A New Method for Operating a Continuous Flow Diffusion Type Ice Chamber to Investigate Immersion Freezing: Assessment and Performance Study

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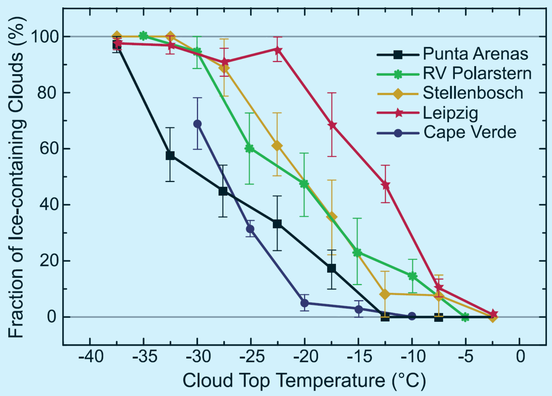
Abstract:
Mixed-phase clouds are a source of large uncertainty in simulating cloud radiative properties. Glaciation in these clouds predominantly occurs through immersion freezing mode where ice nucleating particles (INP) immersed within a supercooled droplet induces nucleation of ice, and the immersion freezing efficiency is commonly measured using direct processing INP systems. In this study, one such system from PNNL was operated in a nonstandard style and evaluated using four ice nucleating particle (INP) species: k-Feldspar, illite NX, and natural soil, and ambient desert dust that had shown ice nucleation over wide span of supercooled temperatures.

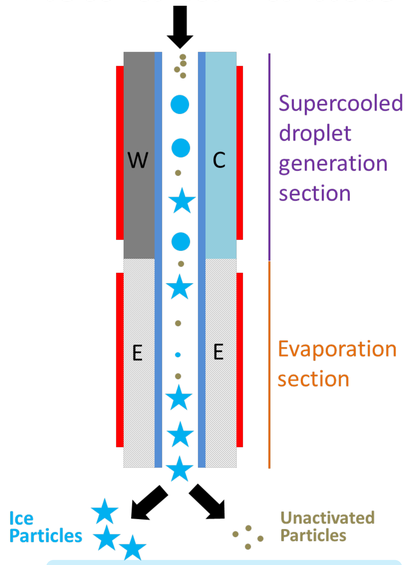
Importance of INP composition and immersion freezing mode:



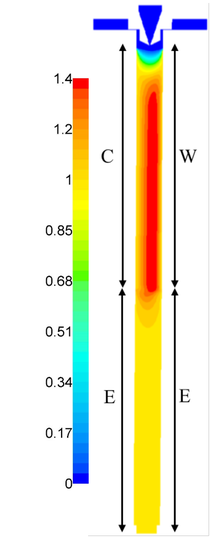
Fraction of ice-containing clouds (adapted from Kanitz et al (2011)) at various locations determined using polarization lidar. These results show the sensitivity of INP composition towards supercooled temperatures.
Reference: Kanitz, T., et al. (2011), Geophys. Res. Lett., 38, L17802.

Summary:
The immersion INP efficiency is investigated using various methods, for *e.g.* cloud expansion chambers: AIDA and Manchester cloud chambers, single droplet freezing substrate technique and using continuous flow diffusion chambers (CFDC). The current PNNL CFDC design is further improved to obtain immersion freezing spectra at higher temporal resolution - close to the precision level as CCN instrument and without droplet breakthrough ambiguity. This performance enhancement is achieved by operating nucleation section of the chamber at higher humidity and independently controlling the temperature of the evaporation section, which is maintained ice saturation conditions at all time. Such measurements are useful where ambient particle concentration is low and mixing state of particles is rapidly changing.

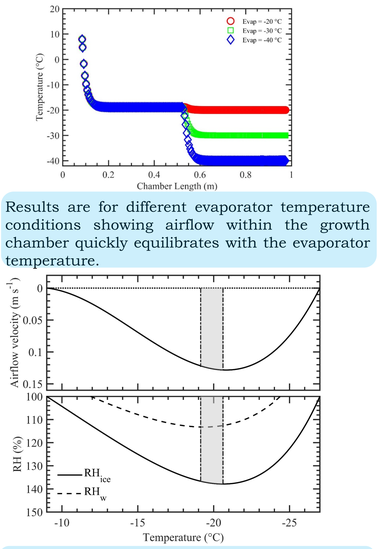
Flow and Particle Characterization



Schematic showing the concept of the ice chamber operated in a nonstandard manner.

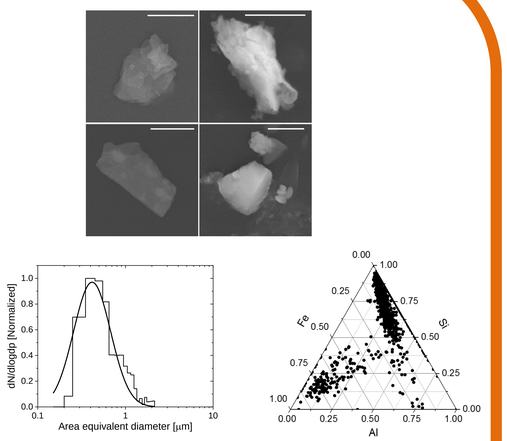


Calculated humidity and temperature profiles within the ice chamber



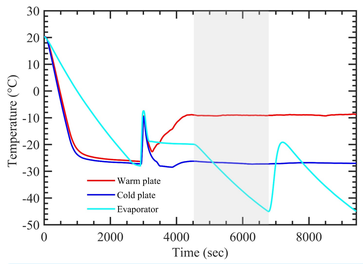
Results are for different evaporator temperature conditions showing airflow within the growth chamber quickly equilibrates with the evaporator temperature.

Idealized airflow velocity and RH conditions within the chamber. The chamber warm wall (left) and cold wall (right) are at -9 and -27 °C.

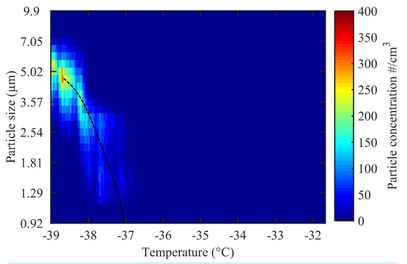


Morphology, size distribution, and ternary diagram of ambient desert dust particles sampled at PNNL location. The particle size distribution with a lognormal fit (0.53±0.02 µm) was obtained after analysis of total 1183 particles. Ternary plot of Al, Si and Fe components of dust particles suggests two distinct types: Si-rich and Fe-rich dust particle. The particles were not coated to eliminate the charging.

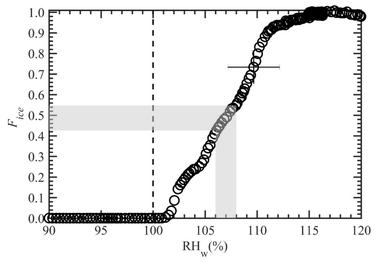
Performance Characteristics



Measured temperature of warm, cold and evaporator walls during an experiment. Shaded area indicates the experimental conditions for ice nucleation study.

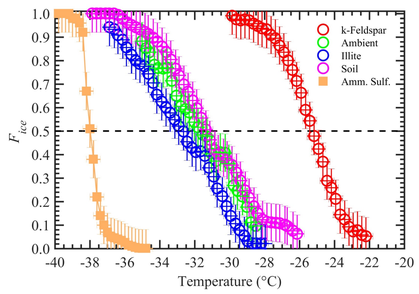


Homogenous freezing of water droplets containing 1 wt. % ammonium sulfate. OPC particle concentrations as a function of ice crystal size at different evaporator temperature.

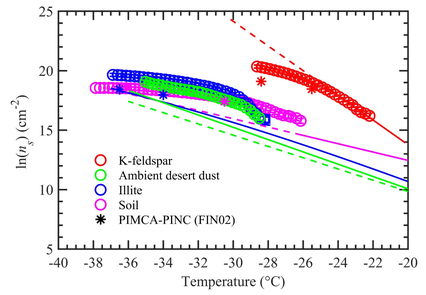


Fraction of frozen droplets at a droplet temperature of -42 °C when RH_w is slowly increased in the growth section. Shaded area shows the experimental conditions when ice chamber was operated in a standard manner.

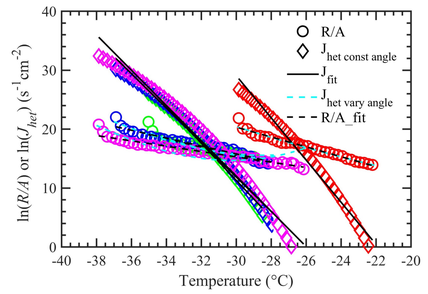
Results



The activated fraction F_{ice} of four INP test species as a function of temperature. The vertical error bar represent the one standard deviation (n = 3). Temperature measurements had ± 0.4 °C uncertainty. Solid square markers represent the freezing temperatures of water droplets containing 1 wt. % ammonium sulfate. The horizontal dashed line represent 50% ice active fraction.



Ice nucleation active site density (n_s) as a function of temperature for four INP test species. The red, green, blue, and magenta lines represent parameterizations for K-feldspar, ambient desert dust, illite-NX, and natural soil, respectively, reported in previous studies. The black color symbols represent n_s values from PIMCA-PINC (*) instrument reported for various INP test species in DeMott et al. (2018).



Normalized nucleation rate (R/A) and heterogeneous ice nucleation rate coefficient (J_{het}) as a function of temperatures for four INP test species.. The red, green, blue, and magenta markers represent measurements for K-feldspar, ambient desert dust, illite-NX, and natural soil, respectively.

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