Geophysical Research Abstracts, Vol. 8, 05138, 2006
SRef-ID: 1607-7962/gra/EGU06-A-05138

Improved Representation of Cloud Droplet Activation and Autoconversion and Their Implications for Estimating Aerosol Indirect Effects

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Accurate representation of the activation of aerosol particles to cloud droplets and autoconversion of cloud droplets to small raindrops is key to quantifying aerosol-cloud-radiation interactions and to estimating aerosol indirect effects, which suffer from large uncertainties and discrepancies between forward GCM estimates and observation-constrained results. New expressions are presented that relate CCN spectra and cloud properties (cloud droplet number concentration and droplet relative dispersion) directly to three common aerosol properties: aerosol number concentration, aerosol mass loading and aerosol relative dispersion. These new expressions also quantify the effect of cloud updraft velocity on cloud droplet concentration and droplet relative dispersion. It is shown that part of the uncertainty in current estimates of aerosol indirect effects is due to (1) the use of either aerosol number concentration or mass loading as the sole aerosol property in parameterizing droplet activation, and (2) to the neglect of the droplet relative dispersion. A new autoconversion parameterization is derived from first principles. This new parameterization unifies existing types of autoconversion parameterizations (e.g., Kessler-type and Sundqvist-type), and theoretically demonstrates that droplet relative dispersion, which has been largely neglected in prior treatments of autoconversion, controls the cloud-to-rain transition.