# Detecting Precipitation and Aerosol Removal from the African Boundary Layer during ORACLES using Water Vapor Heavy Isotope Ratios

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## Introduction

Aerosol radiative forcing is a important source of uncertainty in anthropogenic climate forcing (IPCC 2013). Biomass burning aerosols (BBA) are a key source of aerosols, and central/southern Africa accounts for almost one third of BBA emissions. Black carbon (BC) is a component of BBA with potentially the strongest climate forcing effects. The atmospheric lifetime of BC determines its total radiative impacts. BC is mainly removed via wet scavenging by clouds and precipitation. Therefore, quantifying scavenging is important for climate models.

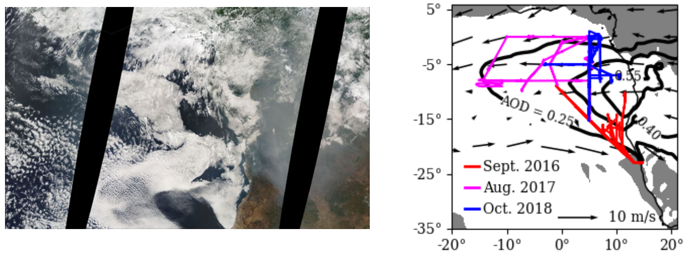


**Figure 1.** (left) MODIS imagery of a BBA plume advecting off Africa in the free troposphere. (right) Flight tracks during NASA ORACLES to sample BBA plumes during three IOPs. MERRA Sept. 2016 mean aerosol optical depth and 500 hPa winds are overlain.

The analysis here explores a novel method for detecting integrated aerosol scavenging in free tropospheric (FT) airmasses using aircraft-measured in-situ heavy water isotope ratio measurements during the NASA ORACLES campaign. It serves as an initial step towards quantifying scavenging with this technique in the future.

## Acknowledgments

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## Methods

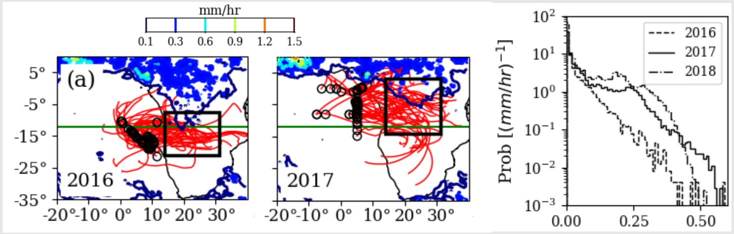


**Figure 2.** (a) HYSPLIT back-trajectories ending at aircraft sampling locations overlain with NASA GPM monthly mean rainfall maps. (b) PDFs of rainfall along the trajectories for each IOP.

### HYSPLIT back-trajectories and co-location with rainfall

During FT sampling, aircraft time, lat/lon, and altitude were periodically used for lagrangian back-trajectories (Fig. 2a). Co-locating points along trajectories with monthly mean rainfall data show for example that 2016 airmasses passed over regions of Africa with lower rainfall than the other two IOPs (Fig. 2b).

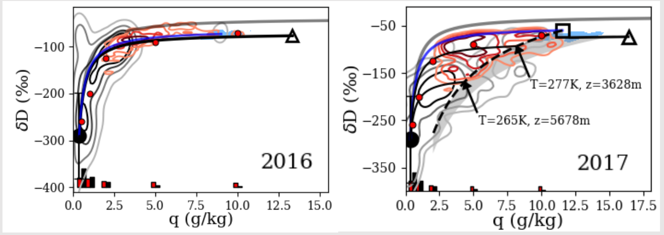


**Figure 3.** PDFs of aircraft in-situ (q) vs. water vapor ratio of D/H (dD-notation). Blue region is near-surface data. Red vs. grey PDFs denote FT air with high vs. low carbon monoxide (used for a separate study). Curves show simple mixing (solid) and precipitation (dashed) processes.

### Mixing vs. precipitation on a (q, dD) diagram

Airmass water concentration (q) and its D/H isotope ratio (δD) take different relationships depending on the hydrologic processes occurring. In two simple cases, air in the FT can be modelled as (1) a mixture of near surface air and very dry air (Fig. 3, blue curve), or (2) precipitating convection which detrains and mixes with dry FT air (following the dashed curve then diverting to one of the solid curves). Figure 3 shows that isotopic evidence of precipitation is stronger in the 2017 IOP than for 2016, agreeing with the back-trajectory analysis.

## Results

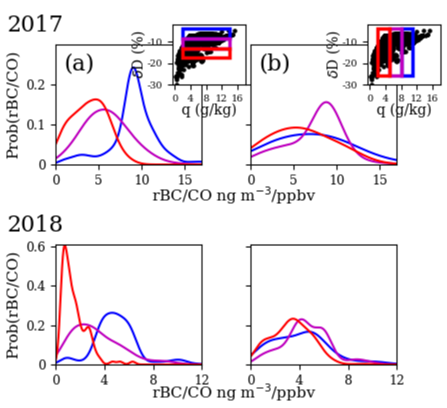


**Figure 4.** (top row) BC/CO PDFs for 2017 FT data grouped by q, dD regions in the respective insets. (bottom row) same as top but for the 2018 IOP. The 2016 data are not used since there is minimal signs of precipitation during that IOP.

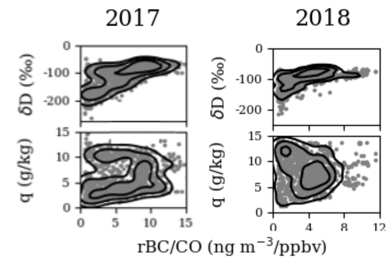


**Figure 5.** Scatter plots of dD vs. BC/CO (top row) and q vs. BC/CO (bottom) for the 2017 and 2018 IOPs.

### Black carbon – carbon monoxide ratios as evidence of scavenging

BC becomes hygroscopic with age and can be scavenged. However, carbon monoxide (also present in BBA plumes) has low water solubility. Therefore, the ratio BC/CO should decrease as BC is scavenged.

Figure 4 shows that when ORACLES data is grouped by isotopic evidence of precipitation (a, inset), PDF peaks of BC/CO shift towards lower values as expected. In comparison, an orthogonal grouping of the data (b) shows no such trend.

### Direct correlation between dD and BC/CO

The q, dD diagram for the 2017 IOP (Fig. 3) shows that for q > 1.5 g/kg, the change in dD during detrainment and mixing is small in comparison to its change during the precipitation process. That is, dD primarily reflects total precipitation; subsequent mixing does not erase this signal.

Therefore, we hypothesized a direct correlation between dD and BC/CO in the FT. Figure 5 (top row) shows that this is the case (correlations of 0.71 and 0.57 for 2017 and 2018 IOPs respectively). As a control, there is little correlation between q and BC/CO (< 0.2 for both IOPs).