



2nd Workshop - Atmospheric Ice Nucleation

Vienna; Austria

26th and 27th of April 2014

Book of Abstracts



TECHNISCHE
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Vienna University of Technology



Preface



Dear Participant!

I may welcome you to Vienna and I wish you a good time at our 2nd workshop. The aim is bringing together three communities of atmospheric ice research: field measurements, laboratory studies and modelers. The joint topic is the ice nucleation in clouds. We will focus on methods and open questions concerning the microstructure and dynamics of ice formation processes in the atmosphere discussing experimental and theoretical methods including chemistry and microphysics. A particular focus will be on heterogeneous ice nucleation by biological particles.

This workshop will be at the weekend before the start of the EGU General Assembly 2014 in the Vienna Austria Centre. Therefore, many workshop participants will come to Vienna and will not need extra travel support. Additionally, the organizers of this workshop also offer a session at the EGU conference, which is called “Atmospheric Ice Particles” AS 3.6 and has a tradition of already five years. However, there is no overlap between the workshop and the conference session, since it is the main aim of the workshop to provide a deeper discussion forum for one subject, i.e. ice nucleation, which cannot be discussed at the conference in necessary details. At the workshop, particularly young scientists will be given the opportunity to talk and to present their recent research while senior scientists will be asked to give overviews and questions.

Vienna 26th April 2014

A handwritten signature in blue ink, which appears to read 'Hinrich Grothe'. The signature is fluid and cursive, written on a white background.

Hinrich Grothe

Organizers

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Location

Vienna University of Technology

The workshop is held in the "Festsaal" (Ceremonial Hall) at the Vienna University of Technology, Karlsplatz 13, 1040 Vienna. This lecture hall is in the 1st floor of the main building of our university, which is situated at the Karlsplatz near Karlskirche.

**Festsaal
(Ceremonial
Hall)**



Ceremonial Hall

Sessions

**Saturday 26th
April**

12:00 - Registration and Buffet

13:00

13:00 - Opening of Hinrich
13:10 the workshop Grothe

Laboratory Measurements I

13:10 - 1st Talk Bernhard Characterization of biological ice nuclei from *Acremonium*
13:20 Pummer *implicatum* and *Isaria farinosa*

13:20 - Discussion

13:25

13:25 - 2nd Talk Janine Ice nucleation activity in the widespread soil fungus
13:35 Fröhlich *Mortierella alpina*

13:35 - Discussion

13:40

13:40 - 3rd Talk Tina Santl Airborne *Pseudomonas sp.* and the ice nucleation activity of
13:50 Temkiv their cell fragments

13:50 - Discussion

13:55

13:55 - 4th Talk Emiliano A new immersion freezing apparatus for biological ice
14:05 Stopelli nucleation research

14:05 - Discussion

14:10

14:10 - General
14:20 Discussion

14:20 - Coffee Break
14:35

Laboratory Measurements II

14:35 - 1st Talk Stefanie Ice nucleation ability of mineral dust particles mixed with
14:45 Augustin biological substances

14:45 - Discussion

14:50

14:50 - 2nd Talk Joseph
15:00 Niehaus Laboratory measurements of contact freezing by dust and bacteria at temperatures of mixed phase clouds

15:00 - Discussion
15:05

15:05 - 3rd Talk Tobias
15:15 Zolles Heterogeneous ice nucleation on mineral dust particles

15:15 - Discussion
15:20

15:20 - 4th Talk André
15:30 Welti Ice nucleation properties of K-Feldspar polymorphs: How important is the crystal lattice?

15:30 - Discussion
15:35

15:35 - 5th Talk Andreas
15:45 Peckhaus Immersion freezing on potassium-rich feldspar particles

15:45 - Discussion
15:50

15:50 - General
16:00 Discussion

16:00 - Coffee Break
16:15

Laboratory Measurements III

16:15 - 1nd Talk Sebastien
16:25 Facq Structures of ice particles formed during homogeneous freezing of micro-droplets of EtOH aqueous solutions

16:25 - Discussion
16:30

16:30 - 2nd Talk Sandy
16:40 James Investigating the Phase Behaviour of Ternary Nitric / Sulfuric Acid Solution Droplets

16:40 - Discussion
16:45

16:45 - 3rd Talk Michel
16:55 Rossi The Nucleation of crystalline Hydrate Films of HCl and HNO₃ under Laboratory Conditions

16:55 - Discussion
17:00

17:00 - 4th Talk Carsten
17:10 Budke A novel optical freezing array for the examination of cooling
rate dependence in heterogeneous ice nucleation

17:10 - Discussion
17:15

17:15 - General
17:30 Discussion

17:30 - Break
17:40

Laboratory Measurements IV

17:40 - 1st Talk Anatoli
17:50 Bogdan Visualization of the freezing process of aqueous organic
solutions

17:50 - Discussion
17:55

17:55 - 2nd Talk Thea
18:05 Schmitt Homogeneous Freezing of Water Droplets and its Dependence
on Droplet Size

18:05 - Discussion
18:10

18:10 - 3rd Talk Baban
18:20 Nagare Determination of Collision Efficiency from Contact freezing
of Silver Iodide

18:20 - Discussion
18:25

18:25 - 4th Talk Ottmar
18:35 Möhler A summary of heterogeneous ice nucleation results from the
AIDA cloud simulation chamber

18:35 - Discussion
18:40

18:40 - General
18:55 Discussion

18:55 Opening of the Buffet and Wine Reception

Characterization of biological ice nuclei from *Acremonium implicatum* and *Isaria farinosa*

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Laboratory studies on fungal ice nucleation (IN) showed that only a handful of fungal strains showed activity, while most others were IN-negative [Kieft and Ruscetti 1990, Pouleur et al. 1992, Hasegawa et al. 1994, Tsumuki et al. 1995, Iannone et al. 2011, Morris et al. 2013, Haga et al. 2013, Pummer et al. 2013]. Recently, IN activity was also discovered in *Acremonium implicatum*, *Isaria farinosa* [Huffman et al. 2013] and some other soil and air fungi.

In laboratory experiments, we found out more about the active sites of these species: Like many biological IN, they can be easily washed off from the cells with water. They were further characterized by determining the impact of filtration (from 5 μm to 100 kDa), heating to 60°C, guanidinium chloride, lipase and papain on the IN activity. Therefore we applied a freezing assay of droplets [Pummer et al. 2013]. Via the Vali formula, we calculated the amount of IN per gram of mycelium, which is more than 10^5 g^{-1} .

The initial freezing temperature of *I. farinosa* (-4°C) was higher than for *A. implicatum* (-8°C). Apart from that, they have a mass of 100s of kDa and are sensitive towards heat, guanidinium chloride and papain. The results indicate that the IN are proteinaceous compounds like those of *Fusarium* spp. and lichen mycobionts, which belong to the same phylum, the *Ascomycota*.

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Ice nucleation activity in the widespread soil fungus *Mortierella alpina*

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Soil organic matter has long been proposed as a source of atmospheric ice nuclei (IN), and biological IN can dominate the fraction active at warmer temperatures¹⁻³. However, the sources of biological IN released from soils remain unclear, even though their role in triggering glaciation and precipitation has recently been supported^{4,5}. Analysis of the cultivable fungi in topsoils from a range of land uses and ecotypes in south-east Wyoming found ice nucleation active (INA) fungi to be both widespread and often abundant, particularly in soils with recent inputs of readily decomposable organic matter. For example, in harvested and ploughed sugar beet and potato fields, and in the organic horizon beneath Lodgepole pine forest, their relative abundances among the cultivable fungi were 25%, 17% and 17%, respectively. Across all soils, 8% of fungal isolates were INA. All isolates initiated freezing at -5°C to -6°C and all belonged to a single species, *Mortierella alpina*, within the phylum *Fungi incertae sedis* (previously *Zygomycota*). By contrast, the handful of fungal species so far reported as INA all belong within the *Ascomycota* or *Basidiomycota* phyla^{6,7}. *Mortierella alpina* is known to be saprobic (utilizing non-living organic matter), widespread in soil and has been previously found in air and rain samples. Sequencing of the ITS region and the gene for γ -linolenic elongase (apparently unique to *M. alpina*) revealed four distinct clades, each affiliated with a different soil ecological niche: cultivated with abundant organic residues, general cultivated, grassland and forest. The IN produced by *M. alpina* seem to be extracellular and easily suspendable macromolecules <300 kDa. Ice nucleating fungal mycelium will ramify topsoils and may release cell-free IN into it. If these IN survive decomposition or are adsorbed onto mineral surfaces this contribution will accumulate over time, perhaps to be transported with soil dust and influencing its ice nucleating properties.

References

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Airborne *Pseudomonas* sp. and the ice nucleation activity of their cell fragments

Santl-Temkiv T.^{1,2,3}, Sahyoun M.⁴, Ling M.^{2,4}, Boesen T.⁴, Hartmann S.⁶, Augustin S.⁶, Stratmann F.⁶, Wex H.⁶, Korsholm U.S.⁵, Nielsen N.W.⁵, Sørensen J.H.⁵, Karlson U.G.¹, Finster K.^{2,3}

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Biogenic IN are the only reported particles that promote ice formation at temperatures close to 0°C. Some common atmospheric bacteria, e.g. *Pseudomonas syringae*, have the unique capacity of forming ice nucleation active (INA) proteins and exposing them at their outer membrane surface. Besides intact INA cells, different bacterial residues, which carry INA proteins, can enter the atmosphere independently and may increase the atmospheric densities of bacterial INA proteins.

We analyzed cultivable bacterial communities during 14 precipitation events and we observed prevalence of strains affiliated with the genus *Pseudomonas*. Screening of isolated bacteria for their ice nucleation activity showed that ~12% carried INA genes. The analysis of backward trajectories and of radar reflectivity images indicated that airborne INA bacteria either came into the cloud through local convective transfer or were transported longer distances by air masses of continental origin. We investigated the presence of small INA bacterial fragments (<220 nm) in two precipitation events and found that they were present at densities of 482 IN per L of rain and 199 IN per L of melted snow. Bacterial fragments that are more abundant than intact cells could thus have additional impact on atmospheric processes. Two INA strains were able to produce outer membrane vesicles (with diameters of ~75nm and ~85 nm), which could be a source of INA bacterial fragments that we observed in the atmosphere. However, the immersion freezing experiments, performed in the laminar flow diffusion chamber LACIS, showed that only a negligible number (< 1.5%) of vesicles were INA. It thus remains unclear what kind of INA bacterial fragments we detected in precipitation samples. Our future plan is to prepare membrane discs carrying single INA proteins and use them as a model for the ice nucleation activity of bacterial fragments, which will help us understand the importance of these fragments for ice nucleation in the atmosphere.

A new immersion freezing apparatus for biological ice nucleation research

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Drop-freezing is a useful technique for the analysis of biological ice nucleators, but current instruments have limitations like evaporation of the sample or its potential contamination.

LINDA (LED-based Ice Nucleation Detection Apparatus) is a new immersion freezing apparatus, where ice nucleation events are automatically recorded, thus improving the precision of the analysis. LINDA is based on the principle of decrease of red light transmission upon formation of ice into a solution. The liquid sample to be analysed (viz snow, rain or air collected with liquid impingers) is divided into small tubes containing aliquots of it and put into a cooling bath, where tubes are placed over a grid of LED lamps. Once a nucleator is activated, the whole aliquot of water in the tube freezes, provoking a decrease in light transmitted through it, which is automatically recorded by a camera placed above the grid.

This apparatus is specifically conceived for the detection of ice nucleators active at warm temperatures ($\geq -12^{\circ}\text{C}$), usually characterised by a vast majority of biological particles, such as bacteria, fungal spores, organic matter on soil.

The improvement of automatic detection in closed tubes ensures the sample to be safely maintained during and after the measurements without risks of contaminations, then leading to its conservation for further analyses. This aspect is of crucial importance to develop new approaches in biological ice nucleation research. For instance, a sample could be stored at low temperatures and its nucleating behaviour studied over time, allowing the potential enhancement of bacterial expression of ice nucleating proteins. In parallel, ice nuclei may be progressively isolated from the whole sample through successive dilution of the aliquots freezing at warm temperatures, thus reducing the interference of other background particles, minimising the loss of sample or cross contaminations during subsequent dilutions.

A brief reference to the results coming from a monitoring field campaign developed at the High Altitude Research Station of Jungfrauoch in the Swiss Alps (3580 m a.s.l.) will be also provided, as an example of field application of this apparatus.

Ice nucleation ability of mineral dust particles mixed with biological substances

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Ice nucleation in the atmosphere has been observed at temperatures higher than -20°C (e.g. Kanitz et al., 2011). In contrast, laboratory studies showed that the most abundant atmospheric ice nuclei (IN), i.e., mineral dust particles, are ice active at much lower temperatures (e.g. Murray et al., 2012). Biological particles such as bacteria or pollen nucleate ice at temperatures similar to those observed in the atmosphere. However, their numbers seem to be too small to explain atmospheric ice nucleation (Hoose et al., 2010). Recent studies suggest, that ice nucleation active (INA) macromolecules, i.e. protein complexes in the case of bacteria (e.g. Wolber et al., 1986), and most likely polysaccharides in the case of pollen (Pummer et al., 2012), which are responsible for the freezing, maintain their nucleating ability even when they are separated from their original carriers (bacterial cell or pollen grain, Hartmann et al., 2013; Augustin et al., 2012). This opens the possibility of accumulation of such INA macromolecules in e.g. soils and the resulting particles could be an internal mixture of mineral dust and INA macromolecules. If such biological IN containing soil particles are then dispersed into the atmosphere due to e.g. wind erosion or agricultural processes they could induce ice nucleation at temperatures higher than -20°C .

To explore this hypothesis, we investigated the ice nucleation behavior of mineral dust particles internally mixed with INA macromolecules. Specifically, we mixed pure mineral dust (Illit) with INA biological material (SNOMAX and birch pollen washing water) and quantified the immersion freezing behavior of the resulting particles utilizing the Leipzig Aerosol Cloud Interaction Simulator (LACIS). To characterize the mixing state of the produced aerosol we used single mass spectrometry as well as electron microscopy. We found that internally mixed particles which containing ice active biological material show the same ice nucleation behavior as the purely biological particles. That shows that INA macromolecules which are located on a mineral dust particle dominate the freezing process.

References

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Laboratory measurements of contact freezing by dust and bacteria at temperatures of mixed phase clouds

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Contact nucleation of ice is thought to play a significant role in the atmosphere where the freezing of water droplets remains one of the biggest uncertainties in current models of the atmosphere. Contact freezing efficiencies for various atmospherically relevant aerosols are reported for the temperature range 0 to -20 °C. The results are discussed in the context of mixed phase clouds, and we find that dry, micron sized dust aerosols can have substantive impact on warm temperature nucleation. Bacteria has the potential to be even more effective. Samples of *Pseudomonas syringae* and *Pseudomonas fluorescens* had widely varying freezing behavior. Nucleation thresholds cannot be easily predicted by the gene markers ice-positive or ice-negative as was done in past years for immersion freezing. In all cases the contact mode dominates the immersion mode freezing.

For Arizona Test Dust, feldspar, or rhyolitic ash, more than $1e3$ ($1e5$) particles sized between 0.3 μ m - 10.0 μ m are required to initiate a freezing event at -20 °C (-15 °C) in the contact mode. An ice negative strain of *Pseudomonas fluorescens* is an order of magnitude more effective than the mineral dusts at every temperature tested. We find that an ice positive strain of *Pseudomonas syringae* reaches its maximum nucleating efficiency of 0.1 twelve degrees earlier than does the *Pseudomonas fluorescens*, similar to the behavior of ice negative and positive bacteria in the immersion mode, as discovered 40 years ago [Maki et al., 1974; Vali et al., 1976]. Surprisingly, cells of the ice positive strain (CC94) *Pseudomonas syringae* which did not express the ice+ gene, showed no contact freezing activity, whereas the ice- strain of *Pseudomonas fluorescens* did.

Heterogeneous ice nucleation on mineral dust particles

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Ice nucleation activities of mineral dust particles were investigated. The experiments were carried out using cryo-microscopy which is an oil-emulsion based method. The immersion freezing mode was addressed with this experimental setup. The studied samples were common inorganic atmospheric aerosols. Single minerals and natural samples were tested. Mineral dust particles are active ice nuclei in the immersion freezing mode up to 256K/ – 17°C. The nucleation temperatures of mineral dusts are much lower than for biological ice nuclei. K-feldspar is the by far most active ice nuclei followed by other silicates. Natural samples which contain more than 5% K-feldspar were also active. The activity of K-feldspar can be attributed to its surface structure and the presence of potassium ions in the surface.

Ice nucleation on mineral dust particles takes place at certain nucleation sites. These sites are domains of molecular sites where water is stabilized in an ice-like structure. To form a good ice nucleation site, the site density of molecular sites needs to be high. More molecular sites are able to form larger domains on the surface, leading to better nucleation sites. This suggests further that the nucleation temperature of mineral dust particles scales with the surface area. The exact configuration of a molecular site is material specific and influenced by the local chemistry and structure of the dust particle surface. A favorable arrangement of the functional groups like surface hydroxyl and oxygen is proposed for the K-feldspar. Potassium ions seem to have a positive or neutral effect on the ice nucleation property of a silicate surface while cations with a higher charge density like calcium and sodium have a negative influence. K-feldspar is abundant in the environment and actually is the most important dust ice nucleus in the atmosphere. The nucleation temperatures of the K-feldspar particles are sufficient to enable further meteorological glaciation processes in high altitude clouds..

Ice nucleation properties of K-Feldspar polymorphs: How important is the crystal lattice?

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Due to the effect of pressure and temperature on the spatial disposition of atoms in the crystalline lattice during rock formation, chemically identical feldspars exist that have different lattice configurations. The feldspar polymorphs also have different physical properties such as cleavage, hardness, specific weight, melting point. In the current study we test the effect of the difference in crystal lattice on the ice nucleation efficiency of these particles.

In the past some authors suggested that it is mainly the chemical factors which are of importance for the ice nucleation efficiency of a substance (e.g. Pruppacher and Sängler, 1955). The identical composition of the feldspar polymorphs offer a natural system where the importance of the crystal structure can be investigated on chemically equivalent particles.

In a set of laboratory experiments using different feldspar polymorphs (Adular, Microcline, Orthoclase) the IMCA/ZINC experimental setup was used to measure the frozen fraction of single immersed, size selected feldspar particles. For each polymorph 200, 400 and 800nm particles were tested to gain information on the size dependency of the nucleation efficiency of the individual species.

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Immersion freezing on potassium-rich feldspar particles

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Recent laboratory measurements showed an increased ice nucleation ability of potassium-rich feldspar particles in the immersion freezing mode [1]. It was suggested that the proportion of K-feldspar in atmospherically relevant ice nuclei is related to their ice nucleation ability. The importance of K-feldspar is further supported by the field measurements, indicating that it can make a mass fraction of up to 24% in Asian and African mineral dusts [2]. In this contribution we present results of immersion freezing experiments with monodisperse droplets of aqueous suspensions of K-feldspar on a cold stage. We show that the ice nucleation activity strongly depends on i) the particle size distribution (in particular the ice nucleation properties of submicron feldspar particles) ii) the weight concentration of the particles in the aqueous suspension and thus on the total particle surface immersed into the droplets and iii) the age of the particles in an aqueous environment. Further a comparison of different K-feldspars is presented indicating that the origin and the processing methods have a significant impact on the IN activity. The mineralogical composition of feldspar samples is analyzed by means of Raman spectroscopy and a quantification of the particle surface is carried out with environmental scanning electron microscopy (ESEM). The results of freezing experiments are interpreted within the concept of ice nucleation active surface site (INAS) density, which allows a comparison with data obtained with different experimental methods (IN counters, expansion chambers, etc.).

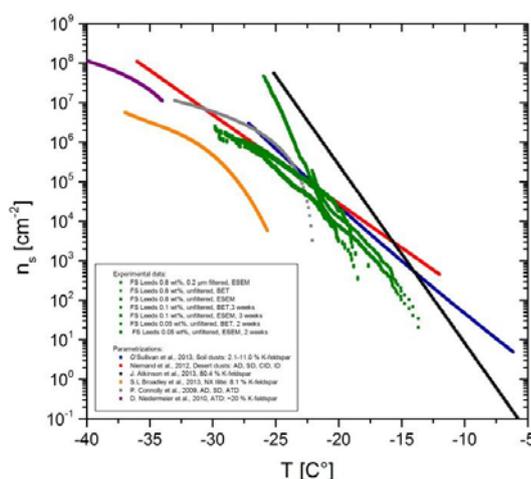


Fig. 1: INAS density for K-feldspar and mineral dusts.

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Investigating the Phase Structure of Ethanol Aqueous Solutions Micro-Droplets During Homogeneous Freezing

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In the upper troposphere, ice particles can form via homogeneous ice nucleation from submicrometric liquid particles or heterogeneous ice nucleation on solid ice nuclei. These atmospheric ice particles form cirrus clouds which play a regulation role in radiation fluxes at the top of the troposphere. Much research has been done in this regard focused on the homogeneous ice nucleation process of pure water particles. However, homogeneous ice nucleation can also occur from aqueous solutions [1].

If the influence of organics of high molecular weight on homogeneous ice nucleation from liquid particles is well-characterized [2], little is known about the effect of oxygenated volatile organic compounds. However, many light organics such as alcohols, aldehydes, ketones are ubiquitous in the upper troposphere [3, 4]. Among them, alcohols and especially ethanol, exhibits very glass transition at low temperature ($T_g=97\text{K}$) in such a way that the formation of amorphous particles is very unlikely [5]. It is therefore relevant to decipher what crystalline structures are formed during the homogeneous ice nucleation of micro-droplets containing ethanol and compared them with structures formed during homogeneous ice nucleation of pure water and aqueous solutions containing organics of high molecular weight. In this study, we present in situ Raman spectroscopy and X-ray diffraction evidences of the formation of hexagonal ice or ethanol hydrate (depending on the ethanol content) during the homogeneous ice nucleation of ethanol aqueous solutions micro-droplets.

References

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Investigating the Phase Behaviour of Ternary Nitric / Sulfuric Acid Solution Droplets

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The literature regarding the phase behaviour of Polar Stratospheric Clouds (PSCs) shows a distinct disagreement between laboratory and field studies. Some PSCs have been shown to be composed of Nitric Acid Trihydrate (NAT) which nucleates on water ice crystals formed during cooling induced by gravity waves. However, other solid PSCs of synoptic scale have been observed in air masses unlikely to contain water ice crystals.

Laboratory studies of nucleation kinetics, which have most commonly investigated binary solutions of nitric acid and water, have tended to find that Nitric Acid Dihydrate (NAD, either the α - or β - polymorph) is at least the primary nucleating phase.

To address this dichotomy, the crystallisation behaviour of solutions of Nitric and Sulfuric acid of concentrations relevant to the stratosphere is under examination using 2 techniques;

- Raman microscopy studies of μl solution droplets suggest that, whilst binary solutions tend to form NAD, inclusion of sulfuric acid leads to rapid formation of NAT.
- To confirm this result, and to examine a more atmospherically relevant regime with greater statistical significance, XRD studies of nl droplets are currently underway.

The Nucleation of crystalline Hydrate Films of HCl and HNO₃ under Laboratory Conditions

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Thin ice films, representative of PSC's, are grown in a high vacuum multidagnostic stirred flow reactor by deposition of a pure thin ice film (1 to several μm) on a Si optical support and subsequently doped with known amounts of HCl and HNO₃. Multidagnostic experiments involving residual gas mass spectrometry (MS) used to monitor both the partial pressures of HCl, HNO₃ and H₂O as a function of time, thus dosing, and FTIR spectroscopy in transmission for the investigation of the condensed phase during growth have been applied. This led to the identification of three ice/HNO₃ substrates of interest: crystalline nitric acid trihydrate (NAT, HNO₃•3H₂O), both in their α - and β -forms, as well as metastable nitric acid dihydrate (NAD, HNO₃•2H₂O). Together with the amorphous HCl/H₂O (amHCl) phase, crystalline HCl hexahydrate (HCl•6H₂O, HH) and pure crystalline H₂O ice presented last year the nucleation data base so far obtained will be discussed regarding common features and differences of the solid phases regarding thermodynamic stability of the corresponding ice phases.

The following results have been obtained (taking results on pure ice as a benchmark) that should help define the nucleation and growth conditions of solid HCl/H₂O, HNO₃/H₂O and pure H₂O ices:

- (i) Pure ice and HNO₃ under NAT growing conditions are characterized by a singularity (peak) in partial pressure of H₂O and HNO₃, respectively, which may be interpreted as the required supersaturation pressure (P_{SS}) of approximately a factor of 2 to 5 over the steady-state or equilibrium vapour pressure of HNO₃. At the nucleation threshold the condensed phase appears as "pure" ice in the case of NAT growth owing to the limited sensitivity of FTIR spectroscopy in the mid-IR. No temperature threshold seems to operate as long as P_{SS} is attained or exceeded. Only α -NAT could be investigated because β -NAT was exclusively generated through spontaneous decay of α -NAT. NAD behaves in a similar manner as NAT regarding PSS despite the fact that it is metastable.
- (ii) The nucleation conditions for HH are different in that no partial pressure singularity or supersaturation pressure requirement was ever observed. Instead, the temperature threshold for nucleation of HH of $T \leq 173$ K is prohibitively low for terrestrial atmospheric

applications. Beyond threshold spontaneous conversion to the amorphous HCl/H₂O phase of the same average composition is observed. HH is therefore metastable at $T \geq 173$ K.

(iii) HH growth is limited by mass transport of HCl across the nascent crystalline phase at the interface. Beyond a thickness of roughly 450 formal monolayers or a dose of 3.5×10^{17} molecules of HCl crystalline growth comes to a gradual halt. Conversely, for NAT and NAD no such mass transport limitation has been observed at the same dose of HNO₃.

(iv) The required H₂O supersaturation for pure ice growth (I_h) on a SiO₂ surface strongly increases with decreasing temperature with an apparent activation energy of 21 kJ/Mol. This activation energy is approximately equal to the activation energy for (surface) diffusion of H₂O on acrySTALLINE ice surface.

(v) The condition for nucleating the (metastable) crystalline HH phase ($T \leq 173$ K) rules out the occurrence of HH in the terrestrial atmosphere under UT/LS conditions: The stable atmospheric HCl/H₂O phase is most likely amorphous which has the advantage that heterogeneous reactions involving HCl such as the important reaction $\text{ClONO}_2 + \text{HCl} \rightarrow \text{Cl}_2(\text{g}) + \text{HNO}_3(\text{ads.})$ occur at a higher efficiency compared to a crystalline surface.

A novel optical freezing array for the examination of cooling rate dependence in heterogeneous ice nucleation

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Homogeneous ice nucleation is a stochastic process, implying that it is not only temperature but also time dependent. For heterogeneous ice nucleation it is still under debate whether there is a significant time dependence or not. In case of minor time dependence it is probably sufficient to use a singular or slightly modified singular approach, which mainly supposes temperature dependence and just small stochastic variations.

We contribute to this discussion using a novel optical freezing array termed BINARY (Bielefeld Ice Nucleation ARraY). The setup consists of an array of microliter-sized droplets on a Peltier cooling stage. The droplets are separated from each other with a polydimethylsiloxane (PDMS) spacer to prevent a Bergeron-Findeisen process, in which the first freezing droplets grow at the expense of the remaining liquid ones due to their vapor pressure differences. An automatic detection of nucleation events is realized optically by the change in brightness during freezing.

Different types of ice nucleating agents were tested with the presented setup, e. g. pollen and clay mineral dust. Exemplarily, cooling rate dependent measurements are shown for the heterogeneous ice nucleation induced by Snomax[®].

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Visualization of the freezing process of aqueous organic solutions

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Upon freezing aqueous solutions separate into ice and a residual freeze-concentrated solution (FCS)¹⁻¹⁰ which freezes^{2,3} or vitrifies⁴⁻⁷ upon further cooling. The morphology and mutual distribution of ice and FCS are essential in fields ranging from food industry^{4,5} and pharmaceuticals^{6,7} to geophysics⁸⁻¹⁰. Yet the freezing process, which governs the formation of ice/FCS, remains not fully understood. In our work, using cryo-microscopy and differential scanning calorimetry we show that aqueous citric acid (CA) and sucrose freeze in two stages, fast and sluggish, and the whole freezing process yields a continuous ice framework (IF) and two FCS regions of different concentration, FCS₁ and FCS₂, which vitrify at two distinct temperatures, $T_{g1,c} > T_{g2,c}$. The FCS₁ is a maximally FCS (MFCS) and interpenetrates the IF, whereas the less concentrated FCS₂ envelops the whole IF/FCS₁. Sluggish freezing proceeds in FCS₂ until it is terminated by the FCS₂-glass transition, $T_{g2,c}$, and then recommences upon warming above a reverse glass-FCS₂ transition, $T_{g2,w}$. The recommenced sluggish freezing in FCS₂ together with a reverse glass-FCS₁ transition, $T_{g1,w}$, produce the T_{tr2} -transition⁴, which has remained misunderstood for decades^{4,5}. Our results and videos demonstrate how ice is formed during freezing, expelling solute from the ice lattice and producing a continuous IF immersed into FCS₁ and enveloped by FCS₂.

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Homogeneous Freezing of Water Droplets and its Dependence on Droplet Size

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The formulation and parameterisation of microphysical processes in clouds, such as phase transitions, still presents a challenge for weather and climate models. This includes the homogeneous freezing of supercooled water droplets which is an important process in deep convective systems, where almost pure water droplets may stay liquid until homogeneous freezing occurs at temperatures around 238 K. Though the homogeneous ice nucleation in supercooled water is considered to be well understood, recent laboratory experiments with typical cloud droplet sizes showed one to two orders of magnitude smaller nucleation rate coefficients than previous literature results. The discrepancies motivated us to re-analyse homogeneous droplet freezing experiments conducted during the previous years at the AIDA (Aerosol Interactions and Dynamics in the Atmosphere) chamber. This cloud chamber has a volume of 84 m³ and operates under atmospherically relevant conditions within wide ranges of temperature, pressure and humidity, whereby investigations of both tropospheric mixed-phase clouds and cirrus clouds can be realised. By controlled adiabatic expansions, the ascent of an air parcel in the troposphere can be simulated.

The new AIDA results, together with the results from single levitated droplet experiments, now allow the conclusion that freezing of droplets even with diameters as low as a few micrometers is a volume dominated process. Furthermore, a contribution of surface induced freezing can be ruled out.

The obtained volume nucleation rate coefficients from AIDA experiments are in good agreement, within error bars, with some previous literature data, including earlier AIDA results, but they do not agree with recently published lower coefficients.

This contribution will show the results from the re-analysis of AIDA homogeneous freezing experiments with pure water droplets and will discuss the comparison to the literature data.

Determination of Collision Efficiency from Contact freezing of Silver Iodide

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Collision efficiency of cloud droplets with aerosol particles is one of the topics of importance for scavenging of aerosol in the atmosphere. Various studies had been carried out by different groups but it has not been possible to measure collision efficiency for temperatures below 0 °C. Collision efficiency is important for contact freezing in these conditions. In our laboratory, we built the Collision Nucleation CHamber (CLINCH) (Ladino et al. 2011) in which water droplet can collide with aerosol particles. In this study, we are attempting to derive empirical collision efficiency with the help of contact freezing of silver iodide particles. Silver iodide has been known for its ice nucleation ability since 1940s (Vonnegut 1947) and we are assuming each collision between silver iodide particle and water droplet will lead to freezing of water droplet in the range temperature range -28 to -36 °C. In CLINCH, size selected 200 nm silver iodide particles collide with water droplets of 80 µm diameter. With the extension in chamber length it is possible to vary the interaction time between particles and the droplets. Our experiments are performed between -10 to -36 °C for various concentrations of particles and different interaction times. Number of collisions between a single droplet and several aerosol particles can be calculated at the experimental conditions. The importance of phoretic forces will be investigated as proposed by Santachiara et al (2012).

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A summary of heterogeneous ice nucleation results from the AIDA cloud simulation chamber

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The formulation and parameterization of primary ice formation in tropospheric clouds is still one of the most incomplete and uncertain parts in cloud, weather and climate models. This includes homogeneous freezing of water and solution droplets, though this part is considered to be well understood and formulated for models, as well as the various modes of heterogeneous ice nucleation like deposition nucleation, condensation freezing, immersion freezing and contact freezing, which involve solid atmospheric aerosol particles as heterogeneous ice nuclei.

During the recent years, numerous laboratory experiments of heterogeneous ice nucleation have been conducted for different aerosol types, but it is still not clear which are the most relevant aerosol types and most appropriate formulations for heterogeneous ice nucleation processes to be considered in models. Some of the parameterisations rely on the classical nucleation rate theory, others describe the ice nucleation activity as function of ice-active sites on the aerosol particle surface.

This contribution will introduce the ice nucleation active site (INAS) density concept as a simple straight forward approach for the model parameterisation of heterogeneous ice nucleation of various aerosols on the basis of laboratory cloud simulation experiments with the AIDA (Aerosol Interaction and Dynamics in the Atmosphere) Aerosol and Cloud chamber facility at the Karlsruhe Institute of Technology. A few minutes will also be spent to introduce recent findings on the pre-activation in glassy and crystalline organic aerosols.

First results obtained with the new portable ice nuclei counter SPIN

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Aerosol particles known as ice nuclei (IN) play an important role in the atmosphere in a number of processes related to cloud formation and cloud microphysics. Despite the progress within ice nucleation research during the past decade, much is still unknown. There is a particular need for data on atmospheric IN number concentrations from observations, as only a small number of these observations exist, while they would provide valuable input for atmospheric modelling (DeMott et al., 2010). In situ measurements with portable IN counters are an important way to gain knowledge in this field. The Spectrometer for Ice Nuclei (SPIN) is a new commercially available portable IN counter manufactured by Droplet Measurement Technologies, Inc. SPIN is a continuous flow diffusion chamber with parallel plate geometry following the design of the Portable Ice Nuclei Chamber (PINC) (Chou et al., 2011). The aerosol sample flows through a chamber where a supersaturation of water vapor with respect to ice is obtained by keeping two ice covered walls at different temperatures (below 0 °C). The aerosol sample is then exposed to an isothermal evaporation section for evaporation of liquid droplets before particle detection with a linear depolarisation optical particle counter (OPC). With SPIN, it is possible to investigate heterogeneous ice nucleation in both deposition nucleation and condensation/immersion freezing modes. We have tested the SPIN chamber with well characterized ice nuclei such as illite and SNOMAXTM, as well as investigated the homogeneous freezing of ammonium sulphate particles. Here we present exemplary results of these studies.

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Investigating the atmospheric ice phase at the high altitude Jungfrauoch site

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One of the major sources of uncertainty in climate model projections is an insufficient understanding of aerosol-cloud interactions. Particularly poorly understood is the formation of mixed-phase clouds (MPC), where ice nuclei (IN), a small but important subset of aerosol particles, facilitate heterogeneous ice nucleation. The resulting cloud glaciation enhances precipitation formation, decreasing cloud cover and lifetime, and affects cloud radiative properties.

To investigate properties of IN in MPCs, small, freshly formed ice crystals must be separated from interstitial particles and supercooled droplets. The ice residuals (IR) contained within the crystals can then be analyzed. The new Ice Selective Inlet (ISI) has been designed to extract small ice crystals from mixed-phase clouds, simultaneously counting, sizing and imaging the hydrometeors contained in the cloud with the use of optical particle spectrometers. The core of the ISI is an evaporation unit with ice-covered inner walls, removing droplets using the Wegener-Bergeron-Findeisen process, while transmitting the ice crystals.

The ISI was deployed at the High Alpine Jungfrauoch Research Station (3580 m.a.s.l) during winter 2014 as part of the CLACE 2014 field campaign. The campaign included comprehensive measurements of cloud microphysics and aerosol properties. A host of online aerosol instrumentation was deployed downstream of the ISI to analyze the physical and chemical characteristics of IR. These included a Grimm OPC, a scanning mobility particle sizer (SMPS) and an Ultra-High Sensitivity Aerosol Spectrometer (UHSAS) for number size distribution measurements and a single particle soot photometer (SP2) and Waveband Integrated Bioaerosol Sensor (WIBS-4) for analysis of the chemical composition, with particular focus on the content of black carbon (BC) and biological particles in IR. IR were also collected using a single-stage impactor for scanning electron microscopy and scanning

transmission x-ray microscopy analysis. Corresponding instrumentation sampled through a total aerosol inlet. By comparing observations from the ISI with those from the total inlet the characteristics of ice residuals relative to the total aerosol could be established. First results from these analyses will be presented.

In-situ detection of ice nuclei concentrations in the free troposphere in the deposition and condensation regime

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Several laboratory studies have shown the efficiency of mineral dust particles to act as ice nuclei (IN) at temperatures below -10°C [1]. The interest in ambient IN number concentration as an input parameter for global and regional climate models is high due to the important role of ice containing clouds in the Earth's radiative balance. However, few in-situ studies of atmospheric IN concentrations have been conducted and up to date none close to a main global dust source such as the Sahara.

In the current work we present IN concentration data from two distinct locations, namely the Jungfraujoch in Switzerland and the Izaña Observatory on Tenerife, Spain. Both locations are high altitude research stations (Jungfraujoch: 3580 m a.s.l., Izaña: 2373 m a.s.l.). During winter, the Jungfraujoch is considered representative for being in the free troposphere as is Izaña during night time if it is not located in the Saharan air layer (SAL). Three field studies have been conducted; two of them at the Jungfraujoch during January/February 2013 and 2014, and one at Izaña during August 2013. Measurements were made using the Portable Ice Nucleus Counter (PINC) [2], a continuous flow diffusion chamber.

IN concentration data in the deposition and condensation mode at various temperatures will be presented for both locations. The results from Jungfraujoch show that IN concentrations in the deposition mode were extremely low, with on average less than 1 IN/l at a temperature of $T = 241\text{ K}$ and a relative humidity of 127 % with respect to ice (RH_i). At Izaña, mean IN concentrations were usually below 10 IN/l as well for the same measurement conditions but increased up to 32 IN/l during a strong Sahara dust event. At the same temperature, IN concentrations were much higher in the condensation freezing regime, where they reached values of 1200 IN/l during the dust event.

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Characterization of the Micro-Orifice Uniform Deposit Impactor-droplet freezing technique (MOUDI-DFT) for size-resolved quantitative measurements of ice nuclei

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Ice formation within a cloud system can significantly modify its lifetime and radiative forcing. Many current instruments for measuring atmospheric concentrations of ice nuclei (IN) are not capable of providing size-resolved information. Such knowledge is useful in identifying the sources of IN and predicting their transport in the atmosphere. Furthermore, those that use size-discrimination to identify IN typically exclude particles with an aerodynamic diameter greater than 2.5 μm from analysis. Several studies have indicated this may be an important size regime for IN, particularly with those activating at warmer temperatures.

The recently developed Micro-Orifice Uniform Deposit Impactor-droplet freezing technique (MOUDI-DFT) addresses these limitations through combining sample collection by a model of cascade impactor with an established immersion freezing apparatus. Here we present a characterization of the MOUDI-DFT and the development of a modified technique which address experimental uncertainties arising from sample deposit inhomogeneity and the droplet freezing method. An intercomparison with a continuous-flow diffusion chamber (CFDC) was performed.

We also show preliminary results from a campaign undertaken in a remote coastal region of western Canada. Correlations between atmospheric IN concentrations and the abundance of suspended submicron and supermicron particles, biological aerosols, carbonaceous aerosols, and prevailing meteorological conditions were investigated.

Research on Airborne Ice-Nucleating Species (RAINS): A Collaborative Research Project Funded by the National Science Foundation

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Microorganisms are abundant in the atmosphere and play important roles in cloud development, cloud chemistry, and ultimately weather. Some microorganisms produce proteins that catalyze the nucleation of ice crystals at significantly warmer temperatures than would normally be required for ice formation. Little is known about the abundance, diversity, and flux of ice-nucleating microorganisms in the atmosphere. Our collaborative research project (Research on Airborne Ice-Nucleating Species or RAINS), aims to examine the diversity and function of ice-nucleating microorganisms in the atmosphere. We are characterizing the taxonomic, genetic, and functional diversity of ice-nucleating microorganisms in rain, snow and air collected from multiple sites in the U.S. and in France. Our research will increase our knowledge of the associations of microorganisms with rain, transforming the way society perceives the relationships between microorganisms and weather. The project will also sponsor an international workshop for early career scientists to highlight recent advances and identify the outstanding scientific questions surrounding microbes at the interface of land-atmosphere feedbacks.

**Expanding our Knowledge of Ice Nucleation Activity in the Fungal Genus *Fusarium*:
From Biological Research Collections to Atmospheric Sampling Missions with Drones**

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The fungal genus *Fusarium* contains a number of important plant and animal pathogens, mycotoxin producers, and ice nucleators. We used an LED-based Ice Nucleation Detection Apparatus (LINDA) to examine the ice nucleation activity (INA) of isolates of *Fusarium* from a large biological research collection (over 60 different species) and from atmospheric sampling missions with drones 100m above the ground in Blacksburg, VA USA (at least 12 species). Preliminary results indicated that seven of the isolates from the biological research collection (representing seven different species) were INA positive at temperatures between -12°C and -5°C. Isolates of three of these species (*F. avenaceum*, *F. acuminatum*, and *F. tricinctum*) have been reported as INA positive in previous studies. However, to our knowledge, the INA of the remaining four isolates (*F. begoniae*, *F. langsethiae*, *F. armeniacum*, and *F. concentricum*) has not been reported previously. One of the isolates from the drone collections (F156N33, *F. avenaceum*) was INA positive at about -6°C. This work expands our knowledge of INA in the fungal genus *Fusarium*, and engenders new hypotheses about the aeroecology of ice-nucleating fusaria in the upper atmosphere (100m above ground level and beyond).

Cloud Conditions Favoring Secondary Ice Particles in Tropical Maritime Convection

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Progress in understanding the formation of ice in lower tropospheric clouds is slowed by the difficulties in characterizing the many complex interactions that lead to ice initiation and to the dynamic, non-steady state nature of the clouds. The present study characterizes the conditions where secondary ice particles, specifically identified as needle or thin columnar types, are observed in tropical maritime convection during the Ice in Clouds Experiment-Tropical (ICE-T), based out of St. Croix, V. I., and the NASA AMMA experiment (NAMMA) in 2006 sampling from Cape Verde, Africa. The properties of the cloud droplet populations relevant to the secondary ice production process, and the ice particle populations, are characterized as a function of temperature and vertical velocity. These secondary ice particles are observed primarily in regions of low liquid water content and weak vertical velocities. Two relatively unique situations are examined in detail. First, ice formation is examined by following the tops of a group of ICE-T chimney clouds as they ascend and cool from a temperature of +7°C to -8°C, examining the production of the first ice. Then, using the data from a cloud system sampled during NAMMA, we elucidate a process that promotes ice multiplication. The intention is that this study will lead both to a better understanding of how secondary ice production proceeds in natural clouds as well as to more realistic laboratory studies of the processes involved.

Nucleation and ice growth on charged meteor smoke particles

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Meteoric smoke particles (MSP) are believed to act as heterogeneous ice nuclei under the temperature conditions in the polar mesopause region leading to the formation of polar mesospheric clouds (PMC). Up to date little is known of the microphysical properties of these nanoscale particles. Their composition is assumed to be represented by the abundance of elements found in meteors vaporized in the lower thermosphere region. In this contribution we present an experimental setup designed to study fundamental microphysical properties of such particles in the laboratory together with first measurements on ice nucleation and ice growth abilities.

Studying nucleation processes with computer simulations: from freezing to cavitation

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Under suitable conditions, first order phase transitions such as the freezing of a liquid or the structural transformation of a solid occur via a nucleation and growth mechanism in which a nucleus of the thermodynamically preferred phase forms in the metastable phase. This process is opposed by a barrier related to the free energetic cost of the interface between the two phases, leading to nucleation times that typically exceed the characteristic times of basic molecular motions by many orders of magnitude. This wide separation of time scales complicates computer simulations of nucleation processes. In this talk, I will discuss how biased sampling in configuration space and trajectory space can be used to address this challenging problem. Using the crystallization of supercooled water and cavitation of water under negative pressure as examples, I will show how molecular simulations can be employed to determine nucleation rates and obtain microscopic information about the nucleation mechanism.

Transferable coarse-grained potential for de novo protein folding and design

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Protein folding and design are major biophysical problems, the solution of which would lead to important applications especially in medicine. Here a novel protein model capable of simultaneously provide quantitative protein design and folding is introduced. With computer simulations it is shown that, for a large set of real protein structures, the model produces designed sequences with a remarkable similarity to the corresponding natural occurring sequences. For an independent set of proteins, notoriously difficult to fold, the correct folding of both the designed and the natural sequences is also demonstrated. The folding properties are characterized by free energy calculations. which not only are consistent among natural and designed proteins, but we also show a remarkable precision when the folded structures are compared to the experimentally determined ones. Ultimately, this novel coarse-grained protein model is unique in the combination of its fundamental three features: its simplicity, its ability to produce natural like designed sequences, and its structure prediction precision. The latter demonstrated by free energy calculations. It is also remarkable that low frustration sequences can be obtained with such a simple and universal design procedure, and that the folding of natural proteins shows funnelled free energy landscapes without the need of any potentials based on the native structure.

Polarizable Force Fields Improve Models of Ice Nucleation

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Ice formation plays a major role in a variety of research fields ranging from biology to physics.¹ In the last decades the importance of heterogeneous ice nucleation was emphasized by its crucial role in climate science.² Recent studies report a range of particles influencing the nucleation process.³ Despite the fact that understanding ice nucleation is a key challenge for climate science, it is not fully clear how the chemical properties of the nuclei surface influence the propensity to form ice.

To generate insight in the ice nucleation process a range of theoretical tools have been used including Molecular Dynamics simulations.⁴ However, deficiencies of classic biomolecular force fields (fixed point charge, no polarization) have become increasingly evident. Therefore, new types of force fields that include terms for polarizability and anisotropic charge distribution such as AMOEBA⁵ (Atomic Multipole Optimized Energetics for Biomolecular Applications) enable new possibilities for inquiry. Polarization effects, which are not covered by conventional force fields, are of major interest, as atoms are able to react to their environment⁶ resulting in a force field which can be used to describe molecules in gas- and condensed liquid and solid phases.

We show how polarizable multipole force fields improve the description of phase transitions over conventional force fields. Subsequently, we examine ordering processes of water molecules around simple chemical systems and demonstrate the importance of polarization for these phenomena.

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Molecular Dynamics of Ice Nucleation

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Understanding ice nucleation is key in a variety of natural and industrial processes. The importance of ice nucleation is exemplified by its crucial role in cold adaption of plant and animal life as well as in local and global atmospheric phenomena.¹ These phenomena have significant environmental and commercial implications, as they influence weather events such as precipitation (e.g. hailstorms, snowfall) as well as broader implications for the global climate. Therefore, an in-depth understanding of the atomic-scale processes involved in ice nucleation has far-reaching implications in a wide variety of academic and commercial endeavors.²

Molecular dynamics simulations are a well-established tool to investigate physicochemical processes on the picosecond to millisecond time scales at atomistic resolution. Environmental conditions, e.g. pressure, temperature gradients or contaminants can be easily modeled. Observed phenomena are analyzed using statistical thermodynamics in order to infer macroscopic systems behavior.

We currently investigate ice nucleation around protein contaminants of various sizes and experimentally determined nucleation potential. Biogenic nuclei are known to form an important part of air particulate matter.^{3,4} We try to determine the relative magnitude of nucleation propensity induced by either particle size or specific pre-ordering induced by directed chemical interactions of the protein contaminant on the surrounding solvation shells. We determine localized solvent entropy⁵ at various points around the contaminant while we subject the system to simulated cooling/heating cycles.

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On the usage of classical nucleation theory in quantification of the impact of bio-aerosols on weather and climate, Modeling study

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Some bacteria, e.g. *Pseudomonas syringae*, have previously been found efficient in nucleating ice heterogeneously at temperatures close to -2°C in laboratory tests. They are also present in the atmospheric boundary layer for a residence time on the order of several days. Therefore, ice nucleation active (INA) bacteria may be involved in the formation of ice and precipitation in mixed phase clouds, and could potentially influence weather and climate. Investigations into the impact of INA bacteria on climate have shown that emissions are too low to significantly have an impact or at least still questioned.

The goal of this study is to investigate the usability of ice nucleation rate parameterization based on classical nucleation theory (CNT) which is widely used in climate models.

Two parameterizations to describe the heterogeneous ice nucleation were compared. Both parameterizations were implemented and tested in a 1-d version of a weather model in different meteorological cases. The first parameterization is based on CNT (CH08) and is a function of temperature and the size of the IN. The second parameterization (HAR13) was derived from nucleation measurements. HAR13 is a function of temperature and it implicitly considers the number of protein complexes attached to either intact bacteria cell or membrane fragments of the cell. The sensitivity of meteorological variables to changes in the relative fraction of cloud droplets containing INA bacteria or fragments here of was investigated.

In this study, HAR13 was found to produce more cloud ice and precipitation than CH08 as the bacterial fraction increases. The ice production using HAR13 was found to be sensitive to the change of the bacterial fraction while CH08 did not show such sensitivity. In classical theory, having larger surface size leads to more active sites. This fact is true in the case of using dust as IN, but it's not necessarily applicable in the case of bacteria. In IN bacteria, the biological microstructure analysis suggests that singular protein complexes are the locations where ice

nucleation occurs. The number of protein complexes does not scale with the surface area of the cell. As a result, dealing with bacteria in a classical way similar to dust is not adequate. The number of proteins is a more important parameter than the size of IN to be considered when modelling the freezing of bacteria and it's likely that CNT is still missing that.

Sensitivity of the classical nucleation theory on thermodynamic and kinetic parameters

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Classical nucleation theory (CNT) can be used to parameterize ice nucleation in cloud droplets as a stochastic process based on thermodynamic and kinetic parameters. Due to the lack of a complete physical model for liquid water, several thermodynamic and kinetic parameters are not known leading to various formulations of CNT. The aim of the presented work is to review the different estimates of thermodynamic and kinetic parameters currently used in the research community and to investigate the sensitivity of the nucleation rate on the choice of parameters. By evaluating experimental data sets of droplet freezing it is possible to narrow down a reasonable range for the parameters. This helps to develop CNT-based parameterizations for freezing of droplets in regional and global climate models, which will improve the representation of cold clouds.

Buffet

Saturday 26th April 2014, 12:00 (Lunch)

Snack:

- Open sandwich and finger food (salad with strips of beef and paprika, red onion and seed oil, mozzarella with tomatoes and basil pesto or chicken liver mousse on port jelly with red pepper)
-

Saturday 26th April 2014, 18:55 (Dinner)

Starter:

- Beef broth with vegetable chunks and rusks
- Ruccula foam soup with cream topping and cardamon

Main Dish:

- Ragout from Falkenstein venison with root vegetables, star anise, napkin dumplings and lingonberries
- Roasted chicken breast on lentils ragout, rosemary potatoes and baby tomatoes
- Bulgur-Curry-Pan with vegetable, roasted almonds and Yoghurt-Chili-Dip
- Fresh salads from the Buffet

Dessert:

- Cake buffet with 3 different cakes (cream cake, poppy-curd cheese-raspberry-and nougat slice)
-

Sunday 27th April 2014, 13:00 (Lunch)

Snack:

- Open sandwich and finger food (salad with strips of beef and paprika, red onion and seed oil, mozzarella with tomatoes and basil pesto or chicken liver mousse on port jelly with red pepper)

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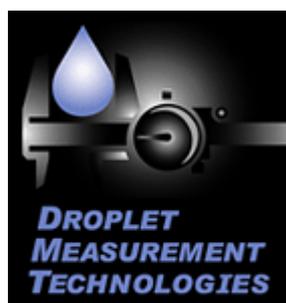
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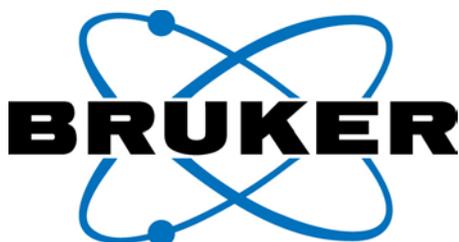
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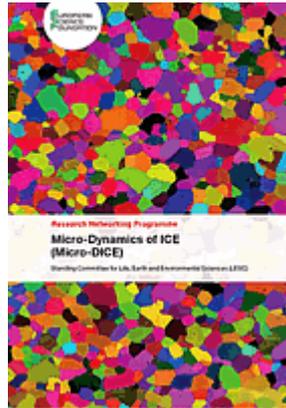
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