Response to Referee #2:

We thank the referee for the careful reading and detailed comments, which will improve the manuscript. Our responses and text modifications are shown in bold. Line numbers refer to the original manuscript currently under discussion.

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.

We will make the following revisions to the text:
a) Insert "Sect. 2 of" before "Part 1" on line 14 of p. 16553.
b) Insert "Sect. 3 of" before "Part 1" on lines 6, 8, and 13 of p. 16554.
c) Insert "Sect. 4 of" before "Part 1" on line 18 of p. 16554.
d) Insert "Sects. 4–6 of" before "Part 1" on lines 6 and 19 of p. 16557.

e) Insert "Sect. 3 of" before "Part 1" on line 22 of p. 16557.
f) Replace "Part 1" (typo) with "Figure 1" on line 16 of p. 16563.
g) Insert "Sect. 3 of" before "Part 1" on line 14 of p. 16567.
h) Insert "Sect. 5 of" before "Part 1" on line 7 of p. 16572.
i) Insert "Sect. 5 of" before "Part 1" on lines 2, 6, and 7 of p. 16575.
j) Insert "Sect. 3 of" before "Part 1" on line 19 of p. 16579.
k) Insert "Sect. 2 of" before "Part 1" on line 13 of p. 16580.
l) Insert "Sect. 3 of" before "Part 1" on line 10 of p. 16581.

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.

We will replace the original text on line 12 of p. 16554 "uncertainty is not known to better than a factor of two (see Part 1)" with "uncertainty in each is estimated to be roughly a factor of two owing in large part to the uncertainty in Robust probe calibration (Grandin et al., 2014) and in the mass-dimensional relationship applied to the nephelometer size distribution measurements (Heymsfield and McFarquhar, 1996)." For the sake of clarity and consistency of terminology between Parts 1 and 2 we will also change "SEA" on line 10 of the same page to "Robust".

At line 16 of p. 16554 we will add "uncertainty in MMD_{eq} is estimated to be roughly 20% owing in large part to uncertainty in shattering artifacts that may contaminate airborne particle probe measurements in a manner that decreases as the moment of the size distribution increases (Korolev et al., 2013; Jackson and McFarquhar, 2014)."

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.

We will replace the original text that starts on line 26 of p. 16555:

> **However, the attribution of the mass-dominating ice to a specific microphysical pathway, namely heterogeneous freezing of water drops, was not assessed in any calculations presented and is limited to informed speculation thus far.**

with the following:

The Lawson et al. (2010) attribution of mass-dominating ice to freezing of water drops by heterogeneous nuclei is consistent with Cziczo et al. (2013), who report cirrus ice residuals being predominantly of mineral or metallic composition in deep convection outflow and synoptic cirrus. To explain compositional dissimilarity between the population of near-cloud aerosols and ice residuals, Cziczo et al. (2013) argue for the predominance of heterogeneous freezing, as discussed further below.

And on line 12 of p. 16580 we will add the following:

Aside we note that an ice multiplication source for maritime conditions might be consistent with ice residuals containing sea salt, sulfate, and organic constituents. For the TC4 and CRYSTAL-FACE campaigns respectively such constituents comprise 34 and 47% of residuals inferred as heterogeneous freezing nuclei (Czico et al. 2013, their Table S1). It is not inconceivable that better sampling of crystals larger than 75 µm in diameter (Cziczo and Froyd, 2014) might alter such statistics.

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

We will break the sentence into two by replacing "(...), which did not genereally [sic]" to "(...). The CRM simulations did not generally".

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 Ze < 30 dBZ”

We will insert "(area delimited by dashed line in the figure)" after "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 "s" in "-2Ms" referred to the sensitivity test for the SAM run in Fridlind et al. (2012), in which the mean thermodynamic profiles were nudged to the observations and which we had inadvertently failed to mention in the original manuscript. We will use the results from the baseline SAM run instead of the sensitivity test and change "-2Ms" to "-2M", which do not affect interpretation of the CRM results.

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.

The sentence will be removed from the figure caption. We will replace "simulations, both using two-moment bulk microphysics (SAM-2M, DHARMA-2M)" with "simulations (SAM-2M, DHARMA-2M), both using two-moment bulk microphysics and sampled every three hours" on line 4 of p. 16557. We will insert "on a domain with a quarter of the horizontal area and restarted from the DHARMA-2M simulation at 03:00 UTC on 23 January (van Diedenhoven et al., 2012)" after "(DHARMA-bin)" on line 15 of p 16557.

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.

As already mentioned in the text and figure caption, the ice particle size distributions from the CRM simulation are obtained from a horizontal line at 11.7 km altitude that intersects the IWC maximum, which occurs within a convective core. As already stated, the large hydrometeors are graupel. It is well established in the scientific literature describing deep convection that large hydrometeors can be lofted despite their considerable fall speeds within convective cores, by virtue of updrafts speeds exceeding fall speeds. A multitude of processes are included in the CRM, including sedimentation, and the reader can consult publications documenting the CRM simulations (and references therein) to get a better impression of the processes included in the simulations. To improve clarity we will insert "within convective cores" after "graupel" on line 26 of p. 16557.

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.

For clarity we will insert the following text on line 13 of p. 16558:

> **Next we describe in Sects. 4.1 and 4.2 the components and setup of the minimal parcel model, which omits all processes not described therein. Sect. 4.3 presents results from the minimal model, followed by a series of sections in which a process or family of associated processes is sequentially added in each: heterogeneous ice freezing (Sect. 4.4), Hallett-Mossop ice production (4.5), particle sedimentation (4.6),**

gravitational collection and raindrop breakup, excluding ice-ice collisions (4.7), ice-ice collisions (4.8), shattering of freezing drops (4.9), and entrainment of environmental air (4.10). We finish Sect. 4 by considering sensitivity of the results to ice properties (4.11), aerosol population (4.12), and cloud-base altitude (4.13).

Why is the parcel expansion treated assuming dry adiabatic ascent instead of moist adiabatic ascent?

We will append a new sentence to the paragraph ending on line 8 of p. 16559:

Latent heat released by water phase change is applied to the air temperature of the parcel using the time step for the process involved (described in next section).

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.

We will insert "seen in upper left panel of Fig. 4" after "updraft speed" on line 19 of p. 16560.

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 …”.

Will do.

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.

We expect readers to refer to figure captions, which describe the panels clearly.

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.

The axis ranges are deliberately uniform across the figures.

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.

On line 18 of p. 16572 we will add the following:

> **Although there are reasons to expect aggregation to be more efficient at warmer temperatures, the observational basis for such an exponential dependence is unclear and current literature offers no alternative forms (Kienast-Sjögren et al., 2013).**

Figure 8: Please add legends to the plot.

Will do.

Technical corrections

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

Indeed that was the intent. Will correct.

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

Will do.

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

Will replace "droplet activation and homogeneous freezing and diffusional growth of hydrometeors" with "droplet activation, droplet homogeneous freezing, and hydrometeor diffusional growth".

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".

We will replace the original text:

> **Parameters that depend on pressure and temperature, such as particle terminal fall speeds, gravitational collection kernel, and coefficients for droplet activation and diffusional growth are updated every 15 s.**

with the following:

Parameters that depend on pressure and temperature are updated every 15 s. Such parameters include particle terminal fall speeds, the gravitational collection kernel, and coefficients for droplet activation and hydrometeor diffusional growth.

REFERENCES

Cziczo, D. J., K. D. Froyd, C. Hoose, E. J. Jensen, M. Diao, M. A. Zondlo, J. B. Smith, C. H. Twohy, and D. M. Murphy (2013), Clarifying the Dominant Sources and Mechanisms of Cirrus Cloud Formation, Science, 340(6138), 1320–1324, doi:10.1126/science.1234145.

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Heymsfield, A. J. and McFarquhar, G. M.: High albedos of cirrus in the tropical Pacific warm pool: Microphysical interpretations1120 from CEPEX and from Kwajalein, Marshall islands, J. Atmos. Sci., 53, 2424–2451, 1996.

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Kienast-Sjögren, E., P. Spichtinger, and K. Gierens (2013), Formulation and test of an ice aggregation scheme for two-moment bulk microphysics schemes, Atmos. Chem. Phys., 13(17), 9021–9037, doi:10.5194/acp-13-9021-2013.

Korolev, A., E. Emery, and K. Creelman (2013), Modification and Tests of Particle Probe Tips to Mitigate Effects of Ice Shattering, Journal of Atmospheric and Oceanic Technology, 30(4), 690–708, doi:10.1175/JTECH-D-12-00142.1.