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Exploring satellite-derived relationships between cloud droplet number concentration and liquid water path using large-domain large-eddy simulation

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Important aspects of the adjustments to aerosol-cloud interactions can be examined using the relationship between cloud droplet number concentration (N_d) and liquid water path (LWP). Specifically, this relation can constrain the role of aerosols in leading to thicker or thinner clouds in response to adjustment mechanisms. This study investigates the satellite retrieved relationship between N_d and LWP for a selected case of mid-latitude continental clouds using high-resolution Large-eddy simulations (LES) over a large domain in weather prediction mode. Since the satellite retrieval uses the adiabatic assumption to derive the N_d (N_{Ad}), we have also considered N_{Ad} from the LES model for comparison. The joint histogram analysis shows that the N_{Ad}-LWP relationship in the LES model and the satellite is in approximate agreement. In both cases, the peak conditional probability (CP) is confined to lower N_{Ad} and LWP, and the corresponding mean LWP shows a weak relation with N_{Ad}. In contrast, at higher N_{Ad} (> 50 cm^{-3}), the CP shows a larger spread; consequently, the mean LWP increases non-monotonically with increasing N_{Ad} in both cases. However, the N_{Ad}-LWP relation lacks, in particular, the negative sensitivity at higher N_{Ad}. This case over continent thus behaves differently compared to previously-published analysis of Oceanic clouds using satellite retrievals. Additionally, our analysis illustrates a regime dependency (marine and continental) in the N_{Ad}-LWP relation from the satellite retrievals. When considering the relationship of the simulated cloud-top N_d, rather than N_{Ad}, with LWP, the result shows a much more nonlinear (positive and negative) relationship and is inconsistent with the satellite retrievals. However, the difference is much less pronounced when the sensitivity (N_d-LWP) is considered for shallow stratiform (adiabatic) than convective (sub-adiabatic) clouds. Comparing local vs large-scale statistics from satellite data shows that continental clouds exhibit only a weak nonlinear N_d-LWP relationship. Hence a regime-based N_d-LWP analysis is even more relevant when it comes to continental clouds and its comparison to satellite retrievals.