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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Testing remote sensing on artificial observations: impact of drizzle and 3-D cloud structure on effective radius retrievals" *by* T. Zinner et al.

T. Zinner et al.

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Thank you for you detailed review. It was very helpful (hopefully) to improve the clarity of the manuscript. We first cite your points of critic " " and reply to it after the "–>"

MAJOR CRITICISMS

Point A " The description of the method for evaluating the results of drizzling clouds with respect to their effective radius needs more explanation. The effective radii of the drizzling clouds as presented in table 1 and 4 are calculated for a bimodal distribution. First, the "true" droplet distribution of the cumulus scenes seems different from the droplet distribution that is used in the retrievals (described in section 3). "

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Interactive Discussion

Discussion Paper

–> Yes indeed. I'm not sure, if I understand you correctly: Sure the assumptions of any retrieval do not contain any wide droplet distribution assumptions.

" In order to match the “true” size distribution the reff value of the bimodal distribution is conserved by playing around with reff1 (cloud droplets) and reff2 (drizzle droplets). Therefore the reff1 value seems to be lowered as compared to the reff1 value of the “true” size distribution. Since the majority of the droplets comprise cloud droplets, small modification to reff1 will largely effect the retrieval results. Therefore the authors should aim for a parameterization that does not change the value of reff1 as compared to the “true” value of reff1. "

–> I think you misunderstood us here. We do not conserve any reff value! We try to conserve the total cross section during our fit and just separate the bimodal or long tailed distributions into two modes. Reff1 and reff2 are fixed to values which best approximate the original DSD only once. Liquid water is redistributed to the two modes accordingly. A scene with "no drizzle" just does not use the second mode (reff2 and drizzle-LWC) at all. No recalibration or change happens to reff1 in that case. Our truth "no drizzle" is just reff1 and its cloud-LWC, while the truth with "drizzle" is the full fit with reff1 and reff2 and the complete LWC. This setup is defined as the truth and never changed during the remainder of the paper. The retrieval uses its own fixed narrow size distribution (completely independent from these fitting considerations!).

" Second, effective radius is calculated as the ratio of the third over the second moment of the size distribution. This calculation is most meaningful for clouds with monomodal droplet size distributions, and less suited to describe the particle size of the bimodal distributions of precipitating clouds. "

–> Though your argument is right in a microphysical sense, this definition of effective radius is the almost only one used in radiative transport and remote sensing, because it is the radiatively most meaningful (at least in the solar spectral range). There is no other quantity for particle size derived by any standard cloud retrieval, second modes

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or tails are neglected by all of them. Thus it has to be the basis of our analysis. Apart from that, the majority of all droplet distributions in our data set (compare figure 4) do not show a clear second mode, but rather a tail to the mono-modal distribution.

" Third, assuming a vertical homogeneous droplet distribution is already unrealistic for no-drizzling water clouds, but even more unrealistic for drizzling water clouds. This should be explained clearly in the paper. "

–> You are right again, but all standard retrievals (in particular the operational MODIS retrieval we investigate) do neglect the vertical inhomogeneity. We now mention that in the section "particle size retrieval".

—> We have taken all your points (Point A) as a motivation to revisit the sections in our manuscript and work on the clarity of the descriptions. The changes to the overall structure you propose later, hopefully helps with this as well.

Point B " As written by anonymous Referee #1, there are several studies that find a relationship between drizzle and particle size retrievals. There seems to be disagreement between the findings of these papers. Some see an increase in effective radius, while others hardly find any influence. The impact of drizzle on the particle size retrievals often depends on the set up of the theoretical experiment. In order to verify the sensitivity to drizzle the authors present results of a theoretical study in Figure 7. This is an important Figure, which provides information on the assumptions made in this study. The authors present a droplet size parameterization for drizzling clouds assuming vertical homogeneity. This assumption is verified for 50 cases. However, to verify its applicability for different depth of the precipitating layer within the cloud profile more information is needed. First, the statistics of the 50 samples used (tau, reff_drizzle, reff_droplets) are missing. Second, error bars for the classical and fitted bimodal distributions. Third, an analysis relative to cloud optical thickness, or even better depth of the precipitation layer relative to the cloud top, would be meaningful. Please clarify these points in this section. "

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–> We have added the additional information you requested to the figure and its description. Figure 7 only shows single scattering properties. The whole section is, though it is important, somewhat misleading in the flow of the presentation, we are aware of this. It is no step forward towards our aim to assess the impact of realistic drizzling cloud structures on remote sensing of effective radius, but merely a check of optical properties we have generated with the bi-modal fit. There is no cloud model, i.e., no assumption of vertical homogeneity involved! Only the two numbers in the last paragraph of the old section 4.1 "Optical Properties": "13% (using 1.6 um) and 17% (3.7 um)" are derived from a very quick purely theoretical forward radiative transfer step (using the homogeneous assumption) and successive backward solution (MODIS retrieval application). This numbers are only presented to show the potential of wide drop size distributions to influence the retrieval, a type of numbers others have presented before (Minnis et al. 2004), regardless of cloud structure. From here we go further in including this microphysical/ optical potential into realistic 3D spatial distributions. Restructuring of the manuscript hopefully helped to clarify this. We moved the sections 3. and 4.1 to the "2. Cloud model" part to make clear that we are involved in the construction of our cloud cases at this stage.

MINOR CRITICISMS

Organization of the manuscript

" The research method conducted in this paper can be presented more clearly. One needs to read the paper several times before the study set-up becomes clear. Consider to present the research method in the following order: > LES simulations (section 2) > Satellite reflectance simulation (section 3) > Satellite cloud properties retrieval (section 4.3) > Evaluation method (scattered over several sections) A schematic representation of the study set-up would be very helpful. "

–> We changed the structure to hopefully improve the clarity. Old sections 3. "Separation of cloud and drizzle mode" and 4.1. "Results, Optical Properties" were included

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into the section 2. "Cloud model" as they all describe the setup of our 3D test data sets and only show some interesting intermediate considerations along the way. Section 4.2 and 4.3. are now section 3. "RT: MODIS image simulation and cloud retrieval" and describe the existing tools used or tested. Section 4 "Results" does now concentrate on the main results from the three cloud cases, which starts with a separate description of the evaluation method.

Introduction

- " Page 1224: " This is why some studies suspect . . .." Can the authors shortly quantify the effects of drizzle on particle size retrievals as found in previous studies? "

–> Done here and in the discussions section.

- " Page 1225 (line 26): This important paragraph of the introduction misses references to the investigations mentioned in this paragraph. Moreover, in this paragraph the authors should present the objective of their paper, so as to emphasis the unique aspects of this paper relative to work done in the past. "

–> Marshak et al. 2006 is cited. We have included Ackerman et al. (1998) as a general introduction into MODIS cloud masking. We added an explanation for the statement about 3D effects depending on wavelengths; a reference should not be necessary now.

Cloud model

- " Page 1228 (line 25): Give for the trade cumulus simulations also the range of optical thicknesses that is considered. "

–> On page 1227 (?!) line 25: The real COTs can be seen in Figure 3a and b?

Separation of clouds and drizzle modes

- " In this section it is not clear what the authors assume with respect to the size distribution. To my observation the authors present a parameterization that relates the original vertical size distribution (of the LES model) to a size distribution the may be

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considered representative for drizzling clouds assuming vertical homogeneity. Please clarify this in this section. "

–> This is not the case. We still have 3D inhomogeneous size distributions, an individual size distribution for each box of the LES model. All we do is reduce 25 size bins to two modes of fixed width and certain effective radius. "Effective radius" in the radiative transfer and remote sensing community does not mean more than one paramete describing a full drop size distribution assuming a fixed width. The community is aware that a retrieval from a passive sensor can only provide one effective radius (which might better be called an "effective effective radius"), where a vertical column of several layer's DSDs exists in reality. The retrieved effective radius is thought to be representative for a certain height rather than being a column average or integral. Nonetheless every forward radiative transfer simulation can of course take into account varying vertical (even 3D) DSDs and their related vertical or 3D variations of effective radius. We tried to add some clarity to the section without introducing too much well known detail for the specialist readers.

- " Page 1231 (line 15): How large are the differences in optical properties found by Minnis et al. (2004)? Please quantify. "

–> We have given some numbers.

Results

- " This section needs some re-organization. Section 4.1: Results of theoretical study Section 4.2 and 4.3 (introductory part): present no results but rather descriptions of the operational retrieval method. As with the LES and parameterized droplet size distributions, these sub-sections may be introduced earlier. Section 4.3.1 and 4.3.2: results of the evaluation of stratocumulus and overcast stratocumulus cases. - Page 1233 (4.3 Particle size retrieval): Consider renaming this section to "Optical thickness and effective radius retrieval". "

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–> We have re-organized these sections as mentioned ... and tried to consider your suggestions.

- " Page 1233 (line 15): “ all operational retrievals .. “ can the authors give some more examples of state-of-art operational methods and the satellites they are applied on (MODIS, AVHRR, ATSR, GOES, SEVIRI, ..) "

–> Added two references for the most important.

-" Page 1233 (line 23): “Instead of using the ..” In this paragraph it is not completely clear what settings the authors used for their RTM. Do they assume PP clouds? Do they assume vertical homogeneous clouds? Do they use the droplet spectra as parameterized after the cloud model analysis?

–> This paragraph is now part of section 3 "Radiative transfer: MODIS ...". Yes PPH cloud simulations are replaced by PPH cloud simulations. We tried to straighten this (originally not very good) paragraph to make it more clear to read.

- " Table 2 and 4: The authors find a small decrease in effective radius retrieval for precipitating clouds. This is opposite of the expected effect. This might be related to the parameterization of the droplet size distribution. Where the size of the water droplets is reduced so as to conserve the effective radius value. Is this realistic with what will happen in nature? In order to match the effective radius size, a large number of cloud droplets is reduced in size (e.g. from 12 to 8.5 micron) so as to conserve the effective radius of the drizzling cloud. How would a precipitating layer affect an effective radius retrieval for a “traditional” PP retrieval as done by the MODIS team? "

–> As mentioned above (your major point A), we do not change the cloud droplet radius reff1 within our 3D cloud when we add the drizzle. All that happens is that the large droplets the drizzle part of the DSD is added (reff2) ... thus the "true" effective radius increases everywhere for simulations with drizzle. And we do not see a "small decrease in effective radius retrieval for precipitating clouds"? In table 2 and 4 all but

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two numbers for "drizzle" are slightly larger than for "no drizzle", the retrieved values as well as "truth" values. We also do not keep the LWC of the cloud constant with and without drizzle, which is what you mean, don't you? The LWC fraction of the drizzle mode is just very small compared to the rest of the cloud water.

Discussion and outlook

- " Discuss how the findings of this study are related to findings of earlier studies and explain reasons for the observed differences. "

–> We extended the discussion.

- In order to translate the findings of this study to users of cloud properties retrievals the authors are encouraged to spend some works on the frequency of occurrence of these clouds in nature.

–> We have added an additional figure, giving a hint on the typical optical thickness and effective radius as retrieved from MODIS for marine liquid water clouds

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