Response to Referee #1 for the manuscript: “Assimilating aerosol optical properties related to size and absorption from POLDER/PARASOL with an ensemble data assimilation system”

Dear Editor & Reviewers,

Thank you for reviewing our submitted manuscript. Your comments helped us highlight and clarify some of our results better. Below you can find our responses for all of the raised questions.

Best regards,
Athanasios Tsikerdekis

Format:

Question
Answer
Quoted text, **added/changed text**, ~~removed text~~

Minor revisions:

L121 and L203 Both the retrieval algorithm of POLDER product and the calculation processes of aerosol optical properties in the model include many assumptions (e.g., aerosol model, size distribution, and refractive index etc.). These basic assumptions are consistent? If not, how did the differences affect the assimilation results.

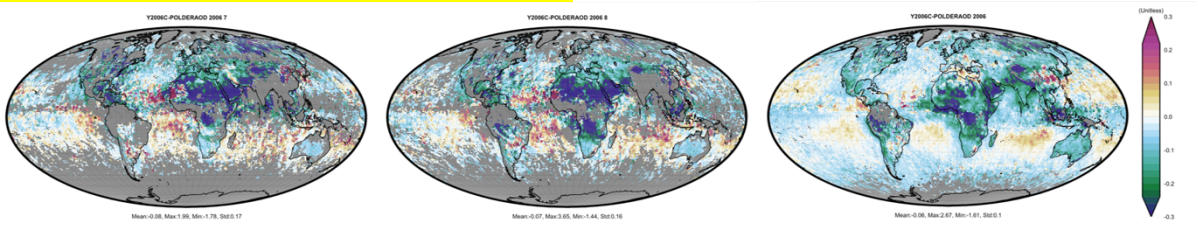
There are some differences. POLDER retrieval algorithm assumes a bimodal lognormal size distribution (fine and coarse) while ECHAM assumes seven size modes (4 for insoluble and 3 for soluble particles) of internally mixed aerosols species. However, the aerosol optical properties we assimilate (AOD, AAOD, SSA, AE) are uniquely defined so there is no ambiguity here. Furthermore in the context of SPEXone (a future Multi-Angle Polarimeter instrument like POLDER), our colleagues retrieved these aerosol optical properties using as input ECHAM-HAM fields (e.g. mixing ratio, number density, refractive index). The differences of retrieved (SPEXone algorithm) and the simulated (ECHAM-HAM) aerosol optical properties were minor. As far as the second part of this question, although very interesting, it is hard to answer within the context of this paper. It would require assimilation experiment under the framework of Observing System Simulation Experiments (OSSEs) where the assimilated properties were retrieved using different assumption in the retrieval algorithm in each experiment.

L345 The authors used randomly perturbed wind to make ensemble members. How about air mass? The wind perturbed method can keep conservation of mass and mechanical equilibrium (e.g., geostrophic balance) produced in ERA-interim?

The wind is perturbed on the nudging data of ERA-interim not on the final wind fields of ECHAM-HAM. Specifically, the wind perturbations is performed by nudging the members of the ensemble into distinct perturbed versions of ERA-interim, thus the mass and mechanical equilibrium for each member is handled by ECHAM-HAM (otherwise the model would crash). Now, the winds in the perturbed ERA-interim versions of course are not consistent in term of geostrophic balance (e.g. ERA-interim perturbed wind and not perturbed pressure do not match), since the wind perturbation was performed as a post-processing analysis on the output of ERA-interim and not by actually creating perturbed runs of ERA-interim. Ideally, the

ERA-interim wind perturbations could be created by having different version of ERA-interim where different observations have been assimilated each time, though this is not available. In our follow-on study we using ERA-5 ten analysis members to estimate wind uncertainty.

L421 It is well known that dust emissions have large inter-annual (seasonal) variations. My concern is that the yearly-mean based rescaling generate additional biases in the simulation.
Thank you for that comment. This is indeed true, especially for dust emissions that fluctuate a lot seasonally. Although note that rescaling factors are only used to remove yearly biases. The timing of dust storms depend on meteorology (e.g. wind speed, soil moisture etc) and it is not affected by these rescaling factors. Plots below show the differences between POLDER – ECHAM for July (left), August (middle) and the whole year of 2006 (right). The positive emissions factor for dust over desert (~1.3) based on the differences of POLDER – ECHAM for the whole year, indeed add biases at some locations in the simulation (Western Sahara). Although in the majority of the Sahara sources, rescaling factors decrease biases, so we consider this scaling still as an improvement compared to not-scaling dust emissions. In addition we chose to use rescaling factors based on a yearly evaluation since our next goal is to expand our experiment for the year 2006.



L459 Subsection 4.2?
Yes, thank you for pointing this out.

L477 Figure 5i should be Figure 5l?
Yes, we have corrected it.

L477 At first, could you explain why MASS caused a large positive bias in the South Atlantic that CONTROL did not cause.
Thank you for that comment. The positive bias over South Atlantic in the MASS experiment is caused by transport. The assimilation of AOD over the Tropics increases aerosol mixing ratio which is then transported by the westward flow over South Atlantic. Now, the assimilation of AOD over South Atlantic should compensate some of that effect by decreasing aerosol mixing ratio, but the results show that assimilating just AOD is not enough to sufficiently resolve that. The inclusion of other observations in the assimilation proves that they provide the additional constrain needed to limit the overestimation of AOD over South Atlantic due to transport. The following explanation was added to the manuscript.

Overall local biases are decreasing after assimilation, however over certain areas biases can be increased, for example over South Atlantic ocean in the MASS experiment (Error! Reference source not found.**h). The assimilated AOD_{550} over Africa in the Tropics increases the aerosol mixing ratio over land, which is then transported westward over South Atlantic. The assimilation of AOD_{550} over South Atlantic should be compensating some of that effect by decreasing the aerosol mixing ratio, but evidently not sufficiently.** ~~On the other hand, it is very important to note that~~ The assimilation of other aerosol optical properties like AE_{550}-

$_{865}$ and SSA_{550} reduce the South Atlantic positive AOD_{550} bias, especially in the case of the TOTAL experiment (**Error! Reference source not found.**l), indicating that the simultaneous assimilation of multiple variable can **improve** the simulated AOD_{550} ~~global~~ spatial representation **in some places**.

L484 You did not show any validation result about aerosol mass mixing ratio.

Aerosol mass mixing ratio is not evaluated. But it is the state vector in the data assimilation and its adjustment leads to a better agreement in AOD. The sentence in question was modified for clarity:

The consistent improvement of AOD_{550} in the assimilation experiments demonstrates ~~ability of the assimilation system to adjust aerosol mixing ratio regardless of~~ **that the inclusion of** different combination of assimilated observations **does not negatively affect AOD_{550}.**

L516-518 What does this mean? Was there problem in BC simulation (e.g., refractive index)? Did model underestimate other aerosol species (e.g., organic aerosols)? Could you make this clear?

Thank you for the opportunity to clarify that. The assimilation of AOD_{550} will adjust the aerosol mixing ratio only based on aerosol's extinction and not on aerosol's absorption. A good example to illustrate this is the Amazon basin where CONTROL experiment underestimates AOD and overestimates AAOD. The assimilation of only AOD will lead to an increase of aerosol mixing ratio, hence AAOD will be increased too (increasing also the overestimation of AAOD further). The paragraph in the manuscript was rewritten to cause less confusion

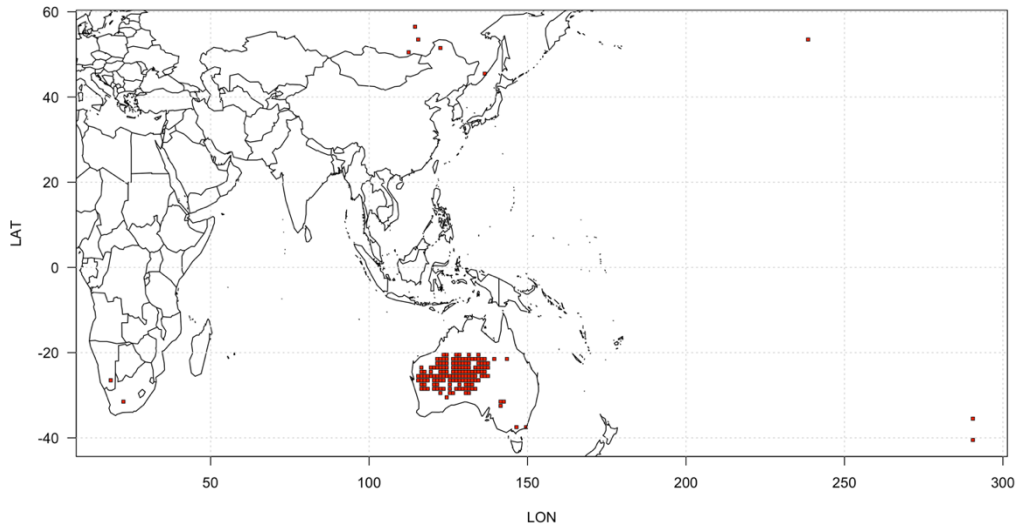
It is interesting to note that in the MASS experiment the AOD_{550} is improved (Error! Reference source not found.**h), but SSA_{550} and $AAOD_{550}$ not so much, especially in regions like South America, Africa and the Atlantic Ocean (**Error! Reference source not found.**h,** Error! Reference source not found.**h). The reason behind that is easiest to explain over South America, where AOD_{550} is underestimated and AAOD (SSA) is overestimated (underestimated) in CONTROL. The assimilation of AOD_{550} (MASS), will increase the aerosol mixing ratio of all aerosols based on their extinction, but it will not account for their absorption. Thus AAOD will be increased along with AOD since more aerosols will be in the atmosphere.** Specifically, in the Amazon basin SSA_{550} of the MASS experiment decreases by 0.032 in comparison to CONTROL, since the BC column burden becomes 4 times higher (FigureS 7b), while the difference of SSA_{550} between POLDER and the model (spatiotemporal collocated points only) increases from -0.084 to -0.117 (FigureS 7c).

Figure 4 It's the wrong way around.

The caption in the figure has been corrected.

Figure 17f Why does MODIS-DB underestimate AODs where POLDER estimates AOD as about 0.1?

The majority of these AOD values are located in the desert area of Australia. The map below depicts the data points of Figure17f that satisfy the following AOD ranges 0.08 < POLDER < 0.12 AND 0.01 < MODIS-DB < 0.02. Different assumptions of the surface albedo by the retrieval algorithms may be causing this high differences between MODIS-DB (low) and POLDER (high) retrieved AOD. Although it is a very interesting topic, it is out of the scope of this paper, thus discussion was not added in the manuscript.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