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Impact of cloud-top entrainment timescale on smoke-cloud interaction over the southeast Atlantic

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From July to October, smoke from biomass burning in southern Africa is lofted over the southeast Atlantic and overlies the extensive deck of stratocumulus clouds there. There are numerous radiative implications of this smoke-cloud colocation, including direct (scattering and absorption), semi-direct (thermodynamic), and indirect (microphysical) effects. Smoke must be entrained into the marine boundary layer (MBL) for indirect effects to occur, meaning the vertical distribution of the smoke, in particular its lowest extent and whether it is in contact with the clouds, is critically important for assessing the radiative effects of smoke in this region. Known satellite and model biases lead to an underestimation and overestimation, respectively, of smoke-cloud contact. However, even if the vertical distribution were known with perfect accuracy, the relatively long timescale (order of days to a week) for entraining free tropospheric (FT) air down into the MBL can confound observations.

We present a combination of in-situ aircraft, model, and geostationary satellite observations from the September 2016 and August 2017 NASA ORACLES (ObseRvations of Aerosols above CLouds and their intEractionS) deployments in the southeast Atlantic to illustrate this challenge and the opportunity for studying the southeast Atlantic in a more “Lagrangian” sense. In general, smoke measurements are well-correlated with observations of cloud microphysics in the MBL but very weakly correlated in the FT (defined as within 100 m of cloud top). This casts doubt on the assumption that above cloud and below cloud smoke properties are near equilibrium that has been made in previous work in the area, for example using the A-train constellation of satellites.

A closer look at two representative flights reveals that very similar instantaneous snapshots of smoke-cloud contact can have markedly different cloud and MBL characteristics due to the history of prior entrainment. In-field model data is subset around back trajectories from the flight observations to show that one flight had been previously entraining smoke-laden air for several days whereas the other had only come into contact with smoke recently, possibly in connection with mid-latitude synoptic conditions. Carbon monoxide measurements rule out an alternative explanation of precipitation (coalescence) scavenging, although drizzle is likely an important factor for other flights and for the region more generally. We propose that adopting a Lagrangian framework accounting for both sources and sinks of aerosol following the MBL flow will lead to a more accurate assessment of aerosol-cloud interactions over the southeast Atlantic.