Atmos. Chem. Phys. Discuss., 8, S12087–S12091, 2009
www.atmos-chem-phys-discuss.net/8/S12087/2009/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Ice supersaturations and cirrus cloud crystal numbers" *by* M. Krämer et al.

M. Krämer

m.kraemer@fz-juelich.de

Received and published: 16 April 2009

First of all, many thanks again for the referees effort to improve the manuscript with helpful comments. Because of the comments overlap, I answered to the comments on ice crystal shattering all referees at once.

> Referee #1 comment:
>
> 2 a) The authors note that ice shattering can occur, but the flaw is that they suggest that there were no large particles that would cause shattering - even though no instruments flew that were capable of measuring large particles. Shattering will alter the concentrations of particles, particularly the small particles, so the calculations given by equations 1 and 2 are not correct.

2 b) In section 3.5.1, the largest concentrations of ice particles are observed at higher temperatures (225-240 K). However, this may simply be due to increased shattering at higher temperatures.

Referee #2 comment:

Regarding ice crystal shattering effects in the particle probes, will this impact the interpretation of the parcel modeling results to follow? Can these effects be 'estimated' and then 'propagated' through the calculations to see if the conclusions are generally similar? This would help address Reviewer #1s concerns about the model calculations with regard to the observations. Also, perhaps another useful paper has been published on ice shattering by S. Davis et al. (2009), JGR.

Referee #3 comment:

1) Ice crystal measurements may not be adequate: At higher temperatures, the 30-um detection limit is too low, and it is not convincing that there is no shattering. These short falls are not fatal, since the main conclusions at lower temperatures will not be altered. The authors are encouraged to rewrite this section and point out that a) the 30-um limit is close to be adequate at the lowest temperatures, and shattering at those temperatures can only increase Nice and therefore will not be in conflict with the conclusions, and b) at higher temperature the missing large particles and shattering can both be important.

To answer this major point we show here the changes we have made in the manuscript. We believe that our arguments are sufficiently convincing to support our conclusions that are drawn from the ice crystal measurements.

ACPD

8, S12087–S12091, 2009

Interactive Comment

New section: 2.2 Ice crystals

For our data analysis, we also use measurements of total ice crystals number concentrations made with instruments mounted on the M55 Geophysika and the enviscope-Learjet using either an FSSP 100 or 300 [de Reus et al. (2008) and references herein; sampling rate is 2 Hz]. The flights are listed in Table 3.

FSSP 100/300 sample particles in the size range 1.5-15/0.3-20μm radius, and ice crystals larger than this size range were not recorded. For a number of flights during the SCOUT-O3 field campaign a cloud imaging probe (CIP) was also operated on the Geophysika aircraft to complement FSSP with measurements in the range from 12.5< R_{ice} <775μm [de Reus et al. (2008)]. From these flights we determined at least 80%, but typically more than 90%, of the total number concentration within the FSSP size range in cirrus at temperatures less than 240 K. Thus, the error in N_{ice} is small, but the error in the mean ice crystal size R_{ice} detected by FSSP could be significant. Therefore, we estimate R_{ice} from the IWC detected by FISH (FISH samples all ice crystals larger than 2μm radius, Krämer and Afchine (2004)) together with N_{ice} from FSSP by assuming that all crystals are spheres of the same size (see Table 2).

Shattering of ice crystals on the inlet FSSP can lead to an overestimate of the ice crystal concentration and IWC [Gardiner and Hallett (1985), Field et al. (2006b), Field et al. (2006a); McFarquhar et al. (2007), Jensen et al. (2009)]. This is valid for clouds where the ice crystal population contains a significant number of particles larger than approximately 50μm (Baumgardner 2007, personal communication) and especially when a flow-straightening shroud is present in front of the inlet [Davis et al. (2009)]. Here, the FSSP does not use a shroud and the largest fraction of our measurements of R_{ice} lie between 3-30μm at temperatures < 200K and mostly up to around 50μm at higher temperatures, while N_{ice} ranges from 0.005 to 60cm-3 (see Section 3.4).

In agreement with de Reus et al. (2008) and Lawson et al. (2008), we do not expect

ACPD

8, S12087–S12091, 2009

Interactive Comment

a significant effect of shattering at low temperatures: Lawson et al. (2008) used a CPI (cloud particle imager), a 2D-S (2-dimensional stereo probe) and a CAPS (cloud and aerosol particle spectrometer) for ice crystal detection up to about 800μm radius during 2.4 h of observation time below 200 K. Jensen et al. (2009) stated that the 2D-S is less susceptible to shattering artifacts, and Lawson et al. (2008) reported that from the images of 2D-S and CPI there was no visual evidence of shattered particles and that the size distributions of all three instruments were consistent.

We cannot, however, completely exclude ice crystal shattering in the warmer ice clouds where the occurrence of larger ice crystals increases. This is discussed in greater detail in Section 3.5.3.

New section 3.5.3: Ice crystal shattering

Shattering of larger ice crystals may have enhanced the number of particles detected in the FSSP size range, especially for the temperature range >205 K (see Section 2.2). The good agreement of our N_{ice} observations with those reported from INCA in this temperature range (see Section 3.5.1) may be due to the same shattering problems as speculated by Jensen et al. (2009). Assuming that the most frequent N_{ice} concentrations are lower and lie between the middle and minimum N_{ice} in Figure 9 (top panel), this implies either that the vertical velocities inducing homogeneous freezing are not higher than about 20 cm/s, or that heterogeneous freez- ing is a major process in this temperature range. Neither of these assumptions are in agreement with current knowledge on cirrus production processes. In addition, the cloud relaxation times would then extend to approx. 5 to 60 minutes (Figure 6), causing a longer lifetime at high supersaturation. We question whether this scenario is consistent with the narrow RH_{ice} frequency distribution shown in Figure 8.

At T < 205 K our observations are consistent with those reported by Lawson et al. (2008) (see Section 3.5.2), and, as discussed in Section 2.2, we do not expect an effect

ACPD

8, S12087–S12091, 2009

of ice crystal shattering at low temperatures. Considering nevertheless that shattered large ice crystals en- hance N_{ice} at low temperatures in our data set and the real ice crystal concentrations are smaller, implies - as for the higher temperatures - that the relaxation times are longer and the steady- state supersaturations becomes higher and exist over a longer period. Thus, our conclusion that the frequent observation of high supersaturations at low temperatures can be explained by conventional microphysics receives even stronger support.

In conclusion, we believe that shattering may occasionally influence the observed N_{ice} , espe- cially at higher temperatures. However, these cases do not significantly impact the pattern of the N_{ice} frequencies presented here or the results and conclusions derived from these measurements.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 21089, 2008.

ACPD

8, S12087–S12091, 2009

Interactive Comment