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Atmospheric
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Discussions

Interactive comment on "Evidence of mineral dust altering cloud microphysics and precipitation" *by* Q.-L. Min et al.

Q.-L. Min et al.

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We thank the reviewer for very thorough and constructive comments and suggestions. They have helped us to improve the quality of the paper and our understanding. We have taken the comments seriously; they will be addressed in the revision.

Here we provide an explanation of the issues raised by the reviewer, starting with the issue of the data itself.

While statistical investigations will provide more general understanding and confirmation, a case study may shine light on detailed physical processes. Our case selection was based on a series of observation from Meteosat-8 at 15-minutes resolution. The time sequence of those RGB composite images of Meteosat-8 satellite has been provided to ACPD in a gif format file as the supplementary material (from 7 to 8 March

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2004). Those images indicate that the selected mesoscale convective system (MCS) was in its mature stage and it lasted for a long time. The mature stage of this system can be also judged from its feature of large stratiform rain area, as explained in Houze (1993, chapter 9). From both Meteosat-8 and MODIS, the spatial distribution of dust did not change much in the two days.

We attempted to minimize the impacts of cloud evolution stages via three steps.

Firstly, we picked a unique case of a mature MSC, in which a portion of the MCS was under the influence of mineral dust. Although there were some internal variations, this case is better constrained than separated MCSs.

Secondly, each convection cell in the MCSs does go through a life cycle including a formative stage, intensifying stage, mature stage and decaying stage. However, the separation of stratiform and convective rains itself constrains the variations due to different evolution. In the TRMM PR 2A25 product, the young, active and violent convection-related rains are identified as convective rains based on its very strong radar reflectivity, which is related to more and/or large particles requiring strong updraft velocity to lift them. While the elder, inactive and weak convection-related rains are identified as stratiform rains based on their weak radar reflectivity and the feature of radar bright band, which indicate weak updraft velocity and vertical mixing. All the convective and stratiform events discussed here were taken from the TRMM product, so that we did not change the general status of rainy areas. Our analysis separates convective and stratiform clouds to study the relationship between these two rain regimes under the influence of mineral dust.

Thirdly, based on Gamache and Houze (1983), the stratiform rain rate is largely determined by the updraft intensity of its related convection core. Relatively stronger convective rain should be associated with relatively stronger stratiform rain. The relative intensity of stratiform rain to convective rain is nearly independent from the updraft intensity and evolution stage. This feature is demonstrated by the tight correlation between the mean reflectivity (and rain rate) of stratiform vs. convective rains in Figure 3, particularly in the dust-free region where the aerosol loading was relatively uniform. Our finding is that for a given convection strength, there is relatively stronger rain in the stratiform rain region of dusty-polluted areas than those in its dust-free counterpart due to the influence of mineral dust. Indeed there are still some differences of evolution stage among those individual cells, especially in the convective rain. Some cells can be relatively younger/elder than others. We believe this is the resaon there are some variation in Figure 3 under both dust and dust-free conditions. However, those points can be easily divided into two groups with very high correlation coefficient (0.9) by using a simple linear regression. The separation of the two groups is statistically significant. It indicates that the scattering associated with possible different stages (in addition to different dust loading, more discussion later) is the second order of variations comparing with the difference between dust and dust-free conditions.

Satellite measurements alone provide no information on air inflow into the storms. Based on NOAA NCEP reanalysis dataset (not show here) and Meteorsat-8 images, the eastern winds dominate at low and mid level and the meridian winds (or the cross-equatorial wind) are very weak. The gradient of zonal mean AOD observed by MODIS (Figure 1c and 1d) persisted from March 5 to March 10, before and after satellite overpass on March 8, 2004. Such dust distribution, zonal variation of AOD, is a very good indicator of dust distribution inside the MCS. Yes, the inflow air can change the inner distribution of dust inside the MCS, consequences of air entrainment and rainfall scavenging. Dust distribution inside the MCS might not be uniform, so that our first sensitivity test was to focus on the dust-free region where the aerosol distribution was relatively uniform. Variation of dust loading inside the MCS could explain some variations of relationship between stratiform and convective rainfall in the dust region, in additional to variations in cloud dynamics, shown in Figures 3b-3d. Nonetheless, the dust loading was much higher in the dust region than in the dust-free region. Changes of dust loading due to the entrainment and scavenging could not alter this much. Again, variations of relationship between stratiform and convective rainfall in the dust region

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are smaller than the difference of the relationship between dust and dust-free sectors.

As stated in the paper and shown in Figure 1c, the zonal mean dust optical depth decreased substantially from 4°N to 1°S and remained relative constant in the area further south. The region from 1°S and 4°S is defined consistently as the dust-free sector. The rest of the area is the dust loaded region. For the sector analysis of PR reflectivity, we have sufficient samples in both dust and dust-free sectors and use a buffer zone between 0.5°S and 1°S. For the convective cell analysis, the cell number is limited in this MCS. Therefore, we included four cells that are partially within the buffer zone into our analysis. Since substantial portion of convective rain pixels of DF1 are inside the dust-free sector, we classified it as a dust-free cell. Even if we remove DF1 from our statistics, the relationship between stratiform and convective rain in the dust-free sector will not change. There is no internally inconsistent definition. However, we will change the wording in the revision to make it clear.

We appreciate the reviewer thoroughly investigated on the samples in each subarea. The pixel statistics are consistent with ours. We have tested with different box definitions, which do not change the final conclusions (i.e. Figure 3).

We did realize that the samples of active PR measurements are not large enough to make a general claim on the impacts of dust on precipitation vertical structure for different weather and climate conditions. As we outlined in the paper, we combined passive microwave, visible and infrared measurements with active PR measurements. The combined measurements provide information from precipitation inner structure to clouds, allowing us looking at dust-cloud-precipitation interaction from different view angles. Fortunately, all evidences from different instruments and directions provide a consistent picture of dust-cloud-precipitation interaction. This rules out a chance correlation. We also emphasize that our study is not looking for the relationship between the spatial distribution of precipitation intensity and AOD. Also our study is a case study. As pointed out in the paper, statistical study and detailed cloud model simulation are warrant to further understand microphysical effects of the dust aerosols on clouds and precipitation as well as cloud dynamic impacts on the microphysical processes

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Interactive comment on Atmos. Chem. Phys. Discuss., 8, 18893, 2008.

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