

# Quasi Steady Relative Humidities and Relaxation Times in Ice Clouds: preliminary results from model calculations in comparison with measurements

MARTINA KRÄMER<sup>1</sup>, STEFANIE SCHLICHT<sup>1</sup>, ALEXANDER MANGOLD<sup>1</sup>, IULIA GENSCH<sup>1</sup>, C. SCHILLER<sup>1</sup>,  
NIKOLAI SITNIKOV<sup>2</sup>, VOLKER EBERT<sup>3</sup>, HARALD SAATHOFF<sup>4</sup>, OTTMAR MÖHLER<sup>4</sup>

Forschungszentrum Jülich  
in der Helmholtz-Gemeinschaft

<sup>1</sup> FZ Jülich, Inst. für Chemie und Dynamik der Geosphäre I: Stratosphäre, Jülich, Germany (email: m.kraemer@fz-juelich.de)  
<sup>2</sup> Central Aerological Observatory, Moscow Region, Dolgoprudny, Russia

<sup>3</sup> Univ. Heidelberg, Inst. of Physical Chemistry, Germany  
<sup>4</sup> FZ Karlsruhe, Inst. für Meteorologie und Klimakunde: AAF, Karlsruhe, Germany

## Introduction:

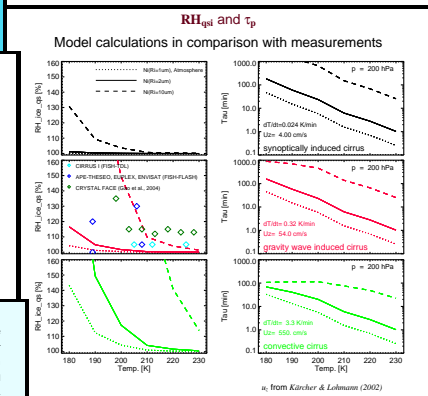
The relative humidity (with respect to ice) in ice clouds is recently found to decrease after ice nucleation, but in many cases ranges inside the cirrus above the saturation value between 100%-180% (e.g. Ovarlez et al., 2002, Spichtinger et al., 2004, Gao et al., 2004). Spichtinger et al. (2004) found that the in-cloud  $RH_{ice}$  decreases with temperature from higher values in cold cirrus down to about 100% in warmer cirrus. Gao et al., 2004 proposed, that the higher  $RH_{ice}$  in cirrus at temper-

atures below 200K is due to surface nitric acid molecules on ice preventing the ice/vapor system from reaching equilibrium.

Here, we investigate –based on the theoretical framework provided by Korolev & Mazin (2003)– the quasi steady  $RH_{ice}$  and the relaxation times  $\tau_p$  in the temperature range 180-230K for natural cirrus and for ice clouds formed at the aerosol chamber AIDA (Research Center Karlsruhe).

We present preliminary results, showing that the quasi steady relative humidities  $RH_{ice}$  increases with decreasing temperature to values clearly above saturation for both natural cirrus and AIDA ice clouds. The supersaturation raises with decreasing integral ice particle size ( $N_i \bar{R}$ ) and increasing updraft velocity ( $u_z$ ). The relaxation times are in the range of hours in cold cirrus clouds. Comparison with field data show good agreement between measured and calculated  $RH_{ice}$ .

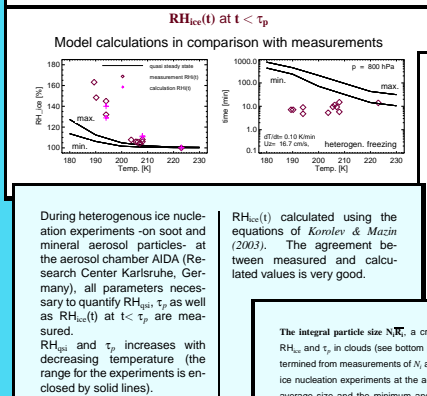
## Cirrus Clouds



The integral particle size  $N_i \bar{R}$ , a crucial parameter controlling  $RH_{ice}$  and  $\tau_p$  in clouds (see bottom panel of the poster), is here determined from the average of ice water content measurements in natural cirrus in dependence on temperature (Heymsfield & McFarquhar, 2002). Under the assumption of ice particle average sizes of 1, 2 and 10  $\mu m$  radius, the respective particle numbers and  $N_i \bar{R}$  are calculated.  
→ caused by the decreasing IWC,  $N_i \bar{R}$  decreases with temperature.

In **synoptically induced cirrus**,  $RH_{ice}$  is around hundred for small ice particles over the complete temperature range. Only in case of larger ice crystals at low temperatures –which is not likely–  $RH_{ice}$  would be higher.  $\tau_p$  is rather long and increases with decreasing temperatures. Assuming larger/smaller ice crystals at higher/lower temperatures,  $\tau_p$  ranges from about 5min up to several days.  
In **gravity wave induced cirrus**,  $RH_{ice}$  is –caused by the higher vertical velocity  $u_z$ – generally higher and  $\tau_p$  is slightly shorter. The included field data points of  $RH_{ice}$  (unknown  $u_z$ ) may probably be taken before the quasi steady state, but confirm the tendency that the in-cloud  $RH_{ice}$  increases with decreasing temperature.  
In **convective cirrus** with very high  $u_z$ , the highest  $RH_{ice}$  should be found, even for small ice crystals at low temperatures. Increasing with decreasing temperature and ice crystal size,  $\tau_p$  ranges from some seconds to about 2 hours.

## AIDA Ice Clouds



During heterogeneous ice nucleation experiments –on soot and mineral aerosol particles– at the aerosol chamber AIDA (Research Center Karlsruhe, Germany), all parameters necessary to quantify  $RH_{ice}$ ,  $\tau_p$  as well as  $RH_{ice}(t)$  at  $t < \tau_p$  are measured.  
 $\circ$  represent measured  $RH_{ice}$  at a time  $t$ ,  $+$  are the respective

$RH_{ice}(t)$  calculated using the equations of Korolev & Mazin (2003). The agreement between measured and calculated values is very good.

The integral particle size  $N_i \bar{R}$ , a crucial parameter controlling  $RH_{ice}$  and  $\tau_p$  in clouds (see bottom panel of the poster), is determined from measurements of  $N_i$  and  $R_i$  during heterogeneous ice nucleation experiments at the aerosol chamber AIDA. The average size and the minimum and maximum number of ice particles forming at heterogeneous freezing of soot and mineral dust particles, are determined in dependence on temperature.

## Sensitivity of $RH_{ice}$ and $\tau_p$ in Ice Clouds to Meteorological Conditions

### The equations of Korolev & Mazin:

Under the assumption that changes in the size of the ice particles ( $R$ ) can be neglected, and that the ice particle number ( $N$ ) and vertical velocity ( $u_z$ ) are constant, the equilibrium supersaturation (at  $\frac{dR}{dt} = 0$ ) is traditionally called quasi steady supersaturation  $S_{qs}$ . The relaxation time to reach the quasi steady state is  $\tau_p$ .

Quasi steady supersaturation  $S_{qs}$ :  
$$S_{qs} = \frac{a_1 - a_2 - b_1' N_i \bar{R}}{b_2 N_i \bar{R}} \quad (1)$$

Relaxation time  $\tau_p$ :  
$$\tau_p = \frac{1}{a_3 - a_4 + (b_3 + b_4') N_i \bar{R}} \quad (2)$$

$a_1, a_2, b_1', b_2, a_3, a_4, b_3, b_4'$  are parameters depending on temperature, pressure, etc. The definitions can be found in Korolev & Mazin (2003).

Supersaturation at time  $t$  ( $S(t)$ ):  
$$S(t) = \frac{S_{qs} - C_0 \exp(-t/\tau_p)}{1 + C_0 \exp(-t/\tau_p)} \quad (3)$$
 where  $C_0 = \frac{S_{qs} - S_{init}}{1 + S_{init}}$  (4)

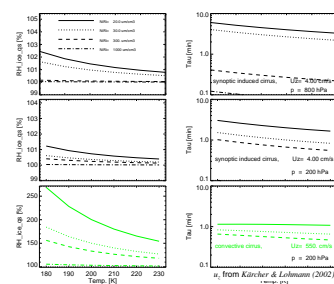
The main parameters influencing  $S_{qs}$  and  $S(t)$  are the integral ice particle radius  $N_i \bar{R}$ , the vertical velocity  $u_z$ , temperature  $T$  and pressure  $p$ .

### $RH_{ice}$ increases with:

- decreasing  $N_i \bar{R}$
- increasing  $u_z$
- decreasing  $T$
- increasing  $p$

### $\tau_p$ increases with:

- decreasing  $N_i \bar{R}$
- decreasing  $u_z$
- decreasing  $T$
- increasing  $p$



$RH_{ice}$  and  $\tau_p$  in dependence on  $T, N_i \bar{R}, u_z$ , and  $p$

## Summary:

Using the analytic expression describing the quasi steady state of supersaturation in a cloud ( $\frac{dR}{dt} = 0$ ) recently provided by Korolev & Mazin (2003), quasi steady relative humidities  $RH_{ice}$  and respective relaxation times  $\tau_p$  in ice clouds are calculated in the temperature range 180-230K for natural cirrus (synoptically induced, gravity wave induced and convective cirrus) and ice clouds nucleated heterogeneously at the AIDA aerosol chamber. We found that  $RH_{ice}$  increases with decreasing temperature to values clearly above saturation

for both natural cirrus and AIDA ice clouds. The supersaturation raises with decreasing integral ice particle size ( $N_i \bar{R}$ ) and increasing updraft velocity ( $u_z$ ). The relaxation times ( $\tau_p$ ) are very fast (in the range of seconds) for higher temperatures, updraft velocities and for large  $N_i \bar{R}$ , and increase to the range of hours with decreasing temperature. Thus, in ice clouds at temperatures below 200K,  $RH_{ice}$  clearly exceeds saturation at ice formation and will reach the –still supersaturated– quasi steady state not until some hours.

## Acknowledgements:

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