Examining Ice Microphysical Evolution in a Quasi-Idealized Simulation of a Squall Line using an Ice Crystal Trajectory Growth (ICTG) Model

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Squall lines have a large impact on the annual rainfall in the mid-latitudes, yet there are still unanswered questions on the mechanisms generating their precipitation structure. Precipitation processes have a large impact on the storm’s intensity, lifetime, and flooding impacts. Ice crystals are involved in modulating the distribution of latent heating throughout the storm during phase change and thus play a role in determining the thermodynamic and kinematic structure of the storm. The current study uses a novel ice crystal trajectory growth (ICTG) model to examine the physical and kinematic mechanisms contributing to the ice structure of a quasi-idealized 3D simulation of a leading-line, trailing-stratiform squall line. This analysis is important for scientific understanding and accurate representation of microphysical processes in numerical models.

Ice crystals are initialized in the leading convective line, and they are advected by the storm-relative winds while simultaneously growing by vapor deposition and riming (or sublimating). To account for variations in the ice particle size distribution, multiple trajectory simulations are conducted for crystals with varying initial diameters. The ICTG model produced a spatial distribution of ice crystals consistent with the precipitation and reflectivity structure of the simulated squall line above the melting level. Trajectory simulations using initially small crystals (< 0.05 mm in diameter) result in the crystals being transported to the forward and rear anvil and the stratiform region. There are two main paths to the stratiform region: one is characterized by sustained interaction with the mesoscale updraft, dendritic growth, and a large final particle size; the other is characterized by lack of interaction with the mesoscale updraft, prolonged sublimation or suppressed growth, and a small final particle size. Simulations using initially large crystals (> 0.5 mm in diameter) result in graupel-like particles that fall out primarily in the leading convective line. These findings support past studies identifying ice particle size sorting in squall lines which result in a local precipitation rate minimum occurring between the convective leading line and trailing stratiform region. The simulated patterns of ice crystal growth and trajectories also hold implications for the latent heating structure and evolution of the overall storm.