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Interactive Comment

Interactive comment on "High ice water content at low radar reflectivity near deep convection – Part 1: Consistency of in situ and remote-sensing observations with stratiform rain column simulations" *by* A. M. Fridlind et al.

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General Comment: As the first part of a serial study of "high IWC-low Z_e" condition that coincide with jet engine power loss, this paper utilized the microphysical properties including IWC, mass size distribution, and derived Z_e sampled during 2010-2012 Airbus campaign to reveal the possible meteorological scenario for that condition. Surprisingly, consistency was found among documentation, in situ measurements, satellite retrieval, surface radar observations, and model simulations, which validate the com-

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Interactive Discussion

Discussion Paper

mon occurrence of “high IWC-low Z_e” condition. This paper is definitely suitable for publication because of its meaningful inspiration in aviation safety. However, a couple of improvements should be made in order to promote the quality of this study.

General response: We appreciate the reviewer’s time and comments, which are addressed point-by-point below. Several points were raised almost verbatim by reviewer 1, and where those occur, we point to those responses to be concise.

Major comments 1. In the title, the authors clarify that the “high IWC-low Z_e” condition happens in “near deep convection” regions. As a result, in the abstract and following discussion of Airbus sampling, “stratiform rain” becomes the major focus. The question then arises, how does the cloud classification work in this study? Figs. 13 and 14 demonstrate the separation of convective and stratiform on radar images, however without a detailed description of classification algorithm. Even for the same condition that Z_e less than 30 dBZ at 11 km (I assume this 30 dBZ value serves as the threshold of classification because it appears on 6 times related to cloud classification discussion throughout the entire paper), it could either be authentic stratiform or the vertical extension of weak convection, and only the examination of entire radar reflectivity column could separate those. The following figure gives an example of radar cross-section associated with UND CSA classification results sampled during MC3E campaign. Clearly, cloud classification can’t separate weak convective and stratiform regions based on only near the cloud top Z_e values, because there is no significant discontinuity in Z_e between those two cloud types. Furthermore, the microphysical properties (even at temperatures < $-20°$C) between convective and stratiform regions are quite different, and the readers could argue that the identification of “high IWC-low Z_e” condition could attribute to the weak convection was mistakenly classified as stratiform due to the lack of 3D cloud information.

Response 1: Two clarifications are needed. The 30 dBZ at 11 km is only a point-wise definition of "low Z_e" based on aircraft radar sensitivity, without reference to classification. Clarification to be added to p. 16508, line 28: "and the Z_e threshold is based on radar sensitivity, without any specified relation to convective or stratiform structures." The S-band observations and 1D modeling are focused stratiform columns only so that poorly constrained vertical motion can be neglected. Clarification to be added to p. 16521, line 7: "Here we will focus on extended stratiform regions where the mean contribution of vertical winds to MDV can be neglected relative to the reflectivity-weighted fall speed of ice at elevations circa 11 km."

2. The morphology should be further discussed, because it is the key explanation of the “high IWC-low Z_e” condition. This study could be carried out from two aspects: (1) By examination of OAP images; (2) Rather than directly applying LH74 relationship to calculate IWC and Smith [1984] method to calculate Rayleigh radar reflectivities, various mass-dimensional relationships and corresponding area-dimensional relationships were developed for different ice crystal habits [Mitchell, 1996], and those relationships should be adopted for better estimation of IWC and Z_e values.

Response 2: Please see responses 3.5 and 3.6 to reviewer 1.

3. Contrary to the assumption that liquid contributions are considered negligible for temperatures colder than $-20°$C, Rosnefeld et al. [2013] found the common occurrence of highly supercooled drizzle and rain near the coastal regions of the western United States even at colder temperature. There is still possibility of supercooled liquid droplets anywhere warmer than $-40°$C, so rather than a fixed temperature threshold, phase separation is suggested if proper instruments are available (like icing detector, CDP, or hot-wire King LWC probe, etc.). Thus, the contamination from supercooled liquid droplets could be eliminated, because as the authors mentioned in the introduction, the role of supercooled liquid water was caused confusion.

Response 3: Please see response 3.4 to reviewer 1.

4. Instead of number size distribution, mass size distribution is intensively investigated in this study, and the solid conclusion is derived that particles within the size range from 150 to 600 micron contribute a large portion of IWC, which is a very interesting feature

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associated with “high IWC-low Z_e” condition. However, mass size distribution is still a derived bulk property, and in this case it is roughly the second moment representation of original number size distribution. It would be nice that the authors could release the number size distribution information without any assumption imposed, because after gamma or exponential functions were fitted to observed number distribution, the fitted parameters could serve as indicators to testify the cloud classification algorithm used in this study, and comparison with previous stratifrom studies becomes easier.

Response 4: Although mass concentration is a derived quantity with an uncertainty of roughly a factor of two (see response 3.5 to reviewer 1), the uncertainty in number (the measured quantity) can easily be a factor of five or more (e.g., Fridlind et al., 2007). We have reasonable agreement of IWC derived from size distributions and Robust probe over a reasonably large dynamic range (cf. Fig 5.), but we have no source of confidence in number concentrations and therefore prefer not to promote their use here.

5. If the “high IWC-low Z_e” condition commonly exists, does it mean there will be bright band of high IWC near the cloud top based on retrieval from radar observation? Surprisingly, even the IWC values were lower than this study, the discontinuity in Z_e-IWC relationship studies were found by Heymsfield [2005] (Figure 10) and further discussed by Wang [2015] based on in situ measurements of stratiform rain. From the following figure, the jump in IWC clearly takes place at the Ze value range from 12 to 15 dBZ, and it was caused by the drastic changes in the overall shape of number size distribution as discussed by Wang [2015] in section 3.4 and Figure 10. This is another reason why detailed investigation of number size distribution is necessary.

Response 5: We agree that future detailed investigation is necessary, and furthermore that it will require robust observations at more elevations, whereas the size distribution data here were intentionally gathered almost exclusively at cruise elevations near $-40°$C (see response 3.4 to reviewer 1).

Minor comments Page 16509, line 9, ‘identifed’ should be ‘identified’.

Response: Correction to be made.

Page 16521, line 26, ‘Reflecitivity’ should be ‘Reflectivity’.

Response: Correction to be made.

Reference

Fridlind, A.M., A.S. Ackerman, G. McFarquhar, G. Zhang, M.R. Poellot, P.J. DeMott, A.J. Prenni, and A.J. Heymsfield, 2007: Ice properties of single-layer stratocumulus during the Mixed-Phase Arctic Cloud Experiment (M-PACE): Part II, Model results. J. Geophys. Res., 112, D24202, doi:10.1029/2007JD008646.

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