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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Ice particles in the upper anvil regions of mid-latitude continental thunderstorms: the case for frozen-drop aggregates" *by* J. L. Stith et al.

Anonymous Referee #2

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General comments.

The observations described in this paper could be of great interest for comparison with models that attempt to represent the microphysical processes occurring in such clouds in detail. Since the development of such models that can reliably reproduce observed cloud and precipitation characteristics underlies a number of key areas including the development of quantitative precipitation forecasting and the accurate simulation of cloud radiative properties, this is a subject of strong current interest. The ability of a cloud to produce such FDA may be expected to depend sensitively on the balance between updraught dynamics lofting significant supercooled liquid water to the homo-

geneous freezing level and depletion of liquid water by heterogeneous freezing and riming processes at lower altitudes. Hence, I consider the paper merits publication. I would qualify this as being subject to minor revision, in response to points identified in the following comments.

The paper presents observations of chainlike and branching frozen-drop aggregates (FDA), similar to observations that have been published elsewhere. I think that one of the principle aims of this paper is to suggest that the conditions for such FDA production may be more widespread than has previously been suggested, including possible production at temperatures warmer than the homogeneous freezing temperature. If this is really the central aim, then in my view, this is not mentioned strongly enough in the Introduction. Also, I think that the evidence presented for such warmer production of FDA is rather weak and might be bolstered.

Specific comments.

p.27023, line 24. Korolev has shown that software procedures based on the distribution of particle inter-arrival times are not completely effective in rejecting shattering artefacts in all cases, especially where high concentrations of small droplets or crystals that naturally have short inter-arrival times are present. Can the authors comment on the extent to which this issue might be present in their data?

p.27025, line 7. Presumably the treatment of current data follows that of Davis et al.? Can the authors confirm this?

p.27025/6, Figs.1/3. Is it possible to give a simple presentation of electrical activity in these clouds, eg. time-coded lightning flash detections? If electrical fields are subsequently being invoked to explain the chain-like aggregation it would be helpful to confirm that the charge separation process is well-advanced and likely to be leading to local enhancements of the electric field. Equally, if charge separation has occurred, it will likely involve graupel production at altitudes below the homogeneous freezing level and hence there is a likelihood of observing the low-density "proto-graupel" as

suggested at p.27033, line 6.

p.27029, line 13. As I understand it, the analysis of CLH-2 data depends on a knowledge of the mass-diameter relationship and a measurement of the size-spectrum so tha the measured mass can be deconvolved with the size-dependent inlet collection efficiency. So, the calculated bulk IWC isn't really independent from the measured size spectrum.

p.27029, line 14. The simple bulk density calculated in Fig.10 is a rather simple approach to these aggregates. Is it possible to produce an analysis that estimates the mass-diameter power-law relationship? Aggregation due to differential settling should produce mass proportional to D-squared (Westbrook et al., 2004, Physical Review E) whereas chain-aggregation should lead to mass proportional to D. Given that the bulk IWC measurement depends on a knowledge of the size spectrum (previous comment), I guess this may not be possible, but it would be useful for the authors to comment further here. Whilst this has some impact on the effectiveness of Fig.11, I think this is adequate for the purpose of showing the dominant contribution to total IWC by small particles in the fringes of the cloud.

p.27029, Fig 12. It's not quite clear to me whether this schematic is supposed to represent a horizontal section through the anvil at a particular height or a vertical section – this should be clarified.

p.27030, Fig.13. It would be helpful to illustrate on this figure (and perhaps also on Figs 1 and 3) the approximate altitude of the homogeneous freezing level (eg. the -38C isotherm). If substantial supercooled liquid is reaching this level, then one would expect to see intensification of the updraught following release of the additional latent heat of freezing.

p.207030, line 21. This weaker updraught may however be a means by which pristine crystals from lower altitudes could be lofted to a level at which they could aggregate with FDA produced higher up.

p.27034, line 25. Is Table 1 to be interpreted as saying that FDA were observed throughout the full range of temperatures given? Please clarify. In this case, I think it would be helpful to show some images of FDA from the warmer temperatures in rf17 so that their shape and character can be compared with others. In this case, it has already been suggested that the images classified as FDA may result predominantly from low-density proto-graupel. Do they, for example, occur in association with larger and denser graupel images? In flights rf20 and rf21, observations of FDA at the warmest temperatures sampled may just be the result of encountering particles that have had a chance to precipitate from higher altitudes at which they grew.

Detail points.

p.27023, line 2. ".. lightning .." p.27023, line 9. ... are described.. p.27024, line 2 and elsewhere. Somebody's word-processor appears not to like the German umlaut. It might be more reliable to adopt the anglicised spelling of Kraemer.

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 27019, 2013.