Nucleation Processes in Deep Convection

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Interactions between atmospheric aerosols and cloud systems are receiving increasing attention as a potentially large forcing to the climate system. Human-induced changes in aerosols (for example, sulfate, black carbon, and organic carbon) alter the transfer of radiation in the atmosphere both directly by scattering and absorbing radiation and indirectly by changing the radiative properties and life cycle of clouds. Past research has focused on the latter problem mostly for stratiform (layered) cloud systems comprised of liquid water. Increasing aerosol is generally regarded as increasing the number of cloud droplets and increasing the reflectivity of these clouds, a cooling (negative forcing) to the climate.

The impact of aerosols on ice clouds associated with deep convection has received considerably less attention. It has been evident since early observations from the Earth Radiation Budget Satellite that ice anvils associated with deep convection exert large shortwave (negative) and longwave (positive) radiative forcing. As a result, changes in ice clouds, which could be linked to aerosols near the earth's surface by deep convection, could be either positive or negative and potentially large in magnitude.

These aerosol-cloud interactions can be studied using cloud-system resolving models, the incorporation of which into general circulation models is a central aspect of the science activities of the Center for Multi-Scale Modeling of Atmospheric Processes. However, doing so requires new methods of treating the microphysical processes in these cloud-system models. In the past, simple methods were used to predict the mass of important microphysical species (cloud droplets, rain drops, ice crystals, snow, graupel) that comprise clouds. These are referred to a single-moment methods. Since the key path by which aerosols change clouds is by changing their sizes and, thereby, radiative properties, a method which predicts both mass and size distribution is required. These methods are referred to as double-moment methods.

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(2007, Vol. 64, pp. 738-761) an economical double-moment method. Cloud droplets and ice crystals are presented by simple size distributions. Parameters which control the shape of the size distribution, from which the masses and numbers of droplets and ice crystals can be inferred, evolve as the convection develops. A key aspect of their approach is its prediction of supersaturation, which is a dominant control on nucleation and depends strongly on the speed of the convective updrafts. Nucleation of the droplets and crystals can be related to aerosol concentrations, providing a basis for studying aerosol-cloud interactions in deep convection.

The predicted microphysical properties are compared with those observed in field experiments. The model reproduces an important observation showing a threshold vertical velocity in deep convection below which few liquid drops exist at the temperature where homogeneous freezing is possible. The model also shows that for deep convection the presence of aerosols in the middle troposphere is important for droplet freezing aloft. This simplified double-moment method provides a strategy for studying a complex set of cloud-aerosol interactions whose impact on climate is still at present largely unknown.