Machine Learning (ML) derived CCN concentrations provide better constraints on the first aerosol indirect effect than aerosol optical properties

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The first indirect effect of aerosols on cloud reflectivity, primarily through an increase in cloud droplet number concentration (N_d), remains one of the most uncertain components of anthropogenic radiative forcing [1,2]. The strength of the aerosol first indirect effect is quantified using relationships between aerosol amount and N_d. For large-scale assessments, these relationships have historically been observed via satellites and serve as critical constraints for climate models calculating radiative forcing from aerosol-cloud interactions (ACIs) [3,4]. They have primarily relied on measurements of aerosol optical depth (AOD) or aerosol index (AI), both of which are column-integrated proxies for Cloud Condensation Nuclei (CCN) concentration. However, these proxies may not be directly relevant for studying ACIs, as the aerosol at cloud base is more relevant. Additionally, aerosol optical properties are influenced not only by particle concentration but also by size distribution. Since CCN represents only a fraction of the aerosol size distribution and varies with particle activation size, there may not always be an obvious correlation between CCN and optical properties, introducing uncertainties in estimating indirect effects when using aerosol optical properties.

To address this issue, we have developed a machine learning approach to estimate the vertical profile of CCN concentration from airborne High Spectral Resolution Lidar 2 (HSRL-2) data, using collocated in situ CCN observations as truth to train a neural network model [5]. Reanalysis data were used to enhance model performance. Our algorithm predicts vertically resolved CCN concentration within a mean relative uncertainty of 20%. Utilizing this new CCN product, we investigate ACIs along with cloud properties retrieved from the Research Scanning Polarimeter (RSP) collected from multiple airborne campaigns. Our preliminary findings indicate that employing our CCN product consistently constrains both N_d and cloud effective radius, R_{eff}, for a wide range of cloud liquid water paths. The separation of indirect effects for different aerosol types indicates the expected differences in cloud-altering aerosol properties. Overall, our approach using ML-derived CCN yields tighter constraints and physically more plausible insights into ACIs than the use of aerosol optical properties.

References

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