The sensitivity of intense rainfall to aerosol particle loading - a comparison of bin-resolved microphysics modelling with observations of heavy precipitation from HyMeX IOP7a

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General comments

The study presents simulations of heavy precipitation event occurred on 26th Sept., 2012 during the HyMeX campaign. The simulations use the DESCAM bin-microphysical scheme which solves for changes in hydrometeors size distributions, including aerosols mas within drops and ice crystals.

One of the major objective of the study is using the detailed bin-resolved microphysical scheme to reproduce quantitatively precipitation characteristics such as: rain accumulation, rain size distribution, spatial and temporal variability - all compared to the observed rain gauges, distrometers and ground radars. Another objective is to check the sensitivity of surface precipitation and raindrop spectra to aerosol number concentration.

Overall the paper structured sufficiently well and present the potential of a bin-scheme in reproducing precipitation characteristics. However, the study suffers from some major deficiencies that force major revision.

Specific comments

The specific comments below refer to the following Major comments bullets:

- The study employed the DESCAM bin scheme but the manuscript is short in description how the bin scheme is doing better compared to previous studies that used 1M/2M/3M bulk microphysics (at least qualitatively). This should be (at least) included in the discussion section.
- There is a serious lack in physical argumentation for several deficiencies in the model results and lack of proper references for the cloud-precipitation-aerosol interaction work done by the community. There is also lack of vertical cloud structure (tendencies or budget analysis) that could links/leads to the surface rain characteristics that is the focus of the paper.
- There is a systematic problem in using the three test cases (HymRef, HymLow and Remote) to deduce the sensitivity to aerosols number concentration. In order to test the sensitivity to aerosol concentration, the systematic way would be to change the concentration of a certain mode of the same aerosols size distribution (ASD). The concentrations in the ASDs modes as shown in the paper differ substantially, which leads to different physical response of the clouds. Otherwise, if the authors stored the number of drops nucleated as function of supersaturation and/or as a function of the ASD dry size ranges -- this would be a preferable approach to isolate the

aerosols effect. In case this is not available, they would need to rephrase their conclusions as far as the aerosol sensitivity is concern. This is further required because they do not present the corresponding vertical cloud structure to help assessing certain deficiencies and/or aerosol sensitivity.

© Pg. 2 lines 2-3: There is no indication which microphysical schemes were used in the referenced papers. (minor)

© Pg. 2 lines 5-6: if previous studies ''succeed'', why were there significant differences in location, intensity and microphysical characteristics? They ''succeed'' according to what standard?

© Pg. 2 line 15: Again, agree in what sense? Did they use large temporal and spatial averaging technique? Is this sufficiently good? I would argue that any reasonable microphysical scheme can be compared to observations to some extent. In that case, why do we invest time to calculate spatial and temporal changes of hydrometeor spectra?

© Pg. 2 lines 20-24: In addition to mentioned above, you might want to stress that 1M/2M/3M bulk schemes have much more tuned microphysical processes / parameters, where bin microphysics have very few constraints apart from discrete grid for hydrometer mass/size into bins. See a comprehensive review in Khain et al. (2015).

© Pg. 2 line 32 – Pg. 3 line 2: Well, there is substantially larger amount of work being done in the cloud physics community than mentioned here. Please read (at least) the following references (and the references within) for a more complete 3D cloud-aerosol-precipitation interactions studies: Lynn et al. (2016), Marinescu et al. (2016), Fan et al. (2018), Marinescu et al. (2018), Shpund et al. (2019a, 2019b).

© Pg. 3 lines 29-30: This needs to be justified as the homogenous nucleation level and/or stratifom parts can easily get to 12-12.5 km easily. In addition, it is probably a way to reduce the computational loading, is this means the interaction between the outer-most and the inner domain are one-way? This should be clearly written.

© Pg. 4 lines 1-2: It looks the DESCAM scheme calculates the aerosol mass dissolves within drops and ice crystals. Within the cloud microphysics community, it is debatable if this worth the additional calculation loading. In part, this is why most of the modeling work uses this method only in warm clouds and/or idealize setup. Apart from the calculation loading, can you comment on how significant is it to your simulations, facing your goals to improve the precipitation characteristics?

© Pg. 4 line 5: Again, facing your goals the reader should understand how main features of the microphysical scheme works. Rain drops of 10mm are extremely rare (some thinks they just do not exist); as such it is important to understand how the scheme handles these potentially numerical artifacts of very large rain drops that aren't stable. This affects for sure your rain size distribution.

© Pg. 6 line 18: Why do you start with describing Figure 4? (minor)

© Pg. 6 line 20: should be sixth moment, not "sixth momentum"? what do you mean in "normalized" here? (minor)

© Pg. 7 line 3: can you please explain from physical perspective what prevent the model (dynamical core + microphysical scheme) from being able to reproduce the change in orientation?

© Pg. 7 line 16-19: can you please comment from the microphysical scheme perspective -- why the area of rain accumulation is different, especially the area of the accumulated rain of ~38 (mm) and below is significantly underestimated. It looks like the scheme (or the setup) has problems in simulating shallow convection and/or startiform clouds.

As a follow up query, how was the corresponding forecast of the 1M/2M/3M bulk microphysical schemes? Could you please comment on that.

© Pg. 7 line 30: Indeed, but the reader may ask himself what in the microphysical scheme lead to this changes? If the paper would have a more coherent microphysical analysis (vertical cloud structure) you would be able to explain that from physical point of view.

In addition, this is an example to the systematic problem in the ASD setup, where the Remote setup has 600 #/cm3 and 250 #/cm3 in the accumulation and the coarse modes, respectively. These modes are readily nucleate to droplets in any typical deep convection systems, and should lead to early rain formation (especially the coarse mode with 250 #/cm3). This is quite different aerosols regime.

© Pg. 8 lines 10-11: Have you checked your low-surface "cold pool"? The question is whether the limited spatial changes in rain results from a dynamical reason or underestimation in low-level rain amount and sizes which limits the evaporation and thus decrease the "cold pool". This is related to the large scale forcing vs. local convective instability.

© Pg. 9 lines 4-5: Regarding your conclusion that "more rain occurs when low particle number prevails" – this is likely to be true for 2 ASDs with different number concentration per modal size in a warm convective system. When you convolve number concentration between ASD modes, the rain can be initiated from different level in the cloud. As the convection becomes deep enough, lower CCN size penetrates to areas where high vertical velocity occurs and thus higher supersaturation above liquid/ice occurs (Sw, Si), and more smaller drops nucleates, which means more vapor is extracted from the atmospheric column (Si > Sw) compared to nucleation at lower levels where Sw is limited by warm rain; this serves as positive feedback that intensify the convection as more drop freezes at higher levels, as well as lead to increase in large/dense hydrometeor size which sediment and force downdraft and further positive feedback.

The above is called 'convective invigoration' that leads to more intense rain rate. In your Remote ASD setup you are not only reducing total aerosol number concentration, but you also "pushes" the clouds to rain-out (warm-rain) substantially earlier due to the increased number concentration in the accumulation and especially the coarse modes. Therefore, based on the limited analysis presented here, your conclusion needs to be rephrased to include the information about the differences in ASDs modal concentration

© Pg. 9 lines 12-13: again, you have forced at least 2 more degrees of freedom in that the Remote ASD has substantially different aerosol number concentration distributed between the modes. You need to address this by dedicated sensitivity test, or at least restrict your conclusions.

© Pg. 10 line 24: the value of 9mm / 5min in Figure 9 cannot be seen. Please comment or correct this value. (minor)

© Pg. 11 lines 25-30: There is no indication of the temperature near the surface and where is the freezing level placed. There is no clear indication how the averaging has been performed (space-wise). Since the model simulations clearly underestimates the area of ~25 mm (and below) and the averaging was made between 900-1000m, it is not clear to me how the RWC = 0.5 g/m3 rain size distribution in Figure 11b are reasonably compared to observations (as shown in Figure 11a). Such RWC are largely in the underestimated area and can be attributed to shallow convection or even to heavily stratiform precipitating clouds. Can you explain this apparent discrepancy?

Furthermore, in principle raindrops grows at the expense of small-medium size raindrops (0.3 – 1.5 mm) as these fall through the cloudy area, but this is quite a simplistic point of view as observations (Figure 11a) indicates that other processes are likely to be responsible for the ongoing supply of these small-medium raindrop near the surface and for vast range of RWC. These process are being determined well above the surface (for instance: melting process; breakup of large raindrop). Thus, based on this simplistic microphysical analysis made here, the conclusion drawn should be very careful as probably the model has some drawbacks in this aspect.

Pg. 12 line 22: what is the context for "superficial" here? (minor)

Technical comments

© Pg. 2 line 27: There is no meaning in "bin resolved"; you probably mean "size resolved".

© Pg. 3 line 26: Maybe "outermost model domain" is preferable. Also, the resolution increases, where the grid spacing decreases.

© Pg. 4 line 1: A microphysical scheme (like the DESCAM) calculates (or prognoses) the temporal and spatial changes in the distribution functions. The overall set up of the dynamical core coupled to the microphysical scheme with the BC/IC "*simulates*" a particular test case and the corresponding fields (rain, CWC, RWC, etc.).

© Pg. 4 line 26: … a third *aerosol distribution* with lower *number concentration* is used.

© Pg. 4 line 33 (and throughout the text): number distribution is confusing. Use number concentration or/and aerosol/droplet/rain size distribution.

© Pg. 11 lines 3: rain size distribution should be noted as RSD and not DSD. DSD is droplet/drops size distribution.

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