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Heterogeneous Ice Nucleation induced by Surfactant Monolayers

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The heterogeneous ice nucleation rate coefficient (j_{het}) of water droplets coated with a monolayer of the surfactant 1-nonadecanol was determined from multiple freezing/melting cycles. Freezing was monitored optically with a microscope for droplet radii between 31 and 48 μm and with a differential scanning calorimeter for radii between 320 and 1100 μm. The combination of these two techniques allows the surface area of the 1-nonadecanol nucleating agent to be varied by more than a factor of 1000, showing that j_{het} increases only by $\sim$5 orders of magnitude over a temperature range of 18 K. This is roughly 5 times less than the change in the ice nucleation rate coefficient for homogeneous ice freezing at around 238 K or for heterogeneous ice freezing in the presence of a solid ice nucleus, such as Al_2O_3. This temperature dependence of j_{het} can be reconciled with the framework of classical nucleation theory, when assuming a reduced compatibility of the alcohol monolayer with the ice embryo as the temperature decreases. We attribute this finding to an enhanced ability of the alcohol monolayer to adapt to the ice structure close to the ice melting point due to larger thermal density fluctuations in the monolayer, which in turn makes the monolayer serve as a better ice nucleus.