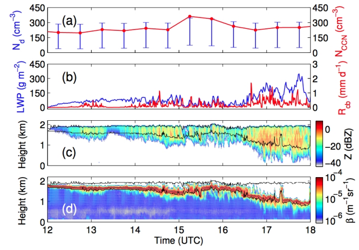
Assessing Aerosol Impacts on Drizzle Intensity and Frequency from AMF Data

Research Highlight

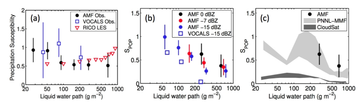
Aerosols have a strong effect on climate through their potential to modify the properties of warm clouds. An increase in aerosol loading could reduce drizzle production; modulate the stability of the boundary layer; and change cloud properties, lifetime, and extent, which is referred to as the second aerosol indirect effect. Recent studies showed that global models significantly overestimate drizzle frequency, calling into question the fidelity with which the second indirect effect of aerosol is captured. Here, we examine aerosol-cloud-drizzle interactions, through synergy between aerosol observing systems and active and passive remote-sensing instruments from the Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF) deployments in the Black Forest, Germany, April-December 2007 and at the Azores from June 2009 to December 2010.

Figure 1 shows an example of AMF measurements at the Azores for a single-layer stratocumulus cloud. The radar and lidar returns show clouds capped at around 2 kilometers, and cloud geometric thickness deepened gradually from 0.3 kilometers to 1 kilometer during the period. During this deepening, drizzle rate at cloud base R_cb (mm d^–1) correlated well with liquid water path (LWP; g m^–2). The cloud condensation nuclei number concentration N_CCN (cm^–3), an aerosol proxy, fluctuated between 200 and 350 c^–3, representing a typical clean environment during the Azores campaign. After selecting single-layer warm clouds as shown in Figure 1, a 28-day long data set was obtained out of 19 months of available observations from the combined AMF deployments, which led to several key findings. First, R_cb statistically significantly increases with LWP and decreases with N_CCN support the concept of drizzle suppression by increasing aerosol and agreeing with many other observational and modeling studies. R_cb is proportional to LWP^(1.68±0.05) and N_CCN^(-0.66±0.08), with an assumed supersaturation of 0.55 percent, which can help evaluate and constrain precipitation rate in models. Second, the precipitation susceptibility to N_CCN ranges between 0.5 and 0.9 and generally decreased with LWP (as shown in Figure 2a). Although this feature agrees well with large-eddy simulations of shallow cumulus, particularly for LWP between 100 and 300 g m^–2, there is still a large degree of uncertainty in our precipitation susceptibility, which can be reduced by including more observations. In addition, analysis and intercomparisons of precipitation susceptibility to other aerosol proxies, such as cloud droplet number concentration, aerosol optical depth, and aerosol index could help resolve outstanding discrepancies among various studies.

Finally, this study highlights the difference in the POP susceptibility to N_CCN (S_POP) between observations from ground-based, aircraft and satellites, and simulations. S_POP from AMF data is higher than that from satellites, and equivalent with aircraft observations and high-resolution simulations (as shown in Figure 2b and 2c). This indicates that the high-resolution multi-scale climate model may have already had the ability to represent aerosol-cloud-precipitation interactions properly, and may not overestimate the response of LWP to aerosol perturbation as previously thought. More experiments, such as intercomparison between high-resolution ground-based measurements and simulations over fixed sites for a longer time period, will provide further confirmation.



A subset of AMF measurements on November 29, 2009, at the AMF deployment on the Azores. Time series of: (a) cloud condensation nuclei number concentration (N_CCN) and the potential range of cloud droplet number concentration (N_d); and (b) cloud-base drizzle rate (R_cb) and liquid water path (LWP). Panels (c) and (d) are time-height plots of radar reflectivity (Z) and attenuated lidar backscatter (#), respectively. The black lines in the panels show cloud top and cloud base.



(a) Precipitation susceptibility to N_CCN as a function of LWP in AMF data, and to cloud droplet number concentration in Variability of the American Monsoon Systems Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS) data and large-eddy simulations from the Rain in Cumulus over the Ocean (RICO) campaign. Error bars in AMF data represent 95 percent confidence intervals. S_POP from AMF data, compared to (b) S_POP from the VOCALS Regional Experiment (VOCALS-Rex) campaign and (c) S_POP from CloudSat and the Pacific Northwest National Laboratory (PNNL) multi-scale modeling framework (MMF) outputs.

Reference(s)

Mann JA, JC Chiu, RJ Hogan, EJ O'Connor, TS L'Ecuyer, TH Stein, and A Jefferson. 2014. "Aerosol impacts on drizzle properties in warm clouds from ARM Mobile Facility maritime and continental deployments." Journal of Geophysical Research – Atmospheres, 119, doi:10.1002/2013JD021339.

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Cloud-Aerosol-Precipitation Interactions