

Interactive comment on “In-situ observations and modeling of nitric acid-containing particles in a cirrus cloud formation region” by C. Voigt et al.

C. Voigt et al.

Received and published: 4 May 2007

Response to anonymous referee 2

We thank the referee for his/her comments, which helped to improve the manuscript.

As stated several times in the paper, based on the observations of small ice crystals at low number densities and high HNO_3 content relative to the ice water content, we develop a working hypothesis that the cirrus cloud was detected a formation stage. It is true that a part of the measurements was taken under conditions which were sub-saturated with respect to ice. In the original manuscript, we refrained from doing a more time resolved data analysis to improve the data statistics and not to lose more data of this short cirrus event. After revision, we now separate the regions with $S_i < 1$ and redo the analysis based on ice cloud observations with $S_i > 1$ to assure ice particle growth.

The differences between the two analyses are minor (8% increase in the $\text{HNO}_3/\text{H}_2\text{O}$ molar ratio). We further change the title to: In-situ observations and modeling of small nitric acid-containing cirrus particles.

In addition, trajectory analyses were performed based on ECMWF data and the measured gas phase water profile. The temperatures of the trajectories were above the ice frost point T_i prior to the observations, decreasing to T_i at the point of observation, consistent with the measurements. However, the temporal resolution of the ECMWF data is not appropriate to study processes with timescales of seconds to minutes, hence we refrain from showing the trajectories in the paper.

Concerning satellite data, a thin cloud with particle properties as discussed in the paper, e.g. very low backscatter, cannot be resolved in most satellite images.

(1) Beginning of section 2 has been changed to: gas phase plus enhanced particle NO_y

(2) The term particles does not exclude ice crystals. It is used in a general sense, meaning aerosol and/or ice particles. In contrast, the term ice crystals excludes aerosol. We changed the manuscript to: In the following, r denotes the particle radius (aerosol and/or ice crystals) and r_i the ice crystal radius, if not directly stated otherwise.

(3) We include the reference to Gamblin et al. (2006).

(4) We add and $\text{HNO}_{3,a}$ denotes the enhanced HNO_3 contained in liquid aerosol. Similar adjustments were made for the IWC equations.

(5) We express the uncertainty in the determination of T_i and S_i more strongly by stating in section 2 that: This method introduces a potentially large uncertainty in determining T_i and S_i in regions with particle observations. Nevertheless, it presents a way to estimate T_i and S_i given that H_2O_g has not been measured directly on that day.

(6) Parallel quasi-simultaneous measurements with the upward facing lidar onboard the

[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)[Discussion Paper](#)

Interactive
Comment

DLR Falcon show the boundary region of a convective cloud about 200 km away from the Geophysica flight track above the Falcon flight track. In addition, the Geophysica measurements show the fading out of a convective cloud. That is why it might be appropriate to stat that: The lidar of the Falcon combined with the Geophysica data suggest that the Geophysica ascended through the boundary region of a convective cloud.

(7) We changed the data analysis and now concentrate on the region that was supersaturated with respect to ice (36302-36398 sec UT and 14.2-14.9 km altitude). The $\text{HNO}_3/\text{H}_2\text{O}$ molar ratio in ice of $5.4\text{E-}5$ is slightly higher compared to the average of the total particle layer ($5.0\text{E-}5$), and is within the experimental uncertainty of $3.7\text{E-}5$ to $8.5\text{E-}5$. The IWC of 0.031 mg m^{-3} in the supersaturated cloud layer is slightly higher but within the error bars compared to the IWC of the total particle layer 0.026 mg m^{-3} . We changed the paper accordingly and add the analyses for the total particle layer as sensitivity study.

(8) The FSSP is designed for measurements at a constant altitude. The sampling efficiency of the FSSP is not characterized or calibrated for measurements taken during ascent or descent.

(9) As detailed in comment (7), we now concentrate our analysis on the ice layer with $S_i > 1$, where ice particle are growing. Of course, this could be a transient phenomenon and we do not know whether those particles will be growing or evaporating after the measurements, as we have stated at the end of Sect. 3: As details of the dynamical evolution of the probed layer are not known, ice formation and growth could have continued (the number of crystals and their average size increased) or ice formation could already have been completed at the time of observation. We further estimate ranges of μ -values the cloud would have obtained in a developed stage, to be able to compare with previous measurements. We do not conclude that the cirrus cloud will grow into its developed stage in reality.

[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)[Discussion Paper](#)

We note that application of the present analysis does not require the actual probed regions to be entirely supersaturated. The model we use in Kärcher and Voigt (2006) and also here is a steady-state analysis of the more complex trapping process. Here, it is only important to have an estimate of crystal size or IWC, as provided by the FSSP, resulting from growth and/or evaporation of individual ice crystals. The reviewer is right to suspect that this issue does matter when one applies the full kinetic trapping approach, as outlined in the original work (Kärcher and Basko, 2004). This, however, would require much more detailed information about cloud and relative humidity, for instance.

(10) We changed section 3.2 to: To avoid interference of $\text{HNO}_{3,a}$ with $\text{HNO}_{3,i}$, we attribute $\text{HNO}_{3,a}$ to $\text{NO}_{y,r}$ as described in Sect. 2.

(11) We choose $\mu_a = 0.4$ as in Kärcher and Voigt (2006), to compare with the previous data analysis.

(12) We choose $\alpha = 0.3$ for HNO_3 is found in Hanson (1992), for example.

(13) See comments (7) and (9).

The typos have been corrected.

Hanson, D.R.: The uptake of HNO_3 onto ice, NAT, and frozen sulfuric acid. *Geophys. Res. Lett.*, 19, 2063–2066, 1992.

Kärcher, B. and M. M. Basko (2004), Trapping of trace gases in growing ice crystals, *J. Geophys. Res.*, 109, D22204, doi:10.1029/2004JD005254.

Kärcher, B. and C. Voigt (2006), Formation of nitric acid/water ice particles in cirrus clouds, *Geophys. Res. Lett.*, 33, L08806, doi:10.1029/2006GL025927.

Interactive comment on *Atmos. Chem. Phys. Discuss.*, 7, 1849, 2007.