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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Influence of heterogeneous freezing on the microphysical and radiative properties of orographic cirrus clouds" *by* H. Joos et al.

Anonymous Referee #1

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This manuscript aims to better understand the influence of heterogeneous freezing on the microphysical and radiative properties of cirrus using idealized cloud resolving model simulations of orographic cirrus clouds. The approach is to perform a set of 38 simulations where the homogeneous and heterogeneous nucleation mechanisms are tested individually and allowed to compete. In addition, the impact of ice nuclei concentrations, temperature, supersaturation threshold for heterogeneous nucleation initiation, and solar zenith angle on the microphysical properties are examined. The ultimate goal is to improve the representation of cirrus in climate models through improved understanding of cirrus processes, though that is not specifically addressed in

this study.

In general, the representation of cirrus in climate models is improving though there continues to be some areas of improvement needed primarily related to the representation of sub-grid scale processes. This study aims to partially address this issue by examining the variation in cirrus properties with different sub-grid processes. However, the findings are not really tied back to climate models but instead are presented as a sensitivity study to show which parameters have the largest impact on the microphysical properties and hence the cloud radiative forcing. They conclude that orographic cirrus will have either a warming or cooling effect depending on IN concentrations, the cloud temperature, and the time of day that the cloud forms. This type of study has been performed previously for synoptic type cirrus, but not necessarily for orographic cirrus so in that sense the results are "new". However, the results are not really all that surprising because it is well known that the cloud radiative forcing depends strongly on the cloud microphysical properties (i.e. extinction) and hence homogeneous and heterogeneous nucleation will certainly produce different radiative effects depending on the ice crystal number concentrations produced. The importance of these results might have been elevated if the authors provided some context regarding how the climate modeling community might utilize their results or suggested a path forward with specific links to climate models. Otherwise, the study by itself may not represent a significant advancement.

The model simulations and approach are reasonable and the presentation of results is generally good, though the text is somewhat wordy and the figures require some improvements. I would not be inclined to accept this paper unless significant changes are made to the presentation and discussion of results, as well as improvements to the significance of the results as they relate to climate models. I have made some suggestions and specific comments that will hopefully help to improve the manuscript.

Specific Comments: 1) The study focuses on orographic cirrus clouds. How prevalent are orographic cirrus and what impact do they have on climate? Are they primarily a regional phenomena or more important than that? 2) P. 18073, Line 16-22: It maybe more succinct to state your objective in this way: "To understand the important contributors to sub-grid processes related to the interaction between dynamics, microphysics, and radiation, we investigate the role of nucleation mechanism, ice nuclei concentration, temperature, and diurnal cycle in modulating the simulation of cirrus microphysical properties." 3) P. 18075, Line25-26: You state that the model represents (simulates?) well the INCA measurements and therefore is suitable for orographic clouds. However, I don't recall that the INCA campaign was dominated by orographic clouds and maybe more representative of synoptic cirrus rather than orographic generated cirrus. Orographic cirrus will certainly have different composite microphysical properties than synoptic cirrus. If your model is tuned to INCA measurements, then I am not sure that the simulations are representative of orographic cirrus. Can you please clarify your meaning in this sentence and state what the expected ice number concentrations might be in orographic vs synoptic cirrus? 4) Figure 2. You state reference temperatures for the specific temperature profiles (229, 220, and 210 K). Can you state what these values refer to? Are they where we expect cloud top to be? You reference Joos 2009, but would be nice to give one sentence about these temperature profiles so that the reader can have a quick understanding without digging up other references. 5) I find myself flipping back and forth to compare figures in order to interpret the results. I wonder if it might be more efficient to combine similar figures to make the comparisons easier. For instance, I would suggest combining Fig. 4 and 7 to show side by side the cloud forcing results between HOM and 10IN simulations (such as two columns with three rows, column 1 has HOM and column 2 has 10IN results). Something similar could be done with Figures 3 and 5. 6) P. 18084, Line 12-13: "Cold temperatures lead to a decreased crystal growth rate…" I don't really agree with this statement. There are many factors that determine the growth rate and an important factor is the total surface area available to uptake water vapor, which is determined by the total ice crystal number that is nucleated. In your simulations, the HOM case produces the largest number of ice crystals at the coldest temperatures (driven by the cooling rates), which

is expected. So indirectly the cold temperatures are impacting the size of the crystals because more crystals formed initially, and hence the growth of crystals is less due to a larger total surface area available to collect water vapor. I would suggest rewording this section and discussing more about the physical mechanisms than the indirect causes. 7) P. 18084-18085: I am not sure that I agree with your discussion concerning the role of temperature in changing the ICNB given the figures as they are presented (Fig. 8 and 9). I think that in order for you to demonstrate the amount of water vapor that is depleted you need to show figures of the ISSR, ice number concentration, and temperature evolution for each simulation (such as height vs time cross sections). You are making some assumptions about the causes of the changes in cloud forcing that I don't feel are supported in the figures that you have presented. It is quite possible that your interpretation is correct, but the evidence is not presented. Please provide more specific examples to support your conclusions. 8) Sec. 4.2.2 Cloud Forcing: What zenith angles are you considering? What latitude do your simulations represent? It seems obvious that the zenith angle will change the cloud radiative forcing (assuming constant microphysical properties). But you seem to imply that zenith angle impacts the microphysical properties themselves. What are the physical processes? Increased heating/cooling in the atmosphere? I am wondering if I have misinterpreted your point. Please clarify how the simulations are different in this section than the previous sections. Are you just taking the simulated cloud properties from previous sections and changing the radiation calculations to represent a different time of day? Is the radiation just a diagnostic process in the model, or does it feedback to the cloud evolution? 9) P. 180087: Shortwave cloud forcing is mainly driven by the optical depth (extinction) of the cloud, which is a function of the ice crystal number concentration and size distribution primarily. The diurnal cycle impacts cloud formation in that it may inhibit cloud formation or increase buoyancy in the atmosphere. I think that it would be more interesting to know how these time of day simulations impact cloud lifecycle and microphysical properties (and hence the cloud radiative forcing). I think that the causal mechanisms related to your conclusions should be discussed in more detail. 10) P. 18087 Line 3:

“. . .ice water content of xx mg mˆ-3. . .” Did you mean to put a specific number in for the “xx” ? 11) P. 18088 Line 15-20: Your statements imply that the cloud evolves exactly the same (same microphysical properties) regardless of whether it started forming at 0600 or 1200 LT. This implies that the radiation has no impact on the cloud evolution and lifecycle. This seems unlikely and implies that you do not have a realistic representation of cloud-radiative-dynamical interactions in your model, but merely computing the radiative transfer on the same cloud with different zenith angles. Please clarify the related discussion. 12) Section 5. Summary and Conclusions: The summary section is really a very long repeated account of the results that are already presented. I suggest shortening this section to present the most salient points and provide some discussion regarding the significance of those results.

Minor editorial suggestions: Abstract (Line 19-21) “If a cloud produces a net warming or cooling depends on the IN concentration, the temperature and the time of day at which the cloud forms.” Suggest minor word change: “A cloud will produce a net warming or cooling depending on the IN concentration, the temperature, and the time of day when the cloud forms.” Figure 2 seems to really be a table, not a figure, and Fig. 2 is mentioned before Fig. 1. Suggest renaming Figure 2 -> Table 1, present before Figure 1, and renumber the rest of the figures. P. 18077, Line 3: “. . .ice water content are used. . .”

P. 18081, Line 4: “...how these microphysical. . .”

P. 18082, Line 17 (and throughout the paper): “INs” -> suggest spelling out “ice nuclei” or use “IN” since ice nuclei is already in the plural form.

P. 18083, Line 14: “. . .rapid growth of ice crystals, which produces IWP values up to. . .”

P. 18084, Line 5: “. . .an overview of all simulations. . .”

Fig. 11 caption: solar
