Contribution ID: **52** Type: **not specified**

A gravity-driven inverse cascade controls the size distribution of raindrops

Friday 21 March 2025 12:15 (15 minutes)

Cloud droplets grow via vapor condensation and collisional aggregation. Upon reaching approximately ≈100 µm, their inertia allows them to capture smaller droplets during descent, initiating rain. Here, we show that raindrop formation is not primarily governed by gravity or thermal diffusion, but by a critical range of drop sizes (3–30 µm) where collisions are largely ineffective and controlled by van der Waals and electrostatic interactions. We identify several pathways to rain. The coalescence pathway, which is slow, involves the broadening of the drop size distribution across the 3–30 µm low-efficiency gap through collisions, until enough large individual droplets achieving efficient collisions have formed. The turbulence pathway relies on air turbulence to bring the droplets together at an increased rate, but we show that this pathway is unlikely. For all dynamical mechanisms, we demonstrate that the initiation time for rainfall occurs at the crossover between the broadening of the drop size distribution and the emergence of individual droplets large enough to trigger the onset of the rainfall cascade. We propose a reductionist, spatially homogeneous and stationary cloud model, the theoretical treatment of which is based on an analogy with the turbulent energy cascade. We show that this cloud is not just a simple idealisation, but can be used to describe in detail observations of drop size distributions, both in clouds and in rain on the ground, and their links with the various growth mechanisms. This surprising agreement opens up new avenues for the parameterisation of cloud microphysics in atmospheric models.

VAT

Session

Enhancing Process Understanding: Model parameter estimation

Preferred Contribution Type

Oral Presentation

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