Atmos. Chem. Phys. Discuss., 10, C10104–C10113, 2010
www.atmos-chem-phys-discuss.net/10/C10104/2010/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Observations of ice multiplication in a weakly convective cell embedded in supercooled mid-level stratus" *by* J. Crosier et al.

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Received and published: 22 November 2010

We thank the referee for their comments and suggestions. Our responses to the comments (along with the original comments in italic) are given below.

This paper presents observations which constitute another demonstration of the workings of the Hallett-Mossop ice-splintering process. Similar evidence has appeared in a handful of other papers. Because that number is relatively small, there is value in augmenting it. This is not one of the strongest of the cases but useful nonetheless.

The major merit of this case is its origin in forced convection along a front allowing the situation to be considered steady-state. The RHI radar sections in Figs 5-8 justify this description; the authors were for some reason taking this for granted or shied away from this interpretation so that the paper doesn't explicitly makes this point but refers to "local convection" and other vague terms. To judge how valid a steady state interpretation may be there should be a clear spatial (drifting) reference established and data presented in relation to that.
We acknowledge the comment that we have omitted the statement that the system is in "steady state". This steady state was suggested in the manuscript but rather tentatively with the words "... stationary front ...". We propose to add the following sentences to the manuscript to clarify this. The radar images presented in Figures 5-8 already demonstrate the steady state nature of the convection.

Section 3 Meteorological Conditions, p19388, line 29.
"Due to the stationary nature of the enhanced reflectivity/convective feature, the system can be considered to be in steady state."

Section 6 Discussion and Conclusions, p19395, line 23.
"This convective feature was observed to be in steady state according to the radar reflectivity structure."

The most important data that is missing is in situ vertical air velocity. Probably because of this, the ice particle observations are presented in statistical form over several kilometers. No clear relationship can be ascertained between the locations of various ice crystal forms and whether they are being transported upwards or are moving downwards. Observations of small crystals at lower altitudes and larger ones higher up is reasonable within an updraft. This evidence is missing. Also, the question *may be asked where do all those small crystals end up. Not all of them grow? Was the outflow from the convection diagnosed? This too is related, of course, to the view of the system as steady state, or not. Lack of clarity on this aspect leads to unease about the interpretations.*

We would like add the following figures/figure captions to the manuscript to complement Figure 12, and the following text. It addresses the size distributions of the ice particles found in the convective regions at different altitudes/temperatures. Data are presented in regions of high/low cloud droplet number concentrations, which relates to regions of updraft/outflow respectively.

Section 4 Cloud Properties, p19393, line 12.

"Average ice particle size distributions in the convective region (15-25 km distance from CFARR) for runs R3-R5, conditionally averaged for cloud droplet number concentrations greater/less than $1\ cm^{-3}$, are shown in Figures 12b/12c respectively. The conditional sampling according to droplet number concentrations is to attempt to separate regions of updraft and thus those capable of sustaining liquid water. The sizing metric used in these plots is the diameter of a circle which would have the same total area as the original particle. This is done because column particles of the same size could have a variety of across/along array measured lengths depending on orientation upon sampling.

The ice particle size distribution at the lowest altitude/warmest temperature (-4.3° C) is dominated by small ($< 300\mu$m) particles in regions of high cloud droplets (Figure 12b) and thus updrafts. These ice particles are those which have been generated by Secondary Ice Production. The particle size distribution in low cloud droplet number concentration regions at the same altitude/temperature is instead dominated by larger particles extending to over 1 mm in size (Figure 12c). These are rimed particles which are most likely falling out of the convective system. At colder temperatures (-6.9° C and -9.3°C), the

high droplet concentration regions have a significant contribution of ice particles $> 300\mu$m to the total number concentration (Figure 12b). This is in strong contrast to the -4.3°C distribution which only contains the smaller particles, and is due to the growth of the columns seen at lower altitudes in the updraft as they are lifted. In the region of low droplet concentrations, large numbers of rimed particles ($D \sim 400\mu$m) are seen at the intermediate level (-6.9° C) falling out of the system. Above this (-9.3°C), little ice is detected in the low cloud droplet concentration region, presumably as most of the large precipitation has already fallen out."

Specific points (page/line as reference).

It would be helpful to show clearly the relative locations of the flight track, the satellite image and the time series in Figs. 5-8. As it is, conversions are needed from lat/lon to radial distance along an oblique line.

In order to increase clarity we have altered Figures 1 and 2 as follows.

Figure 1
Added labels to the radar range rings.
Added label to 253° radial line from radar.
Moved 253° radial line on top of the aircraft flight track.
Added location of nearby radiosonde stations.

Figure 2
Added a box highlighting the location of Figure 1 within the domain of Figure 2.

We feel these changes allow easy comparison of Figures 1 and 2, as well as improved contextualisation of figures 5-8. .

19383/14: not all coalescence is between supercooled drops.
We will remove the word "supercooled".

19384/11: " ... majority of ice in convective clouds .." is too general.
We will reword the phrase to "...majority of ice in convective clouds which span the temperature range -3 to $-8°$ C and have cloud top temperatures $> -30°$ C...".

19384/17: " ... may provide ..." in place of " ... can provide ..."
Change as suggested.

19387/1: The section includes radar data as well, not just meteorological conditions.
We will rename the section "Meteorological Conditions and Radar Data".

19388/18: warm clouds are not "seeded" by ice crystals in the usual sense.
We will replace the word "seeding" with "influencing".

19388/21-24: Why mention this event many hours earlier? What is the evidence fro rimed particles and graupel.
We agree that these two sentances are irrelavent and we will remove them.

19389/25-27: This is confusing: 2 m/s correction is 10% of the vertical velocity? Suspect that it should be horizontal velocity.
Will will reword the following:

"Correcting the Doppler velocities for a $2ms^{-1}$ fall speed, the impact on the derived vertical velocities is only 10%."

To:

"Derived updraft velocities were perturbed by 10% when including a $2ms^{-1}$ ice particle fall speed contribution to the measured Doppler velocity."

19392/18: The relative locations of these data segments (distance) are more relevant than the length of the data segment. Were these data collected in updrafts?
The actual position where the data are obtained will be added to each Figure caption (18.9, 20.1 and 18.8 km respectively). In addition, we will add the following to the text.

Section 4 Cloud Properties, p19292, line 18
"The images were obtained in regions of high cloud droplet concentrations as measured by the CDP, and therefore most likely updrafts."

19392/27: This reference implies a lack of small-scale organization in spite of the steady updrafts depicted. Is there a conflict between this feature and the assumption of vertical continuity?
The non-uniformity is in the horizontal and due to updrafts/downdrafts. This does not affect the steady state/vertical continuity. We will change the following:

"....not uniformly mixed across the convective region, but appear in discrete pockets."

to:

"....not uniformly mixed horizontally across the convective region, but appear in discrete pockets due to the presence of the up/down-draughts." .

19393/13- 19394/14: The aerosol data are fairly marginal to the main theme of

the paper.
We feel the aerosol data are still useful and should be presented.

19394/24: what is meant by 'activation' here?
Change the word "activated" to "nucleated".

19395/21: Can the term "in-efficient" be better defined?
We will alter the following to clarify:

Section 6 Discussion and conclusions, p19394, line 23
" (a) all or some cloud droplets containing inefficient IN which are slowly activated over time, ..."

To:

" (a) all or some cloud droplets containing inefficient IN (which nucleate via a slow stochastic process) which are activated over time, ..."

19397/11: Steady state is assumed here. Does this conflict with 19392/27?
Horizontal variability is mentioned in p19392,l27 and this does not impact on the steady state assumption.

19398/3: The crucial thing is the concentration of droplet $> 24\mu$m in conjunction with graupel. Is this reflected well enough by reference to the mean concentration? Mean values were taken over what flight segment?
We do perform the calculation with the peak droplet concentration found in the updraft as well as the mean. This is already discussed in p19398, l9-13. Ice particle concentrations from the supercooled stratus were relatively invariant and thus sensitivity to droplet concentrations was deemed sufficient.

19398/30: Is there any evidence backing up the suggestion that the crystal type on which riming is occurring has any impact on the HM mechanism? Size and hence riming rate are the important parameters, so there is only an indirect and rather weak link to crystal shape. Presenting this factor as a possible explanation for the discrepancy between observed and calculated values is without good basis.
We are hypothesising that SIP can occur when droplets which are smaller than previously reported rime on ice crystals falling with a sufficiently low fallspeed. This will be investigated in future lab studies. We will add the following to manuscript:

Section 6 Discussion and conclusions, p19399, line 3
"This will be further investigated in future laboratory studies."

19399/13: The caption for fig 15 identifies the source of the data as a flight different from the one discussed in the paper; this is probably ok as long as the same probes and settings were used. In a broader sense, the appendices are important analyses of probe performance but they have no significant impacts on the issue raised in the paper. Perhaps they should be given more detail in a separate paper.
There have been long standing issues with instrument artefacts in cloud microphysical measurements which have skew data interpretation. We feel it is important to present details of the steps we have taken to avoid these issues. The same probes and settings were used in both studies. We will add the following to the end of Appendix A to highlight this.

"The data shown in Figures 15 and 16 are from a subsequent flight and not the study presented in the main article text. However, probe configurations were identical for both flights. The data presented in Figures 15 and 16 are from a case with significantly larger ice mass concentrations/sizes, with ice being

found over larger spatial scales. This makes the data from the case presented in the Appendix more suitable for identification of instrumentation artefacts."

Interactive comment on Atmos. Chem. Phys. Discuss., 10, 19381, 2010.

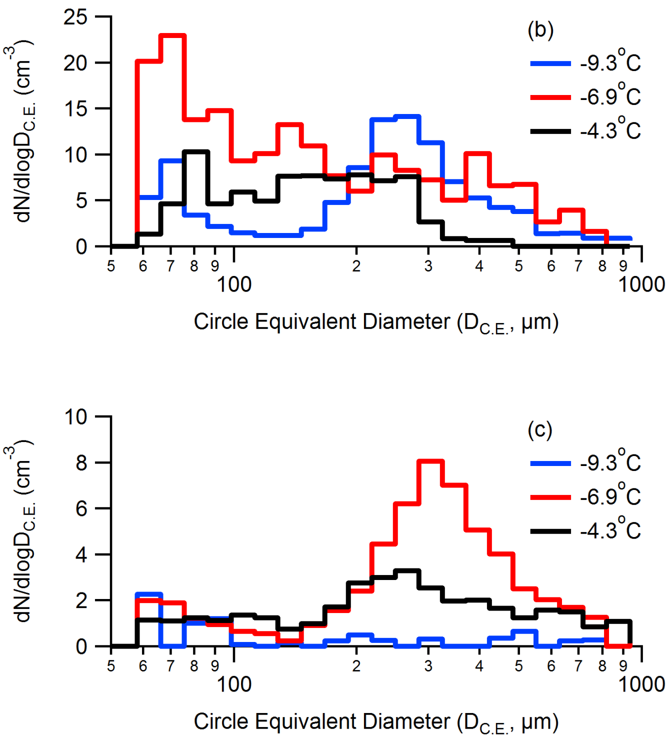

Fig. 1. Figure 12: Ice particle size distribution from the 2D-S in the convective region (15-25 km distance from CFARR) in (b) high (>1cm-3) and (c) low (<1 cm-3) cloud droplet number concentration regions.