Response to Anonymous Referee #1

(Comment) In the manuscript by Pardo et al., the Authors perform a series of simple model based sensitivity tests on aerosol-cloud interactions, with the intention of mapping the sensitivity of cloud properties (number of droplets, droplet size) to several parameters describing the aerosol population. The modelling work is performed with a sectional cloud microphysics scheme coupled to a 1-dimensional column model, which is driven by initial conditions representative of those in the Amazon region and an idealized vertical velocity profile.
Basically, the analysis appears sound, revealing the importance of several aerosol parameters to key cloud microphysical properties. While this is all very interesting, my primary concerns are about the representativeness of the results and the modelling methods used to produce the data for this purpose. Indeed, the Authors state that the 1-d model (the KiD kinematic driver) is designed mainly for testing microphysical schemes with a consistent kinematic framework. This is true, and in my opinion, it cannot account for important cloud dynamical responses to aerosol perturbations, which we by now know are essential to really understand the aerosol effects on clouds, particularly so in convective cumulus clouds. In particular, I find it rather surprising that the Authors do not consider e.g. how entrainment would affect their results. To back up the representativeness of the results compared to actual clouds, the importance of the dynamics should be somehow evaluated. This would most likely require at least a major review before being published in ACP. I will try to outline my concerns in more detail in the specific comments below.

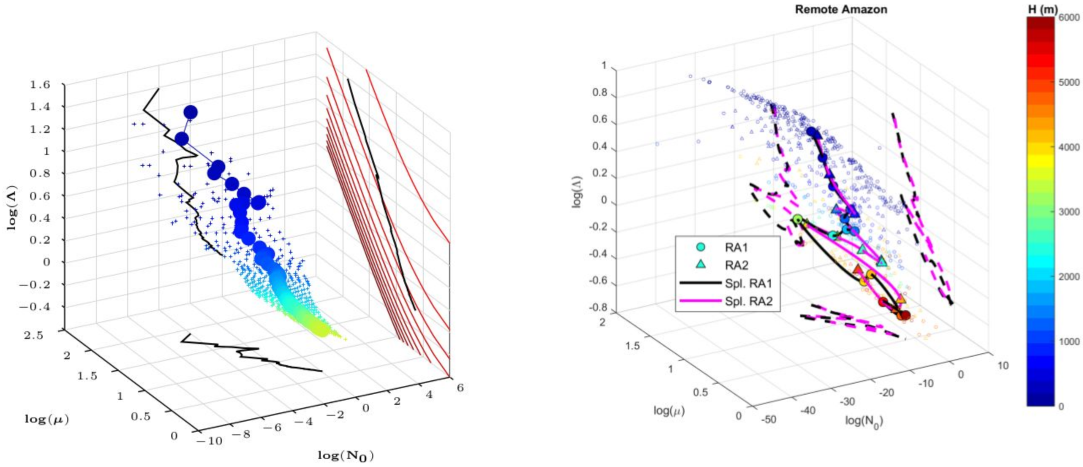
(Answer) We would like to thank Anonymous Referee #1 for revising our manuscript and suggest improvements. The questions raised were very useful and helped us to consider key aspects in the methods employed and in the analysis of the results. We hope the modifications that were introduced in the manuscript, as a consequence, contributes to provide a better insight into the aerosol-cloud interactions. For practical purposes, we provided a detailed explanation of the modifications implemented in the model, in the introduction of the response to Anonymous Referee #2. In this document we provide responses to the issues raised in the review.

1. (Comment) First and foremost, how do you justify using a simple 1-d model, which obviously cannot treat e.g. effects of entrainment, to study aerosol effects on highly dynamic convective cumulus clouds? I agree that you can capture the purely microphysical response with this system (that's what it is designed to do). Even though this is interesting to an extent, I think the results from this setup describe the functionality of the microphysics scheme instead of telling us what we should expect to observe in reality (which can be very different things).

(Answer) We agree the modelling approach employed in this work is highly simplified. In real clouds, there is a much larger variety of process that could enhance or reduce the range of sensitivities that are demonstrated here. Full dynamical models, on the other hand, include many dynamics feedbacks and several subgrid processes that improve the realism of the simulations and provide a more trustable response to aerosol perturbations. However, performing such a large set of simulations with detailed microphysics and high resolution models is computationally challenging and the interpretation of the results less straightforward. Most of the previous studies using a large subset of simulations have been performed with simple models, such as the adiabatic cloud parcel model of Feingold (2003), Reutter et al. (2009) and Ward et al. (2010).

Although the KiD was designed mainly for testing microphysical schemes with a consistent kinematic framework, without a complete representation of the physical processes other than microphysics, different idealized cases (small cumulus, stratocumulus, deep convection, etc) were elaborated to match observations of real clouds. It is common practice to use idealized cases to understand the responses of the system to different situations, ie., sensitivity tests. The KiD, in particular, was also previously used to analyse physical problems like ice nucleation (Field et al., 2012; Herbert et al., 2015) and aerosol-cloud interaction (Gettelman, 2015).

In our study, we reproduce an idealized cumulus from observed profiles of potential temperature and humidity, using in-situ aircraft observations as a reference. The results of our simulations are found to be consistent with the observations from aircraft penetrations on the top of growing convective clouds over the Amazon, performed in the same day of the sounding used to initialize our model (Cecchini et al., 2017b). Figure RR1 shows the evolution of the cloud-top DSD in the phase-space of the parameters of the gamma function for the observation and the simulation (using the original configuration of the model).



(a) (b)

Figure RR1. Gamma phase space representation of cloud-top DSDs for different cloud widths: (a) bin microphysics simulation and (b) observation (Fig. 6 of Cecchini et al., 2017b). Small markers represent 1 Hz data, while larger ones are averages for every model level in the simulation and for 200 m vertical intervals in the observation. The color scale represents the height above the cloud base in meters. Projections on axis planes are represented by black continuous lines, in the simulation, and dashed lines, in the observation. The red lines in (a) are the projections of the surfaces with constant D_{eff}, increasing from top to bottom.

The differences in absolute values between the graphics from Fig. RR1 are determined by many factors. First, when dealing with the modeled cloud, the boundaries can be quantitatively defined; thus, there is more control over the path that follows the top of the cloud, as well as the position of the cloud base. Consequently, the initial portion of the graphic that represents the simulation includes information about the very beginning of the cloud, when the first droplets are activated and occupy only one or two bins of the DSD (leading to larger values of μ), while in the graphic that corresponds to the observation, the first DSDs plotted (lower heights above cloud base) correspond to a more developed stage of the cloud. This is why the simulated trajectory looks like an expanded version of the warm portion of the observed one. However, the qualitative similarity between the simulated and observed trajectories is quite remarkable.

The description of the environmental conditions modulates the simulated DSD evolution and is also responsible for similarities and differences between the observed and simulated warm cloud evolution. For example, changes in the initial aerosol concentration can modify the position and shape of the simulated Gamma phase space trajectory by increasing the values of Λ and N_0 as an expression of more numerous droplets and narrower DSDs. Our sensitivity calculations agree with the calculations of Cecchini et al. (2017a), which use the measurement of the ACRIDICON-CHUVA field campaign at locations with different exposure to anthropogenic aerosol over the Amazon (this comparison is detailed in the response to Anonymous Referee #2).

In order to complement the results already shown in the manuscript, we introduced several modifications in the model, including the treatment of the dynamics and a parameterization of the effect of the entrainment and mixing (a more detailed explanation is provided in the response to Anonymous Referee #2). These new simulations provide an interesting assessment of the effect of increasing the complexity of the process represented by the model. The results obtained from different configurations are consistent, and we believe it would improve our understanding on the importance of those physical processes to evaluate the response of models to different aerosol properties.

2. (Comment) The representation of the aerosol size distribution seems very static. I get the impression that cloud activation does not affect the size distribution shape or mean size, just the number. I think this is not a very robust assumption for a study like this. Do the model simulations assume some sort of aerosol replenishment mechanism?

(Answer) Indeed, in the original version of the model, the aerosol size distribution was static, activation and aerosol regeneration did not affect the shape of the PSD, only the total number concentration. To improve the quality of our analysis, we introduced bins for the aerosol and modified the activation and regeneration processes. This had a notable impact on the simulation, mainly due to the CCN depletion. These modifications and its impact on the results are discussed in the response to Anonymous Referee #2.

3. (Comment) Is the assumed vertical velocity profile consistent with the initial temperature profile, if you think about it in terms of releasing an actual thermal? Moreover, since also the evolution of the updraft profile in time is prescribed, do the initial temperature/humidity profiles evolve consistently with the updrafts?

(Answer) The vertical velocity profile should depend on the buoyancy force caused by the different densities inside and outside the parcel. Since the vertical velocity was prescribed in the original version of the model, there was no need for specifying these two different temperatures. The initial temperature profile was considered to be the temperature of the parcel at any time, plus the increase of temperature due to latent heat release. Meanwhile, the water vapor mixing ratio was advected and also modified by the microphysics tendencies.

To improve the consistency between those variables, in the updated version of the model, the vertical velocity is no longer prescribed, instead, it is calculated at any time and height from the instantaneous temperature difference between the parcel and the environment. The atmospheric sounding is used to define the environmental profiles, and a constant temperature perturbation is introduced at surface, in order to cause an upward displacement. The temperature and humidity fields are then advected, as well as the aerosols and the liquid water.

Minor questions:

1. (Comment) Regarding the discussion on the role of r_a on pages 8-9: the Authors appear to specify a simple unimodal aerosol size distribution for their simulations (which is fine for this study, I suppose). However, the accumulation mode can most of the time be distinguished in observations and the accumulation mode number concentration specifically is often contrasted to the number of cloud droplets. So doesn't the apparent sensitivity on r_a really fall back to separating the specific mode number concentrations?

(Answer) In a sense, yes. However, using r_a is a better approach than simply separating the modes, as it provides a gradual relation between cloud microphysical properties and aerosol size. For parameterization purposes, for instance, it is more desirable to have the r_a and not the mode dependency.

2. (Comment) The manuscript does not really say anything about precipitation. Does precipitation form in the clouds you're simulating? If so, is the aerosol population subject to wet scavenging effects?

(Answer) The precipitation is allowed to form in the model, but the amount of rain droplets is very low, specially at cloud top, we therefore neglect the effect of aerosol washout in the simulations.

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