Simulating Mixed-Phase Clouds: Sensitivity to Ice Initiation

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Research Highlight

The vertical structure and radiative properties of persistent low-level Arctic clouds depend on their microphysics, and thus, estimation of the relative significance of the microphysical processes that occur in these clouds is important. Bin resolved microphysics (BRM) models are efficient tools to investigate the role of different microphysical processes in these clouds. Ice initiation process (IIP) is of crucial importance for the longevity of mixed-phase clouds. To study IIP through nucleation from water vapor and transformation of super-cooled liquid water, as well as the transformation of water vapor due to condensation/deposition, evaporation/sublimation, and the Bergeron-Findeisen process (BFP) in Arctic mixed-phase clouds, we use a BRM scheme (Khain and Sednev 1995,1996) coupled to the Goddard Institute for Space Studies (GISS) single column model (SCM), called the GISS line-by-line (LBL) SCM. Using observations of single-layer stratiform mixed-phase clouds obtained during the Atmospheric Radiation Measurement Program's Mixed-Phase Arctic Cloud Experiment (MPACE) in October 2004 at the North Slope of Alaska (McFarquhar et al. 2007; Verlinde et al. 2007), our simulations with the GISS-LBL SCM consider two mechanisms of ice initiation--with and without the liquid phase.

The first IIP is active in cold ice-supersaturated environments and determines the number of small ice crystals originating from water vapor, whose shapes depend on temperature. The second mechanism of IIP is active at negative temperatures in both water-saturated and under-saturated environments due to the transformation of super-cooled droplets, whose spectrum and masses, as well as degree of supercooling, determine the rate of origination of bigger plate-like crystals. Because the freezing rate depends on the droplet mass, the bigger droplets are likely to freeze faster. These two ice initiation mechanisms act quite differently.

The first IIP is responsible for the supply of small ice crystals with different shapes. These crystals with different shapes grow fast at different rates in a highly ice-supersaturated environment at the expense of evaporated cloud droplets. The second IIP is responsible for the supply of bigger (assuming the droplet spectrum is broad enough) ice crystals that continue to grow mainly due to riming, reducing droplet concentration and water vapor supply for the ice phase due to droplet evaporation. The second mechanism indicates the importance of the aerosol particle spectrum for the IIP. It crucially depends on the shape of the aerosol particle distribution, and not only on the concentration of cloud droplets, but also on the broadness of the spectrum of cloud droplets just activated. Observed and simulated microphysical characteristics (concentration of liquid and solid particles, liquid water content, cloud droplet effective radius for liquid, and ice water content) are quite similar. However, the simulated and observed ice crystal effective radius (Rei) differ considerably. Possible reasons are from numerical diffusion and different techniques used to define Rei.

Techniques used to calculate different microphysical characteristics from observations and essential BRM scheme characteristics (mass grids, mass-diameter relations, hydrometeor densities, capacitances, and terminal velocities among others) should be interrelated. Otherwise, direct comparison of data derived from observations and simulations becomes difficult. We find that Rei definition based on melted radius is more useful for evaluation of the relative importance of different microphysical processes, such as different IIPs.

In our sensitivity runs, originated ice crystals continue to grow in simulated clouds mainly due to the BFP that is identified as a process responsible for the rate of glaciation of single layer mixed-phase MPACE clouds. An adequate treatment of this process is important for models that use BRM or bulk schemes to investigate these types of Arctic clouds. It is difficult to expect that the utilization of different modifications of ”saturation adjustment” widely used in bulk schemes can represent the simultaneous growth rate of cloud particles due to the BFP. In bulk schemes, the droplet activation process does not account for the broad spectrum of newly nucleated cloud droplets. Also, reliable representation of simultaneous evaporation rates for droplets and deposition rates for ice particles due to BFP is limited by "saturation adjustment" assumptions. Therefore, the interpretation of the results with these schemes in the case of mixed-phase clouds must be done carefully. One possible way to improve the creditability of mixed-phase bulk microphysics schemes is the creation of a unified modeling framework that includes a computationally expensive BRM-type scheme and a computationally efficient, but less sophisticated, microphysics scheme. Development of such a scheme should be based on observations and numerical simulations obtained using the BRM scheme that is considered as a benchmark.

Reference(s)

I Sednev, S Menon, and G McFarquhar. 2008. "Simulating mixed-phase Arctic stratus clouds: Sensitivity to ice initiation mechanisms." Atmospheric Chemistry and Physics Discussion 8: 11755–11819.

Working Group(s)

Cloud Modeling