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Atmospheric Chemistry and Physics Discussions

Interactive comment on "A six year satellite-based assessment of the regional variations in aerosol indirect effects" *by* T. A. Jones et al.

T. A. Jones et al.

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Response to Referee #2

Summary: We appreciate the reviewer’s indepth comments and have made substantial changes to the manuscript based on these concerns. Much of the text has been revised to improve clarity and conciseness, while better explaining certain key aspects of this research. In particular, the discussion of uncertainties associated with near coincident retrievals of aerosol and satellite properties has been greatly expanded (see below). Other significant changes include the addition of daily atmospheric conditions and improvement in statistical significance testing. Specifically, we now calculate AIE for thick vs. thin clouds and regions of general rising vs. sinking motion. Vertical velocity is used as a proxy for favorable atmospheric conditions for cloud formation, and as such we hypothesis that increased upward motion should correspond to greater AIE.

For regions where AIE occurs, it is greatest for the thick-cloud, upward motion sample. To keep length manageable, the discussion concerning two regions (Western Pacific and Southern Pacific) was removed as they had very similar characteristics to the Western Atlantic and Southern Indian Ocean, whose discussions remain. With respect to using satellite retrieved aerosol and cloud properties for AIE research, we recognize that there are limitations. To address this, we have discussed various uncertainties in detail and devised a test based on MODIS fine mode fraction values to determine where or not the aerosol – cloud relationships observed were large enough to require explanation beyond the known uncertainties. In most cases, this threshold was met indicating that we are indeed observing actual microphysical interactions between aerosols and clouds. Responses to specific comments are given below.

Major Comments:

1. The Abstract has been revised to better reflect the results presented in the text. However, we believe that a large body of research exists [IPCC 2007] to say that aerosols do have significant impacts on clouds properties and that “may” be unnecessary.

2. See #1

3. The introduction has been heavily revised to improve readability and provide additional focus. For example, discussion of previous AIE research has been broken down into modeling, in situ and ground-based, and satellite sections. Also, we have restated the goals of this research in more of a hypothesis-based form. The introduction now explicitly states that the goals of this study are to calculate AIE for several regions, determine where or not that AIE is a function of cloud and atmospheric conditions, and finally determine if any significant difference exists between dust and anthropogenic AIE.

4. Yes, using a 20x20 km2 footprint does allow for pixels that may be only partially filled with clouds and/or aerosols, resulting in greater uncertainty in AOT retrievals in mostly-

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cloudy cases. We elected not to remove AOT values with cloud fractions of 80 or 90% since they account for a large portion of the data (see Figure 2a) and it is under these conditions that AIEs are most likely to be occurring. Instead, we developed a test using the change in FMF as a function of cloud fraction to determine impact of hygroscopic aerosol growth on the relationship between aerosol and cloud properties. The result of these tests was that in environments where large concentrations of anthropogenic and hygroscopic aerosols exists, FMF decreases approximately 15% from completely clear to almost completely cloudy pixels. Thus, we conclude that for the relationships between aerosol and cloud properties to be significant if the differences are greater than 15% over the given range of values.

5. The greatest uncertainty with this and any research documenting aerosol indirect effects using primarily satellite data is the lack of completely independent, coincident, measurements of aerosol and cloud properties. Based on analysis by Wen et al. [2006], photon scattering was found not to have a large impact on 10 km MODIS AOT values; thus, we use the same assumption here for the 20 km CERES pixels. However, growth of hygroscopic aerosols in the vicinity of clouds remains a problem. To estimate the effect of this growth on aerosol retrievals, we analyze MODIS FMF as a function of cloud fraction. As the cloud fraction of a pixel increases, its FMF decreases by approximately 15% in regions where high concentrations of hygroscopic aerosols exist (Fig. 2c). Thus, we conclude that for the aerosol – cloud property relationships to be physically meaningful, the difference in aerosol properties and cloud properties must be greater than this 15% values (in addition to normal statistical significance testing). Fortunately, this threshold is exceeded in most cases, increasing our confidence that we are indeed observing the results of microphysical interactions.

6. Due to processing limitations, only monthly averaged data were used in the original version of this work. Fortunately, those limitations have been resolved and all statistics have been recomputed using daily NCEP data. (The change did not substantially affect the long-term averages and the conclusions drawn from them).

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7. Yes, this equation does assume that AOT and CCN (via observed effective radius) are directly related. The validity of this assumption has been shown recently by Andreae [2009]. We further address this issue by reporting AIE values only where the relationship is considered significant using the tests outlined above. We agree that there remains a certain ambiguity and any satellite based analysis of AIE, but that using your criteria, many published works such as Matsui et al. 2006, and Quaas et al. 2008 would not be valid. However, we do agree that a certain degree of ambiguity exists with any satellite-based assessment of AIE, and that the best one can do is state where the uncertainties exist.

8. Additional evidence to support the conclusion that we are indeed observing AIE and not artifacts has been introduced through an increase in discussion and the testing described above.

9. Section 4 has been heavily rewritten to improve clarity and readability. Additional evidence for the results are provided using CALIPSO observations from 2006 and 2007. We compare seasonally averaged aerosol layer heights from the level 2 CALIPSO products (while noting its large uncertainties) on a region-by-region basis. We find elevated dust layers in AS and EA, and an elevated fine mode layer in AF. For other regions, aerosol layers are primarily trapped in the boundary layer ($<$1.5 km). These heights are now compared with CTP and vertical velocity data to better assess the importance of aerosol height on the AIE.

10. Figure captions have been improved to better reflect the details in each plot.

11. Yes, the figures only show seasonal cycles; however, we have added the more quantitative analysis of vertical velocity to the results. The monthly averaged figures to remain so that the reader can assess the importance of the seasonal variations in these parameters relative to AIE relative to the overall importance of any one atmospheric condition.

As for the case studies, we agree that one case study does not prove or disprove a

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particular conclusion, and we state as such in the text. However, we (as does the other reviewer) believe that these examples provide insight into the mechanisms present in each region and are evidence that support our overall conclusions. For the record, the case study examples were selected without knowing whether or not they would support the conclusions drawn from the long term regional analysis. 12. Yes, temporal and spatial auto-correlation effects were estimated and taken into account. It reduced effective sample size by approximately one half. This is now stated in the text.

13. To address this concern, we now use daily atmospheric data for the analysis and split the sample into upward vs. downward motion samples. With upward motion approximately representing conditions where thicker liquid water clouds are likely to exist, which should be associated with greater values of AIE. This was indeed observed in all regions where large concentrations of hygroscopic aerosols where present, except in BB for reasons noted in the text. AIE was generally small in EA owing to the presence of dust without any hygroscopic coating, and the possible dominance of semi-direct effects.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 20349, 2008.