Response to Reviewer #1

This study examines and parameterizes the influence of atmospheric convection and aerosol optical thickness (AOT) on the effective radius of ice cloud crystals (Re) using 4 years of satellite data. The satellite retrieved products used in the study includes AOT and Re from MODIS, and a convection (CONV) index derived from the ice water content (IWC) at 215hPa from the MLS. The main body of the study is to parameterize the dependence of re on AOT and CONV over different parts of the world in attempt to explain the differences of the parameters that denote the strength of the influence of AOT and CONV on Re under various meteorological and aerosol conditions.

There have been ample studies concerning the effects of aerosol and convection on cloud particle size. The uniqueness of this study lies in 1) the analyses of wealth of satellite data over a very large spatial domain and long period; 2) the effort of using a simple scheme to describe a very complex problem; 3) understanding the dependence in terms of aerosol and meteorology. Such attempts are useful towards "establish a framework for parameterization of aerosol effect on Re in climate models".

However, the parameterization as proposed may not be suitable for application in any climate models due to following concerns:

General Comments

1. The concept of the convection index (CONV) at a particular level is confusing. The only rational given is the correlation between the CONV and model derived OLR. First of all, why not use the CERES measured OLR instead of modeled one? Second, the instantaneous relationship as shown in Fig 1 (left) is not good to support the argument. The good correlation found in the mean quantities can be driven by large-scale factors (e.g. seasonal changes, spatial variations, etc.), while the influence of aerosol on cloud is instantaneous. Third, why was the IWC at a particular pressure level chosen? One could use IWC at a different level, or cloud top height, or vertical velocity, etc. Forth, it is necessary to explain how the quantity given on Eq. (1) is used as a proxy of convection? For the mean IWC in the denominator, it is not specified the spatial domain over which the mean quantity is computed, let alone understanding its physical meaning.

This study aims to provide quantitative Re-AOT-CONV relationships for different regions, which may serve as a first-order approximation for climate models to simulate the aerosol impact on ice cloud particle size. We choose IWC at 215 hPa (IWC_{215}) as a convective index for the following reasons: (1) ~200 hPa is approximately the level of convective detrainment, and the amount of ice water is proportional to the convective intensity. Shown in Figure 1, IWC_{215} and OLR have good correlations on both instantaneous measurements and grid means. We agree with the reviewer that the good correlation on mean quantities is driven by large-scale forcing and aerosol acts on clouds instantaneously. The positive instantaneous correlation between IWC_{215} and OLR justifies the applicability of IWC_{215} as a convective

index. We found that IWCs at other levels, for example, 147 hPa and 100 hPa, are less correlated with OLR than IWC_{215}. Using OLR gives similar fittings. (2) By mass balance, Re would have a direct dependence on ice water density, i.e., IWC. Previous work such as McFarquhar and Heymsfield (1997), explicitly employed the dependence of Re on IWC, which inspired us to expand that relationship to include aerosol dependence. (3) In climate models, Re and IWC can be direct model output at particular levels. Ideally, we would like to identify their relationships for each model level. As MODIS Re data refer to the height ~1-2 km below cloud tops, using IWC_{215} is roughly in line with the Re height at large domain averages. We plan to continue the current analysis using height-resolved Re (e.g. from CloudSat) and corresponding IWC at that level. We have modified the text to explain it more clearly. The mean IWC in the denominator is the mean value of IWC for each region where the least-squire fitting was performed. This mean IWC is only used as a scaling factor to make CONV unitless.

2. No Physical consideration is given to support the choice of the specific format of the equations. Given enough number of freedom, good fitting can be achieved by different functions. As such, the good agreement between observed and fitted values are not surprising. The assumption that the effects of AOT and CONV on Re are independent ("decoupled" as the authors put it) are contradictory to the later discussion. Yet, it has been widely recognized that the effect of AOT on cloud particle size depends highly on the strength of convection (e.g. Tao et al. 2007, JGR; Lebsock et al. 2008, JGR).

Our choice of the exponential or power law forms is similar to those used in other studies (e.g. Koren et al. 2008, *science;* McFarquhar and Heymsfield 1997). It is true that one can always find a good fitting to observed data with enough free parameters. The uniqueness in our fitting is that a universal formula describes various regions of diverse aerosol, clouds and dynamic properties. The regional dependence is condensed into 4 parameters only (α, β, η, ε). Such universal formula is practically important for application in global models. We agree that physical justification for the choice of function forms needs further investigation, possibly with simple conceptual models. However, it is beyond the scope of this study. We agree with reviewer that AOT and CONV are not independent. Decoupling them in the math formula is a simplification but practically useful. Since the formula roughly captures the observed variations of Re with AOT and CONV, we assume a parameterization of Re in models based on our formula would reproduce the observed Re changes, even though AOT and CONV can vary simultaneously and inter-coupled in the models.

3. It is somewhat arbitrary to simply divide the world into a few geo-locations. While it is true that different regions are subject to the impact of different types of aerosols, within many of the big domains exist many different types of aerosols, including mixed ones. In other word, the model parameters would have wide ranges of values had they been derived over much smaller sub-domains dictated by any a particular type of *aerosols. As the objective of the study is related to climate model applications, such a rough geo-differentiation would not be adopted in any GCMs. It'd make a lot more sense to discriminate according to aerosol types and meteorological regimes. Even though it is unfeasible to classify the entire world this way, it'd be more valuable to choose smaller domains with more uniform aerosols and meteorology in order to better understand the variability of their effects.*

The choice of the regions is based on previous study of Jiang et al (2009), where ice clouds in these regions are affected by aerosol loadings. We agree with the reviewer that aerosol effect on Re depends on aerosol composition and meteorological conditions. It is very useful to classify the Re dependence in the functional space of aerosol type and meteorology. However, the global aerosol composition is not readily available and the meteorological conditions in each region are too complicated to discriminate easily. Furthermore, although aerosol acts on cloud instantaneously and locally, we are more interested in *climatic* effects of aerosols on large spatial domain and over a long period. Our choice of large analysis domains with 4 year means aims to extract the averaged effects of aerosols, rather than instantaneous relationships. We have modified the text to emphasis this gross characterization.

Specific comments:

1. Several papers from the same group are cited with a similar research theme. It is thus necessary to explain the distinction of this study from previous ones.

This study provides more quantitative description of Re-AOT-IWC relations than our previous studies. Also, our previous studies mainly use carbon monoxide (CO) level to define polluted clouds and clean clouds. In this study, we directly use aerosol optical thickness (AOT), which are sampled on to MLS IWC footprints.

2. There are many means of denoting convection strengths used in observation and modeling communities. Give a justification for the selection of the IWC-based on as defined in this study.

See response to General Comments 1.

3. Reference Macfarqure should be MacFarqure

Thanks for pointing this out, we have modified text as suggested.

4. The MODIS Re retrieval is sensitive to the very top of cloud, not about 0.1-0.2 optical depth. Supposing cloud optical depth is 100, the current statement would mean the peak at 10-20, which is totally incorrect.

The MODIS Re for ice clouds is sensitive to 0.1 to 0.2 optical depth from the cloud top (Zhang et al, 2010), not 10% to 20%. So if the cloud optical depth is 100, the current statement still means the peak at 0.1-0.2, not 10-20.

5. Elaborate the GEOS-5, in particular how OLR is obtained.

We have added description in the text.

6. Increase in the Re with AOT is also found from satellite data (Yuan et al. 2007, JGR)

We have modified the text to add in Yuan et al reference. We noted, however, Yuan et al.'s study used MODIS droplet effective radii for liquid clouds, whereas our study used MODIS ice cloud effective radii.

7. On page 9, confusing statement "For CONV>1, it approaches the maximum of 1".

Thanks for pointing this out, we have modified the text for clarity.

8. The study of Menon et al. cannot be used to support the hypothesis of exceptionally strong absorbing aerosols in East Asia, as the study is nothing but sensitivity tests which assumed a very low single scattering albedo (0.85). Several later observation-based studies (e.g. Lee et al. 2007, JGR) found that the mean value is around 0.9 in the region, which implies strong absorbing but not exceptionally stronger than the populated areas.

Thanks for pointing this out, we have modified the text.

9. Fig. 3, what are the dashed lines?

Same as in Fig 2c, the dashed lines in Fig 3 are the occurrence frequency for each CONV-AOT bin.

10. Typo in the figure caption of Fig.2 (not 3).

Thank you for point that out. Typo has been corrected.

11. Missing the article title for the last reference Zhang et al.

Title of this article has been added. Thanks.

Response to Reviewer #2

This paper presents a simple parameterization of ice cloud effective radius (Re) observed from MODIS in relative to convective strength (CONV) derived from MLS ice water content (IWC) at 215 hPa and aerosol optical thickness (AOT) from MODIS. The parameterization in this study is quite straightforward. Although Re is not only function of CONV and AOT and this paper do not consider any other meteorological parameters except two, it can be the first step to understand the role of aerosol on ice cloud in upper troposphere.

General comments

1. The simple comparison between AOT and ice cloud radius can be controversial because AOT represents mostly surface aerosol but ice cloud radius can be influenced by aerosol in upper troposphere. It is not guaranteed that the upper tropospheric aerosol can be the same as total atmospheric AOT as described by author's previous work (Jiang et al. 2009), and can influenced by both AOT and convective activity including rainfall.

In current study and our previous work, one hypothesis for the aerosol effect on ice clouds is through aerosol effect on liquid clouds at the base of deep convective clouds. Thus column-integrated AOT is relevant to the ice cloud particle size. For in-situ formed ice clouds, upper tropospheric aerosol loading would be more relevant. We didn't differentiate deep convective clouds and in-situ formed ice clouds in current analysis. We are interested in the gross feature of Re as a function of AOT and CONV and the height-resolved dependence should be examined in future work.

2. Author assumes that the detection of IWC at 215 hPa infers deep convection. However, cirrus clouds above deep convective clouds can be observed frequently (e.g., McFarquhar et al. 2000). Therefore, it is confused whether MODIS Re can represent top of deep convective clouds.

MLS IWCs at 215 hPa are mainly from deep-convection. The lowest limit of the MLS IWC detection limit is ~0.4 mg/m^3 (Wu et al 2008). Thin circus above deep convection, as those discussed in McFarquhar et al. 2000, are sub-visible cirrus near the tropapuse, which are not detectable by MLS.

3. This paper does not consider cloud top height except for CONV >1. Does author think that cloud top height has minor effect on ice cloud effective radius?

Cloud top height can be related to the strength of convection. Very strong convection can increase cloud top height and thus may reduce the particle size. Therefore, cloud top height influence is implicitly considered in our formulation.

Specific comments

1. You need to add lots of missing references used in this paper to the list. –e.g. Platnick et al, 2003; Remer et al., 2005; Wu et al., 2009; Rienecher et al., 2008; Su et al., 2006; Jiang et al., 2007

Missing references have been added. Thanks for pointing out.

2. (page 3, line 8) Macfarqure -> McFarquhar

Thanks for pointing this out, we have corrected it as suggested.

3. (page 5, line 3) Does 'the mean of all the 215 hPa IWC sample' include clear sky or not?

No, the clear sky sample is not included in this study.

4. Fig 2. Can you show the error or standard deviation?

Standard error bar has been added to all the line plots.

5. (page 8, line 21) Can you show more labels such as 2.0 in Fig 2c and 3?

More labels have been added.