1st REFEREE

ANSWER TO THE SPECIFIC COMMENTS.

Specific comments

p. 26149 l. 6: What length is the model time step?

We added it in the manuscript text.

p. 26149 l. 26: It is not clear whether bacteria were allowed to act only as IN or also

as CCN.

No, it doesn´t, and also added it.

p. 26150 l.18-21: You write that the "IN concentration was assumed to follow 100000 times less the population of bacteria". What are those other IN you talk about? Is it mineral dust? Also, please rephrase the sentence for clarity, as it's not clear what is meant by "100000 times less the population of bacteria".

We changed it there. We used only a fraction of the total bacteria found in cloud water (we erased the *P.syringae* in parenthesis which confused whole sentence).

p. 26150 l. 24-26: Does bacteria concentrations being homogeneous over the whole model domain mean that their vertical distribution is also homogeneous? If yes, this would not be realistic. I find it also problematic that there is no depletion of IN. This would mean that IN-active aerosol do not sediment and are not removed by precipitation. I hope that this is not what the authors had in mind when writing; otherwise it would mean that the model is inherently flawed.

We use the same parameterization used in RAMS and BRAMS. There was no difference of the previous RAMS default or our simulations in those cases. Besides, the cloud dynamic modeling is always re-feed by a mass air coming as new parcels with the same IN and CCN distribution. All cloud modeling work with this assumption. There are many flags that control the BRAMS bulk microphysics parameterization, including model's treatment of IN. Once the user decides for one water category, the model prognoses both mixing ratio and number concentration for that category. In the simulations performed in this work a prognostic IN field was activated in BRAMS, and ice is nucleated from this field as a function of IN concentration and environmental properties. In fact, there is currently no scavenging removal or source functions for IN, but there

are advective and diffusive transport and also interactions with other water categories that remove IN.

p. 26150 l. 27: I am not sure what you mean by this sentence. Do you want to say that you assume in the model that all bacteria act as ice nuclei? As this is probably not the case in nature, I would like to see some discussion on that, or at least your reasoning why all the bacteria in your model act as ice nuclei.

No, we don´t, only a fraction of the bacteria act as IN. We rephrased it.

p. 26151 l.12 Please explain here in deeper detail how the ice nucleation is handled in BRAMS, especially the parametrization. Is it assumed to be the same for all IN species? Maybe rephrase here quickly the formula used from Meyers et al. (1992) and Cotton et al. (1986) that you mention. Why are not some more recent parametrizations used? E.g. Hoose et al., 2010: A Classical-Theory-Based Parameterization of Heterogeneous Ice Nucleation by Mineral Dust, Soot, and Biological Particles in a Global Climate Model. J. Atmos. Sci., 67, 2483–2503. doi: 10.1175/2010JAS3425.1

Yes, it is assumed the same IN, there is no difference among the species, only temperature vs concentration differences (the main reason for Figure 2). Meyers and Cotton is the normal parameterization used in RAMS and BRAMS. To modify it in order to introduce Hoose work is not the proposal of this work and demands far deeper modeling study. Recent parametrizations have been developed to predict global atmospheric ice nuclei distributions. In the cited reference (Hoose et al., 20010) biological aerosol contribution to global atmospheric ice formation is marginal. However, when such parameterizations are examined we see that IN number concentrations at any temperature show high variability, probably related to the specificity source of the particles (see Fig. 2 from DeMott et al., 20010). Although it is known that ice nucleation by mineral dust and soot globally dominates over bacteria, it is important to perform local studies with focus on biological contribution.

P. J. DeMott, A. J. Prenni, X. Liu, S. M. Kreidenweis, M. D. Petters, C. H. Twohy, M. S. Richardson, T. Eidhammer, and D. C. Rogers. Predicting global atmospheric ice nuclei distributions and their impacts on climate. PNAS 2010 107 (25) 11217-11222; doi:10.1073/pnas.0910818107

p. 26152 l. 5: Say here already which values you use for C and not just in lines 25/26.

The C value varies from on storm to another, and the lightning parametrization description here emphasizes that by shown two different values. The actual value used in the simulation is based on few sentences below while we describe how we calculated *fp* and *fnp*, and it introduces the results in Section 3.2. So, we think that it is more convenient to leave the chosen C value with this description to emphasis that it can assume another value if it is desired.

p. 26152 l. 17: This doesn't make sense, why would some ice species like snow be non precipitable? Please explain. Also, I think you are missing a word after "pristine". What is pristine, the ice crystals?

The precipitable ice hydrometeors are those with high terminal fall velocities (i.e., denser and not easily carried by the updraft) and non-precipitable ice hydrometeors are those with smaller terminal fall velocities (i.e., less denser and easily carried by the updraft). The whole concept of cloud electrification is based on the collision between ice particles that can only be done if they have different terminal fall velocities, and the updraft plays the role of guarantying the collisions to happen. Therefore, cloud electrification is mostly built on the region with strong-moderate updrafts where snow and ice-crystal are non-precipitable. We have included this explanation in the text.

Yes, pristine is a kind of ice crystal. It is a typical ice hydrometeor used for cloud microphysics researchers and cloud models. It is important recognize that, according to BRAMS model, water is categorized in eight forms: vapor, cloud droplets, rain, pristine ice, snow, aggregates, graupel and hail. Just cloud droplets are assumed small enough to not fall, while all other categories do fall. In the case of pristine ice, once nucleated, it may also continue its growth by vapor deposition, and is not permitted to grow by any other process. The definition of the pristine ice category is restricted to relatively small crystals, and larger pristine ice crystals are categorized as snow. The snow category is defined in BRAMS as consisting of relatively large ice crystals which have grown by vapor deposition and riming. Together, the pristine ice and snow categories allow a bimodal representation of ice crystals.

p. 26152 l. 20: What is meant by "pristine masses"?

That means the amount of pristine crystals. We added the word "crystal" after "pristine" in order to make clearly. Also, the word "masses " refers to all hydrometeors, that is, masses of hail, graupel, etc..

p. 26152 l. 27: What is the length of the time step used here?

The results are presented every 2 minutes of simulation, and this was corrected in the text.

p. 26153 l. 7: You quote the wrong table here, it should be "Table 2" instead of "Table

1".

We changed it.

p. 26153 l. 9 and following: Please use the established units for reporting cloud water and ice water calculated by the model, i.e. liquid and ice water content respectively in g/m3 instead of g/kg which is a more common unit for the specific humidity. Please check also for conversion errors, as the values given here are three orders of magnitude too high (unless I understood something wrong or you wanted to write mg/kg instead of g/kg). Even in the tropics, the average specific humidity is only around 18 g/kg max. For example, I would expect the in-cloud cloud water content to be around 0.2 g/kg. You might also want to use the cloud droplet number concentrations (in number per m3) or the liquid water path (in kg/m2) to describe the amount of rain and ice produced by your model. Additionally, I find it troubling that here (and in Table 2) you give values obtained by summing up the variables, as this is not how those data are usually handled. See also my comment on Table 2 below.

All **parameterizations inside of RAMS and BRAMS and cloud models in general are given in g.kg^{-1}, (mixing ratio), it is not practical to use g.m^{-3} because air density varies with height. The values are high because they are integrated values over the horizontal and the vertical domain (the whole simulated cloud) and also integrated during the whole simulation (3 hours). The simulation values are shown this behavior because cloud electrification is based on whole amount of hydrometeors produced together with the updraft.**

p. 26154 l. 8: What do you mean by pristine ice crystals? Those formed by homogeneous freezing and thus containing no ice nuclei?

Pristine explanation is above. Homogeneous freezing contains no ice nuclei and it is called super-cooled cloud water.

p. 26153 l.14: Why do you compare the reduction in rain with the results from the Levin et al. (2005) study, as you used bacteria as ice nuclei in your simulation and they did not?

Levin article allowed the mineral dust particles to act as efficient ice nuclei (IN) reducing the amount of rain on the ground compared to the case when they are inactive. Therefore there is a non-biological IN involved in his work. There is no previous articles dealing with cloud simulation using bacteria, so we had to compare our results with non-biological IN.

p. 26154 l. 15: As stated previously, it is important to know the vertical dispersal of bacteria. If it is the same everywhere, one would expect the peak of ice crystal production to be the same in all simulations, as stated. This is why it's also important to know the freezing parametrization of the model.

Yes, it was written above, the vertical distribution is homogeneous, acting as all other IN in BRAMS. It is not the same due the IN concentration and for the default, the temperature. And the peak is not the same due to a very non- linear processes among the crystals, typical for cloud modeling.

p. 26154 l. 19: As bacteria freeze at relatively high sub-zero temperatures, I would have expected the heterogeneous nucleation peak to take place at lower heights.

The same explanation above, the non-linear processes among the ice formation.

p. 2153-26155: I suggest to add information about how different aerosols in your model contribute to the freezing. For example, do bacteria take over when they are added? Also, it is not clear from this chapter, whether there are different aerosol species contained in the model, or just one IN species.

The differences are all based on temperatures and concentrations. There are no differences between the species.

p. 26155 l. 11: I think it's very interesting that the simulations with bacteria produce three times more hail. You might want to cite here the work by Michaud et al. who observed that centers of hailstones contain much more bacteria than the surrounding air. Michaud, A. et al.: The Role of Ice Nucleating Bacteria in Hailstone Formation. 11th General Meeting of the American Society for Microbiology, New Orleans, 2011.

Yes, indeed. Very interesting, we will add it there.

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p. 26156 l. 9: Why did the S2, S3 and S5 simulations produce non comparable values? Please discuss.

As above, it is a typical case of non-linear interaction. There are many processes among the hydrometeors which lead a non linear process.

p. 26156 l.14: This is the first time that we learn that the model has a 2-min time step. Please add this information already to chapter 2.1.

We changed it.

p. 26157 l.14-18: Please rephrase the sentence starting with “These authors...”. You make it sound like you look at the horizontal cloud coverage and incident solar insolation as well, but you didn’t mention those aspects at all in your manuscript.

We changed it.

2 Tables

Table 1: Instead of deposition write deposition freezing. Delete “and” from “Condensation and Freezing” as well as “Contact and Freezing”. If none of these heterogeneous freezing mechanisms take place in simulation 1 to 4, how does ice form then? By immersion-freezing only? What other IN are acting as heterogeneous ice nuclei in S5?

Nucleation of pristine ice crystals may occur even though heterogeneous freezing not being activated. Parameterizations representing homogeneous nucleation of both cloud droplets and inactivated haze particles are represented in the BRAMS model. This nucleation is applied for temperatures at or below -30°C Nucleation is also possible from secondary ice production. This parameterization in BRAMS is based on the Hallett-Mossop theory and is a process connected with riming. During riming process a fraction of the rime splinters into small crystals, therefore categorized as pristine ice.

Table 2: The way those values are presented here is very unusual and confusing. Instead of summing up the variables in the entire domain (horizontal and vertical) for the whole duration of the simulations, I strongly suggest, that the more common liquid/ice water content (in kg/m3) or liquid/ice water path (in kg/m2) are used. This makes the results comparable to other models and simulations.

As it is written above, all cloud model researchers work with $g.kg^{-1}$, due to the fact that air density varies with height. As explained above, cloud electrification is sensitive to the overall production of hydrometeors, so we present the total hydrometeor “ production” for each simulation.

Table 3: Please give a unit for the hydrometeor mixing ratios (usually, it’s g/kg).

We changed it

Table 4: The ice mass flux seems to not vary much between simulations. Please explain why this is so. Also, there is a formatting error in the table: “lightning flashes” should come below “Total estimated”.

The soft variation among the total ice mass flux is based on fact that the vapor amount is the same for all simulations not depending on the IN concentrations. Therefore, the variability of the mass flux depends only on the non-linear processes among the hydrometeors, which is not too much when all non-precitable hydrometeors (or precitable) are taking in account together

(the variation for each one separately is higher). Nonetheless, the small variations on the non-precipitable mass fluxes determined the number of lightning flashes: simulation with smaller fnp had less or none flashes.

3 Figures

Fig. 1a. A map showing the topography (and maybe surrounding vegetation) would be helpful to get a better understanding of the study area.

A map of the area with vegetation plus city is a rather complex one, because the land use of it. We can also provide a map with topography.

Fig. 1b. This figure would be much easier to understand, if it were plotted as a common skew-T log-p diagram, including lines for dry and moist adiabats, as well as isotherms, isobars and constant mixing ratio. It would also be interesting to see where the lifting condensation level and cloud top are, and compare this to the model results.

We did it.

Fig. 2: It would be more logical to plot the concentration (on x-axis) against height (on y-axis). Why is it plotted against temperature? It would be interesting to see how many bacteria are available for freezing at the specific model levels.

Because the main differences of simulations are based on temperature turn points. It is easier to see how many bacteria is active as IN each temperature, look directly at the graphic. This is a typical graphic of IN researchers (see Morris et al., 2008)

Fig. 3: Please bring the pictures of the simulations S1-S5 in a logical order, from left to right and top down (i.e. top row: S1, S2, middle row: S3, S4, bottom row: S5, S6).

Rachel Simulations S2, S3 and S4 are the same except for the fact that the concentration of bacteria changed, so they have produced similar clouds and this is more evident if they are compared/displayed directly in a column as they are right now. S1, S5 and S6 are variations/combinations of the S2, S3 and S4 simulations and their differences are more evident if they are compared/displayed in a column. Therefore, we think that we should not rearrange to a numerical order, as the logic of the simulations are not that.

Fig. 4: I suggest that instead of writing "231" etc. you just write the total number of lightning flashes occurring in each scenario.

The time when the lightning flashes are produced and when they are produced (during the large updraft) are important, so we kept the individual 2-min lightning production, but we have added the total lightning flashes as you suggested.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 26143, 2011.C10378