EGU2020-6138
https://doi.org/10.5194/egusphere-egu2020-6138
EGU General Assembly 2020

Large Graupel Produced by Thin Clouds in the Arctic

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Riming is a critical process for both numerical modeling and microwave remote sensing because of the significant changes to hydrometeor shape and density that occur. Basic continuous collection theory invokes a simple model that assumes a relatively large, massive graupel falls through a homogeneous field of much smaller, suspended supercooled droplets in still air. However, numerous studies have shown that turbulence enhances the rate of collisions between liquid droplets, and even more so for graupel-droplet collisions. Modeling and observational studies of turbulence-induced riming enhancement have all focused on convective clouds with relatively large dissipation rates. Here we combine theoretical work on the analytical solutions of precipitation size distributions with observations and simulations of Arctic graupel to show that this enhancement is common in “thin” Arctic boundary layer clouds with LWP<50gm-2. The median enhancement of rime mass over that expected from continuous collection ranges from 6.4 to 10.7 (for collection efficiencies ranging from 1 to 0.6) for 1,628 carefully selected graupel falling from thin clouds. Analytical solutions for precipitation size distributions imply that average updraft speed must be approximately one-third of particle settling speed to explain the enhancement quantitatively using bulk cloud and precipitation measurements. Analysis of an 8-day thin cloud case revealed that the two days of thin-cloud graupel occurred in conjunction with boundary layer capping inversions that were significantly weaker than on other days of the period. These graupel days were also preceded by boundary layer profiles indicating two days of very strong cloud top radiative cooling – implying that this generated a mixed layer that eroded the capping inversion. Finally, 1-D Lagrangian simulations of graupel settling in turbulent flow show that the particles spend more time in strong updrafts where riming time increases to a significant degree. These findings challenge the current understanding of riming growth and extent turbulence-induced collision enhancement to thin mixed-phase boundary layer clouds in the Arctic. Such enhanced riming leads to increased bulk density of precipitation particles and is therefore expected have strong implications for cloud lifecycles and corresponding radiative balance in the Arctic.