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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Effect of bacterial ice nuclei on the frequency and intensity of lightning activity inferred by the BRAMS model" *by* F. L. T. Gonçalves et al.

Anonymous Referee #1

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This paper investigates the influence of bacteria (*P. Syringae*) on both precipitation (precipitable and non-precipitable ice) and cloud electrification which is connected to the mass fluxes of hail and graupel within storm cells. This is an interesting aspect of heterogeneous ice nucleation presented in form of a modeling case study for a convective event in São Paulo. However, I cannot recommend this paper for publication in its present form since there are two major concerns that I would like to raise: first, the parameterization for the ice nucleation behavior of *P. Syringae* needs revision. Secondly, the estimation of lightning frequency as a function of precipitable and non-precipitable ice mass fluxes is not explained very well and thus it is not comprehensible to the reader. In principle, however, I think that work on this interesting case study should be continued and because of that I have listed points that I find critical as well as technical corrections and hope that this will be helpful to the authors.

Major points:
1) Ice nucleation parameterization

- p. 26150, l. 10-16: A more recent parameterization for homogeneous ice nucleation is given in Koop et. al (2000). Maybe you could compare between the parameterization by deMott (1994) and the one derived by Koop et al. (2000). Also, please cite Pruppacher et al. (1997).
- p. 26150, l. 16-24: For allowing the reader to understand how the maximum concentration of ice nucleating bacteria per l of cloud water was derived, it would be good to proceed in two steps: first, a range of atmospherically observed or estimated bacteria concentrations in air should be given (Amato et al., 2005; Burrows et al., 2009). Then, from observed ice fractions for ice-active bacteria (Möhler et al., 2008; Yankovsky et al., 1981; references in Philips et al., 2009) a parameterization for immersion freezing of *P. Syringae* could be derived. The calculated IN scenarios could then compared to concentrations of ice-active bacteria in cloud water derived from snow samples. If within the model framework the activation of bacteria to CCN was possible, a comparison between this calculated number and observed cloud water concentrations would be even more interesting and would underline the predictive power of BRAMS.
- p. 26150, l. 21-23: “As no observational data were available at temperatures colder than -12°C, the IN concentration for -10°C was used. . .”. Please check references in Philips et al. (2009) for data at lower temperature and as pointed out before consider developing an enhanced parameterization from a wider selection of data. It is not clear to me how the ice nucleation parameterization could be derived based on the information given in Amato et al. (2005, 2007). Maybe a

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reference is missing here.

- p. 26150, l. 24/25: "…*P. Syringae* IN concentrations were assumed homogeneous over the whole model domain…" Does this mean that the bacterial concentration is not only homogeneous over the horizontal dimension, but also over the vertical column? If yes, additional assumptions about the atmospheric distribution of the *P. Syringae* bacteria should be made.
- p. 26150, l. 26: Why is depletion, e.g. by scavenging, not considered?
- p. 26150, l. 27: "All bacteria […] induced ice formation." This is contradictory to the statement in l. 18, where an ice fraction of 10^{-5} is assumed. Please either clarify or delete.
- p. 26151, l. 14: Setting the cutoff for the background ice nucleation at -8°C seems very arbitrary, especially if the authors' intention is to demonstrate that bacteria might have a significant influence in comparison to scenarios where only background IN are present. Does this threshold have a major influence on the results obtained under the assumed environmental conditions?

2) Cloud electrification parameterization

- p. 26151, l. 25/26: Please state how "precipitable" and "non-precipitable" ice masses are defined.
- p. 26152, l. 4: It is not clear where eq. 1 comes from, since the referenced publication by Barthe et al. (2007) is an abstract which does not contain any formula. Also, the functional form of the relation given in Deierling et al. (2008) is different from eq. 1 with
  $f = 9.0 \cdot 10^{-15} \cdot f_{np} \cdot f_p + 13.4$.
  Please give a detailed explanation and reference accordingly. Under which atmospheric conditions can eq. 1 be employed?

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- p. 26152, l. 13 (eq. 3) and l. 20-24: In the publication by Deierling et a. (2008) it is stated that non-precipitable ice is identified with help of the horizontal divergence of the wind velocity. Was this criterion also employed for the numerical simulations in this paper? The non-precipitable ice flux is not given by eq. 3, but by summing up over the components as calculated with eq. 3. Please correct as in Deierling et al. (2008) the flux of non-precipitable ice is given by $f_{np} = m_{NP} \cdot w$ which means that f_{np} and f_p have the same units.

Minor points:

- p. 26144, l. 9-11: The mentioned maximum IN concentrations (10^2 to 10^3 bacteria per l) do not match with the concentrations illustrated in Fig. 2, where IN concentrations correspond to maximum values of 10^2 to 10^4 bacteria per l. Please clarify.
- p. 26144, l. 11: Please point out that the S5 and S6 scenarios based on the RAMS ice nucleation parameterization were used as reference cases.
- p. 26144, l. 13: From the formulation "the chosen radiosonde data" it is not clear how this data is exactly related to the numerical simulations. Please clarify how this data was used for the initialization of the modeled temperature and humidity profile.
- p. 26146, l. 19: In the study by Morris et al. (2008) also values for the bacteria concentrations in rain water are mentioned (up to 10^4 bacteria per l). Please add.
- p. 26146, l. 21-25: The study by Möhler et al. (2008) found maximum ice-active fractions of 10^{-4} for *P. Syringae* and other bacteria species in the temperature range between -7 and -11°C. This value could be added as a second reference for the ice-active fraction besides Orser et al. (1985).
- p. 26147, l. 13-21: In this paragraph the role of mineral dust particles acting as CCN and IN is highlighted. As mineral dust belongs to the most abundant aerosol

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species in the atmosphere, and thus has a major influence on atmospheric processes it certainly deserves to be mentioned. However, for adding value to the manuscript and emphasizing that it is worthwhile to investigate bacteria, it would be necessary to briefly compare the role of mineral dust particles to that of biological particles (e.g., mention CCN activation thresholds, freezing ranges, etc).

- p. 26148, l. 7/8: "…increasing the total amount of electrical charge transferred and the charged centers, which in turn increases the lightning activity in the cloud." How is lightning activity defined here? Is the relation between the number of charged centers and lightning really that straightforward? What role do storm cell structure, cloud dynamic processes and their respective time scales play? Please explain.
- p. 26148, l. 26: Has the BRAMS model also been validated for other regions than the Amazon, i.e. for the urban area of São Paulo? If yes, please add references.
- p. 26149, l. 8: "…according to Gonçalves et al. (2008)." In the referenced publication low level forcing is described as a "hot and wet bubble". Please describe in greater detail how the initialization is performed (temporal and spatial structure) and what part of the radiosonde data is used in this context.
- p. 26149, l. 23-25: "The configuration of additional microphysical parameters in the numerical simulations was adjusted according to values suggested in empirical studies." Please specify which parameters were adjusted according to what kind of empirical studies and add the corresponding references.
- p. 26149, l. 25/26: "…parameters that directly impacted IN were the CCN concentration..." What is the relation between IN and CCN in the model for this statement to be made? CCN and IN concentrations are not necessarily related to each other.

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- p. 26150, l. 1: "...shape parameter of the size distributions..." To which size distributions do the authors refer at this point? To the droplet size distributions? Or to all hydrometeor size distributions? Please clarify.
- p. 26150, l. 6: The authors assume "relatively clear atmospheric conditions". How can this be justified with regard to São Paulo being a highly polluted urban area?
- p. 26157, l. 12/13: "...BRAMS default IN concentration seems to play a secondary role at all, not affecting the total number of flashes..." Do you have any explanation for this behavior?
- p. 26163, Table 2: Ice crystals may be partly belonging to precipitable ice and non-precipitable ice. Therefore it should be considered to differentiate between ice crystals of different sizes and crystals habits.
- p. 26170, Figure 3: The graphical representation of the temporal development of the different hydrometeor species is a very good idea in order to help the reader understand the results of your numerical simulations. However, it would be better if there were different graphs for each hydrometeor species since it is very difficult to distinguish between those species in the figure. Maybe you can restrict yourself to detailed representations of the hail and graupel populations and show integrated values for the other hydrometeor species in another graph.

Technical points:

- Introduction: The introduction contains many interesting aspects of bacteria interacting with the atmosphere not only directly, but also via processes that are influenced by bacteria-induced ice nucleation in clouds. However, this section could benefit from a slight reorganization bringing together aspects that belong together in order to highlight the structure of argumentation as presented by the

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authors, with as a first point the role of bacteria as IN, then their natural abundance and subsequently the influence on both precipitation and rainfall.

- p. 26144, l. 7-9, l. 14-16, l. 22: For the reader it might be easier to follow your line of argumentation, if you mentioned all aspects that were investigated (effect on total rain water, effect on cloud properties and precipitation, and total flash number) in the opening paragraph.
- p. 26146, l. 25/26: The highest concentration of biological IN found by Christner et al. (2008) was 120 IN per l, not 200 IN per l as stated in the manuscript. Maybe you could also mention the number of DNA containing cells ($1.5 \cdot 10^4$-$5.4 \cdot 10^6$ cells per l) from this study.
- p. 26147, l. 1-13: In this paragraph a feedback mechanism involving bacteria and the hydrological cycle is mentioned. As this paragraph could serve more as an overview and a motivation for the research presented, it might be useful to put this paragraph at the beginning of the introduction.
- p. 26148, l. 3/4: “When the electrical potential between these [charged] centers are strong enough to break up the electric breakdown of air, lightning is initiated”. Maybe you can elaborate a bit on this point, i.e., describe the basic process (ionization of air, creation of plasma channels, breakup) and mention that lightning can occur within clouds, but also between cloud bottom and ground.
- p. 26148, l. 9-13: How is this paragraph on precipitation related to the issue of lightning that is discussed before and afterwards?
- p. 26149, l. 20: “. . .complete development of both liquid and ice phases.” What does the term “complete development” mean?
- p. 26150, l. 17: Change “(S3 scenario”) to “(S2 scenario)”.

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- p. 26153, l. 7: Change “Table 1” to “Table 2”.
- Section 3.1: Regarding the structure of this section, it would be easier for the reader if general trends (e.g., decrease in rainfall) would given and then illustrated with a few examples. The authors could also focus more on the interpretation of their results.
- p. 26162, Table 1: Please add a note to the simulation S6 since the different freezing modes were only explicitly considered for the RAMS default parameterization, but not for the bacteria acting as IN.
- p. 26164, Table 3: Please add units [g kg^{-1}]. In comparison to Table 2, rain is not listed as a hydrometeor in Table 3. If suitable, add maximum values and the corresponding time information.
- p. 26165, Table 4: The phrase “lightning flashes” belongs to the fourth column.
- p. 26168, Figure 1c: If available you could add a second figure showing the radar data for 12:00 GMT of March 3, 2003 in order to match the humidity and temperature data presented in Fig. 1b and thus to allow a better understanding of the modeled “hot bubble” before the actually observed convective event at 18:00 GMT which is a point of time not within the modeled time period. Radar data for 15:00 GMT of March 3, 2003 might be used to compare the observed rainfall to the amount calculated in the numerical simulations.
- whole manuscript: Please do a thorough check of punctuation and linguistic accuracy (i.e., complete sentences, spelling and similar).

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