Research Networking Programmes

Science Meeting – Scientific Report

Proposal Title: *Microphysics of Ice Clouds*

Application Reference N°: 5877

1) Summary

The workshop on microphysics of ice clouds was held at the Istituto Italiano di Cultura in Vienna, Austria 11-12 April, 2015. The workshop had a general session, a session on laboratory measurements, a session on atmospheric measurements, a mixed session, and a session on computational methods. The general session provided an overview over important topics of the field, including talks by two well-established research scientists (Heike Wex and Bruce Moffett) and a field scientist working in artificial snow production (Michael Bacher). The other sessions, which were much more research orientated, were mostly occupied with early career professionals (graduate students and post docs) from different backgrounds. Due to the variety of topics, the discussions contained a broad range of subjects. Many of those were deeply fundamental and many questions were asked which engendered a lively and interesting discussion at the workshop.

2) Description of the scientific content of and discussions at the event

Distribution of information and knowledge gain throughout the community was a hot topic. This is especially important when it comes to the associations between laboratory measurements and atmospheric measurements and to cooperation between people from different fields of expertise. For example, one issue that was raised was the use of common (universal) parameters/units for reporting data in publications. This would help scientists to compare data from different studies. The range of temperatures used was discussed at several points, since cirrus cloud temperatures are seldom considered in laboratory studies (and many field campaigns focus on clouds such as these). Additional studies comparing methods are warranted, along with a common (universal) language shared

by the community. This is of great importance since it is crucial that we promote cooperation not just within the already existing community but also with people outside traditional disciplines associated with ice nucleation research.

Many atmospheric processes concerning heterogeneous and homogeneous ice nucleation in the atmosphere and the surrounding processes are understudied, making predictions on ice cloud formation difficult. These clouds are relevant in climatic changes and therefore of great interest to many scientific communities. An ongoing topic which was already discussed in our previous workshop in 2014 was the role of the secondary ice production in the atmosphere. Its atmospheric relevance is still unclear, but it is likely to be one of the most important processes in ice cloud formation. Ideas concerning the appropriate sampling of the atmosphere were discussed. Another important topic considered was the heterogeneous freezing mode, since most in situ measurements are committed in contact mode while laboratory studies mostly rely on immersion freezing, making comparisons among studies difficult. Consequently, one must be cautious in extending laboratory data to real world measurements in the atmosphere.

The inherent variability of field studies engenders unique challenges that may not occur in the laboratory. For example, measuring concentrations of ice nuclei (IN) in the atmosphere is challenging. Another important problem is the rarity of unique ice nucleation events, which are difficult to measure in the field and may be difficult to predict. New field instrumentation and measurements are highly needed to uncover and compare processes and events at different altitudes above ground level with each other and with ground-based measurements.

Mineral dust particles have been a hot topic for quite some time. Many talks at the workshop considered samples like K-Feldspar. Due to the high abundance of these particles in the atmosphere, they are generally believed to be of great importance. However, new results presented at the workshop showed that fresh water IN are understudied and likely underappreciated. Very high concentrations of biological IN were found in natural river systems. Also it was shown that many new or untested species are ice nucleation active, suggesting that are likely to be many new biological ice nucleators yet to be discovered. This is highly important since biological ice nucleation shows significantly higher freezing temperatures than mineral dust particles. Also the role of IN in mediating ecological processes in terrestrial and aquatic ecosystems is largely unknown and understudied. Several existing theories were mentioned and were discussed. Further the exact definition of biological IN and their detection was debated.

The molecular identity of active surface sites is still unclear in most of the cases. This goes for mineral dusts as well as for biological IN. Since this knowledge is crucial for understanding the mechanisms of heterogeneous ice nucleation, it was a hot topic at the workshop. Also it is still unclear throughout the community if a soluble substance can be considered as IN or if it has to be solid. Further, the aging of biological and mineral material in the atmosphere and the effect of this process on ice nucleation abilities have not been studied to date, making predictions on the effect of INs in the atmosphere even harder.

Different approaches and parameters were discussed for modelling ice nucleation in the atmosphere. Still unclear are e.g. the dynamics in mixed phase and cirrus clouds in comparison to aerosol influences. Many new results were presented, some of which address old problems of the field and might show a solution. This shows the importance of such events since the distribution of those findings is crucial for progress of the whole field of expertise.

Another point of discussion was the lack of knowledge concerning the fate of the ice crystals. Since the focus of the research concerning heterogeneous ice nucleation is on the ice nuclei, research on the cloud evolution, crystal properties and possible splintering of snowflakes has been limited. These properties could have huge impacts on ice clouds, and could also be crucial for processes like artificial snow production, where the optimum product is highly depending on the crystal properties. In this context, the old question of cubic versus hexagonal ice was brought up again, which is a topic that still requires some attention.

The topics of discussion were not always of scientific nature. After the last session, there was a lively discussion about the stakeholders associated with ice nucleation. There was an agreement on the necessity of public relations to shed light on what the community is doing. This would help to reach a larger range of people. This is essential to motivate and identify future funding possibilities, and to recruit young scientists which will be the future of our discipline.

3) Assessment of the results and impact of the event on the future directions of the field

In summary, the workshop engendered many fruitful discussions, helped to identify the most urgent questions and brought people from many different fields closer together. Interesting new data were presented, but we still have plenty of unanswered questions which we hope to ‘nucleate’ by interacting closely as a growing transdisciplinary scientific community. As a result of the workshop a list of Research Needs/Hot Topics was created. This list will become a white paper, which is at current in preparation.

4) Annexes 4a) and 4b): Programme of the meeting and full list of speakers and participants

Annex 4a: Programme of the meeting

3rd Workshop – Microphysics of ice clouds

Vienna- Austria

11th and 12th of April 2015

Book of Abstracts

Preface

Dear ESF Workshop Participant,

It is my pleasure to welcome you to Vienna four our 3rd ESF workshop 'Microphysics of Ice Clouds'. The aim is to bring together different areas of atmospheric ice research: field measurements, laboratory studies and modeling. The joint topic is the nucleation of ice in clouds and ice cloud properties. We will focus on methods and open questions concerning the microstructure and dynamics of the ice formation processes as well as the resulting ice clouds in the atmosphere discussing experimental and theoretical methods including chemistry and microphysics.

This workshop will be held on the weekend before the start of the EGU General Assembly 2015 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 are also offering a session at the EGU conference, which is called “Atmospheric Ice Particles” AS3.5 (this session has been ongoing for five years). It is important to note that there is no overlap between the workshop and the conference session. The main aim of the workshop is to provide an open, deep discussion of relevant topics, i.e. ice nucleation and ice cloud properties, which are difficult to discuss in a typical conference setting. The workshop emphasizes opportunities for early career professionals to present their recent research (senior scientists will be asked to give overviews and questions).

We have also added a new component to the workshop this year which will involve 'breakout discussions'. Speakers from each of the sessions will be the 'team leaders' at small breakout discussion groups. They will be charged with leading the discussion of identifying research needs, and reporting back to the group at lunch on the last day of the meeting.

Vienna 11th April 2015

Hinrich Grothe

Organizers

Local Organizers

Prof. Dr. Hinrich Grothe
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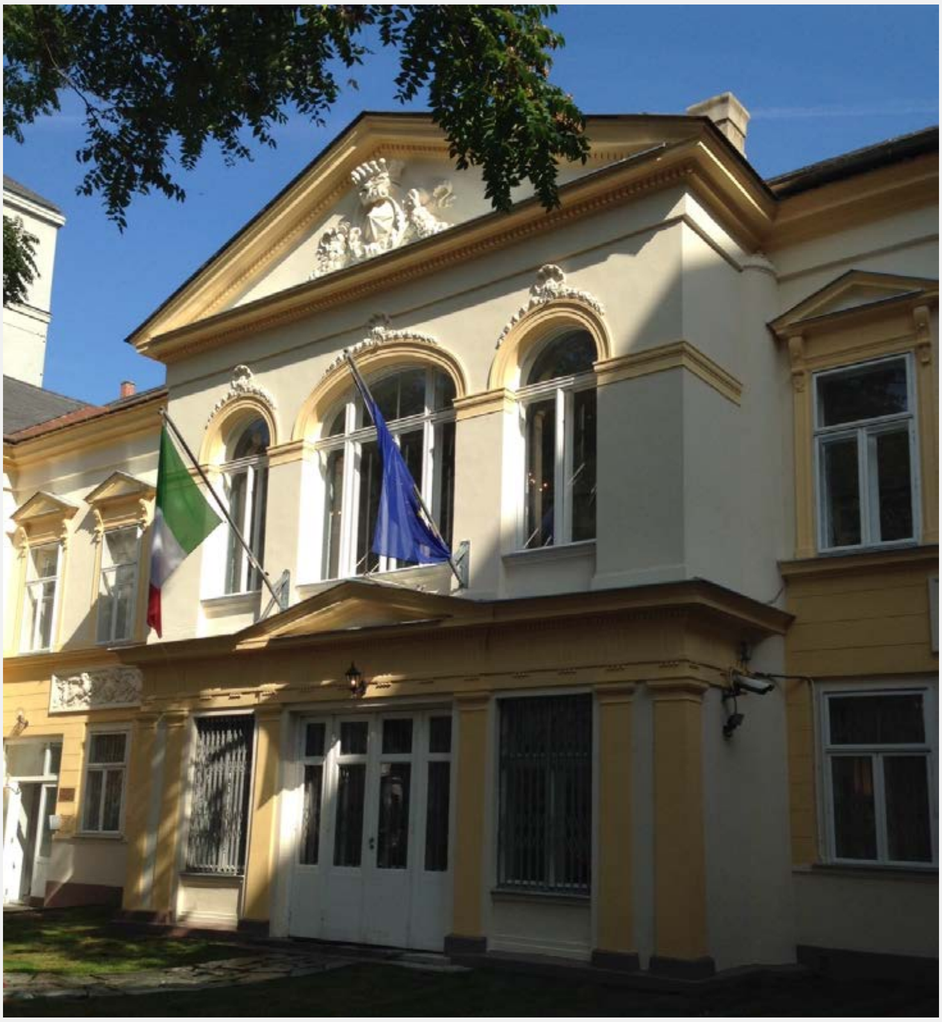
Location

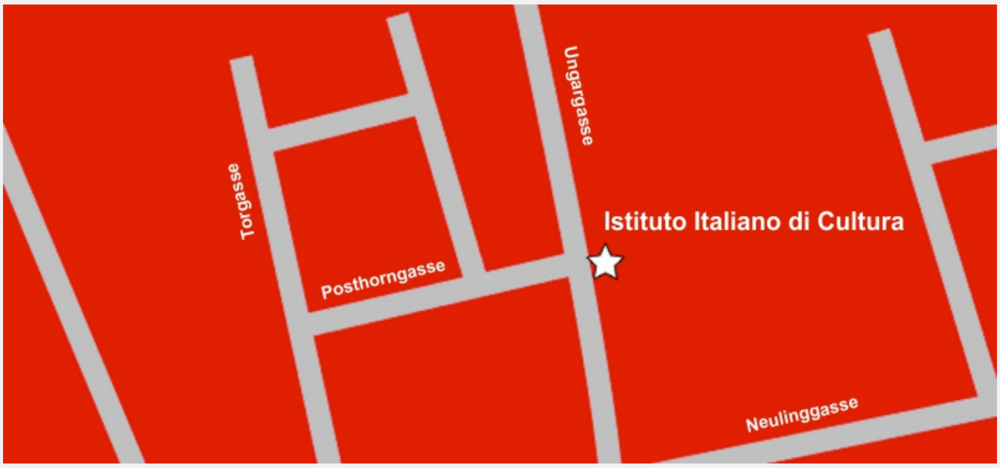
Vienna University of Technology

The workshop is held in the "Italian Culture Institute - Istituto Italiano di Cultura" at Ungargasse 43, 1030 Vienna, which is easily accessible by public transport.

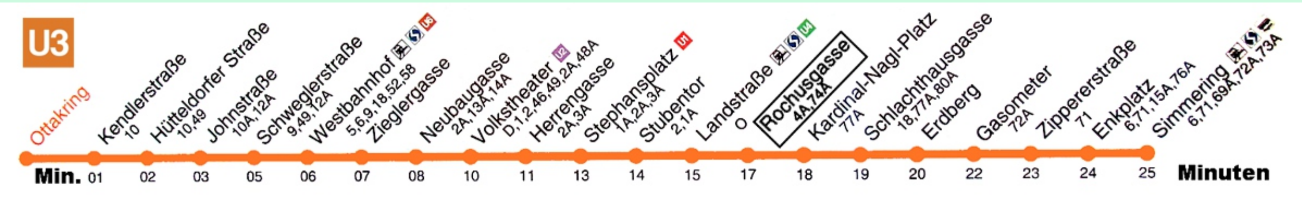
Istituto Italiano di Cultura

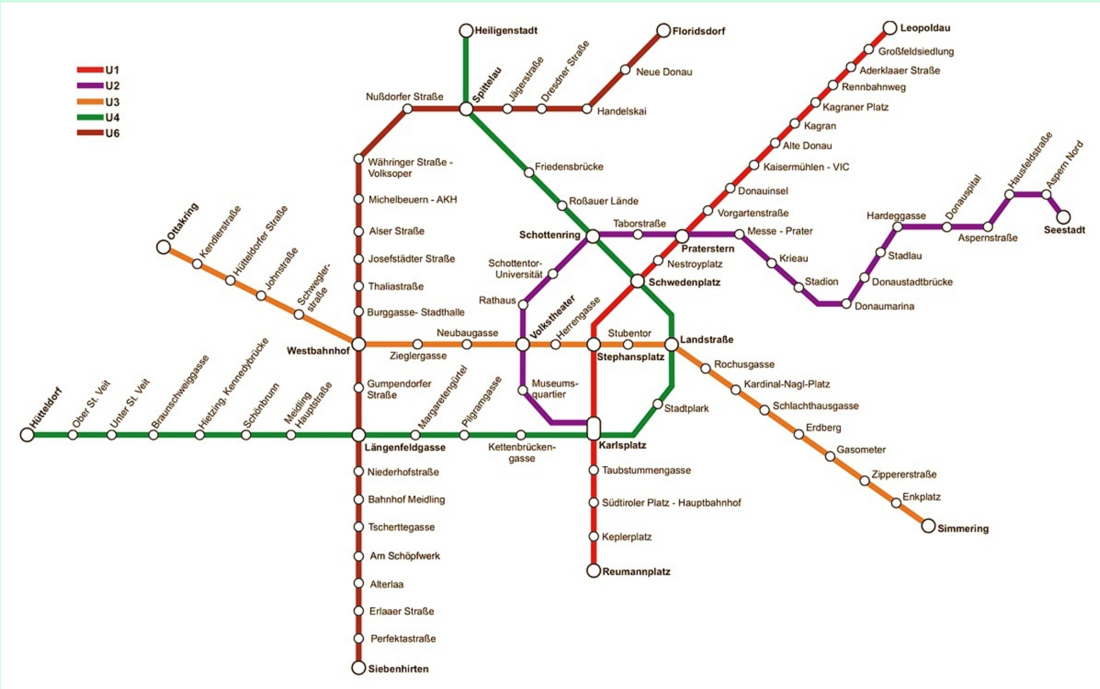


Maps



Transportation





Sessions

Saturday 11th April			
12:00 - 13:00	Registration and Buffet		
13:00 - 13:10	Opening of the workshop	Hinrich Grothe (Vienna University of Technology)	
		Ernst Kanitz (Italian Culture Institute, Vienna)	
General Session			
13:10 - 13:20	1st Talk	Heike Wex	Studying immersion freezing in the lab: what we learned and how we can link to the atmosphere
13:20 - 13:25	Discussion		
13:25 - 13:45	2nd Talk	Bruce Moffett	Fresh Water Ice Nuclei and Cloud Properties
13:45 - 13:50	Discussion		
13:50 - 14:00	3rd Talk	Michael Bacher	Mass production of snow crystals under varying ambient conditions
14:00 - 14:05	Discussion		
14:05 - 14: 30	Break Out Discussion (Coffee &Cakes)		
Atmospheric Measurements I			
14:30 - 14:40	1st Talk	Monika Kohn	A mbient in-situ immersion freezing measurements during spring in Zurich: Estimating the at mospheric relevance of ground -based INP measurements
14:40 - 14:45	Discussion		
14:45 - 14:55	2nd Talk	Bertrand Chazallon	Ice nucleation in deposition mode on surrogate air-plane soot using vibrational micro-spectroscopy: a preliminary study
14:55 - 15:00	Discussion		
15:00 - 15:10	3rd Talk	Emiliano Stopelli	Describing dynamics of biological ice nuclei in precipitation
15:10 - 15:15	Discussion		
15:15 - 15:25	4th Talk	Rebecca Kohl	Ice nucleating properties of aerosol properties in cirrus clouds – first results from the aircraft measurement campaign ML-CIRRUS
15:25 - 15:30	Discussion		
15:30 - 15:45	General Discussion		
15:45 - 16:10	Coffee Break		

Atmospheric Measurements II			
16:10 - 16:20	1st Talk	David Schmale III	Scavenging of ice-nucleating microorganisms from the atmosphere by artificial rain events
16:20 - 16:25	Discussion		
16:25 - 16:35	2nd Talk	Emmanuel Fontaine	Ice crystal variability in MCS observed in oceanic MCS during the Darwin HAIC-HIWC campaign
16:35 - 16:40	Discussion		
16:40 - 16:50	3rd Talk	Anna Luebke	The origin of midlatitude ice clouds and the resulting influence on their microphysical properties
16:50 - 16:55	Discussion		
16:55 - 17:00	4th Talk	Romy Schlage	Microphysical Ice Crystal Properties in Mid-Latitude Frontal Cirrus
17:00 - 17:05	Discussion		
17:05 - 17:30	Break Out Discussion (Coffee &Cakes)		
Laboratory Measurements I			
17:30 - 17:40	1st Talk	Magdalena Bichler	Biological Ice Nucleation
17:40 - 17:45	Discussion		
17:45 - 17:55	2nd Talk	Xiangrui Kong	Molecular Investigations of Atmospheric Ice Formation and Growth
17:55 - 18:00	Discussion		
18:00 - 18:10	3rd Talk	Stefanie Augustin-Bauditz	Immersion freezing of different kinds of combustion ashes
18:10 - 18:15	Discussion		
18:15 - 18:25	4th Talk	Thea Schmitt	New Continuous Flow Diffusion Chamber INKA for Laboratory Investigations of Heterogeneous Ice Nucleation
18:25 - 18:30	Discussion		
18:30 - 18:45	General Discussion		
18:45 - open end	Dinner & After-Dinner Workshop (optional)		

Sunday 12th April			
Laboratory Measurements II			
08:30 - 08:40	1st Talk	Anna Kunert	Identification and Emission of Fungal IN
08:40 - 08:45	Discussion		
08:45 - 08:55	2nd Talk	Fabian Heidelberg	Detection of Ice Crystal Properties in cloud chamber experiments with the CAS-POL Instrument
08:55 - 09:00	Discussion		
09:00 - 09:10	3rd Talk	Andreas Peckhaus	Effect of ageing of K-feldspar on its ice nucleating efficiency in immersion, deposition and contact freezing modes
09:10 - 09:15	Discussion		
09:15 - 09:40	Break Out Discussion (Coffee & Cakes)		
Mixed Session			
09:40 - 09:50	1st Talk	Valentino Bianco	Theoretical and Numerical Analysis of Antifreeze and Ice Nucleator Proteins: Coarse-Grain Approach for Multiscale Study and Bio-Engineering
09:50 - 09:55	Discussion		
09:55 - 10:05	2nd Talk	Jesus Vergera	Distribution and importance of marine biogenic ice nucleating particles associated with organic material in sea spray aerosol
10:05 - 10:10	Discussion		
10:10 - 10:20	3rd Talk	Zhuocan Xu	Ice particle mass-dimensional parameter retrieval and uncertainty analysis using an Optimal Estimation framework applied to in situ data
10:20 - 10:25	Discussion		
10:25 - 10:35	4th Talk	David Tatrai	Two channel airborne hygrometer system for cloud water/ice content determination
10:35 - 10:40	Discussion		
10:40 - 11:05	Coffee Break		

Computational Modelling			
11:05 - 11:15	1st Talk	Jane Cohen	Of rainforests and rain, land titles, bosons (the Higgs), albatross deaths and more
11:15 - 11:20	Discussion		
11:20 - 11:30	2nd Talk	Christian Rolf	Forecasting and understanding cirrus clouds with the large scale Lagrangian microphysical model CLaMS-Ice
11:30 - 11:35	Discussion		
11:35 - 11:45	3rd Talk	Anja Costa	Validation of the large-scale Lagrangian cirrus model CLaMS-Ice by in-situ measurements
11:45 - 11:50	Discussion		
11:50 - 12:00	4th Talk	Luisa Ickes	Sensitivity of Arctic mixed-phase cloud simulated with the global climate model ECHAM6-HAM2 to the heterogeneous freezing parameterization
12:00 - 12:05	Discussion		
12:05 - 12:15	5th Talk	Martin Simmel	Modeling primary ice nucleation in shallow altocumulus clouds
12:15 - 12:20	Discussion		
12:20 - 12:30	6th Talk	Aurélien Podglajen	Interactions between microphysics and dynamics in the formation of TTL cirrus clouds
12:30 - 12:35	Discussion		
12:35 - 12:50	General Discussion		
12:50 - 13:00	Closing Remarks	Hinrich Grothe	
13:00 - 14:00	Lunch Buffet		
14:00	End of the Workshop		

Studying immersion freezing in the lab: what we learned and how we can link to the atmosphere

Heike Wex[1], S. Augustin-Bauditz[1], S. Hartmann[1], D. Niedermeier[1,2], T. Clauss[1], and F. Stratmann[1]

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Ice formation in clouds plays an important role for cloud radiative properties and the formation of precipitation. The first step in the formation of ice crystals is ice nucleation, which can happen along different pathways. In mixed phase clouds, the most important pathway of ice formation is thought to be immersion freezing. For immersion freezing, ice nucleating particles (INP) which are immersed in the cloud droplets, induce the ice nucleation, and the subsequent droplet freezing. Possible INP, are mineral dust particles or biological particles such as bacteria, pollen or fungal spores, or constituents/fragments of the latter.

In the past few years, the number of studies on ice nucleation and particularly immersion freezing has increased tremendously. This presentation will try to show where the community stands, with respect to both:

a) understanding of the ice activity of different INP in the immersion freezing mode, as obtained during laboratory studies, where also different measurement approaches were directly compared, recently, and

b) using results from these laboratory studies in such a way that they can help to understand ice nucleation in the atmosphere, and that useful information for atmospheric modeling can be obtained.

Fresh Water Ice Nuclei and Cloud Properties

Bruce Moffett, *Ocean Lab, Fishguard Harbour, UK*
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Little is known about the emission of ice nucleating aerosols from the oceans. Virtually nothing is known about the emission of ice nuclei (IN) from fresh water sources; their potential to affect cloud radiative and other properties, regionally, has not been investigated. Data will be presented on the number of IN in European and American rivers and a glacier in Svalbard using a novel ice spectrometer. In general the number of high temperature, biological IN are several orders of magnitude higher than those in marine waters.

Bubble bursting is a major route of aerosol emission from sea water, and similar mechanisms must occur in rivers, lakes, and reservoirs. There is also the intriguing possibility that a proportion marine nuclei originate from rivers, and that the spring melt of glaciers will contribute a remarkable number of IN into the oceans.

Reasons for the need to investigate fresh water IN both in laboratory-produced and ambient aerosol will be discussed.

Mass production of snow crystals under varying ambient conditions

Michael Bacher and Johannes Müller[1], Sergey Sokratov[1]

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[2] *Faculty of Geography, Moscow State University*

After finalizing the laboratory trials with artificial production of dendritic snow crystals under regulated environmental conditions, for the first time an outdoor cloud chamber is used in winter 2014/15 to create large numbers of ice crystals of different shape. The cloud chamber consists of a balloon-like structure with a volume of about 20 cubic meters. It is placed in the ski resort of Obergurgl-Hochgurgl (AUT, Tyrol) at an altitude of 2100 m a.s.l. Water is atomized and injected into the cloud chamber by one- or two-phase nozzles. Despite the use of industrial nozzles, the droplet sizes (size distribution) are not fully known. Tests have indicated that smaller droplets are more likely to evaporate faster and therefore allow the formation of purely vapour-grown ice crystals. A short pulse of pressurized air triggers nucleation. Measurements of temperature (along a vertical profile inside the cloud chamber; ambient temperature) and ambient relative humidity as well as air- and water pressure are available for each test. According to the ambient sub-zero conditions the quantity and shape of ice crystals changes. Ice crystals are extracted directly from the cloud chamber and the density of the deposited snow is measured. Tests have produced Graupel-like structures as well as classical dendritic ice crystals. Thus, the field tests shows that a continuous process of fog injection, nucleation and ice crystal growth is possible and can be explored for different industrial application, e.g. the use in wind tunnels or winter sports.

Ambient in-situ immersion freezing measurements during spring in Zurich: Estimating the atmospheric relevance of ground-based INP measurements

Monika Kohn[1*], James D. Atkinson[1], Wan Ting Katty Huang[1], Ulrike Lohmann[1] and Zamin A. Kanji[1]
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To estimate the influence of clouds on the Earth's radiation budget, it is crucial to understand cloud formation processes in the atmosphere. A key process which significantly affects cloud microphysical properties and the initiation of precipitation is the prevailing ice nucleation mechanism. In mixed-phase clouds immersion freezing is the dominant ice crystal forming mechanism, whereby ice nucleating particles (INP) first act as cloud condensation nuclei (CCN) followed by freezing upon supercooling.

In-situ atmospheric studies are needed to understand the ice formation properties of 'real world' particles. We present a recently developed instrument setup consisting of a portable immersion mode cooling chamber (PIMCA) as a vertical extension to the portable ice nucleation chamber (PINC, [1]), in which the frozen fraction of activated aerosol particles is detected by the ice optical depolarization detector (IODE, [2]). With the PIMCA-PINC setup it is possible to measure ambient in-situ immersion freezing on single immersed aerosol particles. An additional immersion freezing technique based on a droplet freezing array [3] is used, where the ambient aerosol particles are sampled in a suspension (d > ~0.6 µm).

In this study, we investigated the ice nucleating ability of natural atmospheric aerosol particles in ground-based measurements during the Zurich AMBient Immersion freezing Study (ZAMBIS) in spring 2014. From the results of the measured INP concentrations and aerosol size distributions at ground level, the frozen fraction of the total ambient aerosol is derived. In order to demonstrate the relevance of the ground level measurements on atmospheric altitudes where mixed-phase cloud formation can occur, aerosol size distributions from the global aerosol-climate model ECHAM6-HAM [4] over Zurich at various pressure levels (altitudes) were used in conjunction with the frozen fraction to predict INP concentrations at these altitudes. This method of prediction leads to reduced INP concentrations at higher altitudes which compare rather well to observations of ice crystal numbers at similar temperatures for cases where it is known that secondary ice formation processes are absent.

[1] Chou et al. (2011), *Atmos. Chem. Phys*., **11**, 4725-4738. [2] Nicolet et al. (2010), *Atmos. Chem. Phys*., **10**, 313-325.
[3] Hader et al. (2014), *Atmos. Chem. Phys*., **14**, 5433-5449.
[4] Neubauer et al. (2014), *Atmos. Chem. Phys*., **14**, 11997-12022.

Ice nucleation in deposition mode on surrogate air-plane soot using vibrational micro-spectroscopy: a preliminary study

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Aircraft emissions have been studied extensively since the late 1960s and the interest was mainly driven by their direct and indirect effects on climate and the generation of contrails [1-4]. Emissions of solid-state particles (soot) from engine exhausts due to incomplete fuel combustion is considered to influence ice and liquid water cloud droplet activation [4]. The activity of these aerosols would originate from their ability to be important centers of ice-particle nucleation, i.e., in promoting ice formation above water homogeneous freezing point. While some experiments focused on ice nucleation on soot particles did not yet reach definitive conclusions, soot are reported to be generally worse ice nuclei than mineral dust, nucleating at higher ice-supersaturations for deposition nucleation and at lower temperatures for immersion freezing. Actually, there are still numerous opened questions on the ice nucleation properties of soot particles [5], most likely due to the lack of information on the abundance, on the physico-chemical properties (structure and chemical compositions) of these aerosols, competition between different ice nucleation modes and dynamical factors that affect ice nucleation. Furthermore, the soot emitted from aircraft may be associated with soluble components like sulphate that can act as heterogeneous ice nuclei and initiate freezing at supersaturation of only 120-130% [6].

Therefore, more detailed studies of aerosol nucleation activity combined with throughout structural and compositional analyzes are needed in order to establish any association between the particles' hygroscopicity and their physico-chemical properties.

In the present preliminary work, surrogate air-plane soot particles (from CAST burner) nucleation activity is monitored using a temperature-controlled reactor in which the sample's relative humidity is precisely measured with a cryo-hygrometer. Formation of water/ice onto the particles is followed both optically and spectroscopically, using a microscope coupled to a Raman spectrometer. Vibrational signatures of hydroxyls (O-H) emerge when the particle becomes hydrated. The ice nucleation potential of different surrogate soot samples can be studied. A correlation with their physico-chemical properties via FTIR, Raman and mass spectrometry analyses is underway.

[1] Anderson et al., Geophys.Res. Lett. 25, 1689-1692, (1998)

[2] Hyashida et al. *Fuel*. 128, 148-154. (2014)

[3] Popovicheva & Starik. *Atmospheric and Oceanic Physics.* 43, 121-141. (2007)

[4] Manninen et al. *Boreal Environment Research*. 19, 383-405. (2014)

[5] Hoose & Möhler. *Atmospheric Chemistry and Physics*. 12, 9817-9854. (2012)

[6] Haag et al., *Atmos. Chem. Phys*., 3, 1791-1806 (2003)

Describing dynamics of biological ice nuclei in precipitation

Emiliano Stopelli[1], Franz Conen[1], Christine Alewell[1], Cindy Morris[2]

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2: INRA, UR0407 Pathologie Végétale, F-84143 Montfavet Cedex, FR

Biological ice nuclei (IN) catalyse the freezing of supercooled cloud droplets at temperatures warmer than -12°C. In order to understand the effective role of such IN in conditioning precipitation on Earth, a key issue to be tackled is to unravel the factors responsible for the dynamics of IN concentrations in the atmosphere.

Over the course of two years 14 sampling campaigns in precipitating clouds were conducted at the High Altitude Research Station Jungfraujoch, in the Swiss Alps, at 3580 m a.s.l. Precipitated snow was analysed immediately on site for the concentration of IN active at -8°C (IN_{-8}) by immersion freezing. Environmental parameters (like temperature of the air, wind speed, the stable oxygen ratio $\delta^{18}O$ of snow, the number of particles larger than 0.5 µm) were used as independent variables to build a set of multiple linear regression models to describe the observed biological IN dynamics.

The best results were provided by the model based on f_V (the fraction of remaining vapour in precipitating clouds, derived from $\delta^{18}O$) and on wind speed. This model not only covered 76% of the total variability observed during the 1st year in IN_{-8} concentrations, which can vary by orders of magnitude even within the same precipitation event (calibration step, n = 91). Compared to models based on other parameters it also made better predictions for the number of IN_{-8} measured during the 2nd year (validation step, n = 15).

This model clearly indicates that the presence of biological IN in the atmosphere is linked to the possibility for uptake and transport of particles to high altitudes (wind speed) but also that IN_{-8} are rapidly activated and selectively lost at early stages of precipitation (f_V). Sahara dust events generally provide the best meteorological conditions for clouds to reach Jungfraujoch while still rich in IN_{-8}. Nevertheless, not all Sahara dust events are accompanied by abundant IN_{-8}, and when abundant, the IN_{-8} are unlikely originated from the desert itself. Moreover, also stormy cold events from Northern Europe can show a large presence of biological IN.

Therefore, the concept that biological IN emissions to cloud height may be linked to specific source regions and times of the year needs to be broadened. The abundance of biological IN in the planetary boundary layer may be larger than it has been thought so far, and under certain favourable meteorological conditions plumes with this high abundance of IN can reach altitudes where they might initiate precipitation. f_V and wind speed are effective descriptors to predict when abundances of IN_{-8} may be large enough to markedly change the content of ice in clouds at Jungfraujoch. Testing the validity of this approach also at other observatories could help to define the scales at which feedback processes of uptake and precipitation of biological IN may occur.

Ice nucleating properties of aerosol properties in cirrus clouds – first results from the aircraft measurement campaign ML-CIRRUS

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Cirrus clouds have an extensive global coverage and occur high in the atmosphere, at altitudes of 8 to 17 km. In contrast to other cloud types their net radiative impact is much less certain. Especially for cirrus clouds occurring in mid latitudes, a transition between net warming and cooling is possible depending on microphysical (e.g., ice crystal number concentration, size distribution, shape) and macrophysical (e.g. cloud geometric thickness and spatial inhomogeneities) properties (Voigt et al, 2013). The ML-CIRRUS campaign in spring 2014 focused on the ice nucleation, the lifetime and the climate impact of natural cirrus clouds and cirrus clouds, which are induced and modified by air traffic. The cirrus clouds were investigated with the research aircraft HALO (High Altitude and Long Range Research Aircraft) over Europe and the North Atlantic.

With the Fast Ice Nucleus Chamber (FINCH) particles, ice nucleating particles (INP), fluorescent particles (FP) and fluorescent ice nucleating particles (F-INP) were optically detected. The activation conditions in the FINCH chamber were set to -30 °C for the freezing temperature and 1.3 for the ice saturation ratio. Under cloudy conditions cloud particle residuals were sampled via the CVI (counterflow virtual impactor) inlet whereas during periods without clouds sub-micrometer particles were sampled via the HASI (HALO aerosol sub-micrometer inlet) inlet. On average the INP-concentrations of sub-micrometer particles (HASI) were in the range of 0.1 to 2.5 L^{-1} and lower than 0.01 L^{-1} when sampling cloud particle residuals Under influence of Saharan dust the mean INP-concentration increased to ~40 L^{-1} in the cloud-free measurement periods (HASI) and to ~1 L^{-1} in clouds (CVI). The ice nucleating fraction of all particles that were detected by FINCH (with ~0.5 µm being the lower detection limit in particle diameter) was larger than 10 % during measurements influenced by dust and below this value without the influence of desert dust, which confirms that Saharan dust seems to be a good ice-nucleating material. On March 29, 2014, the number concentration of accumulation mode particles increased by two orders of magnitude when passing a dust plume over Menorca, while the number concentration of fluorescent particles remained constant. This indicates that the desert dust contained no biological material. In general, most of the measured FP acted as ice nuclei. On the other hand, the mean fluorescent fraction of INP was approx. 30 %. This leads to the conclusion that particles of biological origin are potentially good ice nuclei under cirrus conditions but apparently make up only a certain part of the total number of INP in the investigated regions.

Voigt, C. et al. (2013): HALO Mission on Mid-Latitude Cirrus ML-CIRRUS Science Plan

Scavenging of ice-nucleating microorganisms from the atmosphere by artificial rain events

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Little is known about how microorganisms are scavenged from the atmosphere during rainfall. Microorganisms are abundant and diverse in rain (precipitation) collected near the surface of the earth. Some of these rain-associated microorganisms produce proteins that catalyze the nucleation of ice crystals at significantly warmer temperatures than would normally be required for ice formation, suggesting that they may play important roles in weather, including the onset of precipitation. We conducted a series of field experiments to test the hypothesis that ice-nucleating microorganisms are scavenged from the atmosphere by rainfall. Thirteen artificial rain events were conducted off the side of the Smart Road Bridge in Blacksburg, VA, USA. In each event, sterile water was dispensed over the side of the bridge (simulated rainfall), and recovered in sterile containers following gravitational settling from the side of the bridge to an open fallow agricultural field below (a distance of ~55m from the release site to the collection site). Microbes scavenged from the artificial rain events were cultured on six different types of agar media (R2A, TSA, CA; +/- cycloheximide) and the ice nucleation activity was examined for colonies cultured from the different media types. Mean CFUs scavenged by artificial rain ranged from 83 to 196 CFUs/mL across all six media types. Ice-nucleating microorganisms were recovered from 85% (11/13) of the simulated rain events, and represented about 1% of the total number of colonies assayed from each event. Strikingly, this percentage is nearly identical to the percentage of culturable ice-nucleating microorganisms occurring in about half of the natural rain events studied to date in Blacksburg, Virginia. This work expands our knowledge of the scavenging properties of rainfall, and suggests that at least some ice nucleators in natural precipitation events may have been stripped from the atmosphere during rainfall, thus negating their potential role in the onset of precipitation.

Ice crystal variability in MCS observed in oceanic MCS during the Darwin HAIC-HIWC campaign

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The Darwin HAIC-HIWC field campaign presents an excellent opportunity for studying ice cloud microphysics in Mesoscale Convective Systems (MCS). Since the primary objective of the field project was to search and explore high ice water content regions containing high concentrations of ice crystals, the French research aircraft Falcon-20 from SAFIRE (Service des Avions Français Instrumentés pour la Recherche en Environnement) frequently flew close to the most convective regions in oceanic MCS with relatively strong updraft velocities (w> 20m/s). The Falcon-20 was equipped with optical array probes 2D-S and PIP (precipitation imaging probes), a cloud radar Doppler RASTA (Radar Aéroporté et Sol de Télédétection des proprieties nuAgeuse) and the IsoKinetic evaporator Probe (IKP) measuring the Condensed Water Content (CWC). Most of data were measured within temperatures between 220 K and 240K. Highest Ice Water Content values exceeded 4g/m^3.

The various types of ice crystals encountered during the HAIC-HIWC Darwin campaign are analyzed as a function of particle size (PSD) and associated mass-size m(D) and area-size A(D) relationships (Fontaine et al. 2014). PSD and m(D) relationships are studied as a function of the cloud temperature and convective intensity, deduced from the vertical velocity field below the aircraft calculated from the cloud research Doppler radar RASTA.

The origin of midlatitude ice clouds and the resulting influence on their microphysical properties

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Ice clouds are known to play an important role in the radiative balance of the atmosphere. The nature of this role is determined by the macrophysical and microphysical properties of a cloud. Thus, it is crucial that we have an accurate understanding of properties such as the ice water content (IWC), ice crystal concentration (Ni), and ice crystal size (Ri). However, these properties are difficult to parameterize due to their large variability and the fact that they are influenced by a number of other factors such as temperature, vertical velocity, relative humidity with respect to ice (RHice), and the available ice nuclei.

These factors are largely determined by the dynamics of the environment in which the ice cloud forms. Ice clouds have been observed in a variety of situations such as frontal systems, jet streams, gravity waves, and convective systems. In the work presented here, we explore this concept further by examining how differences in dynamics are translated into the differences in IWC, Ni, and Ri that are found within and between datasets. Data from American- and European-based campaigns are combined to form a large, and more latitudinally comprehensive database of Northern Hemisphere in-situ, midlatitude ice cloud observations.

We have divided the data by meteorological situation and explored the differences and similarities between situations. Additionally, we have found that the origin of the cloud is a key piece of information needed to explain the observations. In situations such as convection and warm conveyor belts, the ice clouds exhibit a higher than expected IWC, and a high Ni of large Ri. This is likely due to the fact that the ice crystals that were observed originated in the liquid or mixed-phase environment and were transported to the cirrus environment. We have also observed cirrus in which the IWC, Ni, and Ri values are more consistent with what we expect from cirrus that formed heterogeneously or homogeneously in the native cirrus environment. Through comparisons to modeling work, we are able to confirm the existence of these two types of ice clouds.

Microphysical Ice Crystal Properties in Mid-Latitude Frontal Cirrus

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Cirrus clouds modulate the climate by reflection of shortwave solar radiation and trapping of longwave terrestrial radiation. Their net radiative effect can be positive or negative depending on atmospheric and cloud parameters including ice crystal number density, size and shape. Latter microphysical ice crystal properties have been measured during the mid-latitude cirrus mission ML-CIRRUS (March/April 2014) with a set of cloud instruments on the new research aircraft HALO. The ice clouds, formed above Europe and the Atlantic, were encountered in different meteorological regimes with respect to different updraft speeds including frontal cirrus, leewave cirrus and high pressure cirrus.

Here, we use and compare data from the Cloud and Aerosol Spectrometer with detection for POLarization (CAS-POL) and the Cloud Combination Probe (CCP), combining a Cloud Droplet Probe (CDP) and a greyscale Cloud Imaging Probe (CIPgs) to derive the ice crystal distribution in the size range from 1 µm to 1 mm. We investigate the variability of microphysical properties in mid-latitude frontal cirrus and their dependence on temperature and relative humidity. Further, we compare the microphysics of these frontal cirrus to cirrus clouds that formed at low updrafts within high pressure systems or at high updraft velocities in lee waves. We quantify statistically significant differences in cirrus properties formed in these various meteorological regimes. In this context we additionally investigate the dependence on ice cloud properties on their origin: in-situ formation versus nucleation of liquid droplets. Our studies of mid-latitude cirrus clouds help to better understand their radiative properties in order to assess their impact on climate.

Biological Ice Nucleation

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Huffman et al. (1) report that after rain events a burst of biological particles can be found in precipitation. The origin of these particles can be bacterial (e.g. *Pseudomonas syringae*), fungal (e.g. *Fusarium acuminatum* spores), and (decayed) plant parts.

Previous investigations in our group (2) showed that both pollen and pollen washing water from plants living near the northern timberline have ice nucleation activity. These facts suggest that other parts of the plants may have ice nucleation activity, too. We extended our investigation to other parts of the plants and further biological materials such as water-interacting and structural polysaccharides, like pectin and chitin, and chemical modifications of these polysaccharides.

A particular focus of our work lies on berries such as sea buckthorn and blackcurrant. We examined the ice nucleation activity of berries found near the northern timberline (juices and extracts) and of other plant materials.

(1) Huffman et al., Atmos. Chem. Phys., 13, 6151–6164, 2013

(2) Pummer et al., Atmos. Chem. Phys., 12, 2541–2550, 2012

Molecular Investigations of Atmospheric Ice Formation and Growth

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A good understanding of ice particles formation and growth is essential for quantitatively predicting the evolution of clouds, and therefore influence the effectiveness of climate models. However, neither of these two processes has been well described for their mechanisms by existing literature.

We employ an environmental molecular beam (EMB) technique to investigate the interactions of molecular helium/D_2O with various substrates, including graphite, several organic surfaces, neat and doped ice surfaces. Thanks to the unique features of the EMB, critical supersatuation and water accommodation coefficient on ice have been determined. In this talk, the experimental observations and interpretations will be discussed, as well as the advantages and limitations of the EMB measurements compared to other experimental methods.

The critical supersaturations necessary to spontaneously nucleate water ice on six different substrate materials are observed to be higher than are theoretically predicted[1]. An analysis based on classical nucleation theory supports the view that at these temperatures nucleation is primarily controlled by the rarification of the vapor and the strength of water's interaction with the substrate surface. For water accommodation coefficient on neat ice, a strong negative temperature dependence has been found, which can be quantitatively described by a precursor model[2]. In addition, acidic adlayers coating ice could enhance the water uptake ability by altering the uptake mechanism[3]. These findings have strong implications for the formation and growth of ice particles in the atmosphere.

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2. X.R. Kong, P. Papagiannakopoulos, E.S. Thomson, J.B.C. Pettersson, Water Accommodation and Desorption Kinetics on Ice, *J. Phys. Chem. A*, 118 (**2014**) 3973-3979.

3. X.R. Kong, E. S. Thomson, P. Papagiannakopoulos, S. Johansson, and J.B.C. Pettersson, Water Accommodation on Ice and Organic Surfaces: Insights from Environmental Molecular Beam Experiments, *J. Phys. Chem. B*, 118 (**2014**) 13378-13386.

Immersion freezing of different kinds of combustion ashes

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Ice particles in the atmosphere influence both, weather and climate. Therefore it is important to know which kind of particles can act as ice nucleating particles (INP) under atmospheric conditions.

In the last years, a lot of effort has been made to investigate the freezing abilities of natural INPs such as dusts and biological particles (Murray et al., 2012, Hoose and Möhler, 2012). However, there are only a few investigations concerning the ice nucleation ability of combustion ashes, which are the remains of fossil fuel and wood combustion and thus a possible source for anthropogenic INPs. Ash particles have similar compositions as mineral dust particles. However, the actual contribution of combustion ash particles to the atmospheric ice nucleation is rather unclear. A recent study by Umo et al. (2014) showed that combustion ashes could have a significant impact on the ice nucleation in clouds and thus should be the focus of further research.

Ash particles can be lifted to the atmosphere by wind (bottom ashes) or directly during the combustion process (fly ashes). In the present study we investigated the freezing behavior of bottom ash particles which originated from wood as well as from coal. Additionally we investigated particles from fly ash from a coal-fired power plant. Particles were generated by dry dispersion and afterwards size selected with a differential mobility analyzer (DMA). The immersion freezing ability of the different ash particles was quantified utilizing the Leipzig Aerosol Cloud Interaction Simulator (LACIS, Hartmann et al., 2011), where exactly one size segregated ash particle is immersed in a droplet.

We found significant differences between the freezing abilities of the different ash types. Particles from wood bottom ashes initiate freezing at rather low temperatures near the homogenous freezing point (around -36°C). Particles from coal bottom ashes show significant higher ice nucleation abilities than the wood bottom ash, with observed freezing temperatures similar to those of clay minerals (around -30°C). The particles from the fly ash showed the best freezing ability, which was significantly higher than the freezing ability of the clay minerals but still not as good as that of K-feldspar.

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New Continuous Flow Diffusion Chamber INKA for Laboratory Investigations of Heterogeneous Ice Nucleation

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To obtain quantitative information on the ice nucleation activity of various atmospheric aerosol species, we have built a new continuous flow diffusion chamber (CFDC) called INKA (Ice Nucleation Instrument of the Karlsruhe Institute of Technology). The CFDC design was originally developed and theoretically described by Rogers et al. (1988). The main part of the new INKA instrument consists of two vertically-oriented, concentric tubes with a total length of 150 cm. Together with particle-free, dry sheath air, the sampled aerosol particles flow through the annular space between these two cylinders. The walls of the annular space are coated with ice and can be set to a preset temperature difference in order to expose the aerosol particles in the sample flow to a well-defined temperature and relative humidity. The bottom part (about 50 cm) of the outer cylinder of INKA is separately cooled, which allows operation in two different modes: In the ice nucleation mode, the CFDC is operated with an ice nucleation and growth section, covering the upper 100 cm of its length. The bottom part is the so called droplet evaporation section, which allows the ice particles to grow on the expense of the evaporating droplets. In the ice growth mode, the full length of the cylinders is operated as a longer nucleation and growth section. Since the wall temperatures can be reduced to values as low as -80 °C, ice nucleation and growth of relevance for both mixed-phase and cirrus clouds can be investigated under well controlled temperature and humidity conditions. In this contribution, we will present the setup of INKA and show first measurements.

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Identification and Emission of Fungal IN

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Biological aerosol particles are ubiquitous in the atmosphere. Recent findings identified a pool of them as potential ice nucleators (IN), which are capable of catalyzing ice formation at relatively warm subfreezing temperatures and thus impact cloud formation and precipitation. Besides well characterized IN of common plant-associated bacteria, IN were also found in a variety of fungal species such as in *Fusarium* and in *Mortierella* recently. In contrast to bacterial IN, fungal IN are poorly understood, but both seem to be based on proteins. *Fusarium* as well as *Mortierella* are widely spread throughout the world and are present in soil and air. To which extent these small, cell-free IN are emitted directly into the atmosphere remains unexplored just as other processes, which probably indirectly release fungal IN e.g. absorbed onto soil dust particles.
In this study, liquid chromatography is performed to fractionate surface protein extract of the fungi and SDS-page just as *de novo* sequencing by mass spectrometry is used to identify the primary structure of the INA protein. A specific IN trap chamber (IN-TC) is designed to analyze the aerosolic transport capacity of fungal IN. Its main principle is based on the emission of particles into a closed gas compartment and the subsequent collection of these particles in water. To verify IN functionality, a customized droplet freezing assay is used.
Preliminary results show that the INA protein of *Fusarium* is contained in the early size exclusion chromatography fractions indicating a high molecular size. Additionally, we could identify a single protein band from IN active fractions at 130-145 kDa corresponding to sizes of IN proteins from bacterial species. Moreover, first data obtained from *Mortierella* seem to be comparable. IN-TC results show a successful proof of principle suggesting the chamber is capable of collecting aerosolic IN generated of fungal washing water.

In addition to the identification of the primary structure of the fungal INA proteins, in ongoing experiments, alive or dead fungal cultures are placed into the IN-TC and a gentle, particle free air stream is directed over the fungi surface. This gas stream is also lead through water to collect particles, which might be emitted either actively or passively by the fungi. Further experiments will be e.g. conducted under different relative humidities. Results obtained from the analysis of various fungal species as well as soil dust fungi mixtures will be revealed.

Detection of Ice Crystal Properties in cloud chamber experiments with the CAS-POL Instrument

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The Cloud and Aerosol Spectrometer with detection for Polarization (CAS-POL) is an aircraft-based instrument for analyzing cloud particles with diameters of 0.5 µm to 50 µm. It uses laser light scattered by the cloud particles in both forward and backward direction to determine the size of individual particles as well as their polarizing properties. From the latter one can derive information about the shape and sphericity of the particles.

In December 2014 we participated in the laboratory campaign on Rough ICE (RICE03) at the cloud chamber AIDA operated by the Karlsruhe Institute of Technology with our CAS-POL instrument. The campaign aimed to study the complexity and roughness of ice particles with varying parameters such as temperature and relative humidity as well as different aerosol types acting as ice nuclei.

Further the CAS-POL Instrument was deployed onboard the German research aircraft HALO in the recent campaigns ML-CIRRUS (March/April 2014) over Central Europe and ACRIDICON-CHUVA (September/October 2014) over the Amazonian basin. We conducted 31 mission flights in mixed-phase as well as cirrus clouds.

Here we use the knowledge we gained during the well-defined lab studies at the AIDA cloud chamber and apply it to data gathered from the in-situ aircraft campaigns. Our goal is to use laboratory information on liquid droplets as a norm for spherical particles and to derive aspherical fractions in clouds in the laboratory and the atmosphere.

Effect of ageing of K-feldspar on its ice nucleating efficiency in immersion, deposition and contact freezing modes

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Recently K-feldspar was identified as one of the most active atmospheric ice nucleating particles (INP) of mineral origin[1]. Seeking the explanation to this phenomenon we have conducted extensive experimental investigation of the ice nucleating efficiency of K-feldspar in three heterogeneous freezing modes. The immersion freezing of K-feldspar was investigated with the cold stage using arrays of nanoliter-size droplets containing aqueous suspension of polydisperse feldspar particles. For contact freezing, the charged droplets of supercooled water were suspended in the laminar flow of the DMA-selected feldspar- containing particles, allowing for determination of freezing probability on a single particle- droplet contact[2]. The nucleation and growth of ice via vapor deposition on the crystalline surfaces of macroscopic feldspar particles have been investigated in the Environmental Scanning Electron Microscope (ESEM) under humidified nitrogen atmosphere.

In this contribution we focus on the role of surface chemistry influencing the IN efficiency of K-feldspar, in particular the connection between the degree of surface hydroxylation and its ability to induce local structural ordering in the interfacial layer in water molecules (as suggested by recent modeling efforts). Our immersion freezing experiments show that ageing have a nonlinear effect on the freezing behavior of feldspar within the investigated temperature range (-40°C to -5°C). On the other hand, deposition nucleation of ice observed in the ESEM reveals clear different pattern between freshly cleaved and aged mineral surfaces. This effect is especially pronounced for surfaces having different crystallographic orientations (001 and 010), with 001 being clearly preferential for ice nucleation. We will discuss the possible atmospheric implications of this ageing process of K-feldspar particles.

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Theoretical and Numerical Analysis of Antifreeze and Ice Nucleator Proteins: Coarse-Grain Approach for Multiscale Study and Bio-Engineering

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In nature there are many organisms able to control the ice nucleation rate of water. This ability allows such organisms to adapt to environmental changes, like large temperatures excursions, and to facilitate the search for food. Bio-molecules such as antifreeze proteins (AFPs) and ice nucleator proteins (INPs) are known to influence the ice nucleation rate, a feature that attracts great interest from a wide spectrum of scientific disciplines like biology and atmospheric science, and it offers several technological applications like cryo-preservation of tissues and increasing frozen food shelf life.

We present a new approach, based on a novel combination of water-protein coarse-grain model, able, for a wide range of temperatures and pressures, to deeply explore the configurational space of a water-protein solutions. Accounting for the influence of protein interfaces on the thermodynamic properties of the hydration shell, we show how the design of specific target protein structures is affected by the solvent properties. In turn we show how the folding properties for different protein sequences, designed at different thermodynamic conditions, change.

Our results will help further to expand our understanding of the mutual effect on the dynamical and structural properties of protein-water solutions, paving the way for the computer based design of artificial functionalized protein sequences capable of influencing the phase of water.

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Distribution and importance of marine biogenic ice nucleating particles associated with organic material in sea spray aerosol

Jesus Vergara Temprado, Theodore Wilson, Benjamin Murray, Jo Browse, Susannah Burrows, Ken Carslaw.

Global weather and climate models are beginning to include cloud ice microphysical processes, hence there is a need to represent the global distribution of ice nucleating particles. In order to address this challenge we are using global aerosol models in conjunction with laboratory and field data to define the ice nucleating ability of various aerosol classes. In this presentation I will show our most recent predictions for the global distribution of INP from desert dust, which is controlled by K-feldspar, and new work on the marine INP associated with the organic fraction of sea spray aerosol. We find that desert dust INP are most important in the northern hemisphere, but marine INP are important in remote regions such as the Southern Ocean, the North Pacific and the North Atlantic.

Ice particle mass-dimensional parameter retrieval and uncertainty analysis using an Optimal Estimation framework applied to in situ data

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The extreme variability of ice particle habits in precipitating clouds affects our understanding of these cloud sys- tems in every aspect (i.e. radiation transfer, dynamics, precipitation rate, etc) and largely contributes to the uncer- tainties in the model representation of related processes. Ice particle mass-dimensional power law relationships, $M=a\cdot(D^b)$, are commonly assumed in models and retrieval algorithms, while very little knowledge exists regard- ing the uncertainties of these M-D parameters in real-world situations. In this study, we apply Optimal Estimation (OE) methodology to infer ice particle mass-dimensional relationship from ice particle size distributions and bulk water contents independently measured on board the University of Wyoming King Air during the Colorado Air-borne Multi-Phase Cloud Study (CAMPS). We also utilize W-band radar reflectivity obtained on the same platform (King Air) offering a further constraint to this ill-posed problem (Heymsfield et al. 2010). In addition to the values of retrieved M-D parameters, the associated uncertainties are conveniently acquired in the OE framework, within the limitations of assumed Gaussian statistics. We find, given the constraints provided by the bulk water mea- surement and in situ radar reflectivity, that the relative uncertainty of mass-dimensional power law prefactor (a) is approximately 80% and the relative uncertainty of exponent (b) is 10-15%. With this level of uncertainty, the forward model uncertainty in radar reflectivity would be on the order of 4 dB or a factor of approximately 2.5 in ice water content. The implications of this finding are that inferences of bulk water from either remote or in situ measurements of particle spectra cannot be more certain than this when the mass-dimensional relationships are not known a priori which is almost never the case.

Two channel airborne hygrometer system for cloud water/ice content determination

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A photoacoustic spectroscopy based two channel airborne hygrometer system has been developed for the determination of atmospheric water vapor concentration as well as cloud water/ice content. The system has to be connected to a gas phase and to a total air sampler mounted onto the wall of the aircraft; these can be a backward and a forward facing samplers. From the gas phase sampler air containing only water vapor is taken into the system to be analyzed, while from the total air sampler the gas to be analyzed additionally contains the evaporated water content of ice crystals and water droplets. The difference of the two determined volume mixing ratios corresponds to the cloud content.
An early version of the measuring systems has been applied within the CARIBIC project -now as a part of the IAGOS project- since 2005.
Laboratory and in-flight comparison measurements have proven the precision, accuracy and dynamic range of the system: it can be calibrated traceable to a reliable humidity generator, can be used in the 0.5-60000 ppmV volume mixing ratio and 100-1100 mbar pressure ranges with 1.5-2 s response time.
Recently efforts were made to turn the system into an even more reliable form with significant size and weight reduction. Therefore a new data acquisition and control system was developed to be the core of the system, new measuring cells were designed and constant pressure operation mode developed.
The system, some measurement results and the latest developments are to be introduced.
The research projects leaded to the presented results have been supported by EUFAR contract no. 227159, Hungarian Research and Technology Innovation Fund (OTKA), project no. NN109679 and by the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 312311.

OF RAINFORESTS AND RAIN, LAND TITLES, BOSONS (THE HIGGS) ALBATROSS DEATHS AND MORE

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This paper will contain two lines of inquiry regarding science and two involving choices in the public policy sphere. The first and second lines will report, in lay terms, on several recent research initiatives--outcroppings of ongoing investigations into land-atmospheric interactions within the planetary water cycle. Based on a diversity of methods and scales, the work I mean to describe features microbial, plant, aquatic, and forest (especially rain-forest)-level, state-of-the-art hypotheses about the formation of rain. I hope, on account of this conference, it may include cloud-based understandings, too. This first line of approach will sort for apparently convergent findings within and among these colonies of research, toward the end of seeing whether we can plausibly generate an increasingly unified and well-validated apprehension of how, when, and where precipitation is causally inspired. The second line of inquiry investigates current gaps in knowledge about this generative capacity, or potentially conflicting ones, with some attention to the (conjectural) interactive proficiencies of rain-forested environments. The third and fourth lines of approach will advance argumentative claims about funding needs for accelerated basic research and the potential need to fund moratoria on deforestation while best practices for title options to protect specially-implicated environmental niches, at critical mass, can be devised. My talk will focus on the first of the four lines sketched above.

Forecasting and understanding cirrus clouds with the large scale Lagrangian microphysical model CLaMS-Ice

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Cirrus clouds play an important role by influencing the Earth's radiation budget and the global climate (Heintzenberg and Charlson, 2009). This is shown in the recent IPCC reports, where the large error bars relating to the cloud radiative forcing underline the poor scientific knowledge of the underlying processes. The formation and further evolution of cirrus clouds is determined by the interplay of temperature and ice nuclei (IN) properties, relative humidity, cooling rates and ice crystal sedimentation. For that reason, a Lagrangian approach using meteorological wind fields is the most realistic way to simulate cirrus clouds. In addition, to represent complete cirrus systems as e.g. frontal cirrus, three dimensional cloud modeling on a large scale is desirable. To this end, we coupled the two momentum microphysical ice model of Spichtinger and Gierens (2009) with the 3D Lagrangian model CLaMS (McKenna et al., 2002).

The new CLaMS-Ice module simulates cirrus formation by including heterogeneous and homogeneous freezing as well as ice crystal sedimentation. The boxmodel is operated along CLaMS trajectories and individually initialized with the ECMWF meteorological fields. In addition, temperature fluctuations are superimposed directly to the trajectory temperature and pressure by the parametrization of Gary et al. (2006).

For a typical cirrus scenario with latitude/longitude coverage of 49° x 42° on three pressure levels, 6100 trajectories are simulated over 24 hours in time. To achieve the model results in an acceptable time, the box model is accelerated by about of factor of 10 before coupling to CLaMS. Now, CLaMS-Ice needs only about 30-40 minutes for such a simulation. During the first HALO cloud field campaign (ML-Cirrus), CLaMS-Ice has been successfully deployed as a forecast tool.

Here, we give an overview about the capabilities of CLaMS-Ice for forecasting , modeling and understanding of cirrus clouds in general. In addition, examples from the recent ML-Cirrus mission will be shown where the forecasted large scale situations are compared with satellite observations.

Validation of the large-scale Lagrangian cirrus model CLaMS-Ice by in-situ measurements

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Cirrus clouds are an element of uncertainty in the climate system and have received increasing attention since the last IPCC reports. The interaction of varying freezing meachanisms, sedimentation rates, temperature and updraft velocity fluctuations and other factors that lead to the formation of those clouds is still not fully understood. During the ML-Cirrus campaign 2014 (Germany), the new cirrus cloud model CLaMS-Ice (see Rolf et al., EGU 2015) has been used for flight planning to direct the research aircraft HALO into interesting cirrus cloud regions. Now, after the campaign, we use our in-situ aircraft measurements to validate and improve this model – with the long-term goal to enable it to simulate cirrus cloud cover globally, with reasonable computing times and sufficient accuracy.

CLaMS-Ice consists of a two-moment bulk model established by Spichtinger and Gierens (2009a, 2009b), which simulates cirrus clouds along trajectories that the Lagrangian model CLaMS (McKenna et al., 2002 and Konopka et al. 2007) derived from ECMWF data. The model output covers temperature, pressure, relative humidity, ice water content (IWC), and ice crystal numbers (Nice). These parameters were measured on board of HALO by the following instruments: temperature and pressure by BAHAMAS, total and gas phase water by the hygrometers FISH and SHARC (see Meyer et al 2014, submitted to ACP), and Nice as well as ice crystal size distributions by the cloud spectrometer NIXE-CAPS (see also Krämer et al., EGU 2015).

Comparisons of the model results with the measurements yield that cirrus clouds can be successfully simulated by CLaMS-Ice. However, there are sections in which the model's relative humidity and Nice deviate considerably from the measured values. This can be traced back to e.g. the initialization of total water from ECMWF data. Reinitiating the simulations with the total water content measured by FISH could improve these results. Other possible sources of uncertainties are investigated, as imposed temperature fluctuations, inaccurate numbers and efficencies of heterogeneous ice nuclei or assumptions concerning the sedimentation rates.

This contribution sums up the results of these investigations and outlines future work on CLaMS- Ice, that will lead to a tool helping to understand the cirrus clouds under the different environmental conditions during ML-Cirrus.

Sensitivity of Arctic mixed-phase cloud simulated with the global climate model ECHAM6-HAM2 to the heterogeneous freezing parameterization

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(3) Institute for Meteorology and Climate Research, KIT, Karlsruhe, Germany

Different methods can be used to parameterize heterogeneous freezing in mixed-phase clouds either based on field experiments, laboratory measurements or using theoretical approaches. In this study a freezing parameterization for immersion freezing based on Classical Nucleation Theory (CNT) and laboratory data from Welti et al. [1] is developed for the GCM ECHAM6-HAM2. This scheme is able to incorporate laboratory data to describe microphysical properties of ice nuclei [2].

As CNT is very sensitive to the description of unconstrained kinetic and thermodynamic parameters in case of homogeneous freezing [3] the sensitivity of immersion freezing to these parameters is investigated. Additionally the estimated CNT approaches are tested in terms of their capability to reproduce time and size dependence of the experimentally observed freezing process.

The developed CNT parameterization scheme for kaolinite, illite, montmorillonite, microcline (K-feldspar) and ATD (Arizona test dust) is then introduced into the global climate model ECHAM6-HAM2 with a two-moment cloud microphysics scheme coupled to the aerosol module HAM [4, 5]. The sensitivity of this scheme is tested in the framework of an Arctic case study. The scheme will be evaluated against an empirical freezing parameterization to study if the choice of a parameterization scheme can influence the representation of Arctic mixed-phase clouds in ECHAM6-HAM2.

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[5] P. Stier et al. The aerosol-climate model echam5-ham. Atmos. Chem. Phys., 5(4):1125–1156, 2005.

Modeling primary ice nucleation in shallow altocumulus clouds

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TROPOS, Leibniz-Institute for Tropospheric Research, Leipzig, Germany

Single-layered shallow mixed-phase altocumulus clouds provide a natural laboratory for the observation of primary ice nucleation. Due to the limited vertical extent of the liquid layer, freezing temperature can be deduced rather precise from temperature corresponding to the cloud altitude obtained either by radiosonde profiles or reanalysis data. Remote sensing observations show the typical vertical profile with a shallow liquid layer at cloud top and (extended) ice virgae below.

The model system AK-SPECS combining a dynamics model of the Asai-Kasahara type with a detailed spectral micophysics model is used to perform sensitivity studies with respect to ice nucleating particle (INP) number size distributions and types expressed by different freezing parameterizations realized by a prognostic temperature-dependent INP distribution. In contrast to the typical AK setup, vertical velocity is prescribed following the observed distributions in the vicinity of the liquid layer. For the cases selected, the liquid phase mainly depends on the prescribed dynamical parameters of the model (location, strength and temporal characteristics of the vertical velocity). However, the ice phase is rather insensitive to the model dynamics (as long as the liquid layer exists) but as expected is highly sensitive to to microphysical parameters such as INP number and ice particle shape.

Interactions between microphysics and dynamics in the formation of TTL cirrus clouds

Aurélien Podglajen, Tra Dinh, Riwal Plougonven, Albert Hertzog, Bernard Legras

Cirrus clouds in the tropical tropopause layer (TTL) control dehydration of air masses entering the stratosphere, influence directly and indirectly the earth radiative balance, and contribute to the local radiative heating. There has recently been debates regarding which of homogeneous or heterogeneous nucleation is the main formation mechanism for TTL ice clouds, and the effect of mesoscale dynamics in cirrus cloud formation. In this work, we use observations of dynamical variables and mesoscale modelling combined with bin microphysics modelling to investigate interactions of microphysics and atmospheric dynamics for cirrus formation in the TTL.

First, we use a bin microphysics model with homogeneous nucleation (Koop et al., 2000) forced by high frequency observations of temperature disturbances gathered during long-duration balloon flights to study the interaction of mesoscale dynamics with nucleation. These simulations show the existence of two regimes for homogeneous ice nucleation : the first one, previously described, for which ice nucleation is limited by the depletion of water vapour by the nucleated ice crystals (vapour-limit events). This regime corresponds to nucleation time scales shorter than those associated with dynamical processes. But the observed temperature variations can also be shorter than the homogeneous nucleation time scale. In this case, a second regime appears where nucleation is stopped by the temperature increase after its initial drop (temperature-limit events).

As described in previous studies, the Ice Crystal Number (ICN) nucleated during vapour-limit events is mainly controlled by the updraft speed (i.e. the adiabatic cooling rate), and shows a strong sensitivity to the ice accommodation coefficient but only a limited one to the aerosol content and nucleation temperature. On the other hand, we show in the simulations and justify analytically that the ICN nucleated during temperature-limit events rather depends on the absolute temperature drop during the event. Therefore, even with relatively strong updraft speeds (0,2 m/s), homogeneous nucleation alone can produce low ICN compatible with observations. Furthermore, T-limit events interestingly exhibit some sensitivity to the nucleation temperature but virtually none to the accommodation coefficient, whose value is highly uncertain from experiments. Unlike vapour-limit events, the ICN from T-limit events is extremely sensitive to the initial vapour content. We argue that this last behavior combined with small-scale vapor heterogeneities may explain the high heterogeneity in ICN observed in recent aircrafts campaigns (ATTREX).

Then, we carry a real-case study of a TTL cirrus using mesoscale and Lagrangian microphysics modelling. We test the sensitivity of the simulated cirrus to microphysical assumptions, focusing on the importance for this case of nucleation assumptions (the presence of heterogeneous IN).

Buffet

Saturday 11th April 2015, 12:00 (Lunch)

Snack:

- Finger food (salad with sheep's cheese and olives, spicy noodle salad, poultry-curry-rice, chicken liver pâté with port jelley and different types of bread)

Saturday 11th April 2015, 19:00 (Dinner)

Starter:

- Beef broth with vegetable chunks and rusks
- Red cabbage foam soup with red cabbage-goat cheese-strudel

Main Dish:

- Roast beef, napkin dumplings and lingonberries
- Chicken rolade with spinach leaves, pepper sauce, wild rice and carrots
- Stuffed cabbage filled with lentil and curry in tomato-zucchini-ragout with parsley potatoes
- Fresh salads from the Buffet

Dessert:

- Buffet with different cakes (Kardinalschnitte , poppy-curd-raspberry- and nougat slice)

Sunday 12th April 2015, 13:00 (Lunch)

Snack:

- Finger food (salad with sheep's cheese and olives, spicy noodle salad, poultry-curry-rice, chicken liver pâté with port jelley and different types of bread)

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Annex 4b: Full list of speakers and participants

ESF - Participation List - Management

ESF ACTIVITY

Unit(s) : LESC
Activity Title : Micro-Dynamics of Ice

PROJECT

Science Meeting : Workshop
Title of Science Meeting : Microphysics of ice clouds
Location : Vienna
Date of Science Meeting : 11/04/2015 - 12/04/2015

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Speakers 27

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Dr. Valentino Bianco	Wien, (AT)	Speaker	Edit	DELETE
Mr. Bertrand Chazallon	Villeneuve d'Ascq, (FR)	Speaker	Edit	DELETE
Professor Jane Cohen	Austin, (US)	Speaker	Edit	DELETE
Ms. Anja Costa	Jülich, (DE)	Speaker	Edit	DELETE
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Mr. David Tatrai	Szeged, (HU)	Speaker	Edit	DELETE
Mr. Jesus Vergera Temprado	Leeds, (UK)	Speaker	Edit	DELETE
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Ms. Zhuocan Xu	Salt Lake City, (US)	Speaker	Edit	DELETE
Mr. Tobias Zolles	Innsbruck, (AT)	Speaker	Edit	DELETE

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