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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 #2

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Review of "Ice crystal number concentration estimates from lidar-radar satellite retrievals. Part 2: Controls on the ice crystal number concentration" by E. Gryspeerdt et al.

This paper uses the ice concentration retrievals described in Part 1 of the 2-part paper to investigate the relationships between ice concentration and both meteorological variables and aerosol properties. As described below, I have serious concerns with the paper as it is written, I do not think all of the conclusions are justified by the analysis presented, and I believe major revisions are required.

1. Citations: Examples where appropriate citations are omitted abound throughout the paper. Perhaps the authors are not familiar with the literature regarding cirrus ice concentrations, in which case I suggest the authors do a thorough literature search and cite appropriate papers. A few examples of missing references are provided here:

1. Page 1, lines 17-18: Numerous observational and modeling papers have been written by U.S. scientists on the issue of aerosol impacts on liquid clouds, but only European studies are cited here (two by co-authors of this paper!).
2. Page 1, line 19: Regarding the impact of aerosols on high clouds, again only one European paper has been cited, but there are many appropriate U.S. scientist-led papers (e.g., Jensen et al., 2016, JAS; Gettelman et al. papers; J. Penner group papers; etc.).
3. Page 2, line 8: In addition to the Korolev reference earlier papers (McFarquhar et al., 2007, GRL; Jensen et al., 2009, ACP) should be cited.
4. Page 2, lines 15-16: The climatology of ice concentrations published by Krämer et al. (2009) was based on a very limited set of measurements, particularly at low temperatures. Measurements from the ATTREX campaign near the tropical tropopause showed much higher ice concentrations at very cold temperatures (Jensen et al., 2013, PNAS; Jensen et al., 2016, JAS). Likewise, the ice concentrations shown by Muhlbauer et al. (2014) were perhaps biased by the limited sampling from a single campaign. The ice concentrations measured during MACPEX with a similar amount of data in the same geographical region and time of year showed the opposite trend with temperature (Jensen et al., 2013, JGR).
5. Page 2, lines 33-34: The dominance of dynamics has been pointed out in numerous other modeling studies (e.g., Jensen et al., 2013, JGR; Jensen et al., 2016, JAS; DeMott et al., 1997, JGR).

6. Page 3, line 8: DeMott et al. (1997, JGR) should also be cited here.
7. Page 3, lines 13-14: Jensen et al. (2016, JAS) should also be cited here.
8. Page 3, line 25: Again, McFarquhar et al. (2007, GRL) and Jensen et al. (2009, ACP) should be cited here.
9. Page 6, line 7: Barahona et al. (2017, Nature) should also be cited here.
10. Page 8, line 12: A number of earlier papers showed high ice concentrations in wave clouds (e.g., Jensen et al., 1998, GRL; Baker and Lawson, 2006, JAS).

2. Page 3, lines 18-22: Small-scale wave-driven vertical motions actually have been characterized by a number of aircraft measurements and super-pressure balloon measurements (e.g., Podglajen et al., 2016, GRL; Podglajen et al., 2017, JAS).

3. Page 3, lines 27-28: As noted in at least one of the referee comments on the Sourdeval et al. Part 1. paper, the ice concentration retrievals in regions with only lidar or only radar signals are highly suspect and insufficiently evaluated by comparison with in situ observations. This issue calls into question the results from this paper (Part 2.).

4. Page 4, lines 11-13: The cloud-top region only represents the conditions near nucleation zones during a short time period just after the transient, localized nucleation events. Differential sedimentation and entrainment rapidly reduce ice concentrations thereafter (e.g., Jensen et al., 2013, JGR). Only in wave clouds is it possible to know where the nucleation zone is located.

5. Page 4, lines 20-22: The classification scheme relies on MODIS data at 13:30 local solar time. So, are the ice concentrations in the remainder of the analysis restricted to times near this local time?

6. Page 4, lines 32-33: Actually abundant recent laboratory experiments have shown that organic-containing aerosols (which are abundant in the upper troposphere) will likely be in a glassy state at low temperatures (e.g., Murray, 2008, ACP; Zobrist et al., 2008, J. Phys Chem.). The aerosols will likely be in a glassy state both at midlatitude and tropical upper troposphere conditions (Wilson et al., 2012, ACP).

7. Page 5, lines 29-30: Ice concentrations produced by heterogeneous nucleation should also increase with decreasing temperature. As shown by numerous laboratory and field studies, ice nuclei abundance increases with decreasing temperature (e.g., DeMott et al., 2010, PNAS).

8. Figures 2 and 3, and discussion thereof: It would be very helpful to provide a brief review of the regime classification from Gryspeerdt et al. (2017). In fact, it is impossible to evaluate the results shown in Figure 3 without knowing the different definitions of ORO 1 and ORO 2.

9. Figure 2 discussion: The differences in N_i frequency distributions between different regimes are actually very slight, and I think they are somewhat exaggerated in the discussion. The main feature apparent in Figure 2 is a clear temperature dependence that is nearly identical in all of the regimes.

10. Figure 2 discussion: The text discusses a peak at temperatures just colder than -35°C. This peak is very subtle in most of the regimes, and in fact it occurs closer to -50°C. Therefore, I do not believe the assertion that there is a clear transition at the liquid water homogeneous freezing temperature (about -38°) is justified. If anything, such a transition would be smeared toward warmer temperatures by ice crystal sedimentation rather than shifted toward colder temperatures as apparent in Figure 2.

11. Figure 3: What are the units for the change in occurrence?

12. Section 4.1: As shown by previous modeling studies (e.g., Kärcher and Lohmann, 2002), the sensitivity of ice concentrations produced by homogeneous freezing of aqueous aerosol to aerosol abundance should be weak. Furthermore, it is entirely possible that N_i frequency distribution differences shown in Figure 6 with different aerosol loadings are simply a result of co-varying meteorology. For example, aerosol loading and ice concentrations could both be enhanced in regions with relatively strong mesoscale updrafts. In recent years, de-convolving the effects of co-varying meteorology has become a requirement for attributing changes in cloud properties to variations in aerosol properties. The same standard should be applied here. Either compelling evidence should be provided showing that the apparent changes in N_i with aerosol loading are not caused by co-varying meteorology or the entire discussion in section 4.2 should be removed.

13. Page 15, lines 14-19: This paragraph starts by stating there is a strong correlation between occurrence of supercooled liquid and the mass concentration of reanalysis dust, then qualifications to this statement are made to acknowledge the lack of correlation in some regions. It would be clearer (and less misleading) to just state that correlations are only apparent in some regions.

14. Section 4.2.2 The same issue about co-varying meteorology discussed above for section 4.1 applies here. Again, either a clear demonstration that co-varying meteorology is not the cause of the correlations needs to be provided, or the section should be removed.

15. Section 5 The same issue about co-varying meteorology discussed above for section 4.1 applies here. Again, either a clear demonstration that co-varying meteorology is no the cause of the correlations needs to be provided, or the section should be removed.

16. Discussion and Conclusions sections: The authors should remove unjustified conclusions. See comments above regarding a transition at the homogeneous freezing threshold, dust impacts, and co-varying meteorology.

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