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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Exploring the differences in cloud properties observed by the Terra and Aqua MODIS sensors" *by* N. Meskhidze et al.

N. Meskhidze et al.

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We would like to thank reviewer for his/her comments. We have done our best to address each of the points as detailed below.

Note: All reviewer comments in italics. All responses by the authors in normal font.

Major Comments:

1. The treatment of atmospheric conditions (or lack thereof) is extremely disappointing. The authors make the assumption early on that averaging over large spatial and temporal scales remove the influence of atmospheric conditions on the results. I strongly disagree with this. Atmospheric conditions can vary significantly in the 3 to 4 hours between Terra and Aqua overpasses greatly influencing cloud properties. You do acknowledge this in the paper, but fail to analyze its importance relative to the aerosol

effects. Somehow, you need to quantify the effects of changes in atmospheric conditions have on cloud and aerosol characteristics, which can be independent of any aerosol; cloud interactions, This is a difficult process, but if it can be shown that would greatly enhance the overall impact of this work.

We totally agree with the reviewer. Manuscript did not include detailed discussion of climatic effects that are known to be controlling factors for diurnal cycle of marine stratocumulus. As the results shown in the manuscript represent averages over 7 years, it was anticipated that day-to-day weather variations - which can be effectively considered to be stochastic "white noise" in this context - should not produce systematic bias that could influence the conclusions. However, if morning-to-afternoon variations in cloud amount and liquid water are associated with regular meteorological conditions (such as regular and marked subsidence in subtropical southeast Pacific), untangling the responses of clouds to regional-scale variations in aerosol abundances from dynamical forcing becomes increasingly difficult. This is particularly challenging for remotely sensed studies, since air masses that exhibit different aerosol properties usually have different histories and are invariably subject to covarying meteorological conditions. Figure 3 in the revised manuscript suggests that days characterized by elevated AODs may also be associated with enhanced afternoon reduction of clouds. To examine the potential contribution of aerosols and dynamical forcing, we have selected a stratocumulus cloud region off the coast of Peru. Previous studies show, that off the coast of Peru and northern Chile vertical velocity at 850 mb level is a good indicator for the diurnal cycle of subsidence (Garreaud and Muñoz, 2004; Bretherton et al. 2004) and therefore large-scale vertical pressure velocity (Pa/s) at 18 UTC (closest to the Aqua overpass) was chosen for as a proxy for the subsidence in our analysis. The vertical velocity at 850 mb level was obtained from National Centers for Environmental Prediction (NCEP) reanalysis data, regridded to 1° to 1° resolution and separated based on MODIS retrieved AOD as "clean", "moderately polluted" and "heavily polluted".If the subsidence is solely responsible for the observed variation in morning-to-afternoon differences in cloud properties for different AOD cases, one expects to

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see the comparable variation in the magnitude of omega and the morning-to-afternoon changes in cloud properties. Figure 4 shows 7-year averaged omega fields (Pa/s) at 1800 UTC (1200 - 1300 LT) and MODIS observed morning-to-afternoon differences in CF and COT plots segregated by the aerosol loading. While location and seasonality of the subsidence (regions with positive omegas) are in a general agreement with the detailed modeling studies (e.g., Garreaud and Muñoz, 2004), Fig. 4 does not indicate the robust relationship between the subsidence and the morning-to-afternoon variation in cloud properties for different aerosol loadings (see also Auxiliary material Fig. S5). Considerable distinction in large-scale subsidence for different aerosol loadings was also not established for 12 and 18 UTC differences in omega fields (not shown). While it is practically impossible to fully separate aerosols from meteorology, and it has been established that climatic factors are controlling location and diurnal cycle of marine stratocumulus, our results indicate that increased aerosol concentration may lead to enhanced reduction of afternoon cloud coverage and optical thickness. This result is consistent with the recent modeling studies suggesting potential reduction of aerosol indirect forcing in polluted stratocumulus clouds (Ackerman et al., 2004; Lu and Seinfeld, 2005; Sandu et al., 2008; 2009).

2. The uncertainty in aerosol retrievals in the vicinity of clouds needs to be discussed in greater detail. You do note that greater uncertainties exist, but you need to explain somewhere how these uncertainties would specifically impact the interpretation of your results. In any satellite-bases assessment of aerosol and cloud interactions, this uncertainty is a necessary evil. You do attempt to take these into account by removing AOT < 0.8, but I believe you may be introducing further sampling uncertainties by doing this. In essence, you may be missing the highest aerosol concentrations, which would be causing the greatest indirect effects.

We agree with the reviewer. The text has been modified to better explain the steps taken for the reduction of the uncertainties in aerosol retrievals in the vicinity of clouds. See our response to comment 7 below regarding the removal of the AOD > 0.8 values.

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Finally, the detailed modeling studies for the aerosol impact on marine stratocumulus clouds show that initial increase in aerosol loadings (corresponding to cloud droplet number concentration (CDNC) from 50 to 500 cm-3) has strong effect on diurnal evolution of the cloud and on temporal and specially averaged cloud properties. However, increase of CDNC > 500 cm-3 (corresponding to polluted cases) does not demonstrate significant change in diurnal variation of cloud properties (e.g., Lu and Seinfeld, 2005; Sandu et al., 2008).

3. Throughout the paper, you show important evidence to support your hypothesis that indirect effects differ between Terra and Aqua overpasses. That is fine, but given the degree of uncertainties present and the poor treatment of atmospheric conditions, I don8217;t think the hypothesis has been proved beyond a reasonable doubt. The results and conclusions need to be reworded to state that the results provide important evidence for differences indirect effects between morning and afternoon, but further research is necessary to fully assess its importance relative to other factors. (I will highlight several occurrences where wording should be modified to reflect this in the Specific comments below.)

See our response to comment 1. We have also reworded conclusions to highlight the fact that while climatic factors are controlling diurnal cycle of marine stratocumulus, our results indicate that increased aerosol concentration may lead to enhancement of afternoon reduction of cloud coverage and optical thickness.

Specific Comments:

4. P 1489, lines 10-15: The sentence starting with 8220;For the vast areas 8230;8221; does not seem to make sense. Are you saying that the presence of aerosols double the reduction of cloud fraction and COT compared to other factors? If so, please state this more clearly.

The text has been modified.

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5. P 1491, lines 19-20: I don8217;t know if I would use the word 8220;intradiurnal 8221;. I think it would be better to just say that we are analyzing differences between morning and early afternoon conditions rather than give the read a false sense that any true time-series analysis is being performed.

The word "intadiurnal" was changed to "morning-to-afternoon" in the revised paper.

6. P 1492, lines 20-28: See major comment 2 concerning the treatment of atmospheric conditions. If you are going to continue with this assumption, please provide some more quantitative assessment of its implications. A single reference to a 10+ year old paper is not enough.

We have provided more quantitative assessment and detailed discussion of the processes believed to be responsible for aerosol induced enhancement of afternoon reduction of marine stratocumulus cloud fraction and optical depth.

7. P 1493, line 8: How much data are removed by using the AOT < 0.8 threshold? Does this introduce any spatial or temporal sampling biases?

We have examined the histograms for AOD distribution (see Auxilary material Figure S1) to show that the number of data points removed by using the AOD <0.8 threshold is negligible and has no considerable effect on liquid cloud fraction or optical depth calculations. We have also modified text to explicitly address this point.

8. P 1493, lines 17 8211; 20: Is it really necessary to fill in missing AOT pixels with surrounding data? How much data does this add? I suspect the results would be similar without doing this, and I believe this interpolation opens an unnecessary can of worms. (If the results are significantly different if missing pixels are not filled in, then that is a major problem).

If the grid box was completely covered by the clouds and no AOD retrievals were available, we used an average of AOD data from the surrounding 1° resolution boxes. Such procedure was implemented to maximize the number of satellite retrievals. Since from

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the time the manuscript was first put together almost two years of additional satellite data became available, we removed the interpolation and discarded the boxes completely covered by clouds. As can be seen from the new figures, the changes in the results are insignificant.

9. P1494, lines 2 8211; 3: 8220;Despite this, there are no known large uncertainties 8230;8221; is a very strong statement, and needs to be backed up by some additional references and/or further discussion.

The additional reference has been included.

10. P1496, lines 24-25: Discuss cloud contamination issues in greater detail here.

See our response to comment 2.

11. P1497, lines 2 8211; 4: Remer in GSRL observed the opposite results, can you explain why yours are different. (I8217;m not saying you are wrong, I8217;m just curious where the difference is).

We believe the reviewer is confused. Remer et al. (2006) paper is about the comparison of Terra and Aqua MODIS aerosol optical thickness over the oceans, here we compare Terra and Aqua MODIS COT and CF. We do not compare AODs. None the less the word and was changed to with; to avoid confusion. Now it reads "...morning-to-afternoon changes in CF and COT, with AOD..."

12. P1497, lines 18 28: You need to show whether or not the 20 30

We have carried out several case studies to examine the vertical distribution of aerosols with respect to clouds. Our studies show that in all three stratocumulus regions aerosols are typically located below the cloud layers. The exception is the region off the coast of South Africa (SAF), where periodic very high AODs are associated with aerosols well above the cloud deck and occasional high aerosol concentrations over stratocumulus clouds decks off the coast of california (CAL) (see auxiliary material Fig. S5). However, during such episodes (particularly over the SAF region) AOD was often

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> 0.8 and therefore, data points were removed from the analysis by the AOD < 0.8 threshold filter.

More statistical data is included in revised Table 1. The t-test was perfomed to show that all means are statistically significant at 95

13. P1498, lines 1-10: Continuing from the last comment, are you saying that since elevated aerosols in the form of dust are located above the stratus deck, then micro-physical indirect effects are unlikely and semi-direct effects or more likely. This would be true, but I don8217;t see any evidence in this paper that vertical distributions in each region fits with your conclusions. You may very well be correct, but more detail is required in the portion of the discussion. It is also important to quantify the relative importance seasonal changes in CF, COT and other factors on your results. It is possible that some of these other factors are the dominant signal with indirect effects being only a secondary factor.

More details are provided in the revised version of the paper.

14. P1498, line 26: Which studies are you referring to?

There were no references to any studies on Pg. 1498 line 26. Authors would appreciate more specifics regarding this comment.

15. P1501, lines 27-28: AOT and ice cloud fraction both increase from morning to afternoon, but I do not agree that the results in Figure 6 necessarily prove that smoke is increasing convection. Is there a significant relationship between Aqua ice cloud properties and AOT? If your hypothesis correct, there should be.

Auxiliary material Fig. S8 can be used as an indication for the possible connection between Aqua ice cloud optical depth and AOD. However, as discussed in the manuscript, we believe that not only the absolute values, but the observed significant spatial contrast between far northern corner of the Amazon basin and so called "arc of deforestation" need to be considered.

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16. P1502, lines 15 8211; 25: Again the results show that AOT and cloud properties vary in accordance with each other, but it does not necessarily imply that the difference are a result of aerosols interacting with clouds. These changes could also be part of the natural variability of aerosol and cloud properties.

See response to comment 1.

17. P1503, lines 2-4: Remove :this is the first time8230;8221;

Fixed in the revised version. Now it reads "...this is the first time we have seen MODIS satellite confirmation of the process occurring"

References:

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