February 6, 2012.

Dear Editor and Reviewers,

Thank you for considering our manuscript entitled “Analysis of co-located MODIS and CALIPSO observations near clouds”, and for preparing such thoughtful reviews. We appreciate the general comments, which capture the essence of our manuscript very well, and we are grateful for the specific comments, which greatly helped improving the manuscript. While, for brevity, our detailed response below describes only the action we took in response to each specific comment, let us mention here that we heartily agreed with the suggestions and thought that the points raised in the reviews were very good indeed.

Thank you again for all your help with the manuscript.

Sincerely,

Tamás Várnai

Reviewer 1, Dr. Jason Tackett

General Comments

This paper describes synergistic use of CALIOP and MODIS data to quantify the distance between clouds over global oceans and to thereby establish a sphere of influence that clouds have on surrounding aerosol properties. Using a statistical relationship based on MODIS observations to correct CALIOP observations of aerosol changes in the vicinity of clouds as the authors have reported is a novel idea and is critically important at interpreting satellite retrievals of this behavior.

Given the importance of the scientific issue discussed (reconciling the influence of clouds on aerosol optical properties) and the novel, synergistic techniques employed using satellite data, I concur that this paper addresses scientific questions within the scope of AMT. The contribution that this paper makes to this topic is clearly evident and attribution is given appropriately to related studies.

I believe that the assumptions employed in analyses of the two satellite datasets are valid though I ask for some elaboration on one assumption in specific comment 1 below. The description of analyses is thorough enough to be reproduced by fellow scientists, though I ask the authors to please expand on their description in specific comment 3 for enhanced clarity. I believe that the main conclusions follow logically from the authors' arguments. All content within the manuscript is relevant – I see no need to reorganize or remove any portions.

Based on the strength of the manuscript and the scientific importance of the topic discussed, it is my recommendation that this article be published within the AMT journal, provided the authors please respond to my comments below which I hope will help enhance the clarity of an already solid article.

Specific Comments

1. P. 6864 line 14: Please provide a justification as to why only the 1 km resolution CALIOP cloud mask was used and why the 5 km resolution CALIOP cloud mask was not used.

We added the following sentences to the manuscript: "*We note that CALIOP also provides a 5 km-resolution cloud mask, which is especially effective in detecting thin cirrus clouds. Since this advantage is less critical in our study (as discussed in Section 3, we examine the vicinity of low-level clouds), the 1 km mask is used, which (i) accounts for small cloud-free gaps in cumulus fields, (ii) provides the distance to nearest cloud at a higher resolution (iii) makes comparisons to the 1 km-resolution MODIS cloud mask easier.*"

2. It would be informative to show the number of samples that went into Figure 3 and Figure 5 either in the manuscript or in an online supplement. If most clouds are separated by 4-5 km, then it seems that there would be relatively few 'clear air' regions 20 km away from clouds. Perhaps just stating that "x samples were included at 1 km from clouds and this number reduced by y% to z samples at 20 km from clouds" would be sufficient.

We added the suggested information to the captions of Figures 3 and 5, which now include the sentences "*The number of used lidar profiles is in the 50,000-150,000 range near clouds, but decreases to about 13,000 for the bin 20 km away from clouds.*" and "*The plot is based on the yearlong global dataset, with the number of used lidar profiles decreasing from over 4 million near clouds to just under 300,000 12 km away from clouds*.", respectively.

3. P. 6866 line 24 -27: Please elaborate on how CALIOP data was averaged with varying distance from cloud edge and used to create Figure 3 and Figure 5. Based on how this analysis was conducted in the three papers cited, attenuated backscatter and color ratio were recorded from cloud top to cloud base with varying distance from cloud for each individual cloud and then medians were computed from samples recorded at identical altitudes. Finally, the median backscatters are integrated from a higher to a lower altitude. Taking the words of the manuscript literally, this is not so clear because these details are in the cited works. It would be tremendously helpful to give more details of how this calculation was accomplished here – even if in just a sentence or two – so the procedure is clear based on this paper alone.

We added the sentence "*The displayed median values are obtained by first vertically integrating backscatter values for each 1 km-size column, and then determining the 50th percentile value of all columns that lie within a certain distance bin.*" to the manuscript.

Technical Corrections

1. Throughout the manuscript, the word "backscatter" is used for the quantity "attenuated backscatter". This may cause some confusion because there are both "backscatter" and "attenuated backscatter" products reported from CALIOP data. So that readers understand exactly which CALIOP product is used, please call the quantity "attenuated backscatter" everywhere it is mentioned as "backscatter", or (perhaps the better option) add something like this to P. 6864, line 16: "(called "backscatter" throughout this paper for brevity)".

As suggested, we added the clarification "(*called "backscatter" throughout this paper for brevity*)" to the paper.

2. P. 6867 line 14: For clarity, please change, "(and hence lidar backscatter)" to "(and hence high lidar backscatter)".

Done.

3. P. 6870 line 9: It may be clearer to say “grow closer together” instead of “grow closer”. Just a suggestion.

Done.

4. P. 6872 line 15: If I understand correctly, please replace “We plan to report on a such follow-up study. . .” with “We plan to report on such a follow-up study. . .”.

Done.

5. Figure 3 vertical axis label: It would be more accurate to label this axis as “Integrated Median 532 nm CALIOP backscatter (/sr)” At first look I thought the units were wrong because backscatter has units of /km/sr, but because this is actually integrated backscatter with units of /sr, the units are correct. Modifying the label would alleviate this confusion for other readers.

We changed the axis label to “*Median vertically integrated 532 nm CALIOP backscatter*”.

6. Figure 4 (a): Please state that the data going into this figure is for the entire year dataset in the caption.

We added the text “*based on the yearlong global dataset*” to the figure caption.

7. Figure 5 caption: Replace “Median CALIOP backscatter” with “Median CALIOP color ratio”. Also, please clarify, were the 1064 nm and 532 nm median backscatters integrated and then the ratio was taken of the two integrated quantities to obtain the color ratio in the figure?

We corrected the caption so it now refers to “*color ratio*” instead of “*backscatter*”. We also added the sentence “*Vertically integrated color ratio is calculated as the ratio of vertically integrated backscatters at 532 nm and 1064 nm*.” to the figure caption.

Reviewer 2

General comments

This paper combines data from the passive MODIS imager, and the active CALIOP lidar, in order to better understand the observed radiative behaviour near clouds, for low clouds (lower than 3 km). First, the authors carefully co-located MODIS and CALIPSO data, using CALIPSO WFC (wide field camera) and considering possible cloud drifting due to the orbit time gap between the two instruments. Then, they compared the MODIS and CALIPSO WFC's reflectance at the wavelength of 650 nm, showing nice agreement and explaining the slight differences in a convincing way.

The heart of this work includes analysis of two optical features as a function of the distance from low clouds: CALIOP backscatter at 532 nm, and CALIOP color ratio (backscatter ratio between 1064 nm and 532 nm). The presented results show a sharp decrease of the lidar 532 nm backscatter as a function of the distance from cloud. The decrease slope and behaviour of the lidar backscatter when increasing the distance from clouds is found to be dependent on the source of the used cloud mask (the examined cloud masks are MODIS 2D mask, MODIS 1D mask based on CALIPSO's orbit, and CALIPSO's 1D mask). The differences found due to the selected cloud masks are properly discussed and presented.

Furthermore, the authors present similar behaviours in the lidar color ratio, and suggest a statistical correction scheme that enables the prediction of the color ratio as a function of the 2D distance from the nearest cloud, based on the 1D distance from the nearest cloud. This scheme may be very useful for future research, when a large dataset is available.

Finally, the authors present a global analysis of cloud fraction and median distance from clouds (of low clouds) above oceans, based on MODIS cloud mask. They show a significant seasonal variability of these parameters and explain some of it with the spatial typical distribution of the analyzed cloud fields.

This paper presents new techniques that can be used for future research, based on existing space-borne instruments. This paper also presents, for the first time, global spatial analysis of low cloud fields. This work's research objective is in the most important area of interest for the research of the transition zone between clouds and cloud-free atmosphere, which is essential for measuring and understanding the total radiative effect of cloud fields.
Therefore, I recommend this paper to be published in Atmospheric Measurement Techniques, with reservation to the authors' response to my comments below, in hope that my comments could help the authors to improve their paper.

Specific comments

1. P. 6862 lines 2-21: Authors should define all abbreviations in abstract (MODIS, CALIOP, CALIPSO), and not only in P. 6864 lines 4-7.

Done.

2. P. 6862 line 21: The value of the mean distance to the clouds, as masked, is valuable. However, the authors should be careful when they use the terminology of "clear sky areas", while later in the manuscript they mention the possibility that these areas may contain "hard-to-detect cloudy cases" (P. 6867 lines 15-20).

We changed the wording from "*maritime clear sky areas*" to "*In maritime areas perceived cloud free*".

3. P. 6863 lines 2-8: Here, the authors present several factors that may affect aerosol size distribution near clouds. I think that the readers would better understand each factor if they had references for the proposed mechanisms affecting aerosol size near clouds.

We included four additional references into the sentence so now it reads "*Several factors can alter particle populations in the vicinity of clouds, for example aerosols swelling in the humid air surrounding clouds (e.g., Twohy et al. 2009, Jeong and Li 2010), aerosol particles merging after cloud droplets merge through coagulation and then evaporate (e.g., Kerkweg et al., 2003; Tackett and Di Girolamo, 2009), a few large particles lingering around after a cloud dissipates (e.g., Xue et al., 2008), and even a few droplets appearing before stable clouds could form (e.g., Koren et al. 2009)*."

Kerkweg, A., S. Wurzler, T. Reisin, and A. Bott, 2003: On the cloud processing of aerosol particles: An entraining air-parcel model with two-dimensional spectral cloud microphysics and a new formulation of the collection kernel, *Q. J. R. Meteorol. Soc*., **129**, 1–18.

Jeong, M. J., and Z. Li, 2010: Separating real and apparent effects of cloud, humidity, and dynamics on aerosol optical thickness near cloud edges. *J. Geophys. Res*., **115**, D00K32, doi: 10.1029/2009JD013547.

Xue, H., G. Feingold, B. Stevens, 2008: Aerosol Effects on Clouds, Precipitation, and the Organization of Shallow Cumulus Convection. *J. Atmos. Sci*., **65**, 392–406. doi: http://dx.doi.org/10.1175/2007JAS2428.1

4. P. 6865 lines 3-9: It is mentioned that a time gap of 72 seconds may result a difference in the images of MODIS and CALIPSO due to cloud movement by winds, and a very nice correction algorithm is presented for fixing this problem. I wonder if 72 second gap may also influence the difference between the images because of cloud formation or evaporation processes, in particular in small cloud fragments which are probably very common in the transition zone (Koren et al., 2008). Perhaps the authors can add this point to the discussion.

Following the suggestion, we added the sentence "*We note that such errors can be further heightened by cloud formation or evaporation during the 72 s between satellite overpasses, especially in the case of small cloud fragments that are quite common in the transition zone (Koren et al., 2008)*."

5. P. 6865 line 21: If this work concentrates in cloud whose top is up to 3 km, as I understand from the caption of Fig. 3, the authors should state it clearly in this line.

To clarify this, we expanded the wording so that the sentence now says "*This study, however, focuses on clouds below 3 km, and we found that the drift exceeds 1 km for less than 10 % of scenes containing only clouds below 3 km.*"

6. P. 6868 line 2: Koren et al., 2007 found the mentioned scales using twenty MODIS granules. The authors are suggested to add to this reference Bar-Or et al., 2011, who found similar scales using global MODIS dataset, with separation between cloud field types.

We added the suggested reference.

7. P. 6870 lines 1-2: The present correction for 1D data presented here is very impressive, but the authors, who stated that it's "statistically account for clouds lying off the CALIOP track", should stress out it may be done only for large statistical set, for a yearlong period, and that the correction may be dependent on the cloud field type (or maybe elevation).

We added the sentence "*We note that the rescaling parameters vary with cloud type*."

8. P. 6870 lines 21-25: The authors are requested to define "summer" and "winter" by specifying dates.

We added the sentence "*We note that winter and summer calculations use data from the December 1-February 28 or June 1-August 31 periods, depending on the hemisphere*."

9. Table 1: The authors are requested to define "summer" and "winter" by specifying dates.

We added the sentence "*Winter and summer data are based of the December 1-February 28 or June 1-August 31 periods, depending on the hemisphere*." to the caption of Table 1.

10. Fig. 5: If this analysis was done on the same dataset that was used for Fig. 4, please mention it. Otherwise, please mention the data time range.

We added the clarification "*The plot is based on the yearlong global dataset*, …" to the caption of Figure 5.

11. Fig. 6(a) and Fig. 6(b): The authors are asked to expand the description of the data used for the analysis presented in these figures. For example, did you calculated the cloud fraction from the 1 km MODIS cloud mask product, or used the cloud fraction product provided by MODIS for coarser resolution? It seems that the resolution of Fig 6 is around 1 degree. Can it be finer using MODIS high-resolution products?

We expanded the figure caption to include the sentences "*Both panels are based on the 1 km-resolution MODIS cloud mask and the MODIS cloud top pressure product (with low cloud top pressure exceeding 700hPa). Panel a uses a 2D*

search to determine the distance to clouds." The resolution in the figure is indeed 1 degree. While a higher resolution would certainly be possible, we chose 1 degree out of the concern that the map becomes increasingly noisy as the resolution increases.

12. Fig 6(a): The authors are asked to describe in the caption whether they have used MODIS or CALIPSO cloud mask for this panel.

We included into the figure caption the clarification "*Both panels are based on the 1 km-resolution MODIS cloud mask…*".

13. Fig 6(a): If MODIS data were used for this figure, it seems to me that the high distance from cloud values close to the poles may be a result of cloud mask data artifacts, caused by ice covered surface. I would suggest the authors to recheck the data quality in these areas and exclude the biased data points from this analysis.

We fully agree with the reviewer's hypothesis about artifacts at high latitudes. Although we forgot to mention it in the original manuscript, out of the same concern we actually used data only from latitudes less than 60° on either hemisphere. To clarify this, we expanded the first sentence in Section 2 to "*This study analyzes a yearlong (November 2006-October 2007) global dataset of daytime satellite data over all oceans free of sea ice between latitudes 60° South and 60° North*."

Technical corrections

1. P. 6865 line 18: please replace ")." with".)".
2. P. 6865 line 27: please replace ")." with".)".
3. P. 6868 line 21: please replace ")." with".)".

In all three cases, the manuscript has already included ".)", and so no change was necessary.

4. Fig. 2: please keep consistency on the axes labels (e.g. mention that MODIS reflectance is R_{MOD} in all axes etc.).

We followed the suggestion and made the labels consistent by using R_{MODIS} and R_{WFC} along all axes.

5. Fig. 4(a) and Fig. 4(b): please keep the same axes scale, so that the slope differences would be clearer. Also, please use the same line width for the linear fits in all panels.

In order to make the slope differences clear, we changed the vertical axis of Figure 4a. The ranges of vertical axes are now 80% of the range of horizontal axes in both panels, which makes the slopes visually comparable.

6. Fig. 4(c): please add date and time of the presented MODIS image.

We added the sentence "*The image was taken by the MODIS instrument on the Terra satellite on November 22, 2003, at 16:40 UTC*." to the figure caption.

7. Please keep consistency in the manuscript when describing area segment sizes ("XX km by YY km" or "XX km x YY km").

We changed the caption of Figure 4, and so now the entire paper consistently uses "XX km by XX km".

8. Please keep consistency in the manuscript and choose either "distance from clouds" or "distance to clouds".

We changed the phrase "*at given distances from clouds*" to "*at given distances to clouds*". As a result, the manuscript now uses "*distance to clouds*" in all cases except for the expressions "*XX km away from clouds*", for which we couldn't find a simple replacement expression involving "*to*".

References

Koren, I., Oreopoulos, L., Feingold, G., Remer, L. A., and Altaratz, O.: How small is a small cloud? Atmos. Chem. Phys., 8, 3855-3864, 2008.

Reviewer 3

General comments

This work presents a method to account for lack of across-track sampling by CALIOP, to better quantify changes in aerosol properties as a function of distance from the nearest cloud. Data employed in this study are CALIOP and MODIS cloud masks, CALIPSO (WFC) and MODIS reflectance at 650 nm, and CALIOP integrated attenuated backscatter at 532 and 1064 nm. The MODIS data provide spatial context in the across-track direction. Analysis of combined CALIOP and MODIS data yields a method to scale CALIOP measured distances to clouds, to account for the influence of clouds lying off the CALIOP track.

Results from this analysis are a valuable contribution to the study of aerosol-cloud interactions and aerosol radiative effects in the vicinity of clouds, and provide a new and innovative method to advance the study of these climatically important atmospheric processes. I would recommend this manuscript for publication, and would request that suggestions put forward in the following sections be considered by the authors as a way of improving the clarity of their manuscript.

Specific comments

While the authors analyze a year's worth of data for ice-free oceans, a portion of these data will include clouds with cloud-top-height (CTH) > 3 km, especially in tropical ocean regions. It would be helpful to include a sentence describing the author's approach to high cloud screening, e.g., was there a requirement that an entire MODIS swath contain no clouds with CTH > 3 km?

To clarify this issue, we added the sentence "*We note that since high clouds are unlikely to influence low-altitude lidar returns from nearby cloud-free columns, the analysis considers clear-sky columns even if high clouds occur nearby, but the distance to cloud is always calculated as the distance to the nearest low cloud*." to the manuscript.

P. 6862 Line 20: For clarity, it would be good to state that this result applies only distances to clouds with CTH ≤ 3 km.

We added this clarification, and so the abstract now includes "*In maritime areas perceived cloud free, the global median distance to clouds below 3 km altitude is in the 4-5 km range*."

Figure 4 a) and Figure 5: Please include the geographical region represented by these figures in the figure captions.

We added to the figure captions of Figure 4a and 5 the clarifications "*based on the yearlong global dataset*" and "*The plot is based on the yearlong global dataset*", respectively.

Figure 6 b): Please clarify how this cloud fraction is calculated. Is it low cloud fraction of MODIS pixels comprising only confident clear and low cloud pixels?

To clarify this, we expanded the figure caption, which now includes the sentences "*Cloud fraction of low clouds*" and "*Panel b considers as cloud (clear) the MODIS cloud mask values "probably cloud" and "confident cloud" ("probably clear and confident clear")*".

Technical corrections

P. 6865 Line 26: Remove parentheses and change "," to ", i.e.,"

Done.

P. 6870 Line 29: Change "over all oceans" to "over all ice-free oceans".

Done.

Figure 6 b): Please reword the caption for Figure 6b): "cloud fraction of low cloud" is not clear.

We greatly expanded the figure caption, which now includes "(b) *Cloud fraction of low clouds. Both panels are based on the 1 km-resolution MODIS cloud mask and the MODIS cloud top pressure product (with low cloud top pressure exceeding 700hPa)*." and "*Panel b considers as cloud (clear) the MODIS cloud mask values "probably cloud" and "confident cloud" ("probably clear and confident clear")*."