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Observed correlations between aerosol and cloud properties in an Indian Ocean trade cumulus regime

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There are multiple factors which affect the micro- and macrophysical properties of clouds, including the atmospheric vertical structure and dominant meteorological conditions in addition to aerosol concentration, all of which may be coupled to one another. In the quest to determine aerosol effects on clouds, these potential relationships must be understood. As bio- and fossil fuel combustion has increased in southeast Asia, corresponding increases in atmospheric aerosol pollution have been seen over the surrounding regions. These emissions notably include black carbon (BC) aerosols, which absorb rather than reflect solar radiation, affecting the atmosphere over the Indian Ocean through direct warming in addition to modifying cloud microphysical properties.

The CARDEX (Cloud, Aerosol, Radiative forcing, Dynamics EXperiment) field campaign was conducted during the winter monsoon season (February and March) of 2012 in the northern Indian Ocean, a region dominated by trade cumulus clouds. During CARDEX, small unmanned aircraft were deployed, measuring aerosol, radiation, cloud, water vapor fluxes, and meteorological properties while a surface observatory collected continuous measurements of atmospheric precipitable water vapor (PWV), water vapor fluxes, surface and total-column aerosol, and cloud liquid water path (LWP). We present observations which indicate a positive correlation between aerosol and cloud LWP only when considering cases with low atmospheric water vapor ($PWV < 40\,\mathrm{kg\,m^{-2}}$), a criterion which acts to filter the data to control for the natural meteorological variability in the region. We then use the aircraft and ground-based measurements to explore possible mechanisms behind this observed aerosol–LWP correlation. The increase in cloud liquid water is found to coincide with a lowering of the cloud base, which is itself attributable to increased boundary layer humidity and a shallower surface mixed layer in polluted conditions. High pollution is found to correlate with both higher temperatures and higher humidity measured throughout the boundary layer. A large-scale analysis, using satellite observations and meteorological reanalysis, corroborates these covariations: high-pollution cases are shown to originate as a highly polluted boundary layer air mass approaching the observatory from a northwesterly direction. The source air mass exhibits both higher temperatures and higher humidity in the polluted cases. While the warmer temperatures may be attributable to aerosol absorption of solar radiation over the subcontinent, the factors responsible for the coincident high humidity are less evident: the high-aerosol conditions are observed to disperse with air mass evolution, along with a weakening of the high temperature anomaly, while the high-humidity condition is observed to strengthen in magnitude as the polluted air mass moves over the ocean toward the site of the CARDEX observations. Potential causal mechanisms of the observed correlations, including meteorological or aerosol-induced factors, are explored, though future research will be needed for a more complete and quantitative understanding of the aerosol–humidity relationship.