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The Efficiency Spectrum of Ice-Nucleating Particles and Its Application to the Parameterization of Ice Formation

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Ice-nucleating particles (INPs) can heterogeneously nucleate ice crystals above 235 K. They hence play a very important role in the evolution of mixed-phase clouds, and subsequently exert a significant influence on the hydrological cycle and the radiative balance of the earth system. However, due to its complexity, heterogeneous nucleation has not been well understood, leading to remarkable differences in the parameterizations of heterogeneous nucleation. These differences have been found to be responsible for the differences in cloud fraction and therefore cloud radiative forcing among the models.
Based on the measurement performed with the continuous-flow diffusion chamber (CFDC), this study derived an efficiency spectrum of INP. The spectrum shows that INP concentration exponentially increases with decreasing efficiency. The efficiency spectrum was then implemented into the classical nucleation theory (CNT) to compare the ice concentration predicted by the CNT with that predicted by the deterministic theory (DT) at different cooling rates. Results show that when the cooling rate decreases from the typical cooling rate for convective clouds ($\sim$1 K min-1) to the typical cooling rate of stratiform clouds ($\sim$1 K day-1), the ice concentration predicted by the CNT becomes progressively higher than that predicted by the DT. This is because CNT allows the INPs that are not detected by the CFDC at the current temperature to contribute to the ice formation while the DT does not. This study suggests that the CNT, into which the efficiency spectrum of INP is incorporated, should be used to parameterize ice formation.