Reviewer 1

This study investigates the impact of aerosols on ice crystal effective radius (Rei) by using satellite data and parcel model. It reveals the different dependencies of Rei and aerosol optical depth (AOD) under high relative humidity (RH) regime and low RH regime. The mechanisms to cause the difference are discussed and approved by parcel model. The results would help better understand ice cloud microphysical process and better estimation of climate effect of aerosols. In general, the manuscript is well organized. Thus, I suggest a minor revision before publication.

Response: We thank the reviewer for the valuable comments. We have followed these comments in revising the manuscript. Point-to-point responses are given below.

The suggestions are list as following:

1. Rei from satellite data retrievals are based on the reflectance of two wavelength (Platnick et al., 2015). Satellite data retrievals need some assumptions and may have some uncertainties. For examples, the surface spectral albedo data is needed to get the retrievals results. This study focuses on East Asia and surrounding areas, for which most regions are land area. Land surface albedo data may have larger uncertainty, compared with ocean surface albedo. Moreover, a gamma particle size distribution consisting of severely-roughened aggregated column is used in satellite data retrievals (Platnick et al., 2015). Single scattering albedo (SSA) and asymmetric factor needed for retrievals are based on this assumption. Do you think how do these uncertainties affects the results in this study?

Response: Thank you for the comments. The MODIS team has performed a comprehensive assessment of the pixel-level uncertainty in R_{ei} retrievals, which has been incorporated in the Collection 6 Level 2 cloud product (MYD06). This uncertainty evaluation takes into account a variety of error sources, including 1) instrument calibration, 2) atmospheric corrections, 3) surface spectral reflectance, and 4) forward radiative transfer model, e.g., the size distribution assumption (Platnick et al., 2015). The pixel-level R_{ei} uncertainties for the samples used in this study are 6.41% ± 4.97% (standard deviation). We used mean R_{ei} within certain AOD bins and the uncertainties are smaller than those for individual pixels. Also, we focus on R_{ei} changes in response to aerosol loading instead of absolute R_{ei} values. For these reasons, the R_{ei} uncertainty ranges are much smaller than the magnitude of R_{ei} trends depicted in our study (Figs. 1 and 3). We note that the current uncertainty evaluation has not considered the assumptions of ice crystal habit, which will be discussed in the response to the reviewer's second comment.

Following the reviewer's comment, we have added the discussion on the uncertainties of satellite retrieval of R_{ei} in the revised manuscript. (Page 3, Line 25 to Page 4, Line 4)

2. The particle in ice cloud may have different types and morphologies. For example, in WRF-CHEM, cloud ice, snow, and grapple are used. Platnick et al. (2015) also mentions “solid bullet rosettes” and “solid aggregate plates”. Optical properties of each types of particle are quite different. Rei is based on gamma distribution of aggregated column in satellite data retrievals. Thus, the shift of Rei may be caused both by shift of particle size distribution and change of particle type. The types of ice particle formed by homogeneous nucleation and heterogeneous nucleation might be different. Do you think the different type of particle would also be a possible reason, besides the shift of size distributions?

Response: We thank the reviewer for this valuable comment. Based on previous studies (Bailey and Hallett, 2009; Lawson et al., 2006; Lynch et al., 2002), the habit of ice crystals is dependent on a number of factors, among which the most important one is temperature, followed by ice supersaturation ratio. In this study we focus on R_{ei} changes with aerosol loading, for which temperature does not appear to have noticeable effect. For supersaturation ratio, the formation of ice crystals under moist conditions (high RH, high CAPE, or negative U200) is dominated by homogeneous nucleation, therefore the ice supersaturation ratio surrounding ice crystals is usually very low and the ice habit is not likely to change significantly with aerosol loading. Under drier conditions (low RH, low CAPE, or positive U200), however, heterogeneous nucleation gradually takes over homogeneous nucleation with aerosol loading increase. Subsequently, the supersaturation ratio surrounding ice crystals would become higher, possibly leading to changes in ice crystal habit. Considering that a single habit (i.e., aggregated column) is assumed in the satellite retrieval algorithm, ice habit changes could possibly induce changes in the satellite-retrieved R_{ei}. However, this retrieval bias should not change our major conclusion about the aerosol impact on ice crystal size, which has been supported by the cloud parcel modeling used in this study.

It should be noted that satellite remote sensing of ice clouds focuses on bulk (averaged) quantity and it is apparent that a single complex rough aggregate shape gives a more consistent retrieval from different MODIS bands and has been adopted for the objective of global ice cloud retrieval. We respectfully submit that at the present time space remote sensing does not have the capability to differentiate ice crystal shapes. The quantitative assessment of the impact of ice crystal habit on satellite retrievals of R_{ei} is a very complicated and difficult task that merits further in-depth study. We have added these discussions in the revised manuscript. (Page 17, Line 13-30)

3. There are many small figures in Figure 1, Figure 3, Figure 4 and Figure 5. Some of them are used to support similar conclusions. Maybe the author could consider placing some of them into supplemental information for better understanding of readers.

Response: Following the reviewer’s comment, we have moved some panels of the original Figs. 3 and 4 to the Supplementary Information (Fig. S4 in the revised manuscript). The remaining panels of these two figures are combined into Fig. 3 in the revised manuscript. For the analysis of the impact of different meteorological parameters, we would prefer to keep the current layout after careful consideration for two reasons. First, the key conclusion of water vapor modulation needs to be supported by the analysis with respect to multiple meteorological parameters, including RH, CAPE, and U200, instead of a single parameter. Second, it may be more convenient to the readers to put these figures in the main text so that they do not need to frequently switch between the main text and Supplementary Information.

4. The criteria for low RH and high RH in Figure 1 and Figure 3 are 45% and 65%. But the criteria for Figure 4 is 43% and 58%. Is there any reason for the differences? Will the criteria affect the statistic results?

Response: The probability distributions of RH (as well as other meteorological parameters) are different for convection-generated and in-situ ice clouds. We used different thresholds so that there are approximately the same samples in each meteorological range. We have also tried to apply the same breaking points for both ice cloud types, and found that the R_{ei}-aerosol relation patterns are retained, but the error bars are larger for some meteorological ranges containing fewer samples.

5. In parcel model results part, water vapor mass mixing ratios and aerosol number concentration are used, which are different from satellite data part, i.e., AOD and RH. Is it possible to use same variables for better comparison?

Response: The reviewer's point is well taken. However, we submit that it is a difficult task to undertake a comprehensive comparison unless a more detailed 3D model is used. In satellite data analysis, we used column/layer AOD and RH averaged between 100-440 hPa (or CAPE, U200) as proxies for aerosol loading related to ice clouds and overall available water amount at the upper atmosphere, respectively. However, the cloud parcel model only tracks the aerosol number concentration and water vapor within a single air parcel. It is clear that a direct and quantitative comparison between satellite observations and model results requires developing a 3-D atmospheric model and analysis, a difficult task for further investigation in the future.

Although the indices are not exactly the same, we submit that the simulated dependency of R_{ei} on aerosols could be used to qualitatively interpret the observed relationships, because the indices used in satellite analysis (AOD and RH averaged between 100-440 hPa) and parcel model (aerosol number concentration and water vapor mixing ratio) are closely correlated with each other, and that the meteorological parameters and aerosol concentration ranges used in the simulations are representative of typical in-situ ice clouds.

We have included these discussions in the revised manuscript. (Page 16, Line 32 to Page 17, Line 12)

References

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