The effect of bacteria and mineral dust as ice nuclei on the formation of snow and graupel simulated with a regional model

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Abstract

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Atmospheric dust particles are one of the most uncertain factors contributing to the effects of aerosols on global climate processes. They may affect clouds directly through their activation into cloud drops or heterogeneous nucleation into ice crystals, thus are of great importance in precipitation development particularly in the mid-to-high latitudes. Laboratory experiments of ice nucleation by clay minerals have been shown by different nucleation modes, including deposition nucleation, condensation-freezing and immersion freezing. Mineral dust particles are commonly found to attach with hygroscopic material, such as sulfate, which may affect their nucleating capability in the freezing modes. Such influences by solute have also been studied experimentally for hematite, corundum and kaolinite particles. These data on ice formation in pure water and in aqueous solution with dust core are crucial for the understanding of natural influence on cloud and precipitation formation. Similar influences can also be exerted by bacteria which are also commonly present in the atmosphere but with higher ice nucleating capability than mineral dust.

In this study, the rates of ice nucleation by mineral dust particles and bacteria measured in the laboratory are theoretically analyzed and parameterized into formulations that may include the solute effect. The parameterization formulas are incorporated into a non-hydrostatic mesoscale cloud model modified with a two-moment warm-cloud parameterization and coupled with a two-moment ice-phase scheme, which explicitly predicts the masses and numbers of cloud particles, to examine the importance of ice processes on precipitation formation. Sensitivity simulations were performed for the role of mineral dust in their ice nucleation by (a) deposition nucleation, (b) immersion freezing in pure drops, and (c) immersion freezing in ammonium-sulfate solution drops. Additional comparison was done with bacteria nucleation in the immersion freezing mode. Various microphysical production terms such as the initiation, deposition growth, riming, melting for cloud ice, snow and graupel have been analyzed to examine the detailed mechanisms through which these ice nuclei affect precipitation formation.

Due to contact angle differences, nucleation by mineral dust by the deposition mode may occur at warmer temperatures than by the immersion freezing mode. Therefore, ice initialization in convective clouds may occur earlier at the lower levels by the deposition nucleation, without which ice formation can occur only when the convection can reach the upper levels where immersion freezing may proceed. Temperatures for immersion freezing are even lower when the solute effect comes into play. However, earlier or stronger nucleation not necessarily lead to more precipitation because up to a certain point the high concentration of ice particles will limit their growth in size due to competition for the available water. In the cases that

we analyzed using typical mineral dust concentration, nucleation in the deposition mode produced a high concentration of cloud ice which grow very fast into snow by vapor deposition. Yet, the snow that formed can grow very little by deposition, as the remaining water vapor is very little. Furthermore, because of the reduction of fall speed due to size limitation, the snow particles are refrained from falling to the lower levels that may provide more liquid water for the Bergeron-Findeisen conversion or riming growth. With only the freezing nucleation, snow and graupel particles are fewer but bigger, and they actually produced more rain when falling to the lower levels and melt. The addition of solute effect further limits the number production of ice and causes more precipitation on the ground. Freezing nucleation by bacteria is by far the most efficient nucleation mode. With the same number concentration as dust particles and assuming they all entered cloud water, bacteria can initiate the highest number of ice particles. But the amount of precipitation on the ground is less as compared to the nucleation by mineral dust.

A series of tests on the number concentration effect also suggested that more ice nuclei does not necessarily lead to more precipitation. These preliminary results suggest that in natural clouds the number of ice nuclei may be quite sufficient, and an increase of them either naturally or artificially may cause an “overseeding” to reduce precipitation. In such an “overseeding” regime, solute effect from pollution might enhance precipitation.