**Reply to:**
***Review of manuscript acp-2014-332***
***Tropical deep convective life cycle: Cb-anvil cloud microphysics from high altitude aircraft observations***
***by W. Frey et al.***

**by Anonymous Referee #2**

The authors would like to thank the anonymous referee #2 for his/her helpful comments and suggestions.
All issues raised by the referee are discussed below and have been incorporated in the revised version of the paper. The referee's comments are typeset in italic, our replies in normal font.

***General comment:***
*Observations of microphysical and optical properties of the tropical deep convection system Hector (Australia) at different stages of development (developing, mature, dissolving) and different altitudes are presented in the manuscript. In addition, the ratio of cloud to aerosol particle numbers are investigated for the various stages. The aim of the study is to analyse the microphysical evolution of Hector and the freezing mechanisms of the ice crystals.*
*The observational part of the paper is convincing and it can be seen from the interesting data set that the data analysis is performed quite thoroughly. However, the interpretation of the observations and the conclusions drawn with respect to the freezing mechanisms and cloud to aerosol ratio are confusing and seems to be not very well though out. This will be further decribed in the specific comments.*
*Thus, I am sorry that I must say that I find the paper not suitable for publication in it's present form. Even so, I like to encourage the authors to revise the manuscript since the topic of the paper is very timely and the unique high quality measurements at high altitudes in a deep convective system merit to be published. I hope that my comments will be helpful.*

**Reply to general comment:**
We have revised and changed the manuscript with particular focus on improving the explanations regarding the interpretation related to the freezing mechanisms. In addition we removed some of the statements which were also viewed as too speculative by the other reviewers. We hope that we were able to meet the reviewer's expectations thereby.

***Specific comments:***
***Abstract***
1. ***P2, line 2:*** *'...life cycle of clouds in a tropical deep convective system.' Would be better 'life cycle of the anvil region of clouds in a tropical deep convective system.'*

**Reply:** Maybe better 'life cycle of clouds in the anvil region of a tropical deep convective system'? We are focusing on the life cycle of the clouds, not on the life cycle of the anvil region.

2. ***P2, line 16:*** *'... indicating a change in freezing mechanisms.*
*This cannot be understood here... and I think this formulation in general should be better 'indicating different freezing mechanisms'.*

**Reply:** Changed, however, it's not only a different freezing mechanism but also a change from one mechanism to another.

3. ***P2, line 18****: 'This is indicative for rapid glaciation during Hector's development.'*
*Can you really derive this statement from your measurements? I would guess that the ice particles in developing phase are from ice nucleation at temperatures colder than -38C and not from frozen drops at warmer temperatures. More detailed comments are given later.*

**Reply:** Please see our replies to your later comments (reply to comments 21-28).

4. ***P2, line 18:*** *'The backscatter properties and particle images show a change from frozen droplets in the developing phase to rimed and aggregated particles.' ... in the mature phase ?*
*See previous comment....*

**Reply:** We rephrased this sentence to:
"The backscatter properties and particle images show a change in ice crystal shape from the developing phase to rimed and aggregated particles in the mature and dissipating stages."

***1 Introduction***

5. ***General a:*** *I would shorten the introduction and discuss only points which are related to the work presented here. For example, heterogeneous chemical reactions on ice surfaces that lead to ozone destruction -or other chemical processes- don't need to be discussed, I think it is well known that those processes does not play an important role in the tropics. Further, also the argument that the observations can serve to evaluate models is not needed to make the study interesting.*
   *It would be enough to concentrate on the radiative impact of the anvil cirrus and also the water transport to the stratosphere.*
6. ***General b:*** *I recommend to give a short overview of the processes that could be responsible for the presence of ice crystals in the anvil, e.g. uplift of mixed phase clouds to higher regions ( (i) ice crystals could have formed by heterogeneous drop freezing or by freeezing of supercooled pure droplets at -38C -though I think the latter process is of lesser importance since in most cases the droplets evaporate by the Bergeron-Findeisen process at higher temperatures; (ii) formation of ice crystals at temperatures lower than -38C by homogeneous freezing of supercooled liquid solutions or heterogeneous deposition freezing).*
   *Without introducing the mechanisms that produce anvil ice crystals it is hard to understand the explanations that are given later in the paper to explain the observations.*

**Reply to 5. and 6.:** We included a paragraph about freezing mechanisms and shortened the remaining introduction.

7. ***P. 3, lines 13-15:*** *'In what manner clouds impact climate and chemistry critically depends on their microphysics, i.e. sizes and numbers of cloud particles, as as well as ice crystal shapes...'*
   *I would say: In what manner ice clouds impact climate critically depends on their microphysics, i.e. sizes and numbers as well as shapes of the ice particles.*

**Reply:** We rephrased as suggested.

8. ***P. 4, lines 12-14:*** *'Satellite and ground based remote sensing on the other hand are not able to obtain observations of microphysical properties.'*
   *This is a repetition of P.3, lines 22-23: Despite the amount of cloud observations from satellite or ground based instruments, those observations are unable to resolve the microphysical structures.*

**Reply:** We removed this sentence.

9. ***P. 4-5:*** *The paragraph about the modelling efforts and problems should be shortened.*
   *On the other hand, the statement on P.5, lines 11-13: 'However, the decay of a deep convective system may have major implications for the formation of subvisible cirrus (SVC), by affecting the background conditions e.g. regarding humidity.' could be explained in more detail, since this is a topic of the study.*

**Reply:** We think that the model problems should be mentioned since it shows that the processes behind the dissipation are not fully understood and thus, is one motivation for our study. Therefore, we only found little shortening potential. We hope that we were able to explain the implications of the dissipating stage for SVC formation in the according part of the introduction.

10. ***P. 5, line 24:*** *' ... convectively formed SVC.'*
    *How does convection produces SVC?*

**Reply:** Rephrased as follows:
"… and simulated the formation of SVC from remnants of deep convective clouds."

11. ***P. 5, lines 26-29:*** *'Thus, gaining more insight of the dissipating stage of deep convective systems, will also be helpful for understanding SVC formation, either from remnants of convection or facilitated through the changed background conditions.*
    *What are the 'changed background conditions'?*

**Reply:** For clarification we added:
"…changed background conditions regarding humidity and processed aerosols (after cloud dissipation)."

12. ***P. 6, lines 6-7:*** *'... is important from the perspective of the radiative budget and also of the satellite data retrieval and analyses.*
    *What is the importance for satellite data retrieval and analyses?*

**Reply:** We added the following before this sentence:

“Satellite observations may find cloud-free pixels next to cloudy pixels that are actually the twilight zone, i.e. containing undetectable clouds and aerosol. These areas show elevated reflectance and have been found to be not reliable for aerosol retrievals (Koren et al., 2007, Wen et al., 2006).”

***2 Experiment and instrumentation***

***13. P. 7, lines 19-21:*** *’The cloud particle data have been thoroughly filtered for shattering artefacts, following the interarrival time approach ...’*
*It would be convincing to show a figure displaying the PDFs of the interarrival times.*

**Reply:** A figure showing the interarrival times and the following text have been added:

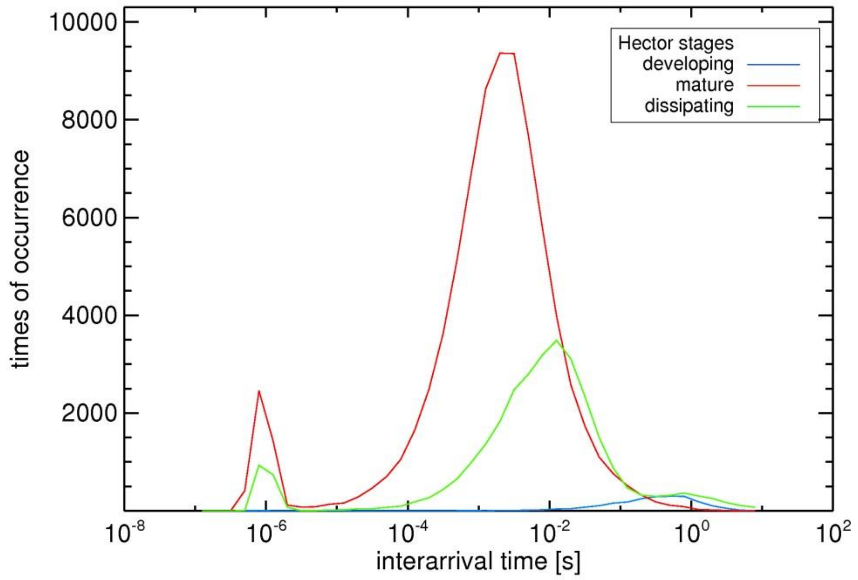


Fig. 1: Frequency distributions of interarrival times used to identify shattering artefacts in the CIP image data. The data are grouped into Hector classification stages as described in Sect. 4.1.

“Frequency distributions of interarrival times for the different Hector development stages (as outlined in Sect. 4.1) are shown in Fig. 1. Shattered particles can be clearly identified by the secondary peak around $10^{-6}$ s.”

***14. P. 7, lines 23-25:*** *’ ... comparisons of the cloud particle data from CIP and FSSP to lyman-alpha hygrometers ..., shattering was not a problem for these particular samplings of Hector clouds.*
*Agreement between IWCs from cloud particle probes and lyman-alpha hygrometers is not an argument versus shattering.*

**Reply:** As discussed in de Reus et al. (2009), we believe that the agreement between the lyman-alpha hygrometers and CIP and FSSP does prove that shattering is not an issue for these particular measurements. De Reus et al. used the data from exactly these two flights presented here plus an additional flight from the SCOUT-O3 campaign to compose their Figure 4, which demonstrates “closure” between the hygrometers and the water vapour instruments. We agree that this kind correlation would not necessarily -in general- prove no-shattering conditions. In clouds that contain higher number concentrations and larger particles (particularly if these have more complex shapes than observed here) shattering does introduce serious artefacts. By such artefacts the number concentrations of particles in the FSSP size range may be strongly affected, while at the same time the IWC is rather insensitive to errors in the FSSP range, because the IWC is mostly “generated” from the larger CIP-sized hydrometeors. However, in the figure by de Reus et al. (2009) the IWCs vary from $10^{-5}$ to $10^{-2}$ g/m³ and the colour-coding shows that for the lowest IWCs the values are sensitive to the FSSP counts as there were little or no large particles present. Significant shattering here would have resulted in a discrepancy between the particle and gas phase instruments. Thus, we believe this is a valid argument here and in a sense we were lucky with the encountered experimental conditions.

***3 30 November 2005 – description of the case***

***15. P. 9, line 21:*** *Please explain what the WRF and UM models are.*

**Reply:** The models have been introduced in the introduction; therefore, we would refrain from repeating this. However, we added the relevant references here in parenthesis.

***4 Microphysical evolution of Hector***

*16.* ***General comment:*** *I find the representation of the observations nicely descriptive, but explanations are missing.*

**Reply:** We accommodated explanations in the revised manuscript.

*17.* ***P. 13, line 10:*** *' ... mean values for ice water content (IWC), ...'*
*Where does the IWC comes from?*

**Reply:** We added an explanation about the IWC in the Instrument section:
"An ice density of 0.917g/cm$^3$ was used to calculate the ice water content (IWC), assuming sphericity in the FSSP size range and using an image to mass relationship as introduced in Baker and Lawson (2006) for the larger particles."

*18.* ***P. 14, line 1:*** *' ... - The ambient temperature became warmer with increasing age of Hector.'*
*It can be seen in Table 1 that not only the temperature became warmer but also RHice is above 100% in all levels except at 350-355K.*
*I was really wondering how the Hector can develop from mature to dissipating in a warmer and supersaturated environment ???*
*Vice versa at 350-355K, how can Hecture mature at RHice = 83% ???*

**Reply:** The RHi is generally close to saturation, especially when considering the measurement uncertainty. Therefore, we would count any RHi in about +/- 10% of saturation as saturation rather than sub- or supersaturated. Furthermore, it is known that supersaturation in cirrus clouds will not be removed immediately, but that RHi of up to and more than 200% have been found in cirrus (Krämer et al., 2009, Spichtinger and Krämer, 2013). In the dissipating stage ice particles sediment out of the cloud, which does not affect RHi in first instance. Warmer temperatures in the dissipating cloud decreases RHi at first but when reaching subsaturation ice crystals will evaporate and thus, a RHi around saturation would be expected.
The rather low RHi in the 350-355K level of mature stage could possibly be explained by entrainment of dry air from the side of the cloud.
We added an item clarifying this to the list in the manuscript.

*19.* ***P.14, 23-24:*** *' ... continental convection is generally thought to produce stronger updrafts and with this larger hydrometeors..'*
*Why is that? Intuitively I would think that stronger updrafts produce more and smaller cloud drops in the mixed-phase temperature range as well as ice particles in the cirrus temperature range.*

**Reply:** This comparison was removed from the revised manuscript.

***5 Backscatter and aerosol measurements and their implication for freezing history***

*20.* ***General:*** *This section contains very long paragraphs without any break. The information about the freezing history is hidden in this long text segments. I recommend to introduce subsections and point out clearly the freezing histories of the different Hector stages.*
*As you will see below, I don't agree with some of the hypothesis about the freezing mechanisms. Please consider these comments and discuss the possible explanations in more detail in the revised version of the manuscript.*

**Reply:** We revised this section and gave more detailed explanations. We also introduced subsections.

*21.* ***P.16, lines 16-18 :*** *'Thus, glaciation had already taken place before the observations in the developing Hector (all cases at T < 200 K), which judging from the satellite pictures was in it's first hour of development.*
*'Glaciation' implies that the ice particles originate from the mixed-phase temperature region (about 4-5 km -or more- below) and stem from frozen drops.*
*How can you know that? Couldn't they just as well have formed directly as ice in the cirrus temperature range starting about 3 km below?*

**Reply:** In the very high updraft speeds (some tens of m/s) that occur in the deep convective turrets, it would take only a few minutes to lift frozen drops by 5km. In case of pure heterogeneous freezing at somewhat higher altitudes we would expect a larger spread in the data. Certainly the ice particles have further grown by deposition (maybe also a minor contribution from riming) causing the broadening of the size distributions. Regarding the number concentrations, not all particles necessarily need to be transported into the upper cloud parts, some may have "escaped" in the turbulent environment before reaching higher altitudes. Photographs and visual observations from the ground throughout the day confirmed that the Hector established itself as a fully developed Cb. (See also Reply to Comment 28 below.) That is why we believe that the particles indeed stem from the mixed-phase part of the cloud and are not formed in situ.

22. ***P.16, lines 19-22:*** *'On the other side, the decreasing levels of depolarization with altitude for the mature and dissipating Hector case, that reflects a change in the average morphology of the particles, suggests an increasing role for the gravitational settling, riming and growth by accretion.*
    *The latter part of the sentence is very speculative. Gravitational settling: couldn't it just be that the largest particles are not transported up to the highest levels by convective uplift? And I don't understand why riming and growth by accretion - which you assume- should be a reason for the decreasing levels of depolarisation.*

**Reply:** Here, what was meant was that a change in depolarisation reflects a change in the average morphology, which is licit to assume because for a change in depolarisation of the whole particle population at least some must have undergone microphysical processes. The sentence "riming and growth by accretion - - should be a reason for the decreasing level of depolarisation." is stronger and it is not what it is said in the text.

Riming and accretion lead to large particles which will first be removed from the upper cloud parts and later also from the lower cloud parts by sedimentation and precipitation. Additionally, less large particle might be transported into the higher cloud layers, as you point out correctly. Generally, the reviews made us aware –as we also mention in our reply to Reviewer Darrel Baumgardner- that we should add a paragraph explaining the interpretation of these particular depolarisation measurements. In general, for a given shape the depolarisation increases with the dimension of the particle (i.e. within the range of dimension not far from the wavelength, here 532nm) up to an asymptotic value (Liu and Mishchenko, 2001), which depends only on shape. Given the cloud particle dimensions, we are in the asymptotic range here! Thus, depolarisation will not increase with increasing cloud particle size. The asymptotic value depends on the particle shape, but in what manner is hardly predictable. For example in case of spheroids with an aspect ratio close to unity it can be shown that they have higher depolarisation than prolated or oblated spheroids. Plates and spheroids give similar depolarisation ratios, while columns have higher depolarisation ratios (Noel et al., 2004). It is, however, safe to say that when the depolarisation ratio of the cloud particle population changes, the average morphology of the cloud particle changes as well. Thus, coming back to the last part of your question, riming and growth by accretion will not decrease the depolarisation because of particle sizes, but if such particles are present in one cloud layer but not in another, this will certainly change the depolarisation. Clearly, in absence of detailed (detailed if not at all impossible) measurements of what happens inside the mixed phase region of the developing cloud such statements remain speculative. We added a sentence like this:
"In absence of good methods for the in situ detection of accretion and riming in the turbulent parts of Cb clouds the statements in this subsection remain speculative. Detailed numerical simulations of the cloud processes are needed for clarification. The same applies to the influence of rimed particles of various sizes on the detectable depolarisation, which could be simulated in a sensitivity study."

23. ***P.16, lines 24-26:*** *'Heymsfield et al. (2005) and Heymsfield et al. (2009) showed that in convective cells with strong updrafts supercooled cloud droplets reach the homogeneous nucleation level (at about -38C) and rapidly freeze there.*
    *I understand Heymsfield et al. (2005) differently: in the mixed-phase temperature range mainly ice crystals from heterogeneous freezing exist at the lowest temperatures (the drops have evaporated due to the Bergeron-Findeisen process in most cases, see above). When the glaciated cloud is lifted to temperatures colder than -38C in weak updrafts, water vapour is depleted at the ice crystals so that RHice never reaches the freezing threshold for new homogeneous ice nucleation of supercooled solution particles (not activated droplets !). In strong updrafts, the water depletion can not compensate the increase of RHice up to the homogeneous freezing threshold and thus new ice crystals form.*
    *A remark from my side: I think that the heterogeneous freezing threshold for deposition freezing in the cirrus temperature range -which is lower than the homogeneous freezing threshold- could be reached in both weak and strong updrafts.*
    *By the way: the size distribution of frozen drops would look different than your observations, liquid cloud drops have a number concentration of around 100 $cm^3$ or more and sizes between 5 and less then 100 µm. The cloud particle number concentrations and size distributions of the developing Hector points more to ice nucleation (heterogeneous or homogeneous) at temperatures colder than -38C.*

**Reply:** Rephrased: "…supercooled cloud droplets MAY reach…"
You say "*In strong updrafts, the water depletion cannot compensate the increase of RHice up to the homogeneous freezing threshold and thus new ice crystals form."*

That means that liquid water droplets can reach this level, where they freeze homogeneously, which is how we understood the Heymsfield references.
We agree to your remark – about reaching heterogeneous freezing thresholds. Therefore, we add a sentence stating that as well the droplets could freeze at lower altitudes.
Since our measurements were performed well above the freezing level (at -70°C or lower) we think that on the way there not all ice crystals stay in the updrafts, reducing the number. Also, due to further cooling, inducing the increase of RHi, the crystals have the chance to grow via vapour deposition, thus broadening the size distributions.

***24. P. 17, line 12:** What do you mean with 'proper efficiency' ? I guess this means that the efficiency decreases with increasing size? Please specify.*

**Reply:** Yes, the sampling efficiency decreases with increasing size for particles larger 1 µm. We changed the text as follows:
"Since the sampling efficiency η of the COPAS inlet sharply decreases for particles larger than 1µm (i.e. η is about 100% for $D_p \leq$ 1µm but ranges below 30% for $D_p >$ 3µm) and aerosol number concentrations are much larger than the cloud number concentrations, the contribution of possibly counted cloud particles in the COPAS system are negligible."

***25. P. 17, line 17:** What do you mean with 'some effects of further processing'? Please specify.*

**Reply:** Outside the convective core clouds may have undergone some ageing. Thus, aerosol particles might be captured onto the ice surfaces or are released when ice particles sublimate. We changed the text as follows:
"In the anvil region (i.e. outside the main up- and downdrafts), where the measurements were obtained, some cloud ageing effects as the release of submicron aerosol by particle sublimation or losses of aerosol particles onto ice surfaces might apply to this estimate."

***26. P. 18, line 2-3:** 'Both findings suggests that these cloud parts were formed under very similar conditions and underwent the same freezing mechanism within a short time.'*
*It is not clear which freezing mechanism you mean? But if you mean homogeneous freezing of supercooled droplets at -38C, I do not agree (see also the previous comment to P.16, lines 24-26).*

**Reply:** We cannot say what exact freezing mechanism took place just that it led to cloud particles with same morphology. We changed the text to:
"Together these findings suggest that the developing cloud parts were formed under very similar conditions and with a similar history of freezing within a short time."

***27. P. 18, line 9-10:** 'The cloud particles in this stage have undergone some riming and aggregation, thus larger ice crystals were formed.'*
*Couldn't the large ice crystals have grown also by diffusional growth?*

**Reply:** Generally, the ice crystals could also have grown by diffusional growth but it is less effective in growing to large sizes (when the initial ice crystals are larger than 10µm, and here we are talking about particles with sizes even exceeding 1000µm). However, in the convective environment it is likely that aggregation and riming are playing the major role in particle growth. Furthermore, it would take much longer time to grow the ice crystals to observed sizes by diffusional growth compared to aggregation and riming. Also the particle images indicate rimed and aggregated particles, while diffusional growth would lead to other shapes, e.g. dendrites or columns, depending on the environmental conditions.

***28. P. 18, line 9-10:** 'Ice multiplication processes as rime splintering (Hallett and Mossop, 1974) during the riming might be the reason for higher cloud particle concentrations ...'*
*The Hallett and Mossop ice multiplication process is large for temperatures between -12 and -16C, a maximum occurs at -5C (enhancement of particles by a factor of $10^4$ to $10^5$ ), but the enhancement reaches unity at a cloud temperature of -20C. So I cannot imagine that this is the reason for the observations of higher ice crystal numbers in the mature Hector stage.*

**Reply:** Our idea was that the strong updrafts would carry the particles formed in the lower cloud parts into the upper cloud parts. The reviewer is right in questioning whether under such strong updrafts the conditions for Hallett-Mossop process would be met. However, other ice multiplication processes can occur at higher altitudes (Vardiman 1978, Yano and Phillips, 2011), when ice particles hit other ice particles, which is well possible in the turbulent conditions. We changed the statement accordingly in the revised manuscript.

*What about the speculation that the developing and dissipating stages are cirrus that formed in-situ, while the mature Hector represents the lifted mixed cloud from below that reached the high altitudes during the time of maximum updraft?*
*Only an idea ...*

**Reply:** We could visually observe the development of the Hector cloud from different ground locations in and around Darwin throughout the whole day of November 30, 2005. The cloud started to form at lower altitudes but grew quickly into the vertical direction. At that stage no cloud layer was present prior to the convective turret. Also, the satellite IR and optical depth pictures do not indicate the a-priori presence of cirrus. The pilot of that flight did not report clouds in those altitudes prior to Hector in his flight debrief. (The pilots were requested for this campaign to take notes of such observations; nowadays one would have a GoPro camera in the cockpit.) Photographs of the clear sky from the ground sites were not taken before Hector developed. But pictures from the developing and mature Hector exist as well as from the early dissipation phase (that is before darkness set in).

Photographs of Hector during its development. Taken by Stephan Borrmann in Darwin. The time steps are from top to bottom:
12:48LT
12:58LT
17:19LT
18:29LT
Thus, the first two images were taken before measurements are available. Here, you can see that still some water remains present at the cloud top.
The third image was taken towards the end of Hector's mature stage, where the anvil is radially flowing out.
The last images was taken before take-off for the second flight, during the measurements of the dissipating stage it was already dark, so no images are available from that stage.

As the analysis of area ratio (please see the reply to General comment #1 of Reviewer 1) shows, there is a great similarity between the mature and dissipating cloud. Thus, we think that these crystals (larger 125µm) are aging crystals from the mature stage. However, the small particles are not included

in this analysis and the depolarisation of the dissipating stage is quite different to that of the mature clouds. This might indeed be a hint for new particle formation. In that case, the smaller particles, or a subset of them, would be newly formed while the larger are leftovers from the mature stage. (As pointed out in Comment 18, the measurements here show a more or less saturated environment, which would not support nucleation unless some nucleation had occurred prior to the measurement in a then supersaturated environment.)
The last point here has been added to the revised manuscript at the end of Section 5.1.

***29. P. 19, line 4 and other places:*** *'aerosol to cloud particle ratio'*
*Isn't it cloud to aerosol particle ratio ? Otherwise the numbers must be much larger ....*
**Reply:** The reviewer is correct; we changed to 'cloud to aerosol ratio' accordingly.

***Conclusions***

***30. P.21, 4-14:*** *'Furthermore it gives indications for a change in freezing mechanisms with increasing time of Hector: the developing Hector shows very similar aerosol to cloud particle ratios and cloud particle morphology, indicating a rapid freezing under similar conditions, as homogeneous freezing.'*
*Which homogeneous freezing do you mean (see my earlier comments) ?*
**Reply:** We removed "homogeneous freezing"
***b)*** *'The mature Hector cases show rimed ice crystals and some chain aggregates, higher aerosol to cloud particle ratios, thus, a change to riming, contact freezing, and aggregation.'*
*With respect to riming and aggregation see my earlier comments - it should be very clear here that this is speculative. Contact freezing, where is that mentioned?*
**Reply:** Contact freezing was mentioned on page 19, line 12, however we removed it here also due to the wishes of Reviewer 1.
***c)*** *Maybe I have overseen it in the long section 5. ... so please restructure this section and line out how contact freezing can explain the many large ice crystals of the mature Hector stage.*
**Reply:** Contact freezing does not explain the many large ice crystals, but may explain the change in cloud to aerosol particle ratio (as stated in Section 5, which now has been restructured).
***d)*** *'In the decaying stage Hector shows a wide variety of aerosol to cloud particle ratios, and the cloud particles have a simpler morphology than the particles in the mature stage, which might be an effect of ageing. Due to the varying aerosol to cloud particle number ratio, these results show that the development stage of the convective cloud system has an impact on the activation ratio and thus has to be taken into account. '*
*I am not convinced about the discussion of the activation ratio (cloud to aerosol particle ratios). What does that mean - the cloud system has an impact on the activation ratio?*
**Reply:** We rephrased to:
"In the dissipating stage Hector shows a wide variety of cloud to aerosol particle ratios, which might be an effect of ageing. Furthermore, according to the area ratio analysis the cloud particles have a similar shape as the particles in the mature stage, also indicating ageing. However, the depolarisation ratios of the dissipating and mature stages differ. Thus, it is valid to speculate that small ice crystals may have nucleated in situ in the ageing cloud."
Furthermore:
"These results show that the cloud to aerosol particle ratio varies with the development stage of the convective cloud system and thus the cloud's development stage has to be taken into account in aerosol-cloud interaction studies."

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