

Interactive comment on “On the observation of unusual high concentration of small chain-like aggregate ice crystals and large ice water contents near the top of a deep convective cloud during the CIRCLE-2 experiment” by J.-F. Gayet et al.

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General Comments:

This is a paper on an important topic and should be published. The authors have an impressive array of data describing this convective cloud. The observation of small chain-like aggregate ice crystals was very interesting. However, the conclusions are somewhat over reaching because only one cloud was documented. There are many

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problems associated with measuring concentrations, size distributions and ice water contents in clouds with the equipment used in this campaign. The authors used state-of-the-art techniques at the time of the measurements, but new and/or improved instruments are required. Although the authors do mention some of the faults of the instrumentation, the reader might be given a somewhat optimistic outlook. The potential errors, because of their importance, need to be better emphasized in the paper, especially in the abstract and conclusions.

The authors mentioned an important problem in the aviation community. There have been many events where commercial jets have experienced engine power loss and even damage while flying in-cloud over convective storms and complexes, probably due to the high ice water contents present. This problem has been described in papers by Lawson et al. (1998), Strapp et al. (1999) and Mason et al. (2006). These papers should be referenced early on in the manuscript. Following recommendations of an industry led Engine Harmonization Working Group/Power Plant Installation Harmonization Working Group (Mazzawy and Strapp, 2007) major projects are now being planned to characterize mixed phase/glaciated clouds through extensive flight campaigns.

An important conclusion of the paper was that the high ice water contents, because of the small associated ice particles, would produce low radar reflectivity signatures. This is not an original conclusion because it was mentioned in Mason et al. (2006) in the context of the engine jet powerloss and damage problem. It is suspected to be the fundamental reason why hazardous regions of high IWC that cause engine events and possibly air data probe events cannot be detected and avoided with current commercial aircraft radars. This earlier work should be acknowledged.

Major Comments:

1.) Ice Particle Size and Concentration Measurements

The authors use the FSSP 300 and CPI probes to determine ice particle concentra-

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tions and the associated size spectra. These probes suffer from ice particles bouncing and shattering off their inlet tubes and the measurements can be totally destroyed by this artefact. Because of the long sampling tube of the CPI, it is particularly susceptible to this problem. Airborne and laboratory high speed camera images show ice crystals bouncing off probe surfaces and going forward into the airstream and even crossing streamlines in the horizontal direction (Isaac et al., 2006; Korolev et al., 2011). Korolev et al. (2011) provide a clear example of how standard FSSP measurements, without modification for artefact mitigation, can be completely destroyed by this problem, especially when large particles ($> 500 \mu\text{m}$) are present, which appears to be the case here.

The FSSP-300 was designed as an aerosol measurement probe assuming spherical particles with a refractive index of 1.58. It is not clear from the reference given, Febvre et al. (2009), how the probe was calibrated to detect and size ice particles. However, Fugal and Shaw (2009) show corrections that are necessary to adjust FSSP measurements, which are normally used to detect liquid drops, assuming the ice particles are shaped like droplets resembling a faceted sphere. The corrections are substantial but there is no indication that the authors have made such calculations.

The definition of the sampling area of the CPI is difficult which is why the 2D-C probe is used to fit the spectra. Since the particles in this case were unusual, and the 2D-C probe was not functioning, it would be difficult to assess the possible errors because presumably a standard sampling area from previous cases was used in the calculation. One cannot fit using the FSSP measurements since the liquid versus ice correction was not made.

2) Particle Mass Calculations

Particle mass calculations are difficult because of the different and sometimes unusual shapes that ice crystals assume in the free atmosphere. The authors made an interesting observation of many small chain-like aggregate ice crystals. However, although

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no mention is made of the assumed shape for particles in the FSSP size range, they likely considered the particles spherical as was done in Febvre et al. (2009) which was referenced for the method. They used a mass-diameter relationship with values of the coefficients which are meant for small columns (Mitchell et al., 1990). Although they stated these values would be representative of the chain-like crystals present, no further justification was given. Both the definitions of shape for the FSSP and CPI measurements could lead to large errors in the calculated mass. The chain-like crystals must project different shapes on the 2D plane of the CPI, depending on their orientation, and this would lead to large errors in itself. So the estimate of a possible maximum error of 100% in mass seems optimistic.

3) Ice Water Content and Reflectivity Measurements

It has been recognized that any future field work in high ice water content conditions at the tops of convective storms need direct measurements of ice water content (e.g. Davison et al., 2009, 2011). Calculating the mass from size distributions can give large errors as mentioned briefly above. Although the Nevzorov probe (Korolev et al., 1998) has been used for many years to directly measure ice water content, it is now recognized that the probe does not capture all the particles that impact (Isaac et al., 2006). Korolev et al. (2008) has estimated this error to be as large as a factor of 3 and has recommended using a modified version of the probe.

The authors show the number size distributions but not the mass and reflectivity distributions. It would be very useful to know the mass median size, and see how the mass and reflectivity spectra behave at the overlap between the two probes. Perhaps the FSSP measurements were not that important in the calculation. For reflectivity, just a few large particles can swamp the calculations and it is possible the maximum sizes were not measured with the CPI. A reflectivity versus size graph would help reduce that concern.

4) Observations of High Ice Water Content

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The authors show high ice water contents in the tops of these convective clouds, as high as 0.5 g m⁻³ as inferred from the spectra measured by the in-situ probes. This is not that unusual as some of the references provided by the authors indicate. However, several significant references were not included. Strapp et al. (1999) found maximum ice water contents in excess of 1.3 gm⁻³, and often sustained ice water contents in excess of 0.5 gm⁻³. Abraham et al. (2004) reported a broad area in extratropical cyclones that were higher than 1 gm⁻³. The ice water content values in these two papers are probably underestimates given what is now known about the performance of the standard Nevzorov LWC/TWC probe (Korolev et al., 2008). An early Royal Aircraft Establishment report by McNaughton (1959), which has been used for years to provide some guidelines to aviation on ice water content, describes measurements made in convective clouds near Entebbe, Singapore and Darwin with total water contents (probably mostly ice) exceeding 5 gm⁻³. Mazzawy and Strapp (2007) summarize these and other measurements in order to come up with "Appendix D – An Interim Icing Envelope" which defines a mixed phase/glaciated icing environment to be used by the aviation industry in certifying engines for operations in these conditions. However, our inability to accurately measure high ice water contents limits these measurements, and those of Gayet et al. Hopefully, when newer probes become more widely used, the measurements will be more accurate.

Minor Comments:

1) P23915 Line 21: More references could be given here. 2) P23915 Line 22-23: Poor sentence. 3) P23916 Line 27: Some references should be given here (e.g. Lawson et al. 1998, Strapp et al. 1999 and Mason et al. 2006). 4) P23917 First Paragraph: It is not clear why all this equipment needs to be mentioned. Perhaps only mention those measurements used for the discussion/conclusions. 5) P23917 Line 13: Aircrafts should be aircraft. 6) P23918 Line 10: Is there a way of making the Mioche et al (2010) reference more available? 7) P23918 Line 25: The error of 4 dBZ depends on the size distribution. If particles are present that are outside of the measurement

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range then very serious errors can occur. This relates to the comment above regarding the reflectivity versus size graph. 8) P23921 Line 21: Why were horizontal winds not measured by the aircraft? 9) P23924 Line 12: Insert the word "of" in the "top of the overshooting cell." 10) P23925 Line 1: Why are the ice water contents not approaching the adiabatic values? 11) P23929 Line 25: Add the Strapp et al. (1999) reference. 12) P23930 Line 20: Remove the word "the." 13) P23931 Line 15-19: This sentence does not make sense. The ice water contents observed are much lower than adiabatic so why does this indicate that entrainment of dry environmental air is not important? 14) P23932 Line 2: 2 m/s should be re-written. 15) Figs. 6 and 7: The print on some diagrams is very small and difficult to read.

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