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Atmospheric Chemistry and Physics Discussions

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

**Anonymous Referee #1**

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**Review of "Multi-satellite aerosol observations in the vicinity of clouds" by Tamás Várnai, Alexander Marshak, and Weidong Yang**

This paper analyzes MODIS and CALIPSO observations of aerosol optical property variability in the vicinity of clouds. As stated in the manuscript introduction, this is an important problem to better understand aerosol-cloud interactions and the direct radiative effect of aerosols as well as to improve satellite retrieval algorithms which need to account for the variability in aerosol properties near clouds. The topic of this paper is thusly relevant and within the scope of Atmospheric Chemistry and Physics. Previous studies which are summarized in the introduction show that aerosol properties are consistently observed to change in the vicinity of clouds which is caused in part by true changes in aerosol properties and in part due to instrument effects. Crucially, a



consensus has not been reached in the literature on the relative contributions of each of these components within the observations.

The authors therefore present a novel method to partition MODIS observations of aerosol variability near clouds into separate components and assess the contributions of each. MODIS observations of near-cloud aerosol changes depends on particles changes in the near-cloud environment, 3-D radiative effects, instrument blurring, and "other" reasons not identified. Two of these components in particular are estimated in a novel manner in this paper. First, the authors use CALIOP observations of enhanced backscatter near clouds to describe particle changes in the near-cloud environment under the valid assumption that CALIOP is not affected by the 3-D effects or instrument blurring which in turn allows them to estimate the portion of the MODIS reflectance enhancement ascribed to particle changes and the reflectance enhancement due to the other effects. Secondly, the contribution of 3-D radiative enhancements due to molecular scattering are estimated using a Monte Carlo model with the MODIS cloud mask along the CALIOP ground track. Though this model does not include the effects of aerosol and surface scattering, it does quantify the minimum contribution due to 3-D radiative effects which is very useful and enlightening approach.

The conclusions drawn by the analysis – that nearly two-thirds of near-cloud enhancement is due to changes in aerosol properties and the remaining contribution is due mostly to 3-D radiative effects and instrument blurring – is an important step forward in understanding MODIS aerosol observations near clouds. These conclusions are based on valid assumptions and methods. The text is clearly written throughout with well-constructed and appropriate supporting figures. Most of my comments below are to encourage the authors to provide a few more details to ensure that the paper completely describes the methods in a manner that is easily reproducible by other researchers. These additions can be easily implemented by the authors and should not inhibit consideration for publication. It is a very solid paper in its current form.

Altogether, this is a strong paper that makes important advances in the understanding of observations of aerosol near clouds. Based on the thoroughness of the analysis, novelty of approach, and importance of results I recommend this paper for publication in Atmospheric Chemistry and Physics after the authors please address my comments.

**Specific comments:**

1. Attenuated backscatter is being used, but is called backscatter. For clarity, explicitly state that attenuated backscatter is used where applicable.
2. State which versions of CALIPSO and MODIS data are being used.
3. Page 32041 (lines 5-6): I suggest adding [Su et al., 2008] to this list of references as it is the first paper (or at least one of the first papers) to average lidar data as a function of distance to cloud.
4. Page 32044 (line 6): Aerosol number concentration can increase near clouds due to detrainment of cloud-processed particles into the cloud-free environment. This should be mentioned as another cause of differences in aerosol near clouds versus far from clouds. What impact would this have on the spectral dependence explanations of figure 2?
5. Page 32040 (line 22): Instrument blurring should be briefly defined somewhere. The Meister and McClain 2010 reference does not call the effect being described as "instrument blurring".
6. Figure 1 a-b caption: Units should be included for integrated backscatter coefficients.
7. Figure 1c: This histogram using the MODIS cloud mask to determine distance to the nearest cloud looks a lot like the histogram in [Varnai and Marshak, 2011, Fig 1(a) inset] that uses CALIPSO to determine the distance to the nearest cloud.



Perhaps this should be mentioned as a way to further support the decision to use the MODIS cloud mask for the analysis rather than the CALIPSO cloud mask.

8. Figure 1 a-b: Why integrate everything below 3 km in altitude? The method should be better explained. If the cloud exists between 0.5 – 2 km, then why is data above 2 km and below 0.5 km included in the integration? Does this assume that the transition zone around clouds occurs the same vertically as it does horizontally; i.e. the rates of change in color ratio and attenuated backscatter are the same vertically as they are horizontally?
9. Section 2: What was used to cloud-clear the CALIOP data? The CALIOP vertical feature mask? The MODIS cloud mask? Please be specific.
10. Page 32044 (line 15): Clarify that it is horizontal resolution being degraded, as in: "degraded from 333 m to 1 km horizontal resolution."
11. Page 32045 (line16): What are the vertical limits of integration of the backscatter? Is the entire column from 40 km to the surface integrated?
12. Page 32045 (line16): Though it is a matter of preference, the most commonly used symbol for integrated backscatter is gamma instead of beta. Consider changing symbols to $\gamma^{P}$ instead of $\beta^{P}$ to be more consistent with other lidar literature [Platt, 1973, p. 1197] and CALIPSO documentation.
13. Page 32045 (line24): More details should be given in the text on how the contributions of surface reflection and Rayleigh scattering were removed from the 0.55 $\mu$m reflectance values. Is there a reference you could also include describing the Collection 6 algorithms which consider wind speed? Perhaps Levy et al. [2013]?
14. Figure 3a caption: Please list the latitude/longitude domains used for the four regions.

15. Page 32046 (line 10): The additional MODIS near cloud enhancement could also be caused by cloud contamination; i.e., a pixel identified as clear when it in fact contains cloud. How well does MODIS cloud identification perform for these low level clouds and how would it impact the MODIS near-cloud enhancements? This should be mentioned in somewhere in the paper (not necessarily here).

16. Figure 4: The vertical axis shows the relative enhancement in terms of $R^{\mathrm{P}}$ when both $R^{\mathrm{P}}$ and $\beta^{\mathrm{P}}$ are plotted (or if you change symbols as suggested in comment 12, $\gamma^{\mathrm{P}}$). Change the vertical axis label or figure caption to accurately explain what is plotted. Maybe place the relative enhancement equation in the caption using the variable x where x can be either $R^{\mathrm{P}}$ (red curve) or $\beta^{\mathrm{P}}$ (blue curve).

17. Page 32046 (lines 17-19): I do not think the calculation of the percent by which MODIS enhancements exceed CALIPSO enhancements in Figure 4, yielding 40-45%, is correct. The closest distance to cloud in Figure 4 shows a CALIOP relative enhancement of 60% and a MODIS relative enhancement of about 85%. Since these are both relative enhancements normalized to 20 km, MODIS relative enhancement exceeds that of CALIPSO by 25%; i.e. 85% $-$ 60% = 25%. I believe the authors calculate the percent difference of the enhancements using (85% $-$ 60%)/60% = 0.42, or 42%.

    However, I think that MODIS enhancements exceed CALIOP enhancements by the difference of relative enhancements in Figure 4 which is around 15-25% in the nearest 5 km. Can the authors please clarify why the difference should not be used? Additionally, if the difference should be used, should lines 18-19 read "...explain roughly three-quarters" as opposed to "two-thirds"?

18. Page 32047 (line 1): The enhancement in cloud fraction leads to a 0.05 increase in clear sky optical depth not cloud optical depth according to [Chand et al., 2012]. This should be corrected.



19. Page 32047 (line 19): Please include more details on how the 15-25% enhancement due to the simulated 3D component was calculated. Is the range due to the varying solar zenith angles? Do we need to know the average 0.55 $\mu$m reflectance at 20 km? Include enough information so the reader can take the numbers in Figure 5a-b and confirm a 15-25% enhancement.

20. Page 32048 (lines 5-6): The text says the black lines shows the nadir reflectance over the median reflectance at 20 km away from cloud. The word "over" sounds like you are taking a ratio when you are in fact taking the difference between the nadir reflectance and median reflectance at 20 km away. Change the language here to better describe the figure.

21. Page 32048 (line 6): Include the median reflectance observed 20 km away from clouds so the reader can calculate percent changes.

22. Figure 6a caption: This is an important figure. It would be worth re-iterating that the solar zenith angle of the MODIS observations was less than 30 degrees (is that right?). Also, consider making the font size larger on the figure itself.

**Typographical comments:**

1. Page 32051 (line 28): Change "are important in the at least half of all clear areas" to "are important in at least half of all clear areas".

**References:**

Chand, D., R. Wood, S. J. Ghan, M. Wang, M. Ovchinnikov, P. J. Rasch, S. Miller, B. Schichtel, and T. Moore (2012), Aerosol optical depth increase in partly cloudy conditions, Journal of Geophysical Research, 117(D17).

Levy, R. C., S. Mattoo, L. A. Munchak, L. A. Remer, A. M. Sayer, and N. C. Hsu (2013), The Collection 6 MODIS aerosol products over land and ocean, Atmos. Meas. Tech. Discuss., 6(1), 159-259.

Platt, C. M. R. (1973), Lidar and Radiometric Observations of Cirrus Clouds, Journal of the Atmospheric Sciences, 30(6), 1191-1204.

Su, W., G. L. Schuster, N. G. Loeb, R. R. Rogers, R. A. Ferrare, C. A. Hostetler, J. W. Hair, and M. D. Obland (2008), Aerosol and cloud interaction observed from high spectral resolution lidar data, Journal of Geophysical Research: Atmospheres, 113(D24), n/a-n/a.

Varnai, T., and A. Marshak (2011), Global CALIPSO Observations of Aerosol Changes Near Clouds, Geoscience and Remote Sensing Letters, IEEE, 8(1), 19-23.

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