Supersaturations and ice crystal numbers in cirrus clouds: field observations and model simulations

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OVERVIEW

Upper tropospheric observations of high relative humidities over ice (RH_{ice}) inside of cirrus clouds have been frequently observed in recent years (i.e. Ovarlez et al., 2002, *GRL*, or Gao et al., 2004, *Science*). High supersaturations, especially inside of clouds could be indicative for unknown microphysical and radiative properties with consequences for climate and the vertical redistribution of water. Peter et al. (2006, *Science*, and references herein) summarized this 'supersaturation puzzle' and raised the question whether it is caused by a lack of understanding of conventional ice cloud microphysics and/or by uncertainties or flaws in the water measurements.

Here, we present high quality aircraft in-situ observations of supersaturations and the respective ice crystal numbers observed during many flights in several tropical, mid-latitude and Arctic field experiments in the temeprature range 185-240K. **In addition, a model case study in a very cold cirrus is performed**.

We show that **very low ice crystal numbers at temperatures $<$200 K are responsible for persistent in-cloud supersaturations** in this temperature range. We further show that these low ice crystal numbers could only be explained by homogeneous ice nucleation in case of very low ($\leq$ 1 cm/s) vertical velocities. Higher vertical velocities -that are very likely to occur- would have produced a larger number of ice crystals which would efficiently reduce the high supersaturations.

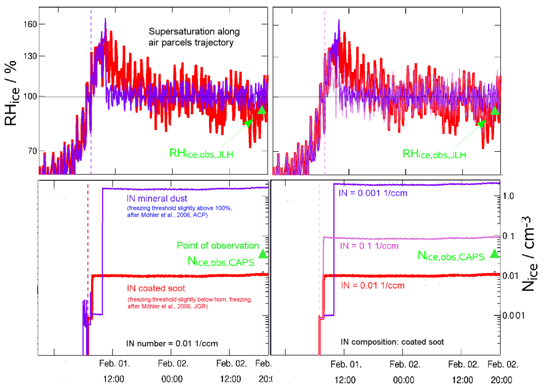
It seems that **the 'supersaturation puzzle' turns into a 'freezing puzzle'** raising a new question: do mechanisms yet unknown exist that suppress or slow down the homogeneous formation of ice crystals at temperatures below 200 K? Very recently, Murray et al., 2008, *ACPD*, and Zobrist et al., 2008, *ACPD*, investigate the suppression of ice crystallisation at low temperatures in highly viscous glass forming aerosol particles as a possible mechanism for the suppression of ice formation.

MODEL SIMULATIONS*

Cold cirrus case study

(Gensch et al.2008, *ERL*, in press)

CR-AVE: WB-57 flight on February 2, 2006



T = 181 - 192 K

Inverse link of ice crystal number & supersaturation

The evolution of supersaturation in cirrus feeds back to the freezing threshold and number of heterogeneous ice nuclei (IN).

Influence of

IN freezing threshold

IN coated soot
(higher freezing threshold)
Few ice crystals ➤ long relaxation times ➤ persistent high supersaturation.

IN mineral dust
(low freezing threshold)
less ice crystals appear in the beginning ➤ subsequent homogeneous ice nucleation event ➤ high ice crystal number ➤ efficient reduction of initial supersaturation.

IN number

Typical IN number
Same as 'coated soot' case.

Low IN number
Same as 'mineral dust' case.

High IN number
No subsequent homogeneous ice nucleation, but even though efficient reduction of initial supersaturation.

*** MAID**
Model for Aerosol and Ice Dynamics
Detailed kinetic microphysical box model including heterogeneous and homogeneous freezing
(Bunz et al., 2008, *ERL*, in press).

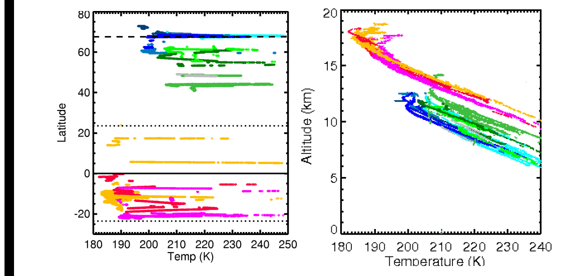
CIRRUS OBSERVATIONS

Measurements in ice clouds:

H_2O_{total}	gas phase + ice H_2O	FISH*	
H_2O_{gas}	gas phase H_2O	FLASH*/OJSTER† * Lyman-α-hygrometer, † open path TDL	
RH_{ice}	Relative humidity over ice	$H_2O_{gas}/H_2O_{sat}(T)$	
IWC	Ice Water Content	H_2O_{total} - H_2O_{gas}	
N_{ice}	Number of ice crystals	FSSP: optical particle counter	
R_{ice}	Size of ice crystals	$[IWC/N_{ice} \cdot 3/(4\,\pi \cdot \rho_{ice})]^{1/3}$	FISH, FSSP

on board of GFD-Learjet (14 km) FISH, OJSTER, FSSP
MDB-Geophysica (20 km) FISH, FLASH, FSSP

Arctic		Midlatitude		Tropics	
◆ Envisat 2003,	2 flights	◆ Envisat 2002,	3	◆ ApeTheseo 1999,	2
◆ Euplex 2003,	3	◆ CIRRUS 2003,	2	◆ Troccinox 2005,	6
		◆ CIRRUS 2004,	2	◆ Scout 2005,	12
		◆ CIRRUS 2006,	5		



Supersaturations

T> 205 K: RH_{ice} group around 100%.
Short water vapour relaxation times?

T< 205 K: broader distribution of RH_{ice},
high supersaturations.
Long water vapour relaxation times?

Ice crystal numbers N_{ice}, vertical velocities u_z and relaxation times τ

T~ 225-240 K:
High N_{ice} (0.5-10 cm^{-3}) are most frequent,
Hom. freezing: $\mathbf{u_z} \sim 10 - 100$ cm/s or higher [a],
τ in the range of minutes.
➤ **efficient reduction of initial supersaturations**

T~ 205-225 K:
Middle N_{ice} (0.05-1 cm^{-3}) are most frequent.
Hom. freezing: $\mathbf{u_z} \sim 5 - 10$ cm/s,
τ several ten minutes.
➤ **still efficient reduction of initial supersaturations**

T< 205 K:
Very low N_{ice} (0.005-0.05 cm^{-3}) are most frequent,
Hom. freezing: $\mathbf{u_z} \leq 1$ cm/s → unlikely!
τ hours to a day.
Heterogeneous freezing or **freezing suppression?**
➤ **persistent high supersaturations**

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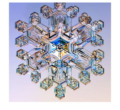
[a] in agreement to Kärcher and Ström (2003, ACP), INCA experiment: N_{ice} = 1–10 cm^{-3}, u_z = 10–100 cm/s T~ 215 - 235 K.

Ice crystal size R_{ice}

(volume equivalent mean radius)

T> 205 K: most frequent R_{ice} distributes between ~5–50μm.

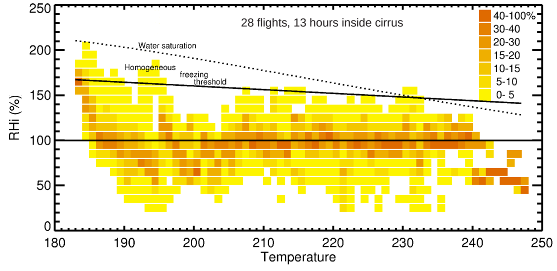
T< 205 K: most frequent R_{ice} decreases from ~20–5μm.



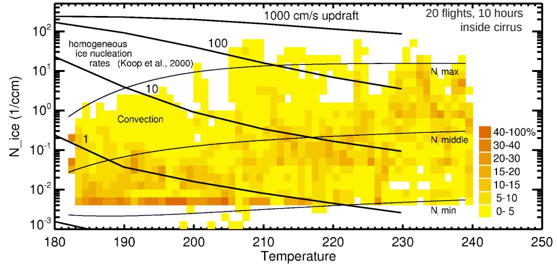
IN-CLOUD

Frequencies of occurence

Supersaturations



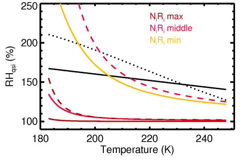
Ice crystal numbers



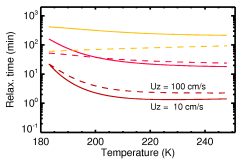
➤ Can we explain high supersaturations inside cirrus by classical microphysics ??

$$RH_{qsi} = \frac{u_z}{N_i\overline{R_i}} \cdot \frac{a_0}{b_i} - \frac{b_i^\star}{b_i} \qquad \tau = \frac{1}{a_0 \cdot u_z + (b_i + b_i^\star)(N_i\overline{R_i})}$$

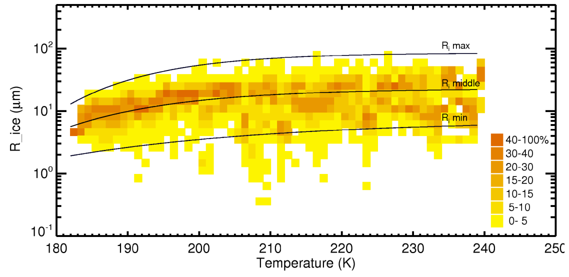
Steady state supersaturation



Relaxation time



Ice crystal sizes



Supersaturation pdf's in the two temperature regimes