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Homogeneity of subgrid-scale cloud-clear air turbulent mixing and impact on microphysics in large-eddy simulation of boundary-layer clouds

D. Jarecka (1), W. W. Grabowski (2), H. Pawlowska (1), and H. Morrison (2)

(1) University of Warsaw, Institute of Geophysics, Faculty of Physics, Warsaw, Poland (dorota@igf.fuw.edu.pl), (2) National Center for Atmospheric Research, Mesoscale and Microscale Meteorology Division, Boulder, Colorado, United States

Mixing of cloud with dry environmental air leads to the evaporation of cloud water and may change significantly spectrum of cloud droplets. This may affect optical properties of clouds. Interactions between entrainment and cloud microphysics are poorly understood and they remain a significant source of uncertainty in aerosol indirect effects. The issue is whether the entrainment and mixing results in the reduction of only the droplet size (as in the homogeneous mixing), only the droplet number (as in the extremely inhomogeneous mixing), or both the number and the size (as in the inhomogeneous mixing). On the theoretical grounds, homogeneity of the small-scale mixing depends on the relative magnitude of the time scales for droplet evaporation and turbulent homogenization.

Results from direct numerical simulations of the interfacial cloud-clear air mixing suggest that a simple relationship exists between the ratio of the relevant time scales (of turbulent homogenization and droplet evaporation) and the slope of the mixing line on the diagram representing the relative change of the droplet number versus the change of the droplet radius. These results are used to design a relatively simple subgrid-scale representation of mixing characteristics in a large-eddy simulation (LES) model with a double-moment microphysics scheme (i.e. predicting the cloud water mixing ratio and cloud droplet number concentration). In this representation, the homogeneity of the subgrid-scale mixing is locally predicted at each model time step as a function of local conditions. Results from simulations of boundary layer clouds show that a wide range of mixing scenarios takes place in a cloud, and the range may change with height above the cloud base.

Changes of the cloud droplet spectrum also depend on the humidity of the environmental air entrained into a cloud. Results suggest that the entrained air is usually significantly more humid than the environmental air far away from the cloud edge. This limits the effect of subgrid-scale mixing on cloud microphysical characteristics.