Responses to Referee 2

The manuscript addresses a very important question within the cloud modelling community: How do aerosol perturbations affect the vigor of deep convective clouds and the resulting cumulative precipitation and precipitation intensity. Various modelling studies (e.g., Khain et al., 2004; Fan et al., 2009; Khain and Lynn, 2009), in addition to the conceptual review of Rosenfeld et al. (2008) have analyzed this problem in detail. Previous studies have shed light on the significance of relative humidity, vertical wind shear, and microphysical model (i.e., bin or bulk microphysics) on the aerosol-induced effect on deep convective clouds. More specifically, Fan et al. (2009) demonstrated that the effect of increases in the aerosol number concentration may increase precipitation in low shear environments, while the effect may be reversed, i.e., precipitation decreases with an increase in aerosol loading, in high shear environments. Since the sign of the aerosol-induced effect is strongly linked to the magnitude of the vertical wind shear, the use of a three-dimensional (3D) dynamical core is necessary to fully resolve the dynamical effects of changes in aerosol number concentration the inherent lack of symmetry. In the absence of any horizontal winds, one can imagine that a convective cell could remain symmetric as it evolves. However, e.g., Khain and Lynn (2009), even if the initial thermal perturbation is symmetric, the resulting storm is not symmetric as a result of shear and dynamical feedbacks caused by phase changes in and around the cloud. These features cannot be captured with a 2D axisymmetric model. Hence, given the demonstrated importance of shear in a 3D model (Fan et al., 2009) and the use of a less sophisticated, 2D axisymmetric model in the current manuscript, it is recommended that the work not be accepted for publication in ACP.

We strongly disagree that the paper should not be accepted for publication in ACP. We agree with the reviewer that the axi-symmetric model has limitations in the dynamics in the way the reviewer suggests, but importantly, it has the ability to study the microphysics that 3D models do not. There are many factors that can affect cloud and precipitation. Cotton et al. (2010) pointed out that the type of cloud and precipitation of a system is determined by six factors: water vapour content of the air (both relative and absolute humidity), temperature, aerosol types and amounts, static stability, vertical motion, and vertical shear of the horizontal wind. Those factors offer a huge scope of research on cloud and precipitation. Each of them needs more study, ideally together. As a first step, we pragmatically focused on the special case of no wind shear, with the axisymmetric model. Although there have been some studies on aerosol-cloud-precipitation, many questions still need to be answered, especially with detailed analysis of microphysical processes involved. The referee listed several papers which make progress in this field. Interestingly, the review paper by Rosenfeld et al. (2008) in Science cited our paper (Cui et al., 2006) using the same model. Moreover, those papers deal with the interaction in a different way from our paper. They calculated the budget of latent heat release as in Khain et al. (2004). Our paper compares the contributions from the warm rain process and melted ice particles. We found that the precipitation results mostly from the melting of graupel particles. We then reveal the relationship between the amount of graupel particles and aerosol loading with detailed analysis of the cloud microphysical processes. We believe our study provides new insight into the nature of the impact of aerosol and thermodynamics on precipitation in mixed-phase deep convective clouds.

We agree with the referee that wind shear is an important factor. The paper of Fan et al. (2009) certainly made progress in this direction. However, the joint effect of aerosol and wind shear on precipitation is not yet fully understood. For example, Pastushkov (1975) found that there are two types of convection under different wind shear conditions. For the strong case, there is a resonance value of shear, at which the degree of the intensification of convection has a maximum. What are the effects of aerosol under weak and strong cases? How do clouds change with different aerosol loadings near to or far from the resonance value of shear? How does the shape of wind speed profile affect the cloud? Those questions need to be investigated in the future.

We recognize the limitations of the axi-symmetrical model and respect the referee's comments. We added the following to fully address the limitations in the summary and discussion section.

"The use of the axi-symmetric model imposes limitations on the generality of the results, as with any study. The effect of the vertical shear of horizontal wind is the most obvious. For example, Weisman and Klemp (1986) discussed how wind shears and buoyancy can be used to estimate storm type and storm lifetime. Jorgensen and Weckwerth (2003) showed convection as a function of shear and convective available potential energy for individual convective storms and mesoscale convective systems. In weak wind shear environments, convection tends to produce single cells rather than long-lasting severe storms. In reality, convective clouds occur under low wind shear conditions (e.g., Wilson et al, 1997; Ahijevych et al., 2000; Tompkins, 2001; Rangno and Hobbs, 2005; Steiger et al., 2009). Our simulations only investigate the response of the microphysical processes to aerosol without wind shear. Our results cannot be generalized to severe storms.

Asymmetric features in and around clouds may develop in a 3D model with wind shear even if the initial perturbation is symmetric (Khain and Lynn, 2009). For example, cloud particle size sorting results from wind shear, which could affect the interaction between drops and ice particles. Other observations found that there is no direct evidence of size sorting in some cases (e.g., Szumowski et al., 1998). Nevertheless, the asymmetric features cannot be captured with our axisymmetric model.

Lopez et al. (2009) performed 3D simulations and found that shear is not capable of creating realistic anvil clouds, unless they also modify the cloud physics. Their results indicate that cloud physics is not less important than wind shear.

We have been aware that further model improvements are required. As a next step in the future, we will conduct simulations with wind shear with a new large eddy simulation model with the bin-resolved cloud microphysics.”

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