An observational study on the vertical development of shallow cumulus and congestus clouds and its sensitivity to aerosol concentrations

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Marine shallow cumulus and congestus clouds are important for radiation and the water cycle. Such clouds are particularly susceptible to aerosol and climate perturbations, but are generally not well represented by climate models. Combinations of high-resolution models and observations are needed to better understand the sensitivity of the micro- and macrophysical properties of cumulus and congestus clouds to aerosol and dynamics variations. However, satellite retrievals of microphysical properties of such clouds are generally highly biased or uncertain due to, e.g., 3-dimensional radiative transfer effects and mixed-phase or supercooled cloud tops. Here, we use airborne polarimetry and in situ observations from NASA's Cloud, Aerosol and Monsoon Processes Philippines Experiment (CAMP^{2}Ex) to explore the microphysics of shallow cumulus and congestus as a function of altitude, aerosol concentrations and environment. We show that the polarimetric retrievals of cloud drop size distributions and number concentrations agree very well with in situ observations. The observations show that liquid water path generally scales with cloud top height squared as expected, while droplet number concentrations decrease rapidly with altitude. The droplet number concentrations and size distributions are shown to highly correlate with aerosol number concentrations retrieved by the polarimeter in the vicinity of clouds. For moderately high aerosol number concentrations, droplet size distributions widen as cloud top height increases and eventually develop a bi-model structure indicative of collision-coalescence processes. For very low aerosol number concentrations, wide droplet size distributions are observed at low cloud tops already indicating that in such cases collision-coalescence processes occur very early in the cloud lifecycle. NASA's PACE satellite mission, to be launch in early 2024, includes a hyperspectral imager and two polarimeters, enabling similar accurate and rich aerosol and cloud observations as presented here on a pixel scale of about 5x5 km^2. While PACE's retrievals are expected to be a large leap forward, to observe the cloud microphysics at the resolution at which processes occur, spatial resolutions below 100 m are necessary. We will discuss challenges and possibilities for such high-resolution multi-angle polarimetric observations from orbit.

Keywords: aerosol, clouds, microphysics, airborne, future missions