***Interactive comment on* "Multi-satellite aerosol observations in the vicinity of clouds" *by* T. Várnai et al.**

**Anonymous Referee #3**

The authors analyze the contribution of aerosol particle size and number concentration changes, 3D effects, and the effect of the MODIS instrument point spread function (PSF) to increasing MODIS reflectances as a function of distance from clouds. They use MODIS and CALIOP data and show that real aerosol changes contribute 70 to 85% of the increase and 3D effect and instrument PSF account for the rest. The paper is short and well written. I have comments clarifying some issues. With this the revision including these clarifications, I suggest publishing the manuscript.

Thank you very much indeed for the thoughtful and helpful comments and suggestions!

My concern and question are how the inconsistency of cloud detection by MODIS and CALIOP is handled. On page 5 line 20 to 22, the authors describe that the analysis uses MODIS cloud mask. As a consequence, there must be cases when CALIOP sees no cloud at all when MODIS has cloud contaminations. If this happens and backscatter is averaged including these cases, increasing the CALIOP signal toward clouds is diluted. Is there any possibility that the difference between MODIS reflectance and CALIOP backscatter increase is due to this? If cloud contaminated

MODIS pixels are excluded from the analysis, it has to be stated clearly because MODIS data users have no way to screen such pixels unless they co-locate CALIOP data. For that reason, the result of this study is cleanest possible estimate of the contribution of aerosol, 3D, and PSF effect. The error in the aerosol optical depth, for example, by cloud contaminations might be much larger than the 3D and PSF contributions described in this manuscript.

The analysis excludes all pixels where the MODIS cloud mask indicates the presence of clouds, even if the CALIOP sees no clouds at all. In other words, the study only uses pixels where the MODIS mask indicates no clouds. It is quite likely that—as mentioned in the paper—some of these pixels do in fact contain undetected cloud droplets. However, we think that undetected cloud droplets affect CALIOP data even more than MODIS data. This is because even when the MODIS mask is correct in declaring a pixel cloud free, the corresponding CALIOP measurement may be cloud contaminated as (*i*) clouds may drift or develop during the 1-2 minute difference between MODIS and CALIOP overpasses (*ii*) the colocation of atmospheric columns observed by MODIS and CALIOP is not perfect, for example due to differences in view directions and exact footprints. In turn, a larger cloud contamination for CALIOP than MODIS strengthens near-cloud increases more for CALIOP than for MODIS. Therefore cloud contamination cannot cause the difference between MODIS reflectance and CALIOP backscatter increase near clouds—if anything, it makes us underestimate this difference. To address this issue, we included the following sentences into the discussion of Figure 6a:

“The second reason why we may overestimate the blue area is that since we use the same MODIS cloud mask for both MODIS and CALIOP data, cloud contamination may give a larger boost to CALIOP near-cloud enhancements: Differences in CALIOP and MODIS field-of-views and clouds drifting or developing during the 1-2 minutes between MODIS and CALIOP observations may result in cloud droplets affecting CALIOP data even if MODIS data is cloud free.”

**Other minor comments:**

Page 2 line 9 to 11: The statement is misleading since a large part of direct radiative effect comes from dusts, which are present with no direct relation to clouds.

To clarify this, we expanded the sentence to “This study examines systematic cloud-related changes in particle properties and radiation fields that influence satellite measurements of aerosols in the vicinity of low-level maritime clouds.”

Page 3 line 13: Particle populations. I suggest using number concentration.

We couldn’t find “particle populations” in page 3 line 13, and so we didn’t change the wording.

Page 7 line 18: Instrument effect. This effect is called several different ways, including instrument blurring, point spread function. I prefer a use of the point spread function.

We see the reviewer's point and we made the wording more consistent—although our preference was to replace "point spread function" by "blurring" in Figure 6. (We kept "point spread function" in the paragraph just below Equation (1), where the text refers to the actual function.)

Page 8 line 9 through 16: This section describes things are not included in the simulation. Please add things that are included in the simulation.

The key process included in the simulations is described in page 32047 of the original ACPD paper, in lines 6-9. We added to the description of things not considered in the simulations (lines 14-18) a brief reference to the things included, and so the text now says "At present, the simulations include only cloud and Rayleigh scattering, but not aerosol and surface scattering."

Page 9 line 8 and 9 and equation 1: This is a big assumption since aerosols are submicron particles, i.e. the size equivalent to the wavelength. It assumes that the relative change of backscatter is the same as relative change of the phase function of the angle between the sun and nadir view. It works for the overhead sun but is there any theoretical base for this assumption for other angles?

This is a very good point: The assumption of the same relative change in lidar backscatter and solar reflectance is not fully accurate when there are near-cloud changes in particle size distributions. (In contrast, the assumption is inherently accurate when only particle number concentrations change near clouds, as the corresponding changes in volume scattering coefficients cause the same relative change in single-scattering reflectances for any source-detector geometry.) The concern is that when the particle size changes, the scattering phase function can change differently for lidar backscatter (180° scattering angle) and solar reflectance (in our study, ~132° scattering angle).

To examine this issue, we calculated the ratio of phase function values for 132° and 180° scattering angles ($P_{132°}/P_{180°}$) as we increased the particle size through hydration for the nine aerosol models used in MODIS dark target aerosol retrievals. (These models are described in the Remer et al. (2005) paper referenced in our manuscript.) To simulate particle size changes for each of the nine models, we increased the radius of particles by 33%. We then calculated new refractive indices for the swollen aerosol populations using the hydration method described in Gassó et al. (2000), and performed Mie calculations for the new size distributions and refractive indices. Since the scattering coefficient is roughly proportional to the second power of radius, increasing the radius by a third causes the scattering coefficient to increase by ~78%, which is similar to the largest enhancements observed in Figure 4 of the manuscript.

Figure R1 below shows the $P_{132°}/P_{180°}$ ratios for each of the nine MODIS aerosol models, with lines connecting the results for original radii and the radii increased by 33%. The results show that the $P_{132°}/P_{180°}$ ratio values drop for all models except Model 8, which is a dust-like model unlikely to dominate our global dataset. The drop for all other aerosol models imply that as particles grow, the changes in phase function should boost the CALIOP signal more than the MODIS signal. This means that the phase function effect cannot explain why near-cloud relative enhancements are larger for MODIS reflectances than CALIOP backscatter. Instead, the results suggest that, since without the phase function effect the CALIOP curve would be even more below the MODIS curve, our assumption overestimates the blue area in Figure 6a—that is, the contribution of real particle changes to the observed MODIS reflectance enhancements. (We note that similarly to the simulated hydration process, the $P_{132°}/P_{180°}$ decreases if the coarse mode fraction increases due to the presence of undetected cloud particles.)

As the MODIS product puts the average fine mode fraction of our dataset to 58%, the magnitude of the phase function effect may be a bit closer to the small values for fine mode than the larger values for coarse mode aerosol models—and might boost the ratio of enhancements in CALIOP and MODIS data by 10-20%. We hope to revisit this issue using more detailed data analysis of the upcoming Collection 6 MODIS aerosol product.

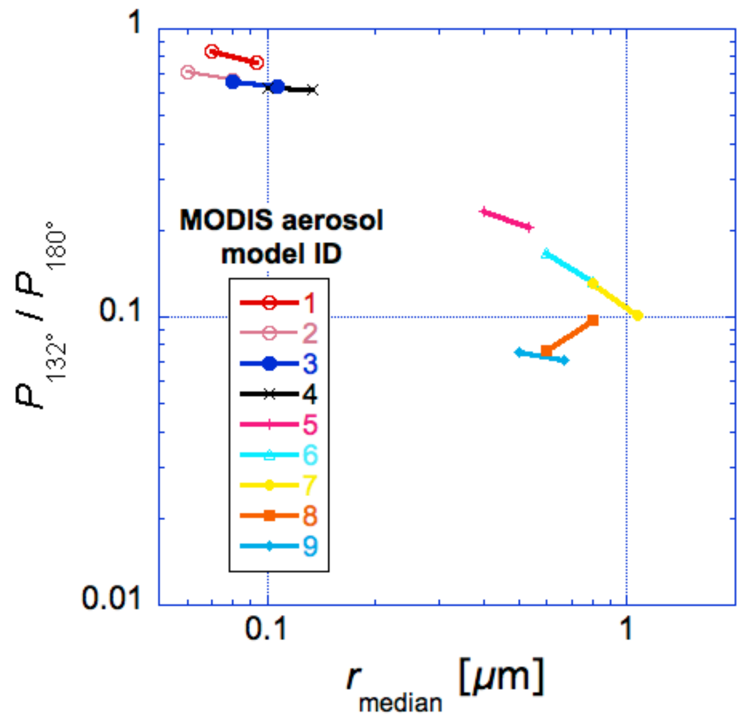


Figure R1: The effect of particle size changes on phase function values for MODIS and CALIOP scattering angles.

To discuss this issue, we added the following paragraph to the manuscript just below Eq. (1):

“We note that using Eq. (1) likely overestimates the blue area for two reasons. First, the equation doesn’t consider that near-cloud changes in particle size can change the scattering phase functions differently for lidar backscatter and for MODIS solar reflectance. The comparison of Mie calculations for the nine MODIS aerosol models (Remer et al. 2005) and for modified versions of these models where particle size is increased according to hydration calculations (e.g., Gassó et al. 2000) suggests that ignoring phase function changes has especially strong effects for coarse mode aerosols, and might overestimate the blue area by 10-20%—though this issue will require further detailed analysis. The second reason why we may overestimate the blue area is that since we use the same MODIS cloud mask for both MODIS and CALIOP data, cloud contamination may give a larger boost to CALIOP near-cloud enhancements: Differences in CALIOP and MODIS field-of-views and clouds drifting or developing during the 1-2 minutes between MODIS and CALIOP observations may result in cloud droplets affecting CALIOP data even if the corresponding MODIS observation is cloud free. As a result, the blue area is considered a likely overestimate or upper bound of enhancements due to particle changes."

Page 10 line 20: I am a little bit bothered by the use of 2/3 here while percentages are used for others. Looking Figure 6c, the aerosol contribution is 70 to 85% to me. I suggest changing 2/3 to 70 to 85% including the abstract.

Indeed, the figure seems to suggest that two-thirds is at the low end of particle effects. However, as we now point out in the new paragraph just below Eq. (1), we likely overestimate particle effects (see our response just above), and so two-thirds feels a safer rough descriptor. To clarify this point, we added the following sentence to the discussion of Figure 6c: "As discussed above, however, these results are likely to slightly overestimate the real particle effects and will need to be refined in future studies."

References:

Gassó, S., Hegg, D. A., Covert, D. S., Collins, D., Noone, K. J., Öström, E., Schmid, B., Russell, P. B., Livingston, J. M., Durkee, P. A. and Jonsson, H. (2000), Influence of humidity on the aerosol scattering coefficient and its effect on the upwelling radiance during ACE-2. *Tellus B*, **52**: 546–567. doi: 10.1034/j.1600-0889.2000.00055