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Probing Individual Ice Nucleation Events with Environmental Scanning Electron Microscopy

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Heterogeneous ice nucleation is one of the processes of critical relevance to a range of topics in the fundamental and the applied science and technologies. Heterogeneous ice nucleation initiated by particles proceeds where microscopic properties of particle surfaces essentially control nucleation mechanisms. Ice nucleation in the atmosphere on particles governs the formation of ice and mixed phase clouds, which in turn influence the Earth's radiative budget and climate. Heterogeneous ice nucleation is still insufficiently understood and poses significant challenges in predictive understanding of climate change. We present a novel microscopy platform allowing observation of individual ice nucleation events at temperature range of 193-273 K and relative humidity relevant for ice formation in the atmospheric clouds. The approach utilizes a home built novel ice nucleation cell interfaced with Environmental Scanning Electron Microscope (IN-ESEM system). The IN-ESEM system is applied for direct observation of individual ice formation events, determining ice nucleation mechanisms, freezing temperatures, and relative humidity onsets. Reported microanalysis of the ice nucleating particles (INP) include elemental composition detected by the energy dispersed analysis of X-rays (EDX), and advanced speciation of the organic content in particles using scanning transmission x-ray microscopy with near edge X-ray absorption fine structure spectroscopy (STXM/NEXAFS). The performance of the IN-ESEM system is validated through a set of experiments with kaolinite particles with known ice nucleation propensity. We demonstrate an application of the IN-ESEM system to identify and characterize individual INP within a complex mixture of ambient particles.