High ice water content at low radar reflectivity near deep convection: Part II. Evaluation of microphysical pathways in updraft parcel simulations

General comments

The authors present a study trying to explain the formation of high ice water contents with low radar reflectivity (>2 gm^{-3} and <30 dBZ). These regions occur in the vicinity of deep convection and have caused jet engine power loss of aircrafts more than 100 times over the last 25 years.

To further examine these areas, measurements with an Airbus A340 have been performed in tropical areas at aircraft cruising altitudes.

This manuscript is part two in a series of two publications. Part 1 presents the in-situ measurements performed by the Airbus and this parts examines possible microphysical pathways for the formation of such ice clouds.

A microphysical parcel model is used to examine possible formations paths. Surprisingly, they find that slow updrafts leads to larger masses explained by reduced competition for diffusional growth and a longer time to grow.

This ice, formed vapor-grown at relative warm temperatures, is called “fluffy” ice and match the sizes measured at anvil outflow.

The manuscript is interesting, well written and well-structured. The topic is of great importance for the security of the aircraft industry. It is suitable for publication in ACP after some minor corrections.

Specific comments

Many statements in the paper refer to part 1 of this manuscript. Please state which section and / or figures in part 1 you refer to for the different statements.

In the manuscript I miss discussion of the uncertainties of the Airbus measurements. It is simply stated, that this is shown in part 1 of the manuscript. These properties are important to know for the comparison with the simulated results. Please add this information to the manuscript.

p. 16555, ll. 26-27 and p.16556 ll. 1-2: Cziczo et al. (2013, 2014) did measurements on this for cirrus clouds, which also may form through convective outflow. They found that most of the cirrus have formed through heterogeneous nucleation. Please add a sentence or two on this, as well as the references.

p. 16557, ll. 2-8. This sentence is long and quite complicated. Please change to two sentences for clarity.

p. 16557, l. 10 please reference to the dashed line in Fig. 2 (>2 gm^{-3} and <30 dBZ) after "but these are rare where Z_e < 30 dBZ"

Figure 2: Please change title of the left panel to: SAM-2M or SAM-2Moment. The left and middle panel should have the same text after the hyphen. Then it is much clearer on a first sight which kind of model was used.
The model description "Simulations with two-moment (…) as described by von Diedenhofen et al. (2012)" belongs rather in section 3 "CRM Simulations" than in the figure caption.

Section 3 and Figure 3: What are the detection limits for the airbus measurements? How realistic are the simulated particles with area-equivalent particle diameters larger than 700 µm? Would these large particles not sediment out? Is sedimentation considered in the simulations? Please comment on these issues in Section 3.

Section 4.1: Is heterogeneous nucleation on ice nuclei also included? Results using heterogeneous nucleation is presented in Section 4.4. and therefore it should also be mentioned here. Why is the parcel expansion treated assuming dry adiabatic ascent instead of moist adiabatic ascent?

p. 16560, ll. 19-26. Please refer to Fig. 4 before the long description of the vertical profile of updraft speed as the profiles are shown there.

Figure 4, Caption: I would change tor order of the first sentence. First describe the plots "Profiles of parcel updraft speed (w) …" and then "for simulations with droplet activation …".

Figures 4-6: Please label the panels with e.g. a,b,c,d,e and f and refer to the respective panels in the text instead of to the Fig. including all panels. Please also add this to the further referenced figures with different panels.

Figure 7, right panel: Why is the limit on the x-Axis as high as 1.4? There seems to be a slight difference between the curves which would be better seen if the upper limit of the x-axis would be e.g. 1.1 or 1.2.

p. 16572, section 4.8: Ice-ice collisions has also been examined by Kienast-Sjögren et al. (2013) who found also a small effect of aggregation for temperatures below -40ºC but may be important for warmer temperatures. As particles are expected to form at warmer temperatures, aggregation may be important here. Please add a discussion on this and this reference to this section.

Figure 8: Please add legends to the plot.

Technical corrections

p. 16595, Figure 2, line 5: Do you mean „center and right panel“?

p. 16558, l. 18: Please add a full stop (.) after “particles”.

p. 16560, l. 12: Please remove the “and” after “droplet activation” and replace with a comma.

p. 16560, l. 13-15: There are too many “and” in this sentence. Please replace at least one of them with e.g. “as well as”.

References

Cziczo, D. J. et al. Clarifying the dominant sources and mechanisms of cirrus cloud formation, Science, 2013.

Cziczo, D. J. and K. D. Froyd, Sampling the Composition of Cirrus Ice Residuals, Atmospheric Research, 142, 15-31, 2014.

Kienast-Sjögren, E., Spichtinger, P., and Gierens, K.: Formulation and test of an ice aggregation scheme for two-moment bulk microphysics schemes, Atmos. Chem. Phys., 13, 9021-9037, doi:10.5194/acp-13-9021-2013, 2013.