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The Accommodation Coefficient of Water Molecules on Ice and its Role for Cirrus Clouds

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I. Motivation

One of the parameters governing the growth of ice crystals in cirrus clouds is the **accommodation coefficient of water molecules on ice** α. α describes the sticking probability of water molecules colliding with the surface of an ice particle. It is relevant for the ice growth in the kinetic regime, i.e. for sub-micron ice crystals.

However, the **magnitude of α is still unclear**. Experimental results vary between unity and values below 0.01 [Haynes *et al*., 1992].

Model calculations suggest that **values for α between 0.1 and 1 do not have a significant impact on ice growth in cirrus clouds**. Lower values however could explain the observation of unexpectedly high ice number concentrations and supersaturations within cirrus clouds [Gierens *et al*., 2003; Lohmann *et al*., 2008].

II. Theory of Ice Growth

For **spherical ice crystals**, the mass increase per time can be described by the following formula [Pruppacher and Klett, 1997]:

$$\frac{dm}{dt} = \frac{4\pi r\,(S_{ice}-1)}{\frac{RT}{e_{sat,i}\,D_v^*\,M_w} + LH},$$

where r is the ice particle radius, S_{ice} the saturation ratio, and $e_{sat,i}$ the saturation vapor pressure with respect to ice. R, T, and M_w are the gas constant, absolute temperature, and molar weight of water, respectively. LH describes the growth-impeding effect of the latent heat of deposition.

The **accommodation coefficient** α enters in the modified diffusivity of water vapor in air

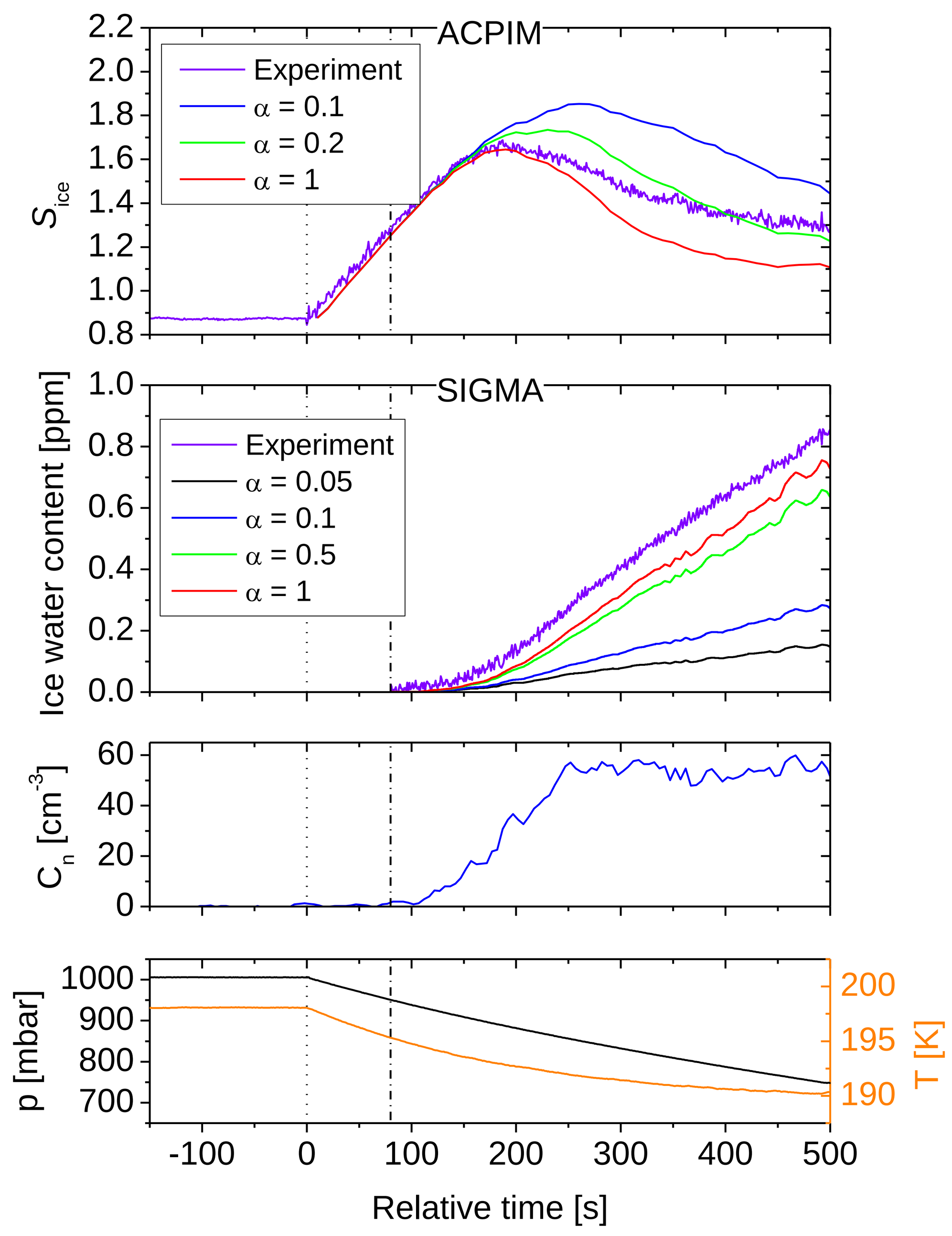
$$D_v^* = \frac{D_v}{\frac{r}{r+\Delta_v} + \frac{D_v}{r\alpha}\left(\frac{2\pi M_w}{RT}\right)^{1/2}},$$

where Δ_v is the vapor jump distance.

III. AIDA Cirrus Experiments

Dedicated experiments examining the ice crystal growth for **deposition nucleation** in the **temperature range from 190 K to 230 K** were carried out at the cloud simulation chamber AIDA [Möhler *et al*., 2003].

As aerosols, **hematite** particles and **graphite-spark generator (GSG) soot** were used.



Example experiment of the AIDA studies

- Dotted line: start of the experiment, i.e. start of pumping
- Dashed-dotted line: ice onset

Water vapor and total water are measured by two **tunable diode laser (TDL) hygrometers** [Fahey *et al*., 2009]. From the difference of these two measurements, the ice water content is derived.

The ice number concentration C_n is measured by an **optical particle counter (WELAS)**.

IV. Modeling

Two models are used to derive the accommodation coefficient α from experimental data:

- The **Aerosol-Cloud-Precipitation Interaction Model (ACPIM)** [Connolly *et al*., 2009]

Pressure / Temperature / Total water → S_{ice}

Aerosol size distribution → Ice number concentration ↑ S_{ice}

- The **Simple Ice Growth Model for determining Alpha (SIGMA)**

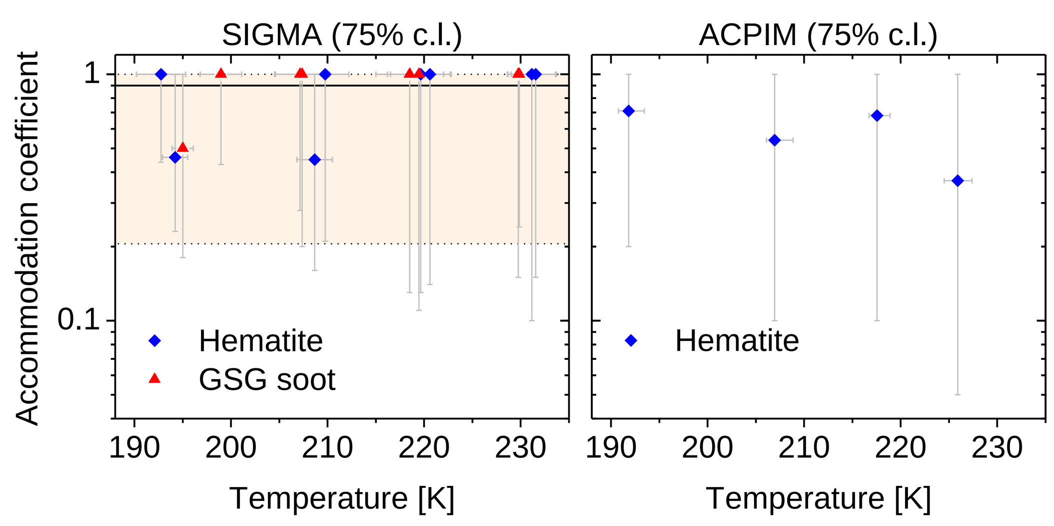
Pressure / Temperature / S_{ice} / Ice number conc. → Ice water content

V. Uncertainty Estimate

Accuracies of the experimental data sets used for a **Monte Carlo (MC)** uncertainty analysis:

	Accuracy	ACPIM	SIGMA
S_{ice}	5%		•
Total water	5%	•	•
Ice number concentration	20%	•	•
Aerosol number concentration	20%	•	
Aerosol size distribution	10%	•	
Temperature	0.3 K	•	

VI. Results



Temperature dependent values of α for a set of 16 individual AIDA experiments. The error bars are obtained from the MC uncertainty estimate described previously.

- Both models in **good agreement** with each other with all best-fit points in the range 0.1-1
- **Lower values than 0.1 excluded** by the error estimate, independent of the aerosol type (SIGMA)
- **Temperature averaged value** $\alpha = 0.9^{+0.1}_{-0.7}$ (SIGMA)

VII. Conclusions

- The ACPIM and the SIGMA model are in **good agreement** despite their different approaches in determining α
- In the temperature range from 190 K to 230 K, **values between 0.1 and 1 for α** are preferred by both models
- The **uncertainty analysis** excludes α-values below 0.1 with a **temperature averaged value** $\alpha = 0.9^{+0.1}_{-0.7}$ (SIGMA)
- These results suggest that **α does not have a significant impact on ice growth** in cirrus clouds

Acknowledgements

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