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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Study of cloud droplet number concentration using the A-Train satellites" *by* S. Zeng et al.

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General comments: This paper presents a comparison of the CDNC retrievals based on two methods, one using MODIS observation and the other using CALIOP observation. This is an interesting topic and of great importance for understanding aerosol-cloud-precipitation interactions. Although there have been several algorithms developed for satellite-based CDNC retrieval, as far as I know this is the first systematic comparison of two independent retrievals on global scale. As such, it is a significant contribution to the literature. However, as pointed out by other reviewers, there is quite some space for improvement. Please see my comments/suggestion below. I hope after a major revision this paper could become a classic reference for satellite-based

CDNC retrievals.

Major comments: 1) Other than some equations, there is very little introduction or explanation of the retrieval methods. I understand that both methods have been introduced in previous studies, but it is necessary to give the readers some background about the retrieval methods, e.g. their theoretical basis, advantages and limitation, to help the readers understand the results presented later. It is also necessary to give more details about the retrieval algorithms. In particular, it is important to describe the quality control process used to filter the data and the parameters used in the algorithm.

We added more introductory information about retrieval methods and data filtering in section 2. "Overcast water clouds are filtered with a combination of CALIOP, MODIS and POLDER products. In the study we also remove thin clouds with optical thickness of less than 5 as detected by MODIS because those thin clouds have large uncertainties to retrieve cloud optical thickness and effective radius (Zhang et al., 2013)" "CALIOP uses layer integrated depolarization ratio (δ) and droplet effective radius (r_e) to retrieve the CDNC (N, unit: cm^{-3}, see Equation 1, corresponding to Equation 9 in Hu et al., 2007). It is based on the fact that extinction coefficients (β=$r_e^{1/3}$(1+135 δ^2/(1-δ^2)), see Equation 3 in Hu et al., 2007) of water clouds are related to δ and re. Depolarization is related to multiple scattering while droplet size determines the backward proportion of single scatter and absorption. The total extinction (β) is a sum of extinction for each single droplet (β_s=$2\pi r_e^2$). We get droplet number concentration as shown in Equation (1)"

Here are some information I think should be given to the readers: What is the retrieval resolution? MODIS cloud effective radius and liquid water path are made at 1km resolution. CALIOP has a 333m footprint but does horizontal averaging up to 80km to get better signal, POLDER foot print is about 6km but does cloud effective radius retrieval at 200km. Given the dramatic difference of instrument resolution, it is important to tell the reader at which resolution is the retrieval made. How does the resolution affect the CDNC retrieval?

We added the resolution information in section 2 as follows: “In our study, collocated data from level 2 CALIOP/CALIPSO, MODIS/Aqua and POLDER3/PARASOL products was extracted along the CALIOP track at 5km horizontal resolution.” The spatial resolution can impact both r_e and COT retrievals and can impact CDNC retrieval. Larger biases corresponding to a horizontal inconsistency between MODIS and CALIOP spatial resolutions mostly come from heterogeneous clouds, one can also refer to section 4.2. Although the POLDER effective radius is averaged at 200 km, the retrievals can be only obtained for very homogeneous clouds. As clouds are homogeneous at 200 km, smaller biases are related to different spatial resolutions.

How was the liquid water content (LWC) lapse rate computed for the MODIS method? the LWC lapse rate is dependent primarily on temperature and also weakly on pressure. Which temperature is used in the computation? Cloud top temperature? The temperature at cloud base/lifted condensation level? We added more explanations in section 2.2 as follows:

“C_w is an adiabatic lapse rate, which is an function (defined by Grabowski (2007), Appendix A5) of temperature (we used cloud top temperature from MODIS), pressure (we used cloud top pressure calculated from CALIOP cloud top altitude) and water vapor saturation pressure (a function of temperature defined by Linblom, J. and B. Nordell (2006), Equation 8).” We used the MODIS cloud top temperature and the CALIOP cloud top pressure because these two parameters can be directly retrieved from satellite observations.

Which cloud mask and thermodynamic phase products are used to screen out the ice clouds and multiple layer clouds?

We used a combination of CALIOP, MODIS and POLDER cloud products to determine the overcast (Cloud Fraction=1 for MODIS and POLDER) water (liquid water phase from the three sensors) clouds. We added this sentence in section 2: “Overcast water clouds are filtered with a combination of CALIOP, MODIS and POLDER products.”

Doesn’t the CALIOP retrieval algorithm require the cloud to be opaque? Does MODIS have similar requirement? Have the thin clouds been screened out from the comparison?

In theory, the CALIOP retrieval doesn’t require the cloud to be opaque. However for thin clouds, the retrievals of effective radius have large uncertainties. To ensure the accuracy of the MODIS and CALIOP CDNC retrievals, we used “MODIS COT >5” to remove thin clouds, because when COT <5, large uncertainties exist for retrievals of COT and re. We added this sentence in section 2: “In the study, we also remove thin clouds with optical thickness of less than 5 as detected by MODIS because those thin clouds have large uncertainties to retrieve cloud optical thickness and effective radius (Zhang et al., 2013).”

2) What really confuses me is that the authors emphasized several times in different places that clouds are usually sub-adiabatic, i.e. f_{ad}<1 (for example in line 14 on page 29040 it is mentioned “The MODIS CDNC values (derived with f_{ad} = 0.8) are quite close to in-situ observations for stratocumulus over the Chile–Peru coast”). However, f_{ad} is still assumed to be 1 in the retrieval. Why? It is even more confusing to see that later in the discussion the authors attribute some the difference between MODIS and CALIOP based retrievals to the fact that entrainment leads to sub-adiabatic clouds. If so, why not use some more realistic value; say 0.6 or 0.8 for f_{ad} in the first place? Some explanation is necessary.

In our study, f_{ad} is assumed to be 1, which means adiabatic. This is because we don’t have direct measurements of this parameter and its value could differ from region to region. The value 0.8 is from the in-situ observations of stratocumulus over Chile-Peru coast, which is not representative of the whole globe. Since we don’t exactly know how much is adiabaticity degree, it may be better to assume it adiabatic than use a constant 0.8, which allows us to better see the bias directly linked to adiabatic assumption (instead of adiabaticity degree of 0.8).

3) The paper claims that it is a comparison on global scale, but the fact is the comparison is only made over oceans. Is there any particular reason that limits the algorithms to be only applicable to maritime clouds? if so, please explain it to the readers. If not, I'd suggest the authors to add comparison over land.

The objective of our study is to compare the two CDNCs over oceans. CDNC retrievals over land result in less sampling and are not currently satisfactory. Over land, both retrievals of r_e and COT are more uncertain compared to over ocean. Our results also show worse correlations between the two CDNC over land compared to over ocean. (Please see figures below). We changed the title of the paper to "Study of cloud droplet number concentration over ocean using the A-Train satellites". We also adjusted the abstract as follows: "In this paper, r_e values obtained from MODIS/Aqua and POLDER/PARASOL (two passive sensors, components of the A-Train) are used to constrain CDNC retrievals from CALIOP. Intercomparison of CDNC products retrieved from MODIS and CALIOP sensors is performed over ocean,. . ."

Figure 1. Geographical distributions of CDNC derived from MODIS (a), CALIOP (b), and their relative differences (c). The MODIS 3.7μm effective radius is used for the calculation. (Please see fig. 1 below)

Figure 3. Relationship between the MODIS and CALIOP CDNCs over ocean (a) and over land (b). The dashed line is the x=y line, and the solid line is CDNC linear regression line. The color bar represents the logarithm of pixel number. (Please see fig. 2 below)

Specific comments: 4) Line 8 page 29037: Twomey effect requires the total cloud water to be same.

"Increasing the number concentration of precursor aerosols may lead to a decrease in cloud effective radius and, therefore, to an increase in cloud albedo" -> "For the same total cloud water content, increasing the number concentration of precursor aerosols may lead to a decrease in cloud effective radius and, therefore, to an increase in cloud

albedo"

5) Line 13 page 29039: The CLAW hypothesis has been challenged/criticized by many papers. I think it is a good idea to give a couple of references of the other side of the story. See the paper below. Ayers, G. P. Cainey, J. M. The CLAW hypothesis: a review of the major developments. Environmental Chemistry 4, 366–374 (2007).

As the paper discussed potential relationship between CCN and CDNC, we cited it in the introduction as follows: "Recent researches argue on if the marine biosphere plays a non-negligible role in regulating cloud microphysical properties in a pristine oceanic atmosphere, and so far many studies have examined to see biogenic influence on cloud microphysics (Charlson et al., 1987; Lana et al, 2012; Ayers and Cainey, 2007)"

6) If my understanding is correct, the CDNC based on Eq. (1) is the so-called "effective CDNC" which is the product of CDNC and a constant that is related to the effective variance of the cloud droplet size distribution. If so, this needs to be clarified. Same thins for Eq. (2).

Done, we add a sentence to clarify this: "Same to Equation (1), the true droplet number concentration is a product of N_{ad} and k"

7) where does the parameter "k" at line 21 of page 29039 come from? Clarification is needed.

We clarified this in section 2.1 as follows: "As real cloud droplets are not monodisperse distributed, the true droplet number concentration is the product of N and a factor k. k is the ratio of effective radius to volume radius and is assumed constant at 0.6438 in our formula by considering a gamma distribution of the droplets with a effective variance of size distribution (v) equal to 0.13 for MODIS (k=1/((1-v)$\times$(1-2$\times$v)); Hu. et al. 2007)."

8) I think k=(1-v)*(1-2v).

It depends on if it is multiplied by k or divided by k. In our study, we multiplied by k, which is equal to 1/((1-v)$\times$(1-2$\times$v).

9) At line 4 on page 29040 about MODIS effective radius retrieval: Zhang and Platnick, 2011 actually showed that MODIS effective radius bias is dependent on many different factors. Heterogeneity effect is just one of the them. it is not correct to say “Droplet effective radius derived from MODIS tends to be larger than the true value, mostly because of neglecting horizontal photon transport”

“Droplet effective radius derived from MODIS tends to be larger than the true value, mostly because of neglecting horizontal photon transport (the 3-D radiative bias) within heterogeneous clouds (Zhang and Platnick, 2011)” -> Droplet effective radius derived from MODIS tends to be larger than the true value mostly because of neglecting cloud entrainment and horizontal photon transport (the 3-D radiative bias) within heterogeneous clouds (Zhang and Platnick, 2011)

10) In section 3.2, it is difficult to say whether Figure 2 reflects the truly seasonal cycle of CDNC because only one year of data were used in the analysis. If the authors want to study the seasonal cycle, more data should be included. Or, it should be pointed out in the text and in the caption that this is only for the year 2007_2008.

In the caption of Figure 2, we added a sentence to clarify it: “for a year from Dec. 2007 to Nov. 2008”.

11) In figure 3, it seems MODIS CDNC retrieval overestimates CALIOP retrieval. This goes back to my question above. If a smaller f_{ad}, say f_{ad}=0.8 is used in MODIS retrieval (which seems more reasonable to me), MODIS and CALIOP results would be in good agreement. So the assumption about why f_{ad}=1 is used in the MODIS retrieval really needs to calcified and justified.

Reviewer is right. If the MODIS CDNCs are multiplied by 0.8, their values are more comparable with the CALIOP ones. With adiabatic assumption f_{ad}=1, we can directly see the differences due to adiabatic assumption. Adiabatic bias in some regions may be larger than 0.8 while in other regions they may be close to 0.8.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/13/C12794/2014/acpd-13-C12794-2014-supplement.pdf

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 29035, 2013.

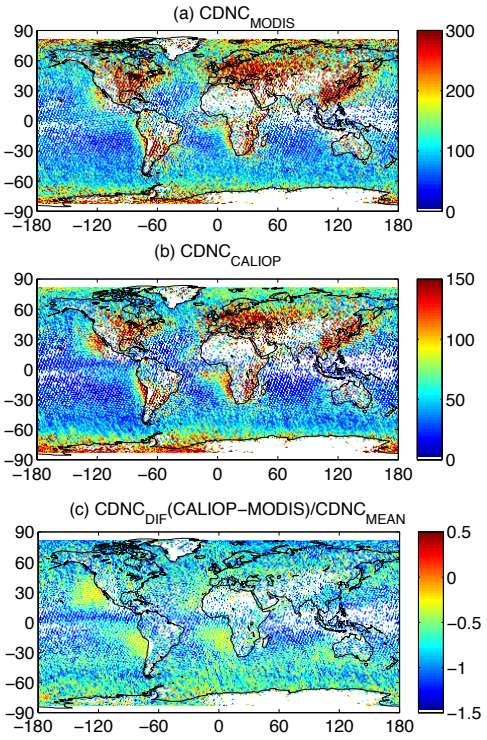
(a) CDNC$_{MODIS}$
(b) CDNC$_{CALIOP}$
(c) CDNC$_{DIF}$(CALIOP−MODIS)/CDNC$_{MEAN}$

Fig. 1.

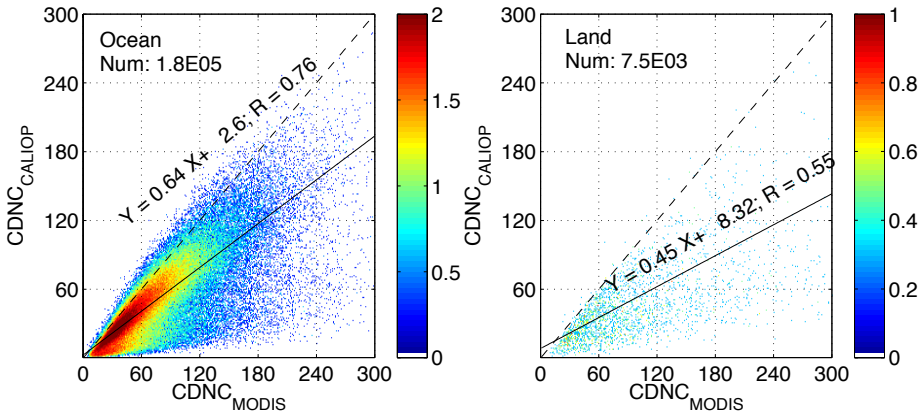
Ocean
Num: 1.8E05
Y = 0.64 X+ 2.6; R = 0.76
Land
Num: 7.5E03
Y = 0.45 X+ 8.32; R = 0.55
CDNC$_{CALIOP}$
CDNC$_{MODIS}$

Fig. 2.