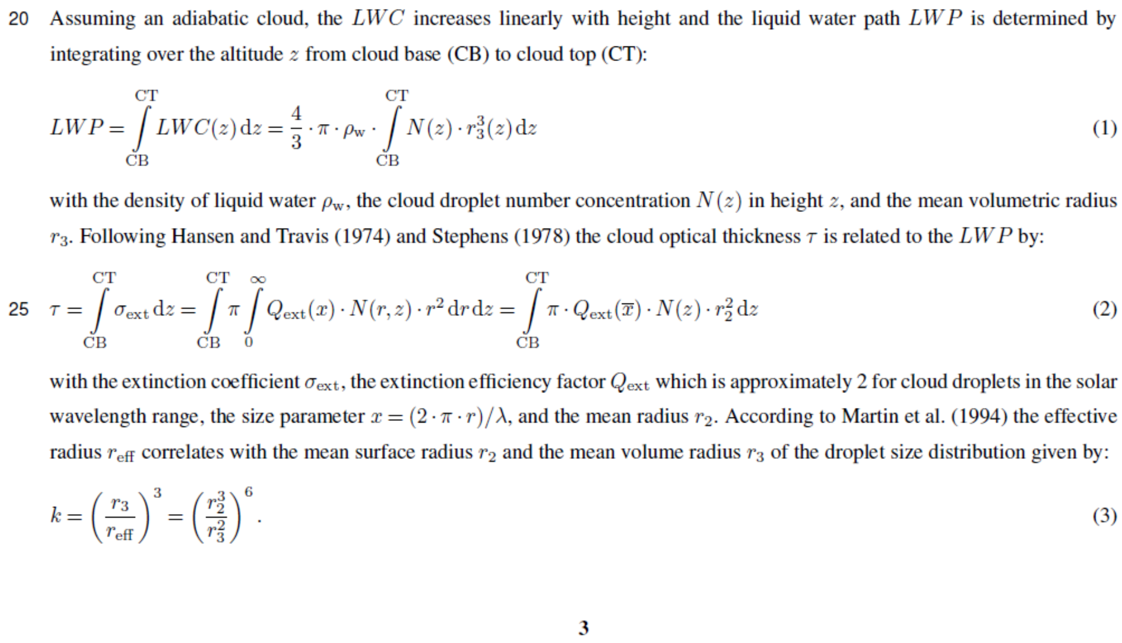
Response to Anonymous Referee #2

The comments of the reviewer have been helpful to improve the manuscript. We thank the reviewer for the suggestions. Detailed replies on the reviewers comments are given below. The reviewers comments are given bold while our replies are written in regular roman letters. Citations from the revised manuscript are given as indented and italic text.

P2 L32 : Perhaps mention that Q_ext is around 2 and thus the coefficient in equation 1 is 2/3. It would be helpful for those not as familiar with VNIR cloud retrievals.

A: Now the derivation of the equation is described in more detail. Explicitly stating Qext approx. 2. The change in the manuscript is copied here as a screenshot to provide better readability because of the equations.



Assuming an adiabatic cloud, the LWC increases linearly with height and the liquid water path LWP is determined by integrating over the altitude z from cloud base (CB) to cloud top (CT):

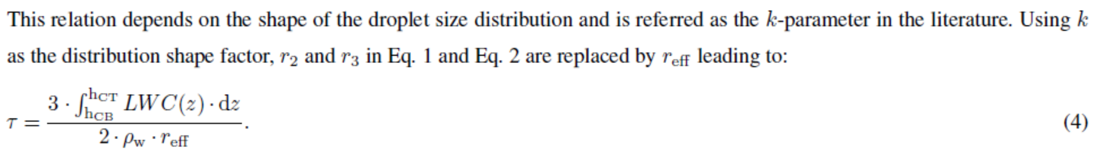
$$LWP = \int_{\mathrm{CB}}^{\mathrm{CT}} LWC(z)\,\mathrm{d}z = \frac{4}{3}\cdot\pi\cdot\rho_{\mathrm{w}}\cdot\int_{\mathrm{CB}}^{\mathrm{CT}} N(z)\cdot r_3^3(z)\,\mathrm{d}z \quad (1)$$

with the density of liquid water ρ_{w}, the cloud droplet number concentration $N(z)$ in height z, and the mean volumetric radius r_3. Following Hansen and Travis (1974) and Stephens (1978) the cloud optical thickness τ is related to the LWP by:

$$\tau = \int_{\mathrm{CB}}^{\mathrm{CT}} \sigma_{\mathrm{ext}}\,\mathrm{d}z = \int_{\mathrm{CB}}^{\mathrm{CT}} \pi \int_{0}^{\infty} Q_{\mathrm{ext}}(x)\cdot N(r,z)\cdot r^2\,\mathrm{d}r\,\mathrm{d}z = \int_{\mathrm{CB}}^{\mathrm{CT}} \pi\cdot Q_{\mathrm{ext}}(\overline{x})\cdot N(z)\cdot r_2^2\,\mathrm{d}z \quad (2)$$

with the extinction coefficient σ_{ext}, the extinction efficiency factor Q_{ext} which is approximately 2 for cloud droplets in the solar wavelength range, the size parameter $x = (2\cdot\pi\cdot r)/\lambda$, and the mean radius r_2. According to Martin et al. (1994) the effective radius r_{eff} correlates with the mean surface radius r_2 and the mean volume radius r_3 of the droplet size distribution given by:

$$k = \left(\frac{r_3}{r_{\mathrm{eff}}}\right)^3 = \left(\frac{r_2^3}{r_3^2}\right)^6. \quad (3)$$



This relation depends on the shape of the droplet size distribution and is referred as the k-parameter in the literature. Using k as the distribution shape factor, r_2 and r_3 in Eq. 1 and Eq. 2 are replaced by r_{eff} leading to:

$$\tau = \frac{3\cdot\int_{\mathrm{h_{CB}}}^{\mathrm{h_{CT}}} LWC(z)\cdot\mathrm{d}z}{2\cdot\rho_{\mathrm{w}}\cdot r_{\mathrm{eff}}}. \quad (4)$$

P2 L18: Bennartz and Rausch (2017) doesn't assume a constant LWC vertically, but a sub-adiabatically stratified, linearly increasing LWC of roughly 80% of the purely adiabatic value

A: Bennartz and Rausch (2017) are extracted from the enumeration and are named separately with the correct cloud profile description.

"… They are a useful tool, providing large spatial and temporal data sets. Based on passive remote sensing in the solar and terrestrial wavelength range, N is estimated combining the results of bi-spectral retrievals of cloud optical thickness and reff and cloud top temperature TCT by Brenguier et al. (2000), Quaas et al. (2006), and Zeng et al. (2014). They assume a constant LWC and N throughout the cloud vertical profile, which is not necessarily fulfilled in nature. Slightly deviating, Bennartz and Rausch (2017) assume a sub-adiabatic profile where the LWC increases linearly with height by approx. 80% with respect to the adiabatic value."

P5L25: The k-parameter shows up in equation 3, but there is no mention of what k represents until page 12. It may be helpful to provide the reader a little more information on k rather than leaving them hanging for 7 pages.

A: The k-parameter is introduced early in the section of the text which was suggested by the reviewer. The description of the k-parameter is included in the derivation of the tau-lwc-relation. Please see answer to comment #1.

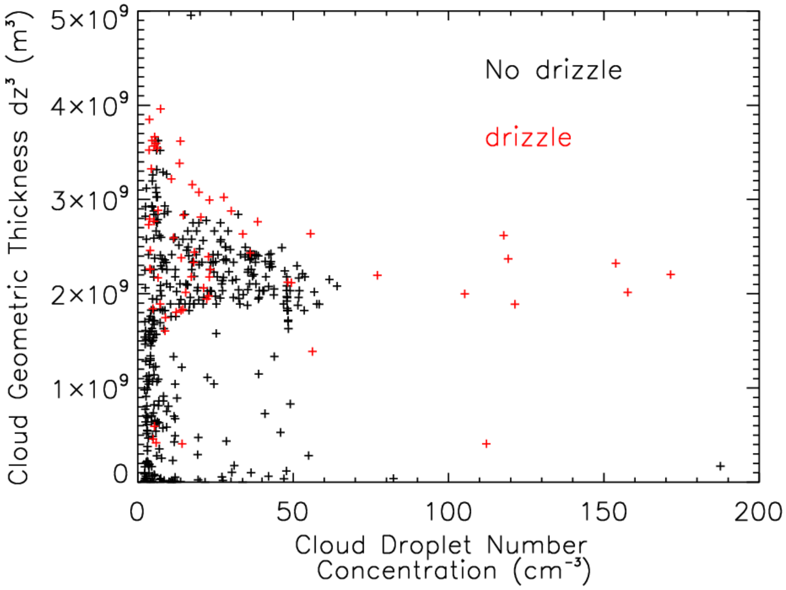
P11L19: With regard to the effective radius retrievals, SMART's absorption channel around 1.6 microns, which has a significant amount of vertical penetration into the cloud relative to 3.7 or 2.1 micron absorption channels. For an adiabatically stratified cloud, the re represents the cloud-top value. So, 1.6 microns would underestimate the true re,LWP and thus N. I understand that it is a limitation of the instrument, but it may be worth mentioning this and how it may impact your retrievals especially when comparing to microwave LWP. It is mentioned in the conclusions on P31 of the manuscript, but would be worth mentioning again in this section.

A: Now the potential bias in the retrieved reff and according estimated N due to the varying penetration depth of the reflected solar radiation is stated in this section.

"The effective radius is derived with the radiance ratio method, using a ratio of measurements at 1050 nm and 1645 nm. Compared to retrievals using larger wavelength, e.g. 2.1 or 3.7mu m, reff retrieved by the SMART measurements does not only represent the cloud particles at cloud top. The vertical weighting function for 1.6 \mu m covers significant amount of information from lower cloud layers (Platnick, 2000). Therefore, retrieved reff are smaller than the actual cloud droplet size at CT which are considered in Eq. 12 to calculate N. This leads to a systematic overestimation of N calculated from SMART measurements."

P19L7: The study used radar measurements to identify potentially precipitating observations. Since Z is more sensitive to larger droplets, it can't easily identify drizzle cases, as you mention. For the cases in section 6, I think it may be helpful to augment the radar with a VNIR ratio of cloud geometrical thickness and CDNC to identify potentially drizzling cases that radar can't identify. Van Zanten and Stevens (2005) for example establishes ratios of H^3/N for identification of drizzle in stratocumuli. For the transition to trade cumuli, this may not be clear-cut, but nevertheless is may help reduce the misclassification of drizzling clouds, which would affect the statistics on retrieved optical parameters.

A: The publications by Van Zanten et al. (2005) and Pawlowska et al. (2003) are mentioned in the text. The correlation of dz^3 on N, as a measure for the drizzle reduction rate, was tested on the data presented in the manuscript but did not show any statistical significant separation for drizzle and non-drizzle sections. As mentioned in the text the retrieval of N will be biased in case of drizzle events and therefore, a separation on basis of retrieved N and the measured cloud geometric thickness is not possible. Despite that, a plot of dz^3 as a function of N is provided here:



"Estimation of the drizzle rate on basis of dz and N as proposed by Pawlowska and Brenguier (2003) and vanZanten et al. (2005) is not possible as retrieved N is biased by the process of drizzle formation and, therefore, not applicable with the presented instrument setup of HALO."

P25: Figure 6. I don't see any mention of it in the body of the manuscript.

A: Figure 6 is now discussed in the text. Mean and median values for the analysis are included and summarized in a table.

"Figures 6a and b 5 show the normalized probability density function (PDF) of LWP retrieved by HAMP and SMART separated for precipitating and non-precipitating clouds. For the non-precipitating clouds, the distributions of LWP retrieved by SMART and HAMP are dominated by clouds below 100 gm. Higher LWP are obtained for regions with precipitation, where the distribution is shifted towards larger values of LWP. The PDF of LWP_A and LWP_B show a dominant mode at around 150 gm-2. A second smaller mode is present for LWP_A at 80 gm-2 and LWP_B at 50 gm-2 for both instruments. The agreement of the LWP retrievals, utilizing reflected solar radiation from CT (method A) and passive microwave measurements (method B), indicate that the cloud microphysical properties are sufficiently determined by the SMART retrieval, despite the assumption of an adiabatic cloud profile in method A."

P32: Of the three methods A,B, & C, which is best? and when? I didn't feel like I got a clear and concise message on that in the conclusions. I feel like the conclusion section broadly covered this, but not concisely.

A: The author tried to formulate the conclusion more precisely and emphasizing the advantage of each method under the specific cases. Simultaneously the length of the conclusion was reduced.

“From the synthetic measurements and the two cloud cases it can be concluded that method A is suggested for optically thin clouds with (LWP < 100 gm3) while method B should be preferred for optically thicker clouds. For homogeneous clouds when the cloud boundaries can be determined precisely from the active radar, lidar, and dropsonde measurements, the resulting gamma_calc can be determined and used as a correction factor in the calculation of N as the optimal case. The synthetic measurements showed that the differences between modeled Ncld and retrieved NC;lib or NC;R with method C, are significantly reduced comparing to method A or B, for all three cloud cases. This indicates that a correction with gamma_calc is vital and necessary for the calculation of N of shallow trade wind cumulus using remote sensing techniques. Otherwise systematic overestimation of retrieved N is present and not feasible.”

Please also see the latex difference file, where the changes become visible in the manuscript.