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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Ice crystal number concentration estimates from lidar-radar satellite retrievals. Part 2: Controls on the ice crystal number concentration" *by* Edward Gryspeerdt et al.

Anonymous Referee #1

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General Comments: This manuscript may advance our understanding of cirrus clouds considerably, especially in terms of homo- and heterogeneous ice nucleation and the dependence of those processes on topography, ice nuclei concentration, and aerosol concentration. However, the temperature dependence of the retrieved ice particle number concentration Ni (Dmin = 5 μm) appears at variance with global in situ observations of Ni, and this should be mentioned. Some recent literature was overlooked, and by discussing the results from these other studies, the arguments made in this study will be stronger. The manuscript is well organized and well written, and the quality of the

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Discussion paper

figures is good. Major and minor comments are listed below.

Major Comments:

1. Page 5, lines 11-19: Over what temperature domain is the “glaciation index” proxy for INP applied?

2. Figure 1a: These results make sense theoretically since homogeneous ice nucleation (hom) is sensitive to temperature. But in situ measurements in the tropical tropopause layer (TTL) show relatively low ice particle number concentrations (Ni, Dmin = 5 μm) there (e.g. Jensen et al., 2013, PNAS). Spichtinger and Krämer (2013, ACP) have offered a dynamical explanation for the relatively low TTL Ni (Ni < 30 L-1 typically). Since TTL cirrus appear more extensive and generally at higher altitudes than tropical anvil cirrus (Gasparini et al., 2017, J. Climate), it seems that Ni retrieved over the tropics at $\sim$ -70°C would be strongly influenced by TTL cirrus, but in Fig. 1a tropical Ni values are maximum at -70°C, being $\sim$ 135 L-1. Please discuss this apparent paradox.

3. Figure 1b and p. 6, lines 5-15: Fig. 1b is very similar to Figs. 11 and 12 in Mitchell et al. (2016, ACPD). Regarding the higher Ni over mountainous terrain outside the tropics, this finding and explanation was also reported in Mitchell et al. (2016). Although this paper was rejected since the editor felt the retrieved Ni values were too high, and therefore could not be used to infer nucleation modes, no arguments cast doubt on the spatial and temporal relative differences in Ni, which still appear meaningful. The results in Fig. 1b are more compelling when it is shown that two very different satellite retrieval techniques produce similar results in terms of the relative differences in Ni.

4. Page 7, lines 7-8: Please note here that the study by Krämer et al. (2009, ACP), based on five cirrus cloud field campaigns that measured Ni, does not show a strong temperature dependence for Ni. On average, Ni slightly decreases with decreasing temperature.

5. Page 7, lines 10-11: Perhaps I missed something, but I am not seeing Ni as high as 100 L-1 in Fig. 2 for T $\sim$ -15°C for the orographic and convective regimes.

6. Page 9, lines 32-34 and page 10, line 1: The Ni measurements reported in Krämer et al. (2009) were sampled over the size range 3.0–30 μm or 0.6–40 μm diameter, which accounted for at least 80% (but typically > 90%) of the total N in a PSD. Thus, these observations can be compared with Ni(Dmin = 5 μm) but not with Ni(Dmin = 100 μm).

7. Page 12, lines 6-14: Most of this argument is not clear to me, and moreover, the physics of cirrus clouds is very complex and does not lend itself to these simple arguments. The authors are encouraged to read Spichtinger and Gierens, Part 1a and 1b (2009, ACP).

8. Page 12, lines 29-32: Consider citing Zhao et al. (2018, ACP), since they use satellite remote sensing and cloud modeling to demonstrate how increasing aerosol concentrations act through homogeneous ice nucleation to decrease the effective radius in cirrus clouds (note that decreasing re often corresponds with increasing Ni).

9. Page 15, lines 12-13: Does not a higher INP concentration promote a LOWER supercooled liquid fraction over Siberia?

10. Page 15, lines 29-32: The study by Zhao et al. (2018, ACP) may be of interest, since they demonstrate that the relationship between cirrus cloud effective radius (re) and column aerosol optical depth (column AOD) and the relationship between re and the cirrus cloud layer dust AOD are similar. That is, for the region and time of study, there was a correlation between dust aerosols affecting cirrus clouds and the atmospheric column integrated AOD.

11. Page 16, lines 10-14: The "negative Twomey effect" described here was also observed in the satellite remote sensing study by Zhao et al. (2018, ACP).

12. Page 17, lines 3-9: It should be noted here that this argument assumes relatively

glaciated conditions at -20 C are indicative of relatively high INP concentrations for T < -50 C, which is stretching this assumption quite far.

Minor Comments: 1. Page 8, lines 4-5: By “increased homogeneous nucleation directly into the ice phase”, are you referring to the freezing of aqueous haze aerosol particles?

2. Page 9, lines 2-3: Note that CCN do not need to be activated (i.e. cloud droplets) for homogeneous freezing; they can be dissolved as unactivated haze droplets (Koop et al., 2000, Nature). Perhaps this was the intention of this sentence, but it was not clear.

3. Page 9, lines 6-7: Barahona and Nenes (2008, JGR) are another good reference for demonstrating “the updraught limited nature of many cirrus clouds” regarding homogeneous ice nucleation.

4. Page 12, line4: Should “part one” be “Part 1”?

5. Figure 7: The “b” label is missing on this figure.

6. Page 19, line 23: Suggest modifying sentence to read: studies based on satellite remote sensing, in situ, theoretical and modeling results.

7. Page 19, lines 28-29: Good citations for this sentence are Diao et al. (2017, JGR), showing observational evidence for ice nucleation near cloud top, and Spichtinger and Gierens (2009, ACP), showing modeling evidence for this, and how nucleation rate profiles vary with updraft speed.

8. Page 20, line 11: A => At?

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