Reply to Anonymous Referee #1

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We thank the referee for his/her helpful comments. Our replies are listed below.

I have several concerns. Mostly I worry that the single campaign focus and recommended parameter choices may not be generally applicable globally. The authors do not state this quite well enough in the conclusions as noted below. The paper is not overly long, and so perhaps a figure with some of the other observations mentioned (Kramer et al 2009) would be appropriate to see if the results here hold up in different regions, particularly since these other observations have a different slope of the temperature v. ice number concentration relationship. You already have the data from the simulations, and the Kramer et al observations are easily accessible.

In this paper we focus on synoptic cirrus in mid-latitudes. From the analysis of measurements from multiple campaigns, we believe that the observed relationship between temperature (T) and ice number concentration (Ni), as discussed in the paper, is a consistent feature in the reliable (although limited) data available so far.

The limited amount of measurements of cirrus clouds to date can be divided into two categories: older ones that were obtained using the Forward Scattering Spectrometer Probe (FSSP), and the newer ones that used the two-dimensional stereo-imaging (2D-S) probe. The FSSP is known to have the potential problem of overestimating Ni when clouds contain a significant number of relatively large (diameter > 50μm) particles (Gardiner and Hallett, 1985; Field et al., 2003; Field et al., 2006; McFarquhar et al., 2007; Jensen et al., 2009), while the 2D-S has been shown to be less susceptible to shattering artifacts (Lawson et al. 2008, Jensen et al., 2009). The Kraemer et al. (2009) dataset, which contains FSSP measurements from only four flights in mid-latitudes, indicates surprisingly high ice crystal number in the 235 K - 245 K temperature range (median around 1500 #/L, mean around 2700 #/L, Fig. R1a), although at lower temperatures (205K-225K) the trend of increasing Ni with decreasing temperature is clear. Because of the possible issues with FSSP at warmer temperatures, and the short record (4 flights) that makes it difficult to obtain robust statistics for the model evaluation, we did not include Kraemer et al. (2009) data in our analysis.

Among the more recent campaigns that used the 2D-S probe, there is another one that collected data from cirrus in the Northern Hemisphere mid-latitudes: the NASA Mid-latitude Airborne Cirrus Properties Experiment (MACPEX) in April 2010. The flight trajectories covered mainly the Houston area, and revealed qualitatively the same increase of Ni with decreasing ambient temperature (Fig. R1c) as shown in the SPARTICUS campaign (Fig. R1b). We therefore think the Ni-T relationship obtained in

this study is robust. One might think that with SPARTICUS and MACPEX combined, the amount and coverage of observations are still very limited. However, these are the major measurements available with 2D-S in mid-latitudes for the climate model evaluation.

In the revised manuscript, we have added the discussion above to Section 5 (Results). In addition, following the reviewer's comment, we make it clear in the revised conclusions that the present paper focuses on synoptic cirrus in the Northern Hemisphere mid-latitudes. We clarify that we have not done any analysis or evaluation in the topical regions where the ice nucleation mechanism in cirrus cloud can be very different from mid-latitude cirrus (e.g., Jensen et al. 2013), and that our recommended parameters may not be the best choices there.

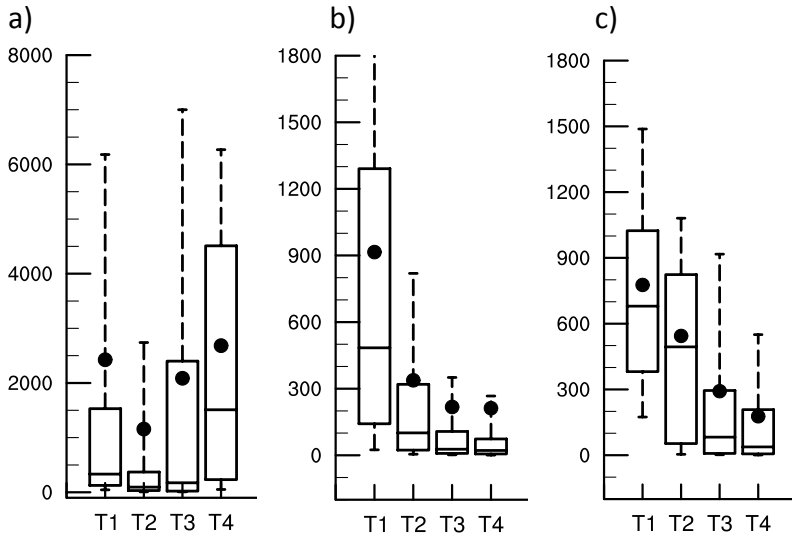

Fig. R1. Box plots showing observed ice crystal number concentrations (unit: L^{-1}) versus ambient temperature in cirrus clouds in the Northern Hemisphere mid-latitudes, from (a) the Kraemer et al. (2009) dataset which used the FSSP probe, (b) the 2D-S probe of the SPARTICUS campaign, and (c) the 2D-S probe of the MACPEX campaign. T1 - T4 stand for different temperature ranges (T1: 205K-215K, T2: 215K-225K, T3: 225K-235K, T4: 235K-245K). The two whiskers of each box denote the 10th (lower) and 90th (upper) percentiles. Hinges from bottom to top are the 25th, 50th, and 75th percentiles, respectively. Black dots denote the mean values. In panel b), the observed 90th percentile in the T1 (205–215K) temperature range is 1981 L^{-1} and goes off the chart.

References:

Field, P., Heymsfield, A., and Bansemer, A.: Shattering and particle interarrival times measured by optical array probes in ice clouds, J. Atmos. Ocean. Tech., 23, 1357–1371,

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Lawson, R. P., Pilson, B., Baker, B., Mo, Q., Jensen, E., Pfister, L., and Bui, P.: Aircraft measurements of microphysical properties of subvisible cirrus in the tropical tropopause layer, Atmospheric Chemistry and Physics, 8, 1609–1620, doi: 10.5194/acp-8-1609-2008, http://www.atmos-chem-phys.net/8/ 1609/2008/, 2008.

McFarquhar, G. M., Um, J., Freer, M., Baumgardner, D., Kok, G. L., and Mace, G.: Importance of small ice crystals to cirrus properties: Observations from the Tropical Warm Pool International Cloud Experiment (TWP-ICE), Geophysical Research Letters, 34, L13 803, doi:10.1029/2007GL029865, http://dx.doi. org/10.1029/2007GL029865, 2007.

Page 1204, Line 13: Where and when was the campaign?

The sentence is changed into

"During the SPARTICUS campaign, about 200 hours of data were collected between January and June in the year 2010, between Boulder, CO and the Southern Great Plain (SGP) site of the Atmospheric Radiation Measurement (ARM) program (Fig. 1)."

Page 1204, Line22: What are the parameters? Mentioned fmax and deposition coefficient already.

The parameters are the maximum freezing fraction (*fmax*) of dust aerosols, the deposition coefficient (alpha) of water vapor, and the threshold diameter (*Dcs*) which distinguishes cloud ice and snow. This is clarified in the revised paper.

Page 1205, Line 12: Note where the ARM SGP site is.

Geographical locations of Boulder, CO and the ARM SGP site are added to the sentence.

Page 1206, Line 11: How is anvil defined?

In the campaign log and pilot notes, anvil occurrence was reported when a cirrus cloud attached to a deep convective system was observed during a flight. In such a case, we excluded the whole flight from our analysis.

Page 1206, Line 18: Somewhere you should mention recent similar work by Gettelman et al 2012 (Gettelman, A., X. Liu, D. Barahona, U. Lohmann and C.-C. Chen, Climate Impacts of Ice Nucleation, J. Geophys. Res. Atmos., 117, D20201, doi:10.1029/2012JD017950), who looked at BN and LP in CAM5, focusing on the ice nucleation and the radiative effects of anthropogenic aerosols on cirrus. The study also looks at temp v. ice number.

In the revised manuscript, we cite the work of Gettelman et al. (2012) at the beginning of the "Results" section.

Page 1211, Line 18: This should be Gettelman et al 2012, see earlier comment.

In the discussion paper we intentionally cited the work of Gettelman et al. (2010) because this work introduced the LP05 ice nucleation scheme into the CAM model. In the revised manuscript we also cite the work of Gettelman et al. (2012) and point out the main contents of their study.

Page 1211, Line 20: It is not so different: most ice nucleation of the pure ice phase is probably occurring in cirrus.

We agree with the reviewer's comment. In order to better clarify the differences between our work and that of Gettelman et al. (2012), the following text is added in the revised manuscript:

"Gettelman et al. (2012) compared the two schemes in CAM5, focusing on the ice nucleation and the radiative effects of anthropogenic aerosols on cirrus from a global perspective. In this paper we look specifically into the SGP region and concentrate on parameter-induced sensitivities."

Page 1212, Line 25: concentrations ... are dominated

Corrected.

Page 1213, Line 1: Would it be better to make zonal mean plots of one or both of the quantities from figure 4, hom and het in the same simulation.

In the revised manuscript, two panels are added to Fig. 5 (zonal mean plots) following the referee's comment. We keep Fig. 4 as it is since it shows the statistics in the SGP area thus helps to interpret Fig. 3.

Page 1218, Line 14: But it may result in over fitting a parameterization to a particular circumstance, which is not generally applicable. What about looking in other regions to see if these relationships hold or look more like the Kramer et al data.

The danger of overfitting indeed exists. However, currently there are only two campaigns (SPARTICUS and MACPEX) that used the 2D-S probe to measure cirrus clouds in mid-latitudes. We've added an Appendix A in the revised manuscript to show that the evaluation against the MACPEX data leads to the same conclusion as drawn in the discussion paper. The Kraemer et al. (2009) dataset, on the other hand, has a relatively short temporal coverage (only 4 flights) in the mid-latitudes, and were obtained with the FSSP probe which may have the possibility of overestimating the ice crystal number concentration due to the shattering of large crystals (typically happening at warmer temperatures). This is confirmed with the analysis of the Ni-temperature relationship above 235K obtained in their data. However at lower temperatures, the relationship between Ni and temperatures agrees with those in the SPARTICUS and MACPEX data.

The Kraemer et al. (2009) data also include flights in the tropics where measurements associated with lower temperatures are less susceptible to the shattering problem. Theses data are indeed useful for evaluating and constraining model behavior. Liu et al. (2012) have shown that when the ambient temperature is lower than 205 K, the crystal number concentrations simulated with CAM5 (with either the LP05 or BN09 scheme) are more than an order of magnitude higher than observation. A possible reason is that the impact of glassy organic aerosols, which can become efficient ice nuclei thus inhibit homogeneous nucleation (Jensen et al., 2010; Murray et al., 2010; Jensen et al. 2013), are not considered in the current model. Given that the LP05 and BN09 simulations are very similar in this temperature regime, and both have large positive bias compared to the observations, we think it would not be very informative to use the Kraemer et al. (2009) data to compare the two schemes in the way we did in the present paper.

In the revised manuscript we have added comments in the "Conclusions" section on the potential overfitting problem.

Reference:

Jensen, E. J., Pfister, L., Bui, T.-P., Lawson, P., and Baumgardner, D.: Ice nucleation and cloud microphysical properties in tropical tropopause layer cirrus, Atmospheric Chemistry and Physics, 10, 1369–1384, doi:10.5194/acp-10-1369-2010, http: //www.atmos-chem-phys.net/10/1369/2010/, 2010.

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Toon, O.B., and Gao, R.: Ice nucleation and dehydration in the Tropical Tropopause Layer PNAS 2013 110 (6) 2041-2046, doi:10.1073/pnas.1217104110, 2013.

Murray, B. J., Wilson, T. W., Dobbie, S., Cui, Z., Al-Jumur, S. M. R. K., Moehler, O., Schnaiter, M., Wagner, R., Benz, S., Niemand, M., Saathoff, H., Ebert, V., Wagner, S., and Kaercher, B.: Heterogeneous nucleation of ice particles on glassy aerosols under cirrus conditions, Nature Geoscience, 3, 233–237, doi: 10.1038/ngeo817, 2010.

Page 1219, Line 1: Is the regime you are looking at dust dominated or not? How can you apply to other regions?

In the CAM5 model the parameter fmax is applicable only for dust aerosols because other types aerosols are not considered as heterogeneous ice nuclei for cirrus clouds. Figs. 7 and 8 in the paper indicate a clear sensitivity of the model results to fmax in the SGP area, while in Fig. 9 the impact of fmax is significant in all latitudes poleward of 20N. These are the basis on which we made the statement the referee pointed at.

Page 1219, Line 10: But what about other regions? Is this better or not? Page 1219, Line 21: But there are observations available: you even cite them. The Kramer et al observations are well used in the literature: perhaps you should add a figure comparing to them to see if the results hold up between models and observations.

As pointed out above, the Kraemer et al. (2009) data have too few flights in the mid-latitudes, which meanwhile may likely be affected by the shattering-induced observational error at warmer temperatures. In the tropics, where the ambient temperature of cirrus clouds is generally lower thus the Kraemer et al. (2009) data are expected to be less susceptible to the shattering problem, the main discrepancies between CAM5 simulations and the observations are possibly related to missing mechanisms (e.g., heterogeneous nucleation of glassy organic aerosols) in the model rather than the parameters described in this paper. We thus do not use the Kraemer et al. (2009) dataset for model evaluation in the tropics in the present paper.

In response to the referee's comments, the following sentence is added to the corresponding paragraph:

"Again, we point out that this recommendation is based on measurements from the SPARTICUS campaign. With the recommended range of α *value, the simulated ice crystal number concentrations also agree well measurements from the MACPEX campaign. Whether this range is also the best for other regions remains to be seen when more observations become available."*