (at $\tau = 10$). This results in an increase of ΔL at $\tau = 5/10$ from 400 m/250 m to approximately 500 m/450 m. However, the reflectivity-difference threshold of 5 % (now adapted to 6 % with regard to Schäfer et al. (2013)) between IPA and 3-D simulations is chosen with respect to the measurement uncertainty of the imaging spectrometer AisaEAGLE. Indeed, the same measurement uncertainty causes then larger effects for clouds of higher optical thickness. Otherwise, the measurement uncertainty of the instrument is a reasonable value for the threshold, whereas it is difficult to justify the use of 3.5 %, 3 %, or some other values. However, we have revised this part to better clarify the use of ΔL_{crit} *(now* ΔL_{HPT}*)* and ΔL. In this context we have also revised the statement on the threshold choice. The revisions we made are:

"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 $\Delta L = 300$ 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 γ_λ = 0.87 for the clear-sky case to γ_λ = 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."

Page 1442, lines 5-6: It appears to me that in Figure 12 the spread of radiance distributions over sea and ice are much larger for Scenario 1 than for scenarios 2-4. So I suggest some correction or clarification, for example by describing what is meant by "spread".

➔ The reviewer is right. The spread of radiance (now reflectivity) distributions over bright sea ice and dark ocean water are much larger for Scenario 1. This is due to the smaller floe size in Scenario 2-4, compared to Scenario 1. Therefore, the large radiance/reflectivity values from Scenario 1 cannot be reached by Scenario 2-4. We revised this part to better clarify the reason for the different results.

"… All γ_λ values that are not included in the single water peak, result from the 3-D effects. Above ice, the distributions of Scenario 2-4 are shifted to lower γ_λ compared to Scenario 1. This is because the diameter of the floes is even smaller than in Scenario 1. Thus, the large reflectivity values of Scenario 1 cannot be reached by Scenario 2-4 (compare Fig. 11)…."

➔ Furthermore, we had to revise the whole fourth section with regard to the other reviews. The part with respect to our comment on the "spread" is not included anymore.

Page 1441, lines 17-18: It is a very interesting observation that 3D effects reduce the scene average reflection, and I wonder if the authors could offer an explanation for this. For example, could 3D surface-cloud interactions involving double surface reflection explain the reduction?

➔ The radiation, which reaches the cloud after its reflection on the sea ice will be scattered again by the cloud into several directions. Of course, part of it is also scattered into the direction of the dark ocean surface. There, due to the low albedo, most of the radiation will be absorbed and not reflected back into the direction of the cloud. This part of absorption does not exist in the IPA simulations. This results in a lower scene average reflection for the 3-D simulations compared to the IPA simulations, which leads to a lower ratio $R_{3D/IPA}$. To address this mechanism more clearly to the reader, we included the following sentences.

"This reduction originates from the absorption of the radiation, which is scattered by the cloud base back into the direction of the dark ocean surface. This part of absorption does not exist in the IPA simulations, which in comparison leads to a lower scene average reflection in the 3-D simulations."

Page 1454, Table 1: Either in the table or somewhere in the text it would be important to discuss the level of Monte Carlo simulation uncertainty. Most importantly, how do they compare to the deviations from 100% in Table 1?

➔ It is true that we missed to discuss the level of Monte Carlo uncertainty. In the revised manuscript we have included a quantitative value.

> *"$2.2{\cdot}10^9$ photons were used in each single model run, which resulted in a noise level of the 3-D simulations less than 1 %. This value is much lower than the measurement uncertainties of AisaEAGLE."*
>
> *"Yet, the overall 3-D effect is relatively small with $R_{3\text{-}D/IPA}$ ranging from 96.5 to 98.4 %, but is still significantly above the noise level of the 3-D simulations."*

Page 1443, lines 21-23: I suggest considering another possible explanation for the Figure 13 frequency distributions being broader in the observations than in the simulations: the possibility that clouds may have been at a higher altitude or were geometrically thicker in reality than in the simulations. In order to support or disqualify this hypothesis, it would help to mention the top height (and/or thickness) of observed clouds, for example by discussing results from the AMALi lidar mentioned in Page 1426. Alternatively, the simulations could be repeated assuming higher cloud altitudes.

➔ We agree with the reviewer that the reason for the broader frequency distributions of the observations compared to the simulations is not well discussed in the original manuscript. However, we think that it is not likely that the broadening is due to differences in the cloud top altitude, rather than due to cloud base altitude and cloud-inhomogeneity effects. The cloud top is well defined by measurements with the AMALi, whereas AMALi 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 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."

Page 1445, lines 26-29: I recommend elaborating a bit more on the suggested technique, mainly to explain why a retrieval far from any sea ice would be needed for applying the correction factors in Figure 15 to pixels near clouds.

➔ We removed the statement on a possibility to correct these effects as in practice to many assumptions have to be used making a correction meaningless.

Page 1447, lines 10-12: I am not sure if I fully agree with the statement that the enhancement over water is stronger than the reduction over ice. It is true that in Table 1 the total reflectance is enhanced, so in this sense the "winning" effect is indeed the enhancement over water. However, the table also shows that the enhancements over water have smaller magnitudes than the reductions over ice. I suspect the enhancement of total reflectance occurs only because in the simulated cases ice covers much smaller areas than water does. So in cases of higher ice coverage the overall effect might be a net reduction, not enhancement.

➔ It is true that the total effect of enhancement above dark ocean water and reduction over bright sea ice is a function of the sea-ice coverage and floe size in the corresponding scene. In the simulations the water surface covers most of the scene biasing the averaged results. Therefore, we removed the original statement from the summary. However, for large ice floes which can be treated as an infinitely expanded ice edge as described in Section 4.2.1 and if the sea-ice and dark ocean coverage is of equal area, the reduction over the bright sea ice is stronger than the enhancement of the reflectivity over the dark ocean water. Please compare to Figure 8 in the resubmitted manuscript. For most scenarios with large flows this will result in a total reduction of the domain average radiance independent on the fraction of sea ice. As it cannot be ruled out that smaller flows result in an opposite effect, we removed this statement from the summary.

Wording:

Page 1424, lines 25-27: I suggest moving this sentence to the next paragraph, as it discusses the topic of that paragraph.

➔ The last sentence belongs to the next paragraph. We changed this according to the reviewers suggestion.

Page 1425, line 7: I suggest replacing "Here" by "In Section 2".

➔ Changed according to the reviewers suggestion

Page 1428 line 18, page 1429, lines 21 and 22: The word "both" should be replaced by "the two".

➔ Changed to "the two"

Page 1432, lines 2223: The words "in dependence" should be replaced by "as a function".

➔ Changed according to the reviewers suggestion

Page 1434, line 25: I suggest clarifying early which figure contains the grey lines, perhaps by mentioning Figure 7 in or around line 21.

➔ We have revised this part.

"The most general case of an ice edge is an infinitely straight ice edge. This case is comparable to Fig. 4a. Fig. 8 illustrates the results of the 1-D (grey lines) and 3-D (black lines) simulations. …"

Page 1437, line 3: I believe "geometrical" should be replaced by "optical", as Equation (4) does not include geometrical thickness, but the first sentence after the equation describes the way the equation coefficients change with optical thickness.

➔ At the given point, "geometrical" has to be replaced by "optical". We have revised this accordingly. Furthermore, there was a mistake with the labeling of the single curves. The legend was the wrong way around. Please find the revised version at Reply-Figure 1, for which one we have also included a second panel that presents the dependency of ΔL on the cloud geometrical thickness.

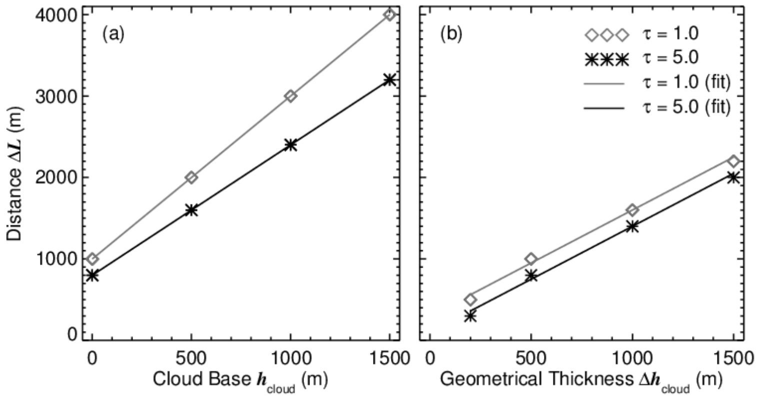
"For two model clouds with a geometrical thickness of 500 m and values of $\tau = 1$ and $\tau = 5$, Fig. 10a shows ΔL as a function of the cloud base altitude h_{cloud}. Similarly, Fig. 10b shows ΔL as a function of the cloud geometrical thickness Δh_{cloud} for low-level clouds with $\tau = 1$ and $\tau = 5$ 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 $\tau = 1/5$."



Reply-Figure 1: Revised Figure 9 (now 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."*

Page 1437, line 5: "proofs" should be replaced by "proves".

➔ corrected

Page 1438, lines 10-15: I suggest refining the wording to make it clear that curvature affects both large and small ice floes.

➔ We have revised this by the following:

"For any water point near the ice edge, the ice area located close to this point is reduced with increasing curvature. The curvature affects both small and large ice floes and lowers the 3-D radiative effects slightly until the maximum effect, which is reached for an infinitely straight ice edge."

Page 1438, line 24: For clarity, I suggest mentioning the pixel size here.

➔ We have included remarks on the pixel size.

"This is due to the insufficient representation of the circular shape of the small ice floes by squared pixels with 50 m edge length."

Page 1443, line 24-26: To prevent any confusion, I suggest clarifying that Table 1 shows results for idealized scenarios.

➔ We have revised this according to the reviewers suggestion.

"In addition to the results from the idealized scenarios in Sect. 4.2.3, Table 1 shows the ratios $R_{3\text{-}D/IPA}$ between the results of the 3-D and IPA simulation for the realistic sea-ice scenario. Compared to the idealized scenarios in Sect. 4.2.3, for the realistic sea-ice scenario the differences between the IPA and 3-D simulations are larger above dark ocean water and smaller above bright sea ice."

Page 1444, line 8: "roll" should be replaced by "role".

➔ corrected