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Interactive Comment

Interactive comment on "A better understanding of cloud optical thickness derived from the passive sensors MODIS/AQUA and POLDER/PARASOL in the A-train constellation" *by* S. Zeng et al.

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We are very grateful to the reviewer for his very careful reading and useful comments that helped in improving a lot our manuscript acp-2012-148 entitled "A better understanding of cloud optical thickness derived from the passive sensors MODIS/AQUA and POLDER/PARASOL in the A-Train constellation".

After discussions with co-authors, the reviewer will find our answers to his suggestions below. The reviewer's comments are given first and followed by our answers.

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Interactive Discussion

Discussion Paper

As a general remark, the authors should explain clearly in the introduction the innovative aspects of their study, in particular in view of the already exisiting cloud climatologies and of the references that already deal with similar topics, (e.g. Zhang et al., 2009; Zeng et al., 2011). Furthermore, figure axes and color scales should be explained in detail.

Actually, this paper follows the research presented in Zeng et al. (2011), which discussed cloud cover differences between MODIS and POLDER. Cloud phase comparisons are discussed in Zeng's dissertation (Zeng, 2011) and should be soon published. As cloud optical thickness is one of the main parameters that characterize clouds, the work ended with COT comparisons. This analysis are part of a larger effort to identify and quantify differences and uncertainties of POLDER and MODIS cloud products in an attempt to contribute to establishment of climate records for cloud properties. In Zhang et al. (2009), COT differences was discussed but only for ice clouds. Here, we present a more extensive study that covers water and ice clouds COT differences. We added the paragraph below in the introduction: "In a previous study, Zhang et al. (2009) discussed COT differences between POLDER/PARASOL and MODIS/AQUA for ice clouds. They concluded that they are principally due to the choice of microphysical model used in the algorithm. Here, we made more extensive comparisons of POLDER and MODIS COT for ice and also for water clouds. We discussed differences not only in terms of microphysical model but also in terms of sensor spatial resolution and viewing geometry. This work follows and is based on previous statistical comparisons of POLDER and MODIS cloud fractions and cloud thermodynamic phases (Zeng et al., 2011a, 2011b)."

P. 11737, l. 25: Are there further differences in the microphysical and optical description of liquid clouds between POLDER and MODIS apart from the fact that POLDER must use fixed effective radii? This is an important information for Sect. 4.2.

Except the difference in effective radius value, there is no other difference between the POLDER and the MODIS algorithms in description of liquid clouds. We added in

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section2: “Concerning liquid clouds, MODIS algorithm uses a natural lognormal size distribution for water droplets with an effective variance of 0.13 while POLDER algorithm uses a gamma distribution with an effective variance of 0.15. Optical properties are computed following Mie theory. The main difference comes from the values of the assumed particle effective radius which vary for MODIS but is fixed in POLDER algorithm with only two distinct values over ocean and land.”

P. 11738, l. 6: POLDER uses a single and fixed Inhomoheneous Hexagonal Model (C.-Labonnote et al., 2000; Labonnote et al., 2001): please explain what you mean by single and fixed, in particular whether a particle size distribution is considered in this approach.

Our previous statement was not clear. POLDER COT derivation for ice clouds is based on the Inhomoheneous Hexagonal Monocrystal (IHM) Model (C-Labonnote et al., 2001), which consists of the optical properties of hexagonal ice crystals containing spherical air bubbles. The paragraph was modified (in section 2): “POLDER uses a fixed model, the Inhomogeneous Hexagonal Monocrystal Model (IHM) (C.-Labonnote et al., 2000, 2001), which assumes that light is scattered by randomly oriented hexagonal ice crystals containing air bubbles aimed at reproducing real crystals imperfections. Optical properties of a single crystal of 40 μm with an aspect ratio of 2.5 are considered. Note that although the IHM model corresponds to a single particle size, it has been designed to provide an optimized global angular consistency of POLDER multi-angle COT retrievals.”

P. 11738, l. 19–22: The averaging procedure for POLDER COT is a weighted averaging according to p. 11748, l. 5–7. This should already be mentioned here.

It is correct. A weighted averaged procedure is indeed applied as mentioned in page 11748. We modified here: “. . ., which is afterward weighted averaged over the 16 directions and provides a mean COT and its standard deviation.”

P. 11738, l. 26–29: Main differences between POLDER and MODIS should also in-

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clude the different viewing geometries of the two instruments.

This was modified in the paper: “The main differences between the POLDER and the MODIS processing lines that can affect the retrieved COT in case of thick clouds are thus the initial resolution (POLDER: 6×7km2, MODIS: 1×1km2), the differences in cloud microphysics assumptions and the ability of POLDER to observe different viewing geometries. ”

P. 11739, l. 5–8: Please give a more detailed explanation of the PM dataset. Even if it can be found in Zeng et al. (2011), it would make it easier for the reader to have it here as well. A part of this description is already given in the present paper anyway. That PM means POLDER-MODIS is obvious, nevertheless it could be mentioned explicitly. In contrast to Zeng et al. (2011), it should be mentioned that only 20×20 km2 pixels that are classified as cloudy or partially cloudy by both instruments at the same time are considered for this study.

We added in section 2: “. . . using the PM (POLDER-MODIS) dataset, which contains both POLDER and MODIS level 2 official cloud products collocated and reprojected on a common sinusoidal grid (Zeng et al., 2011). POLDER single orbit files are used as reference for collocation of coincident MODIS granules. For each individual POLDER product orbit file, the sinusoidal grid used for collocation is centered at POLDER ascending node longitude. Optical thicknesses for both sensors are then averaged at 20×20km2 resolution from the official level 2. Cloud fraction is determined from the initial resolution of each instrument that is from about 3x3 pixels for POLDER and 20×20 pixels for MODIS. Note also, that only 20×20 km2 pixels that are classified overcast cloudy or partially cloudy by both instruments at the same time are considered for this study to limit impact of differences in cloud detection.”

P. 11739, l. 12: With respect to cloud fraction, please explain where this information comes from. For POLDER: is this only the result of the aggregation to the 20×20 km2 pixels? For MODIS: is the 250×250 m2 considered here?

The CF computation is based on the PM dataset at 20×20 km2 from about 3×3 POLDER official level-2 pixels and 20×20 MODIS official level-2 pixels. 250×250 m2 is not considered here as official MODIS level 2 Collection 5 products have been used directly, which to the best of knowledge do not use directly 250×250m2 information (even though some information s reported in individual cloud mask bits). We added at the end of paragraph 2: "Optical thickness for both sensors is then averaged at 20×20km2 from the official level 2 products. Cloud fraction is determined directly for each instrument at their own initial level 2 product resolution that is from about 3×3 pixels for POLDER and 20×20 pixels (at nadir) for MODIS."

P. 11739, l. 15–16 and Fig. 1: It is not clear from Fig. 1 that POLDER COT is generally larger than MODIS COT. Please use the same scale from 0 to 30 in all plots in Fig. 1 and add also some value in the scale between 0 and 30. This sentence is in part contradicted by the next Figures where MODIS shows larger COT than POLDER. Please explain.

Whether POLDER or MODIS COT is larger depends on cloud phase (figure 1). So our statement "POLDER COT is generally larger than MODIS COT" was only true for the cases ice-ice or POLDER-ice/MODIS-liquid. Therefore, we deleted the sentence "with generally higher COT values for POLDER" in the paper. Concerning the color scale, we did not change them, as we want to show that the distributions are similar for the two sensors. With the same color scale, as POLDER COT is much smaller than MODIS one in some cases (i.e. ice clouds), its spatial variation would not be easy to get. The third column in figure 1 shows the COT differences between POLDER and MODIS.

P. 11739, l. 21–22: You say that most of the convective clouds are composed of ice. Please specify this sentence: it is actually the part of the convective clouds that can be seen with passive space-borne instruments that is mainly composed of ice. In the lower part of the clouds liquid water is present though.

We modified here: "...where convections processes are strong. Clouds are vertically

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extended and their tops are primarily composed of ice particle. Passive space-borne sensors in solar and thermal infrared range classify therefore them as ice even if water in liquid phase is present below."

P. 11740, l. 26: You introduce the scaled optical thickness here as well as the asymmetry parameter g (g is not explained here at all). A detailed explanation of the scaled optical thickness is given on p. 11745, l. 22–27. Please move that explanation to this point of the manuscript including eq. 1, which should be inserted directly after where g is the asymmetry coefficient (p. 11745, l. 24).

This was modified in the paper and a definition of the asymmetry parameter g was added.

P. 11741, l. 10–12: Why does POLDER COT increase polewards? Please explain.

Actually, both COTs increase polewards, certainly because thicker clouds are found in storm tracks of both hemispheres. However for the Polder-liquid/Modis-ice phase class, POLDER COT increases more rapidly than MODIS ones. This may be associated to different asymmetry factor g of crystals and droplets. In this case (POLDER-liquid/MODIS-ice), the inconsistency in cloud phase determination leads to larger POLDER COT. We added: "As we will discuss in section 4.2, here positive COT differences (POLDER-MODIS) arise primarily from different asymmetry factor used in the retrieval as a consequence of different cloud phase assumption and effective radius selection."

P. 11741, l. 19–20: Why is there almost no latitudinal variation in POLDER COT? Please explain.

This certainly attribute to the lower spatial resolution and multiangle capability of POLDER, which leads to frequent observation of cloud edges regardless of high or low sun conditions (corresponding to different latitudes). This in turns leads to lower COT and flat latitudinal variation. MODIS however with its high spatial resolution and

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single view retrievals, tend to be more sensitive to cloud edges towards high latitudes where sun is oblique. We added in the text: “As POLDER has a lower resolution and multiangle observation capability, POLDER CF tends to be less sensitive to sub-pixel cloud fraction and most of subpixel holes are not seen regardless of the latitude, generally leading to higher cloud fraction in broken condition and therefore to smaller optical thickness. MODIS with its higher spatial resolution characterizes more fractional clouds and thus finds thicker and more fractional clouds towards the high latitudes. This is consistent with the fact the product COT$\times$CF shows closer variations.”

P. 11742, l. 8–11: Why is there a peak in spring in Fig. 3a? Please explain.

The peak does not appear only in Spring but it exists a seasonal variations. We added at the end of section 3.3: “Clouds are thicker over ocean in winter of the two hemispheres and over land in summer of the two hemispheres. The first may be attributed to frontal system depressions and winter storms. Over land in summer, thicker clouds may be associated to convection that develops in the early afternoon. ”

P. 11742, l. 21 and Fig. 4, 5, 7: Pixel-to pixel comparisons are performed by means of two-dimensional histograms. Please explain this fact and explain the color scale as well. It was modified in the text and in the figure captions.

P. 11743, l. 17: Different spatial resolutions can explain part of the differences between the cloud fractions of the two sensors. Which additional reasons could also explain these differences?

As we explained in the referenced paper (Zeng et al. 2011a), sensor spatial resolution difference leads globally to a cloud fraction difference of about 10% with a higher cloud cover for POLDER compared to MODIS combined mean. We mentioned this because it also impacts COT of broken clouds with POLDER showing globally lower COT. However, it is also true that this is not the only reason causing cloud cover differences between the two sensors. We showed also that cloud fraction differences are regionally influenced by cirrus cloud detection, high aerosol loading, bright surface issues. To be more accurate, we add this sentence in the paper: “As discussed in Zeng et al. 2011a, cloud fraction disagreement is due to the difference in the sensor spatial resolutions, to the misclassification of heavy aerosols loadings or to a bad detection of thin cirrus.”

P. 11745, l. 22: What about differences in microphysical models for water clouds?

Following a previous comment of the reviewer, we already added precisions about liquid microphysical models used in the algorithm in section 2. We reminded them here: “. . .for ice clouds where different microphysical models are used (see section 2). For water cloud, the main difference comes from the particle size which is fixed for POLDER (9μm over land and 11μm over ocean) and determined from its near-infrared channel for MODIS.”

P. 11746, l. 1: Please explain what you have plotted in Fig. 7 (overcast ocean...). It was modified in the text and in the figure captions.

P. 11747, l. 2: Here and in Sect. 4.3 you talk about rainbow directions, but you probably mean cloudbow directions. Rainbows are produced by precipitation (i.e. rain drops) while cloudbows stem from the much smaller liquid water droplets that make up the cloud. Please correct/comment on this. This was indeed a misuse of language. We modified it in the whole paper.

P. 11747, l. 5–19: Please discuss the effect of a fixed ice cloud effective radius used by POLDER for the comparison with MODIS. You also mention in the Conclusions (11750, l. 19) that cloud particle sizes conduct to the main differences between POLDER and MODIS. I think this issue is not clear enough and deserves a more profound explanation.

We added in page 11747, before the 2nd paragraph: “COT retrieval for ice clouds is complex because it depends on the microphysical models used, which present a large diversity in terms of shape and size. The strategy followed in the algorithm of MODIS and POLDER is completely different (Zhang et al. 2009). PODLER used a fixed ice cloud model, the IHM (Inhomogeneous Hexagonal Monocrystal) model, which was found to match, at the best, angular measurements of ice clouds made by POLDER. That implies that the shape, size and thus phase function used in the POLDER algorithm is constant. MODIS, which used several models built from in-situ observations of cirrus clouds (Baum et al., 2005), has variable distribution and size particles that are determined by its near infrared channel. " and few lines below in the 2nd paragraph: "COT is smaller for POLDER compared to MODIS because they use different phase functions with, at 865nm, an asymmetry factor of 0.766 for POLDER and a value between 0.775 and 0.8808 for MODIS. For MODIS, less energy is thus returned backward and the optical thickness of the cloud needs to be higher to match the measurement." In the conclusion, we added: "As POLDER does not measure information on particle size, it uses the fixed IHM model, whereas for MODIS, different size and shape distributions were built with effective radius determined from the near infrared band. The comparison of the quantity of scaled optical thickness confirms the phase function used is of primary importance for the determination of the COT for ice clouds. Use of this product allows to account a part of the difference due to microphysical models."

P. 11748, l. 7–9: Please explain that polar graphs in Fig. 8 represent the azimuth angle (0–360_) and the viewing zenith angle (0–??).

To understand better Figure 8 and 9, we modified the captions: "Figure 8- Polar graphs of POLDER COT for overcast oceanic liquid clouds for different solar zenith angles (1st, 2nd lines and the 1st column of the 3rd lines) and of MODIS COT for all sun incidence angles (lower right corner). Polar angle represents relative azimuth angle between the satellite and the sun (from 0° corresponding to backscattering direction to 359°). Polar radius corresponds to the sinus of the satellite zenith angles (from sin0°=0 to sin90°=1). Colors encode the averaged COT values for a given set of geometries. 0° relative azimuth angle corresponds to backscattering direction. SZA means solar zenith angle range. There is a poor satellite sampling for relative azimuth angles between 240°-300°

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for POLDER and between 60°-120° and 240°-300° for MODIS.”

P. 11748, l. 16: It is not really clear that COTs increase with solar zenith angle since large COT ranges and variabilities are shown. Do you base your assertion on mean COT values? Please quantify this sentence.

We added Table 1: Mean COT computed for the different sun incidences angles represented in the polar graphs in Figure 8 And we also added, just after l.16 “We also observed this in Table 1. In this table, mean COTs for each polar graph are computed and increase from 7.70 for high solar elevation to about 20 for low solar elevation.”

P. 11748, l. 18–19: The 3D effects mentioned here are 3D radiative effects that should be sketched explicitly in addition to the references.

We developed our explanation about 3D effects with this sentence: “...on the other hand due to 3D radiative effects first evidenced by Loeb and Davies (1996) from ERBE observations. They were reproduced with Monte-Carlo simulations by Loeb et al. (1997) and Varnai (2000), which showed a larger increase of 3D nadir and backward reflectances with solar incidences compared to 1D ones leading to a retrieved optical thickness, which increases with solar zenith angles. This is explained by side illumination effects due to 3D cloud structures not accounted for in the plane-parallel cloud approximation used in operational algorithms.”

P. 11748, l. 22–23: Is the COT in forward directions 75% or 50% of the angular mean? What do you mean with forward directions? Is it only the forward direction φ=180âŮę or a range of φ around 180âŮę? Please explain.

To be precise, we explained in the text what we called forward directions : “...thtv > 55° and around phiv=180°” In these directions for low solar elevation, retrieved COT can be as low as 50% of the mean angular value. We modified the text to be clearer.

P. 11748, l. 25: Please illustrate the role of cloud heterogeneity in this context.

References were badly cited, we changed them to Zinner and Mayer (2006) and Varnai (2000). In addition, to illustrate more clearly about cloud heterogeneity effects, we wrote: “This comes partially from the so-called plan-parallel bias. The non-linearity of the reflectance in function of COT leads to an underestimation of the mean optical thickness (Zinner et Mayer 2006). At low solar elevation, the plan-parallel bias amplify or limit the shadowing and illumination effects induced by 3D cloud structures, which respectively decreases or increases the retrieved COT (Varnai, 2000, Varnai and Marshak, 2002, Iwabuchi and Haysaka, 2002).”

P. 11749, l. 11: The rainbow/cloudbow directions should be indicated explicitly using azimuth and zenith angles in order to identify them clearly in the figures.

We modified the sentence and wrote: “In addition, for low sun, we distinguish a bow with smaller COTs in the cloudbow directions located to about 40° from the backward directions (i.e., when sun incidence is 60°, cloudbow is situated for ÏŢ= 0° near 20° of viewing angle).”

P. 11750, l. 25–26: Please make this sentence However,... more explicit.

We deleted this sentence. “However, our study outlines the strong interest to measure the angular variation of reflected solar radiation. ”

Figures: modified in the paper.

Technique corrections: modified in the paper

References: modified in the paper

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 11733, 2012.