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The Present and Future of Lagrangian Cloud Modeling: From the Centimeter to Kilometer Scale

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Clouds are one of the most complex systems in the atmosphere, as the processes that constitute a cloud are of inherent multi-scale nature. Among the many challenges in cloud physics, representing the effects of turbulence on cloud microphysics is one of the most intriguing, with implications for precipitation development, cloud optical properties, and hence the role of clouds in the climate system. Lagrangian cloud models (LCMs) are a new approach for simulating cloud microphysics, which has been developed over the last decade. LCMs overcome the limitations of many previous cloud microphysical models, and enable new insights on important cloud microphysical questions, such as aerosol activation and regeneration, the role of giant aerosol particles in precipitation formation, and the effects of turbulent supersaturation fluctuations. In this presentation, we will introduce a new LCM approach for representing the effects of unresolved turbulence on cloud microphysics, focusing on the entrainment and mixing process. As the spatial scales of entrainment and mixing are usually smaller than the resolution of most dynamical models used for the simulation of clouds, unresolved mixing tends to be too fast, and the entire process may be misrepresented. Our new approach represents these unresolved scales by tracking air parcels, allowing for the explicit representation of entrainment and mixing on scales as small as a few centimeters, while entire clouds on scales as large as a few kilometers are covered simultaneously. Thus, we are able to represent different mixing scenarios such as homogeneous and inhomogeneous mixing naturally, applying only a minimum of assumptions. By highlighting how the mixing type changes during the lifecycle of a cloud, we outline how this scale-interactive approach can play a pivotal role in solving future problems in cloud physics.