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Responses to reviews

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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Note to the editor

We thank all of the reviewers, whose comments have led to significant improvements in the analysis and, thus, our manuscript. We are grateful that reviewer#1 (and #2) found that the manuscript is much improved, and close to ready for publication.

Changes in the manuscript and the reply to the individual remarks of reviewer #2 are marked in red for easier notice.

Responses to reviewer #1's comments

I've read the authors response, and most of the points were addressed reasonably well. The manuscript seems appropriate to the NHESS journal and I do not have any particular objection or further inquiry for/before acceptance of the manuscript.
Thanks.

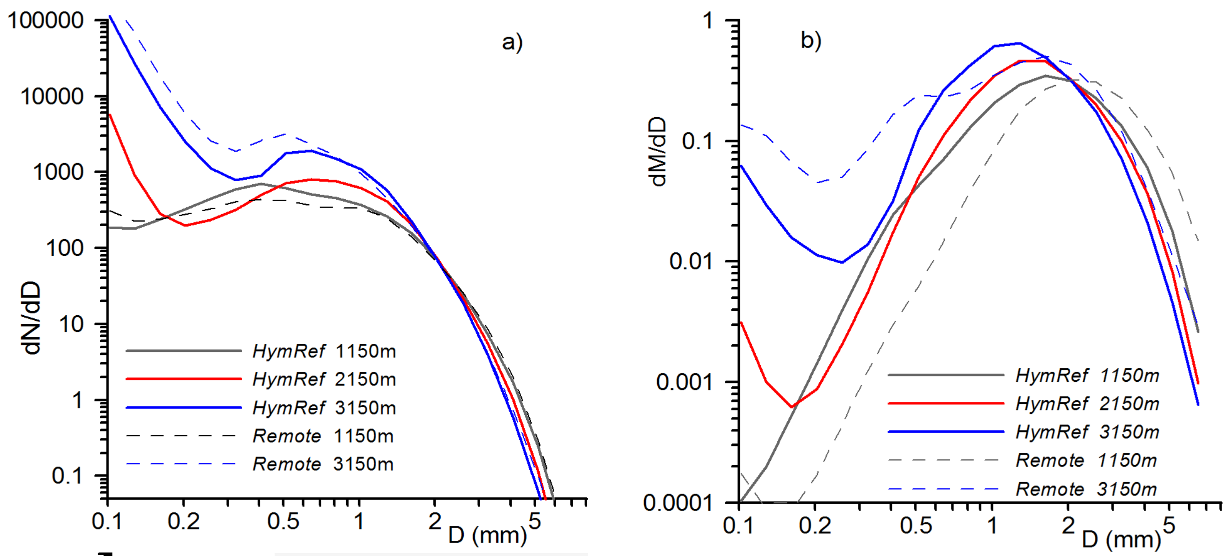
Responses to reviewer #2's comments

Thanks to the authors for the detailed answers. With the correction on aerosol populations, the paper now effectively demonstrates both that the bin scheme DESCAM is able to produce reasonable amounts of precipitation in a 3D, real-case simulation of a convective system, and that there is a sensitivity to the aerosol population, therefore pushing for the use of aerosol-aware cloud physics schemes.
My remaining comments are:

General comments

- The vertical cross-sections are a welcome addition which provide a better view of the simulated clouds, but, I expected a bit more in terms of processes leading to the ground level rain characteristics. The presented results are interesting, and the authors state that the focus on rainfall simulation fits the NHESS journal well, but as a cloud physics scientist, I still miss some physical process understanding, which are briefly mentioned in the conclusion, such as:
  - how is the rain size distribution evolving with height ? and is this evolution depending on the number of aerosol (even if we have no observations to compare to) ?

We selected for the same model time as in Fig. 6 (8:20 UTC, see the revised paper) three cloud-layers (at 1150, 2150 and 3150 m above sea level) each with a depth of 300 m (i.e. ±150 m). For each layer the modeled droplets spectra were averaged amounting typically to 2000 spectra per layer. Figure R3a shows the resulting number distribution, Fig R3b the mass size distribution. The continuous lines give the spectra of *HymRef* for the three layers. With decreasing altitude, the raindrop size distributions illustrate that the number of small drop sizes decreases while the number of larger sizes (> 2mm) increases. The increase of the large drop sizes with decreasing altitude becomes more obvious in the illustration for the mass distributions of Fig. R3b. This behavior confirms our statement, that collection-coalescence is responsible for the shift of the water mass to the larger raindrops.



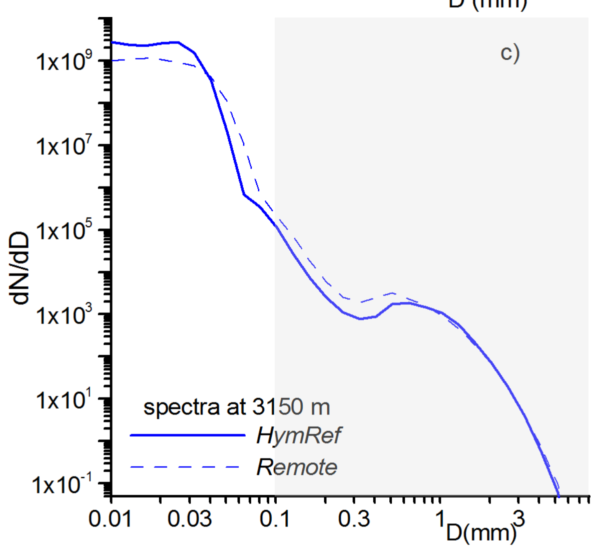


Fig. R3: Modeled number distributions (a and c in $m^{-3}mm^{-1}$) and mass distributions (b in $g\ m^{-3}\ mm^{-1}$) for the three atmospheric layers below the melting level at 8:20 UTC. The grey area in c highlights the size interval represented in a.

The modeled spectra of the *Remote* case at 1150 and 3150 m were also depicted in Figs R3a and b (dashed lines). This allows a comparison of *HymRef* spectra with those of clean atmospheric conditions. We note, in agreement with our findings detailed in the paper, that a lower aerosol number in the initial atmospheric conditions leads to larger raindrop sizes. This analysis also confirms this vertical behavior over the entire layer where warm rain dominates. This result confirms the findings already explained in the paper, we did not include these additional Figs in the paper.

When comparing the droplet numbers between *Remote* and *HymRef* at 3150 m, it is surprising to see that also small raindrops in the diameter range from 0.1 to 0.7 mm are more frequent in the *Remote* scenario. In order to understand what this result of *HymRef*, we extended the drop size distributions to size ranges of cloud droplets (down to 10µm). Fig. R3c shows that the high concentration of small drops formed in *HymRef* restricts to sizes below 30 µm. This again is coherent with our statements on the effect of aerosol number concentration on the cloud droplet evolution.
Differences between the mean spectra, especially for raindrop sizes > 2 mm, are quite weak (see Figs R3a and b). Results for the mean spectra depend strongly on the horizontal location of the selected grid points. As noted above, altitudes were taken above sea level. Due to the complex terrain of the Cevennes and Vivarais Mountains, the vertical distance between underlying topography and e.g. 3150 m varies between 1850 to 2850 m. Thus, cloud modeling over complex terrain makes it quite difficult to distinguish and to explain the processes dominating for cloud and precipitation formation. The permanent changes in up- and downdrafts modify continuously the field of relative humidity causing regions with strong condensation rates and others with evaporation and strong rainfall. Thus, detailed physical process understanding has to be locally restricted to regions where dynamical, thermodynamical and thus microphysical conditions are similar.

- o why are the lower precipitation amounts underestimated, is this only due to initial & coupling conditions or also linked to microphysics or other processes (turbulent mixing, entrainment, dynamics,...) and is this a usual feature of specific to this case ?

This is definitely due to the initial conditions. We run the same case with WRF for an identical model setup (initial and boundary conditions, size and resolution of outermost and nested domains). WRF (using the Morrison or the Thompson scheme) produces the same location and horizontal extension for surface rain over the Cevennes Mountains.

Unfortunately we cannot add here (i.e. on the public site of Copernicus) a figure of this comparison with WRF, as it is part of a paper that will be submitted to another journal.

- The correction on aerosol populations answers the main issue with the paper, as the new Figure 2 shows that the three aerosol populations are in fact ordered from the high CCN concentrations (*HymRef*) to the low CCN concentration (*Remote*), (almost) consistently for all particle diameters. This still seems cumbersome (it would have been easier to, e.g., divide the real population concentration by 2 and 5, and keep the same size distribution shape), but there is no issue with that anymore. Regarding aerosols, I still have other questions:
  - o above 3km, the concentration is fixed at ~900/cm3, so the same value for all cases, so the studied aerosol impact is only linked to the aerosols at cloud base, and those transported inside the cloud by updrafts, and neglects the effect of aerosol entrainment from cloud sides/top during the cloud formation. This is stated in the authors' answers, is not a problem but should be mentioned in the manuscript.

Initial number concentrations of aerosols above 3 km differ for each scenario. We join this information, as proposed by the reviewer, in the new Fig 2b. Our simulations use a 3D Eulerian model, wherein all prognostic variables (i.e. also each aerosol, drop and particle bin) are transported by advection, sedimentation and turbulent mixing in all possible directions. Thus, no effect of aerosol entrainment from cloud sides/top is neglected.

- Maybe the new Fig.2 could also include a second panel showing the aerosol number concentration (sum of the three modes) for each experiment along the vertical?
  done

Minor comments

- p2 l15 : Tau~~ff~~four et al. (…) with ~~a~~ **the** two-moment scheme (…)
  Corrected

- p2 l29-30 : Although most studies using bin schemes are performed in 2D or idealized configurations, some bin schemes have already successfully been used for real cases of deep convection, (although not for HyMeX cases), even for aerosol-cloud interactions assessment (eg. Iguchi et al 2008, Fan et al. 2012). So, here and in the conclusion, maybe this could be modified: “test if the DESCAM bin scheme is able to ...” ?
  We modified the introduction and the conclusion as followed:

  - in the introduction section, before the description of the main objective of the paper, we included the following text:
  “*Only few studies (e.g. Iguchi et al., 2008; Fan et al., 2012) have been focused on real deep convective systems with a bin microphysics scheme in a 3D dynamical framework, and none of them was applied to an intense precipitating system as usually observed in autumn over the western Mediterranean basin*.”

  - the conclusion was modified as follow:
  “*A major objective of this study was to test if a bin resolved microphysics module in a 3D mesoscale model is successful in reproducing a real case of intense precipitation usually observed over the western Mediterranean basin*.”

- p2 l31: Although bulk models are indeed less precise than bin schemes, they usually perform well enough for convection and are able to produce high amounts of precipitation. Studies of HyMeX cases cited in this paper indeed prove that point (Hally 2014, Duffourg 2016, etc), especially for cases involving strong synoptic forcing of orographic lifting. Although some errors and/or uncertainty remain, they are not attributable to the microphysics only. The same can be said for this case using the DESCAM bin scheme (indeed, the conclusion states that some differences with observations may very well be due to the initial and lateral boundary conditions). “Often have difficulties” is a bit overstated and mixes all uncertainty sources in simulations. Maybe change for something like “rely on much more assumptions and approximations to predict ...” ?

We modified following your suggestion.

- p13 l.14: see comment above about other bin schemes used in 3D real case simulations
  See our response above.

- p15 l.33: See comment above about bulk schemes. The statement "better represented as they are generally in bulk models" is vague and not justified. Again, of course they can be improved and the bin scheme is valuable in this regard, but bulk schemes have been used successfully for high impact weather forecasts and warnings for quite some time, and generally produce reasonable amounts of rain for Mediterranean heavy precipitating cases.
  We clarified the manuscript: "*Regarding the other objective of the current investigation, our study showed the potential of a bin-resolved modelling to reproduce the heavy precipitation periods usually observed over the Cevennes area. Even though the weaker precipitation was underestimated in the model, the peak values that would warrant an alert to the population were well represented. This bin-resolved modelling also provides a better understanding of the rain microphysics processes compared to bulk models as the microphysics is explicitly represented.*"

References:

Fan, J., L. R. Leung, Z. Li, H. Morrison, H. Chen, Y. Zhou, Y. Qian, and Y. Wang (2012), Aerosol impacts on clouds and precipitation in eastern China: Results from bin and bulk microphysics, J. Geophys. Res. Atmos., 117(D16), n/a–n/a, doi:10.1029/2011JD016537.

Iguchi, T., Nakajima, T., Khain, A. P., Saito, K., Takemura, T., and Suzuki, K. (2008), Modeling the influence of aerosols on cloud microphysical properties in the east Asia region using a mesoscale model coupled with a bin -based cloud microphysics scheme, based cloud microphysics scheme, J. Geophys. Res., 113, D14215, doi:10.1029/2007JD009774.