Name of research institute or organization:

Institute for Atmospheric and Climate Sciences, ETH Zurich

Title of project:

Field measurements of aerosols acting as ice nucleating particles and their influence on mixed-phase clouds

Part of this programme:

GAW-CH
CLACE

Project leader and team:

Dr. Zamin A. Kanji (Project Leader)
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Project description:

For an improved understanding of ice and mixed-phase clouds, measurements of ice nucleating particles' (INP) concentrations are performed on a regular basis at the High Altitude Research Station Jungfraujoch (JFJ). Continuous measurements of INP concentrations in an environment relevant for clouds containing ice are rare, as there is no commercially available instrument to measure INP concentrations in real-time in continuous automated fashion. We perform measurements with our newly built Horizontal Ice Nucleation Chamber HINC, designed by Dr. Kanji, several times a year in different seasons (winter, spring and summer), to extend existing INP measurements from our group (see Figure 1) and to identify if there is an annual cycle of free tropospheric INP concentrations. Although the High Altitude Research Station provides most time of the year free tropospheric conditions, convectively lifted air from the boundary layer may reach the station in spring and summer during daytime. By measuring during day- and night-time in these seasons, we therefore want to investigate the influence of convectively lifted boundary layer air on the INP concentration as compared to free tropospheric conditions during night-time. We also want to address the question if the influence from boundary layer air is related to phenological periods, like the influence from biological aerosols. Furthermore, we want to compare its influence on INP concentrations to Sahara dust, as JFJ is regularly affected by Sahara dust events in spring and which influence the INP concentrations significantly as has been published by our group in 2011. Last but not least, our project aims to investigate the influence of meteorological conditions on the INP concentration.

The main progress in this year was the design, development and validation of HINC, the horizontal ice nucleation chamber. The first field campaign with HINC was conducted in August 2014. The results are compared to the previous measurements performed with the Portable Ice Nucleation Chamber PINC (Figure 1). They reveal, that the INP concentration both in the deposition nucleation and condensation freezing mode during August 2014 are closer in value to previous winter time measurements. However, we do not have measurements from August in previous years to make a direct comparison. The INP concentrations in the condensation freezing mode in February 2014 were a factor of 10 higher compared to the deposition mode in the same month. Interestingly, the HINC measurements in August in the condensation mode only show an INP concentration of a factor of 2 higher than the deposition mode nucleation. INP concentrations in August 2014 are higher than in February 2014, but are lower than in March and June 2009. Spring is also known as the season where JFJ is often influenced by Saharan dust events or air masses, thus this is not surprising as the higher dust concentrations may be contributing to the high INP concentrations observed in spring. The higher INP concentration in the spring and summer could also (in addition to Saharan dust) be from particles in convectively lifted boundary layer air which JFJ typically experiences in spring and summer afternoons. Therefore it is difficult to assign the influence of INP specifically to dust particles or convectively lifted boundary layer air except in cases of known intense Saharan dust events (Chou et al., 2011). However, spring is also a time when biological material like pollen particles or fragments thereof from the boundary layer air could be reaching JFJ which could lead to an increase in INP concentrations corroborating laboratory studies which have shown biological material to be very effective INP.

INP concentrations in winter were collected as part of the CLACE 2014 campaign in January and February. The concentration of INP was measured with the Portable Ice Nucleus Counter (PINC). Like in the previous CLACE 2013 campaign, an adiabatic lens concentrator was applied to enrich particle concentration in the sample air. This allowed for a decrease in the detection limit and to be able to measure very low INP concentrations. To continue observing the annual variability in free tropospheric IN concentrations in the deposition mode at JFJ, PINC was operated at the same conditions as in 2009, 2012 and 2013 as shown in Figure 1. For the first time in 2014, condensation freezing at 241 K and a relative humidity above water saturation were studied additionally to mimic mixed phase cloud conditions which was then repeated with HINC in August 2014 (see above).

INP concentrations in the deposition mode are shown in Figure 2a. They were found to be with 2 IN/stdl similarly low as in winter 2013 and lower than during winter 2012. Many data points fell below the detection limit which are indicated as green drop lines. In the condensation mode, IN concentrations are about one order of magnitude higher (see Figure 2b). In both modes, only little temporal variation was found throughout the campaign. On February 16, 2014 a strong increase in IN concentration in the condensation mode was observed. This is likely related to an increase of aerosol particles at sizes above 0.7 µm diameter during that time. A weak correlation of IN concentration at water supersaturated conditions and particles above that size was found for the whole time of the campaign.

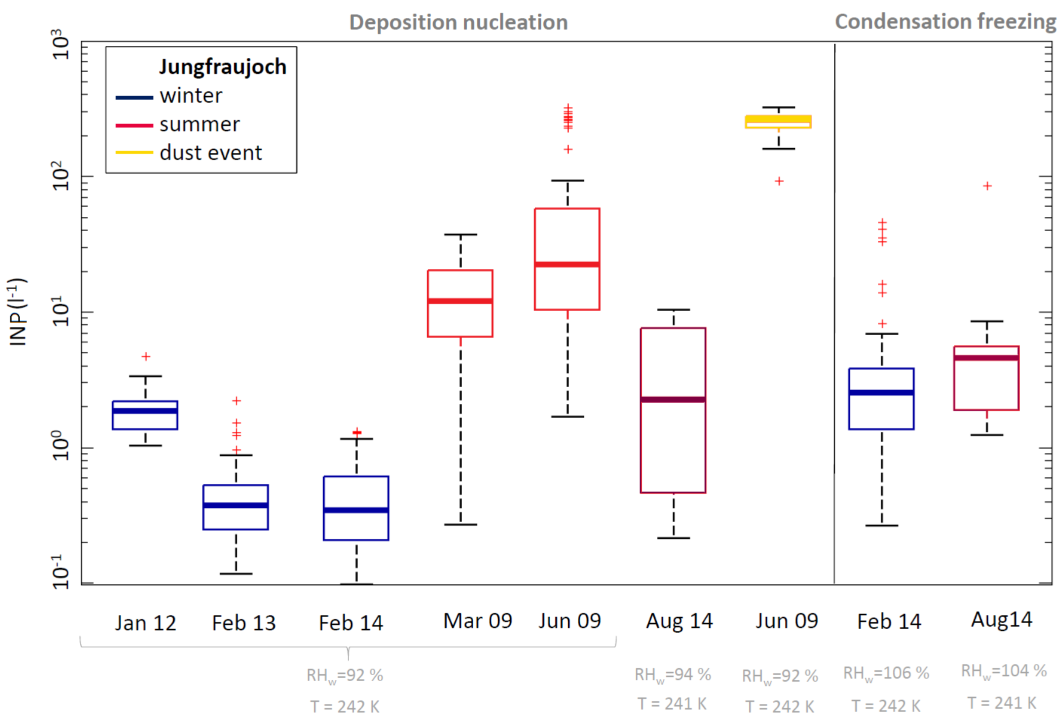

Figure 1. INP concentration measurements at Jungfraujoch, performed with PINC (March 09 – February 14) and HINC (August 2014; dark red).

The results support the findings from earlier years that INP concentrations during winter time in the free troposphere are ≤ 2INP/stdl generally very low. At supersaturated conditions, IN concentrations are about an order of magnitude higher. As found in earlier studies, these concentrations are about two orders of magnitude below the average ice crystal concentrations found at JFJ in the winter. This is partially due to the upper size cut off of the total aerosol inlet which only allows small, freshly formed ice crystals to enter the inlet. Also, the relative humdity at which the PINC is sampling in the deposition mode is lower than what the aerosol particles experience in a cloud. Lastly, secondary ice forming processes may be a reason for this discrepancy.

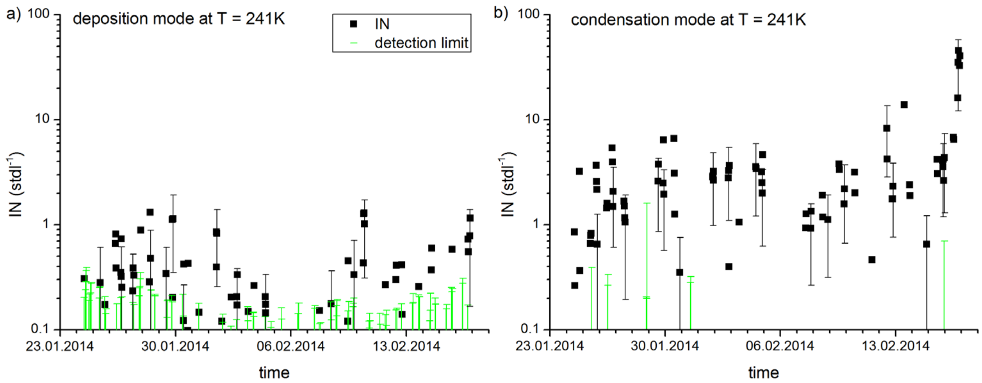

Figure 2. a) IN concentrations at T = 241 K measured with PINC during CLACE 2014. a) deposition mode (RH_w = 93 %, RH_i = 127 %) . b) condensation mode (RH_w = 103 %, RH_i = 141 %) . Data points below the detection limit are shown as green drop lines to indicate the range they potentially cover. Twenty error bars are drawn in each plot for lucidity.

Cloud Microphysics Measurements

Field measurement: The digital holographic imager HOLIMO II instrument took part in the CLACE 2014 campaign during January/February 2014. Unfortunately, some technical issues occurred during the CLACE 2014 campaign. Due to high humidity inside the inlet, water condensed on the optics. With this higher noise level, it was not possible to determine liquid droplet concentrations, because cloud particles below 20 µm could not be detected reliably. Consequently, the data analysis algorithm has to be modified and restarted with adjusted parameters and will concentrate on the analysis of the ice crystals.

Data analysis:
We continued the analysis of the *in-situ* measurements of MPCs with HOLIMO II at JFJ during the last years. Each HOLIMO II image (the so called hologram) yields single particle information like size and shadowgraph for hundreds of particles within a well-defined sample volume (which can be up to a few hundreds). Advancements in data processing software now offer phase-resolved size distributions, concentrations, and water contents, with a sampling rate that sees variations in these parameters on a 25 m length-scale in a MPC.

We analyzed 16 distinct cloud events, which represent a time period of 50 h. The field data reveal the conventionally unstable co-existence of water droplets and ice crystals, i.e. the presence of only a partially-glaciated MPC maintained at JFJ for over several hours. At JFJ a larger frequency of intermediate glaciation conditions was found than in in-situ aircraft observations of MPCs associated with frontal systems by Korolev et al. (2003). The higher longevity of these intermediate glaciation conditions of MPCs at JFJ suggests that higher updraft velocities, and therefore higher water-vapor supersaturation, sustain the longer life time of liquid drops thus making long-lived MPCs. The JFJ location has a steeper topography for northerly winds, meaning higher updraft velocities, than for southerly winds. In addition, the measurements show more intermediate values of glaciation for cases where air massed are coming from the North with the higher updraft velocities than from the South which has consistently either fully-glaciated or almost no glaciation in its MPCs.

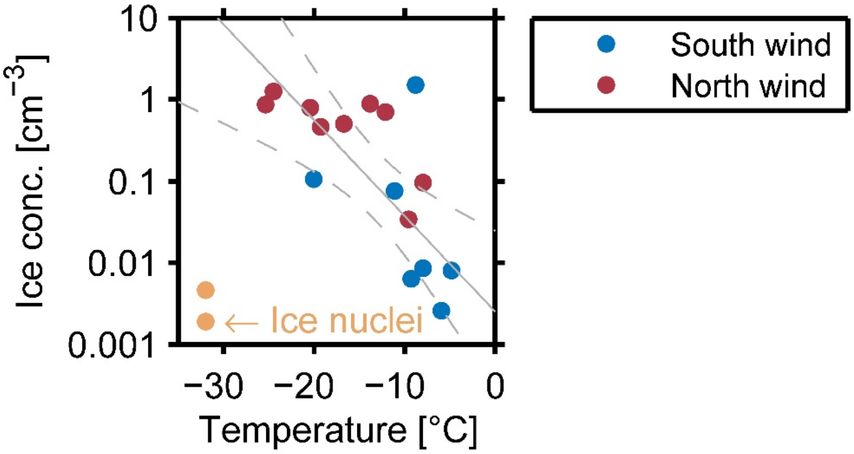

Figure 3. Temperature dependency of mean ice concentration of the south wind (blue dots) and north wind (red dots) cloud cases measured by HOLIMO II. The concentrations of INPs (yellow dots) measured by PINC were by two order of magnitude lower.

In addition to the longevity of MPCs, unexpected high ice crystal concentrations were observed (Figure 3); two order of magnitude larger than the simultaneously measured INP concentrations by PINC. This discrepancy indicates that a large fraction of the ice crystals may not be forming via primary ice nucleation, but be re-suspended snow from wind turbulence or secondary-ice formation processes have a significant influence.

Instrument development:
During the last year we designed and constructed a new version of the digital holographic instrument called HOLIMO 3M. The new design of HOLIMO 3M has an open path configuration (Figure 4), which allows the ambient air to freely stream in-between the two towers, where the pictures of the particle ensemble are recorded. Therefore, no active ventilation has to be applied, which would result in non-isokinetic sampling and destroying the local distribution of the cloud particles.

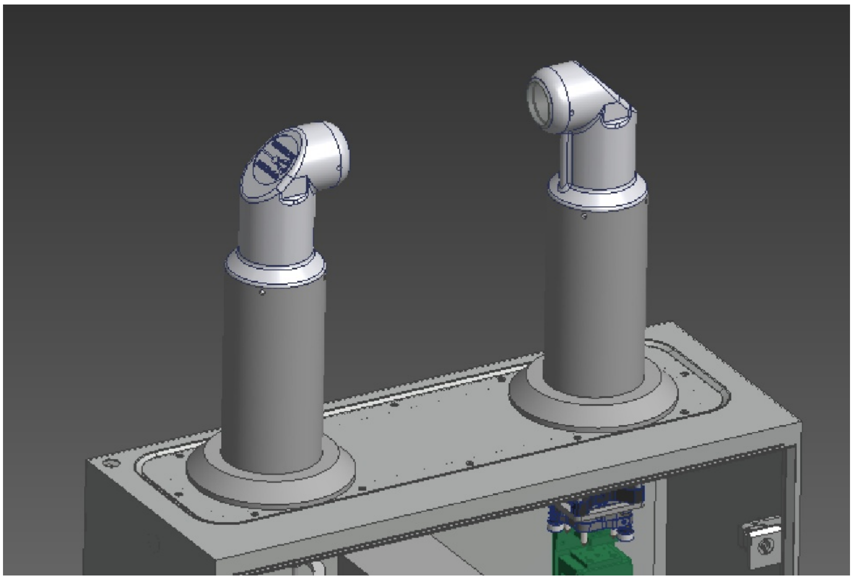

Figure 4. The open-path configuration of the HOLIMO 3M instrument. Between the two towers, single particle information about the ensemble of cloud particles is obtained.

Instead, with the new configuration, the measurement of the spatial distribution of the cloud particles on a mm-scale is possible. HOLIMO 3M uses a 1.8 times magnifying, both-sided telecentric lens system from Sill Optics, which allows a detection volume of 3 cm^3, which is an increase of a factor of 10 compared to HOLIMO II at a comparable resolution. Because the design is of HOLIMO 3M is mainly based on commercial available hardware, other research groups interested in *in-situ* cloud measurements could easily replicate it.

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Radio and television

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vimeo.com/104689819

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