

Aerosol-cloud-precipitation interactions in developing cumuli: in-situ, remote sensing and modeling studies in the vicinity of Houston, Texas

Greg M McFarquhar

Cooperative Institute for Severe and High-Impact Weather Research and Operations and School of Meteorology, University of Oklahoma, Norman OK, USA

Abstract

Anthropogenic aerosols have large impacts on Earth's radiative forcing through modification of cloud properties. Although earlier studies on cloud indirect effects concentrated on cloud brightening and precipitation suppression, it is now recognized that aerosol impacts are more complex and include various feedbacks that must be considered. But it is difficult to disentangle variations in clouds caused by aerosols from meteorological influences. Summer clouds near Houston, Texas form frequently in contrasting aerosol conditions (pristine over Gulf, continental west of Houston, and polluted east) and surface forcing (land-ocean interface). Here data acquired during two recent campaigns near Houston, the Experiment of Sea breeze Convection, Aerosols, Precipitation and Environment (ESCAPE) and Tracking Aerosol Convection Interactions Experiment (TRACER) are used to examine aerosol-cloud interactions in cumuli.

During ESCAPE two aircraft sampled 219 intense convective core segments along the coast of Texas and Louisiana. These observations are used to investigate aerosol impacts on the microphysics and dynamics of convective clouds through the aerosol induced condensational invigoration mechanism. This hypothesized mechanism requires the presence of large supersaturations to allow for nucleation of ultrafine aerosols into cloud condensation nuclei (CCN) at much higher levels above cloud base than typically occur. With current technology, it is challenging to directly measure supersaturation, which is derived here from microphysical observations assuming quasi-steady state conditions (S_{QSS}) in updrafts. Increases in S_{QSS} and updrafts with height above cloud base, as well as increased occurrence of S_{QSS} above 1% in pristine compared to polluted conditions indicate potential for invigoration. However, only one extreme peak S_{QSS} of nearly 10% in an updraft of 21 m s^{-1} in the mixed-phase region of a storm was noted, showing occurrence of S_{QSS} larger than 5% was quite rare. These observations are guiding sampling strategies for future planned measurement campaigns to further assess invigoration. Additional analysis with TRACER data uses a random forest algorithm to identify in situ vertical velocity, temperature and surface fine-mode aerosol mass concentration as the most important environmental factors influencing cloud microphysical properties. Precipitable water vapor 2–6 km lapse rate, 0–8 km bulk shear, and fine aerosol mass ($Mass_f$) were identified as key predictors of cell lifetime. Parcel model simulations are shown to successfully replicate the observed dependencies, with enhanced CCN activation being more important than changes in collision-coalescence rates in affecting cloud properties.