Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2017-570-RC2, 2017

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Model simulations with COSMO-SPECS: Impact of heterogeneous freezing modes and ice nucleating particle types on ice formation and precipitation in a deep convective cloud" *by* Karoline Diehl and Verena Grützun

Anonymous Referee #1

Received and published: 8 August 2017

The present manuscript investigates the effect of various heterogeneous freezing/nucleation modes for primary ice production in an idealized convective cloud case with 3D simulations using COSMO-SPECS with a horizontal resolution of 1 km. The model benefits from the bin-microphysics (SPECS) scheme, which allows an accurate representation of microphysics and the distinction between the different freezing modes. Sensitivity simulations with warm-microphysics only, homogeneous freezing solely, single heterogeneous freezing modes (immersion freezing, condensation freezing, deposition nucleation and contact freezing) with various aerosol concentra-

tions and afterwards combined with homogeneous freezing, were conducted. The single freezing modes are most prominent under different conditions (temperature and present liquid cloud droplets) and thus do not directly compete with each other. The sensitivity of precipitation formation on single heterogeneous freezing modes combined with homogeneous freezing was analysed with various aerosol concentrations. The additional heterogeneous freezing modes can increase and decrease the precipitation amount compared to homogeneous freezing only. The onset time of precipitation and the accumulated precipitation rate is affected less strong than location distribution and intensity. The concept of testing different freezing modes sequentially in a bin-microphyisics scheme is done in an accurate way and therefore this article qualifies for publication in ACP.

General comments

Do your results agree or disagree with the current literature? e.g Hande 2016 testing also different freezing modes for several cloud types including convective cases. ... I think the present study could benefit from comparison to other studies.

Also, better curve out the advantage that the bin-microphysics has compared to often used 2-moment microphysics.

P2; L20-21:

small trigger effects are mentioned frequently in the course of this article. Can you give a detailed explanation what these small trigger effects are? Is it the triggered glaciation process of the cloud, which includes ice growth, Wegener-Bergeron-Findeisen process, multiplication processes, collision beside others? Can you give an idea on how sensitive those triggered processes are to parameters that need to be set e.g. for collision processes, in the model? How sensitive are model results to the setup of this parameters compared to the sensitivity on the here tested heterogeneous freezing processes? Is the feedback on dynamics also one of the triggered effects?

P3; L16:
The original COSMO model works with a Kessler-type ... That is true, but for scientific purpose on investigating cloud microphysics more sophisticated microphysical schemes are used, such as two-moment schemes for warm and cold microphysics. Can you recommend on the advantage of your bin-microphysics approach compared to often used two-moment schemes?

Motivate why heterogeneous freezing modes are important although homogeneous freezing is dominant in convective clouds.

P8; L10-28:
The definition from Korolev 2003 distinguishes between liquid, mixed and ice cloud. I do not agree with the definition of mixed-phase clouds with IWF above 0.1. That also includes completely glaciated clouds. How do you define the mixing ratio? Is that the whole water column, so the ice water path and liquid water path, when you say integrated ice water content? Is that comparable to the definition from Korolev 2003, which refeers to the mixing ratio within the observational volume? See also the updated article about mixed-phase cloud definition Korolev et al 2017.
What does this analysis tell? Does contact freezing hardly nucleate any ice crystals? Are the few INP directly sedimenting out?
If have the feeling the purpose of this analysis using IWF is to figure out if the single freezing modes can produce a sufficient amount of ice. That could be included in **Ice water contents**.

Specific comments
P1; L10:
delete: as essential process

P1; L22-27:
Sentence to complicate: Try something like: In comparison to the reference case, with homogeneous freezing only, such small perturbations due to additional heterogeneous freezing rather effect the total precipitation amount. The temporal development and local distribution/ structure of precipitation are more likely affected by such perturbations.

P1; L22:
collision with pristine ice particles; How are secondary ice processes considered in the model?

P3; L18-20: Is wind transported? Is transportation (advection) of temperature and pressure the only process considered in the dynamical core? Which timestep was exactly used in the present study (10s or 100s)?

P2: L21-22:
Again, which timestep is used?

P8;L24 - P9;L2; P11;L24-L27:
Please avoid description of the Figure, which should be part of the caption in the text. Give interpretation instead.

Figure 3:
The description is confusing. Do you mean the middle panel with: Lower panel: vertical velocities . . . ?

Figure 8:
The text in the legend is not focussed, hard to read and there are too many information on this plot. Can you make two plots; e.g one for immersion mode and another for contact and deposition?

P11; L11: Is it: In some cases **the accumulated** precipitation **amount** stayed constant during the next hour and increased at later times. So that mean **no precipitation**?

P11; L21-25: Why do you call the simulations now cases 1-4 without intuitive names. Can you analyse the cloud properties with the same simulations as done for precipitation, to be consistent? As far as I understand some of the *cases* are the same as used before for precipitation analysis. E.g. imm 0.001% plant is case 2 now?

Figure 11:
I think this plot should show how additional freezing modes contribute to the amount, location and temporal evolution of precipitation. This is done for two aerosol setups. Make a clear distinction between the two sets e.g by line pattern or even in two separated plots.

Table 3:
Think about showing the deviations from the reference simulations. Would be easier to catch which modes contribute to enhancement of precipitation amount or suppresses precip.

Technical corrections
P1; L10: In deep convective clouds, heavy rain **is** often formed involving the ice phase.
P2; L29: acronym BAP not necessary because never used again
P3; L28: fraction, ϵ
P4; L26: temperature, T.
P4; L27: delete temperature
Eq: 1: Insert that n_m is a function of T
P5; L3: delete: () in citation Diehl and Mitra
Equations in general: Some look blurred, in general derivations, d, should not be italic as well as subscripts.
P6; L18; ϵ already introduced, delete soluble fraction
P6; L19: INP (replace ice nucleating particles with INP everywhere after INP was introduced. Check also all other abbreviations.)
P10 and following: You could use ice crystal number concentration (ICNC) instead of description like numbers of ice particles per m^3. eg. ICNC up to $10^{-4}\,\mathrm{m}^{-3}$ were reached ...
P11;L30: 1a ; delete 1
P12;L16: Internally mixed INP in the immersion mode; Is this another subsection? I guess numbers are missing.

Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-570, 2017.