Heterogeneous ice nucleation on mineral dust aerosols

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Karlsruhe Institute of Technology

campaigns within VI-ACI

- within the framework of the Helmholtz Virtual Institute Aerosol-Cloud-Interactions (VI-ACI) three campaigns were accomplished:

→ IN11 (see IfT contribution)

→ ACI02

→ ACI03

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campaign ACI02
overview

- heterogeneous ice nucleation of particles with different surface area and roughness
- temperatures: $\sim$ -44°C (first two weeks); $\sim$ -28°C (last week)
- aerosols: monospheres, BCR, ATD, GSG soot (only last week)
- coatings: sulphuric acid, SOA
- effect of different coating thicknesses on CCN and IN particle properties

campaign ACI02

Objective	Instruments	Institute
aerosol generation and characterization		AIDA team
ice residue sampling	PCVI	
droplet and ice particle detection	Welas OPC	
droplet/ice cloud retrievals	FTIR extinction spectroscopy	
in situ scattering and depolarisation	SIMONE	
water vapour and total water	TDL	U-Heidelberg
hygroscopic growth measurements	LACIS-mobile	IfT (Katrin Mildenberger)
cloud activation measurements	CCNC (from ICG-2)	
chemical aerosol characterization	W-TOF AMS	ICG-2 (Christian Spindler), U-Man
single particle analysis	SPLAT and ALABAMA	MPI-Mainz (Marco Brands)
soot detection for AMS measurements	SP-2 soot detector	Aerodyne (Achim Trimborn)
ice nuclei measurements	FINCH	U-Frankfurt (Werner Haunold)
aerosol sampling and analysis for ice nucleation	FRIDGE	
habits of ice crystals and droplets	HOLIMO	ETH (Peter Amsler)
particle imaging	CPI	U-Man (Ian Crawford)
TEM analysis of aerosol and ice residual samples	TEM grid sampler	U-Darmstadt (Martin Ebert)

campaign ACI03
overview

- role of organic coating on the IN efficiency of desert dust particles (AD2, SD2) at mixed-phase and cirrus cloud temperatures
- investigation of heterogeneous IN potential of flame soot (CAST soot)
- CCN and IN behaviour of internally and externally mixed aerosols
- new instrument test and comparison of capabilities and sensitivities for measuring and characterizing ice nuclei in ambient air

campaign ACI03

Objective	Instruments	Institute
aerosol generation and characterization		AIDA team
ice residue sampling	PCVI, TEM grid sampler	
droplet and ice particle detection	Welas OPC	
droplet/ice cloud retrievals	FTIR extinction spectroscopy	
in situ scattering and depolarisation	SIMONE	
water vapour and total water	APicT, APeT	U-Heidelberg / AIDA team
cloud activation measurements	CCNC-200	AIDA team (Caroline Oehm)
chemical aerosol characterization	C-TOF AMS	MPI-Mainz (Paul Reitz,
single particle analysis	ALABAMA	Marco Brands)
soot detection for AMS measurements	SP-2 soot detector	DLR-IPA (Bernadett Weinzierl), MPI-Mainz (Adam Wollny)
Bioaerosol Spectrometer	WIBS	AIDA team (Martin Schnaiter), U-Man (Michael Flynn)
aerosol sampling and analysis for ice nucleation	FRIDGE	U-Frankfurt (Werner Haunold)
ice nuclei measurements	CFDC	CSU (Anthonny Prenni)
	PINC	ETH (Zamin Kanji)
ice and droplet measurements	SID-3	U Hertfordshire (Joseph Ulanowski), IfT (Tina Clauß, Alexei Kiselev)
	PHIPS	AIDA team (Ahmed Abdelmonem)
	NIXE-CAPS	ICG-1 (Jessica Meyer)
	2D-S	U-Man (James Dorsey)

surface site density (n_s) concept (Connolly et al., 2009)

- freezing of water by three different dusts - Asia Dust-1 (AD1), Sahara Dust-2 (SD2) and Arizona Test Dust (ATD)
- temperatures between -12°C and -33°C
- model ACPIM was constrained to the thermodynamic time series taken during the experiments and was used to calculate n_s
- polynomial curves were fitted to this data of ice-active surface site density vs. temperature

→ curve fits were used independently within the model to simulate the ice formation rate

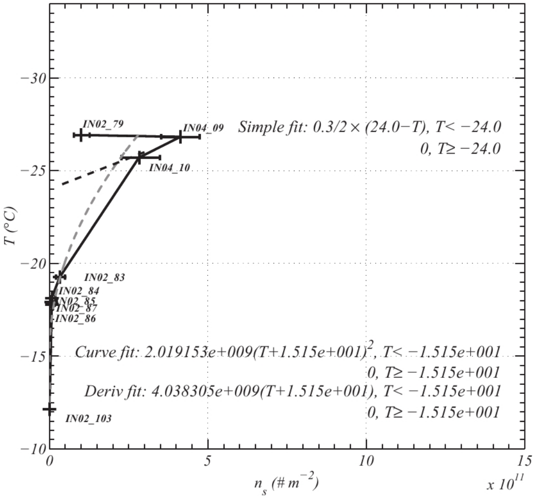
ACPIM

Aerosol-Cloud and Precipitation Interaction Model

- bin microphysical model (Connolly et al., 2009)
- includes aerosol thermodynamics following Topping et al. (2005a,b)
- solid inclusions within the solution (such as mineral dust) can be taken into account
- description of the important liquid and ice phase microphysical processes
  - → activation of drops
  - → ice nucleation
  - → aggregation
  - → coalescence
  - → riming
- uses measured T, p and total water mixing ratio

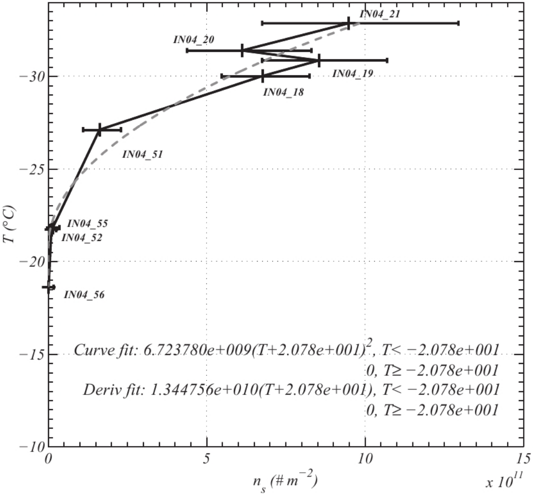
ATD freezing mode

Connolly et al., 2009



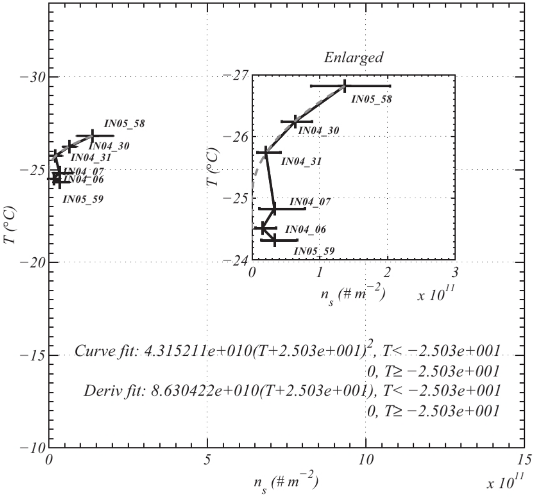
AD1 freezing mode

Connolly et al., 2009

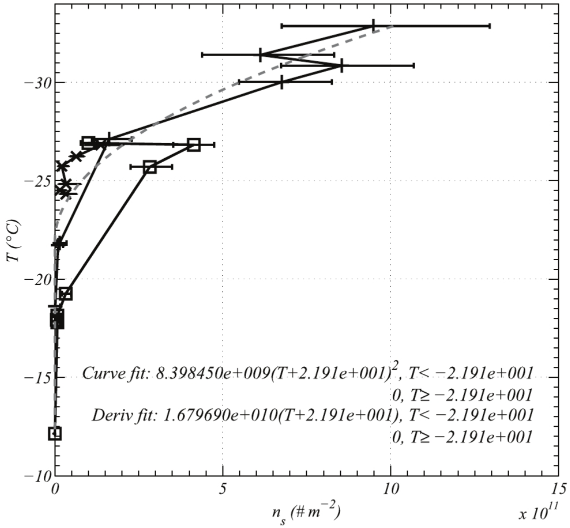


SD2 freezing mode

Connolly et al., 2009



All freezing modes
Connolly et al., 2009



surface site density concept (Connolly et al., 2009)

results

- polynomial yields to a good agreement between measurement and model for AD1 and SD2
- poor agreement for ATD using the overall fit in ACPIM

→ more experiments between -20°C and -24°C needed

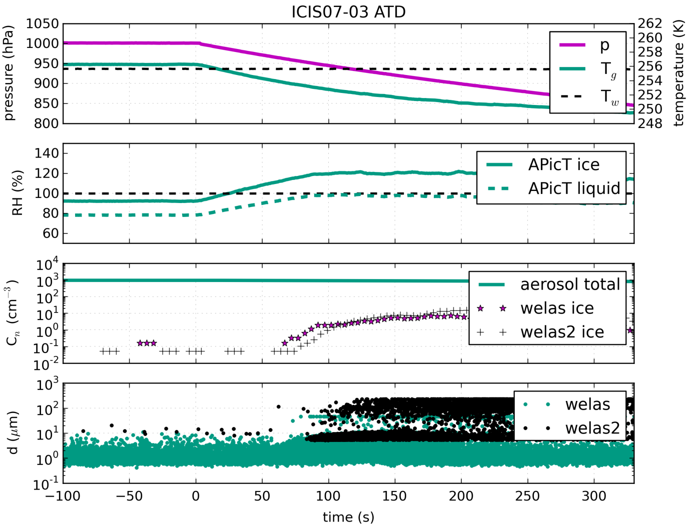
IN experiments with ATD

Aerosol	-20°C to -25°C	-30°C
ATD	3, 4, 5, 23, 24	6, 7, 8, 15, 16, 1, 2, 3
ATDcSOA		4, 5
ATD+SOA		17
ATDcSOA0.4		22
ATDcSOA2.0		23
ATDcSOA6		19, 20
ATDcSA	26, 27	8, 9, 63, 64, 65
ATD+SA	25	22
ATDcSA60		25, 26
ATDcSA80		28, 29
ATDcAS	28	10

Table: AIDA campaigns: IN05, IN07, IN08, IN09, IN11, IN12, ICIS07, ACI02, ACI03

derivation of n_s from AIDA experiments

experiment



calculation of n_s using AIDA experiment results

calculation of surface site density n_s

$$n_{ice}(0 \rightarrow T_1) = n_0 \cdot (1 - e^{-A \cdot n_s(T_1)})$$

$$n_{ice}(0 \rightarrow T_1) \approx n_0 \cdot (1 - (1 - A \cdot n_s(T_1)))$$

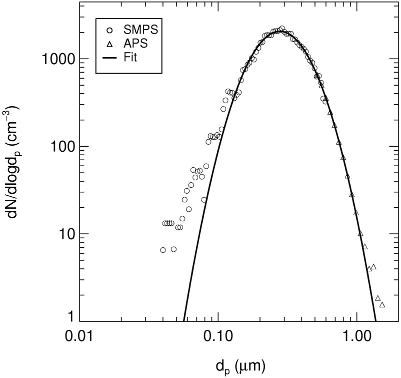
$$n_{ice}(0 \rightarrow T_1) \approx \underbrace{n_0 \cdot A}_{n_{s,ae}} \cdot n_s(T_1)$$

$$n_{ice}(0 \rightarrow T_1) \approx n_{s,ae} \cdot n_s(T_1)$$

$$\longrightarrow n_s(T_1) \approx \frac{n_{ice}(0 \rightarrow T_1)}{n_{s,ae}}$$

size distribution

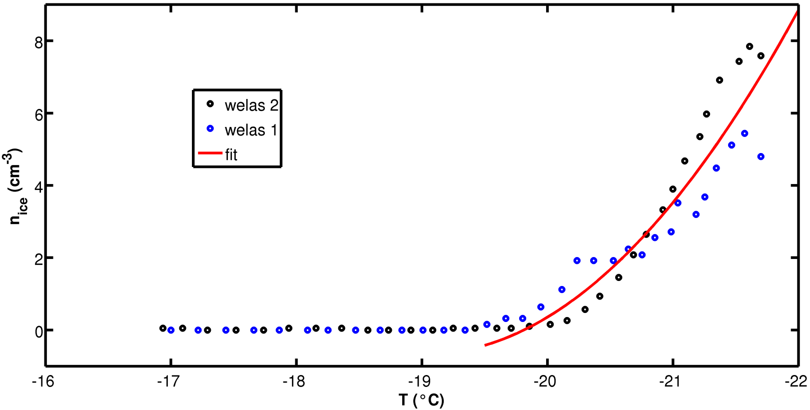
experiment ICIS07-03 with ATD



calculation of $n_{s,ae}$

$$n_{s,ae} = 3 \cdot 10^{-6} \frac{cm^2}{cm^{-3}}$$

derivation of n_s from AIDA experiments
experiment ICIS07-03 with ATD



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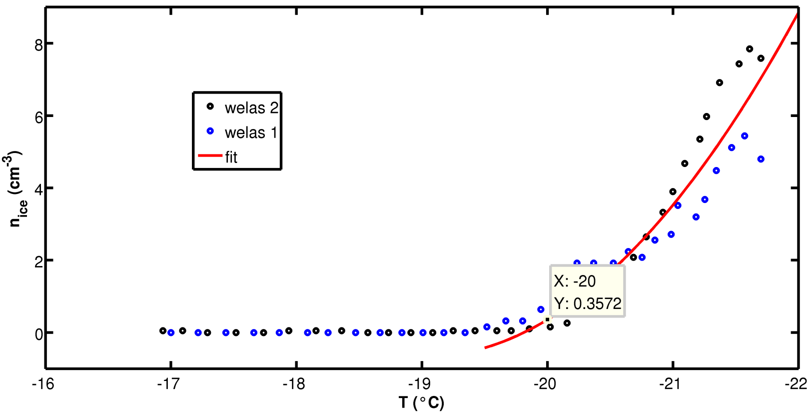
experiment ICIS07-03 with ATD



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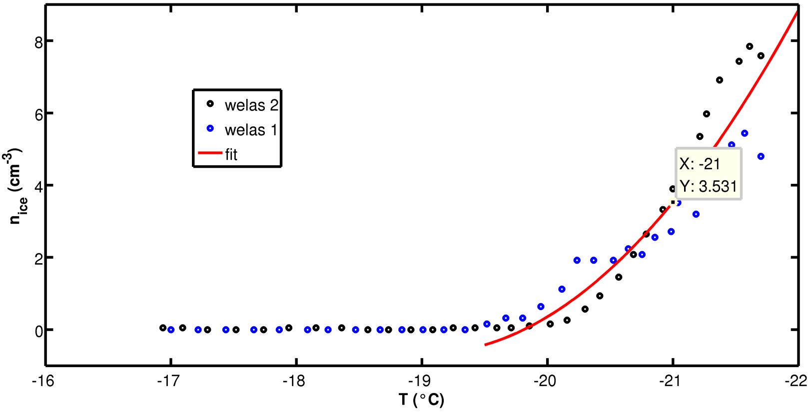

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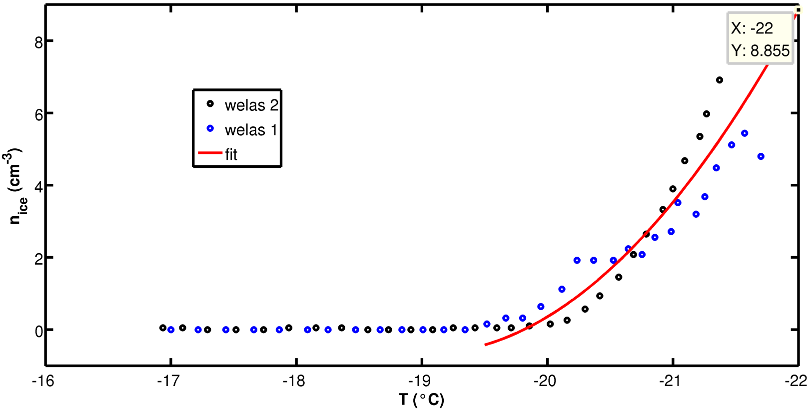
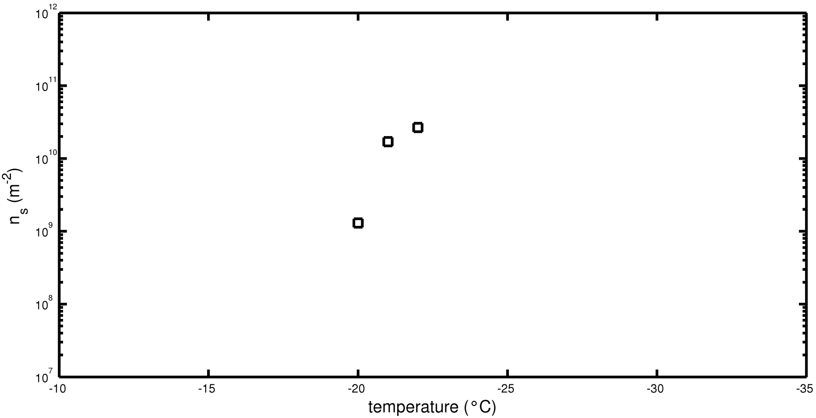


calculation of n_s using AIDA experiment results

results for n_s

$$
\begin{aligned}
n_s(-20^\circ C) &= 0.13 \cdot 10^{10} m^{-2} \\
n_s(-21^\circ C) &= 1.7 \cdot 10^{10} m^{-2} \\
n_s(-22^\circ C) &= 2.67 \cdot 10^{10} m^{-2}
\end{aligned}
$$

comparison of calculated n_s vs. temperature



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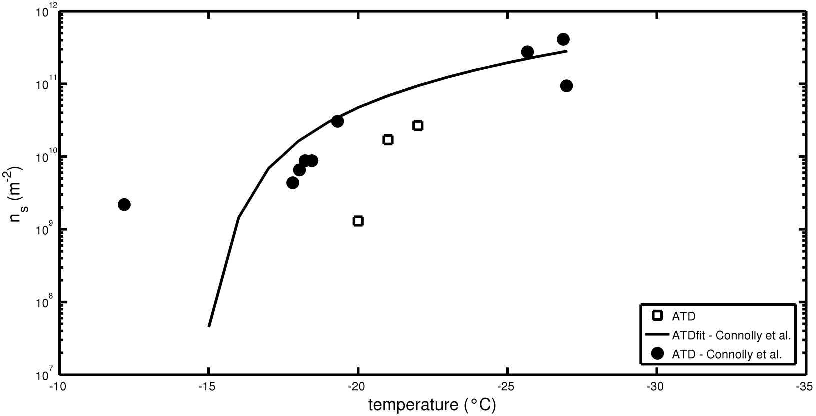

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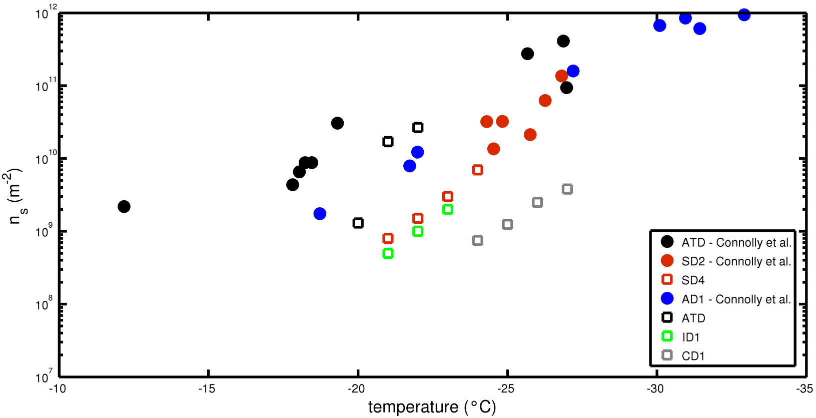

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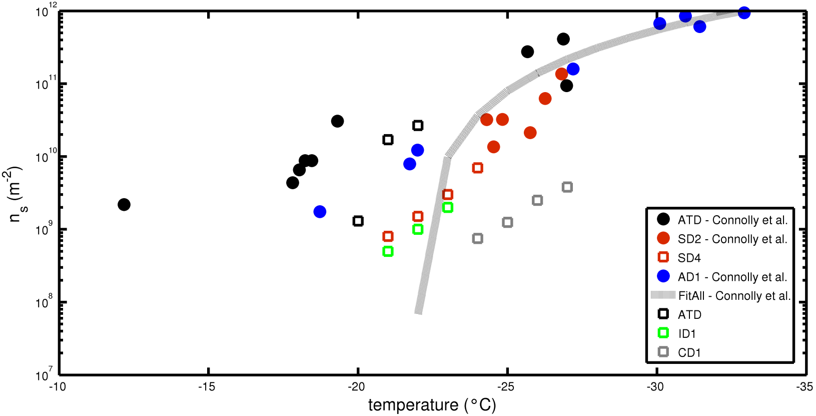

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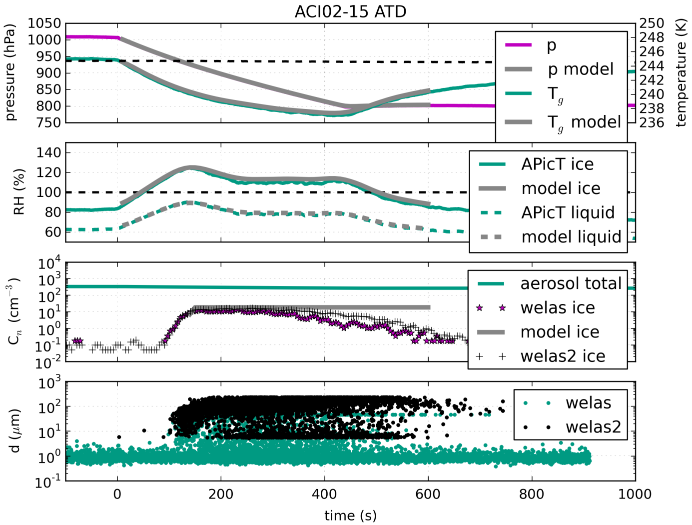
surface site density concept

deposition mode ice nucleation on ATD



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