Bridging Biomass Burning Field Observations with Laboratory Studies

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Biomass Burning Breakout
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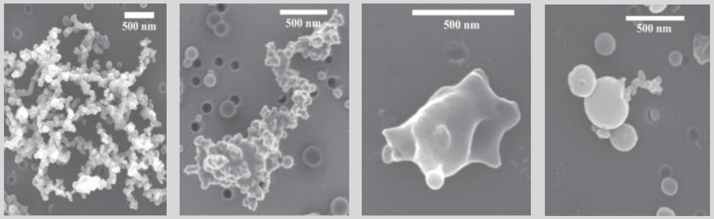
Climate Impacts of Biomass Burning (BB) Emissions and Black Carbon (BC) Aerosols

- **Large source of Carbon to the atmosphere**
  - Particles: Black Carbon (BC), Organic Carbon (OC), Brown Carbon (light-absorbing in the visible and UV)
  - Gases: CO, CO_2
  - Largest source: Southern Africa

SEM Images of 4 Types of BC in BB
China et al., Nature Communications, 2013



Bare Thin Thick Inclusion

- **Largest source of BC globally – most highly light absorbing particle**
  - 6-9 Tg/year with up to ~0.6 W/m^2 atmospheric warming *IPCC, 5AR*
  - 2^{nd} most important in global warming, most uncertain, underestimated *Bond, JGR, 2013*
  - Expected to increase in the future (increased drought and extreme events)

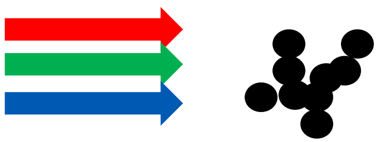
- **BC directly warms the atmosphere, OC cools**
  - Mixtures in BB – complex climate impacts (indirect effects: clouds, precipitation)
  - Aerosol mixtures are highly variable which results in uncertainties in the climate impacts
    - Internal versus external mixtures, morphology, hygroscopicity, physical and optical properties, etc.
  - BB Emissions age in time – changes properties of the aerosol (physical, optical, chemical)

Carbonaceous Aerosol Optical Properties + Direct Effects

- **"Model" Soot: Fresh fractal, uncoated/denuded**

Cross et al., ACP, 2010

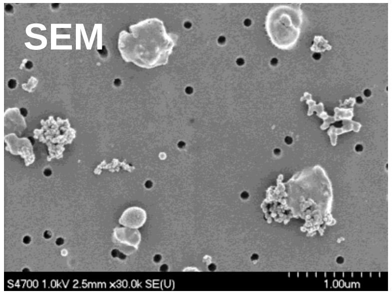
781 nm
532 nm
405 nm

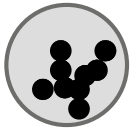


Absorption Angstrom Exponents (AAE)

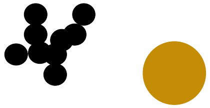
$$\frac{\beta_{\lambda}}{\beta_{\lambda_0}} = \left(\frac{\lambda}{\lambda_0}\right)^{-AE}$$

- **Ambient Mixtures are heterogeneous – internal and external mixtures**

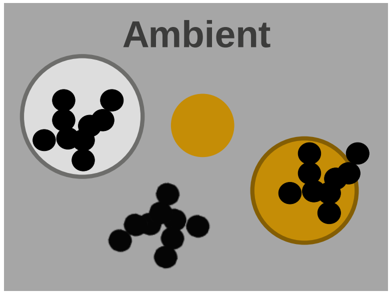




Internal mixtures (clear coatings)



External mixtures (Brown Carbon)

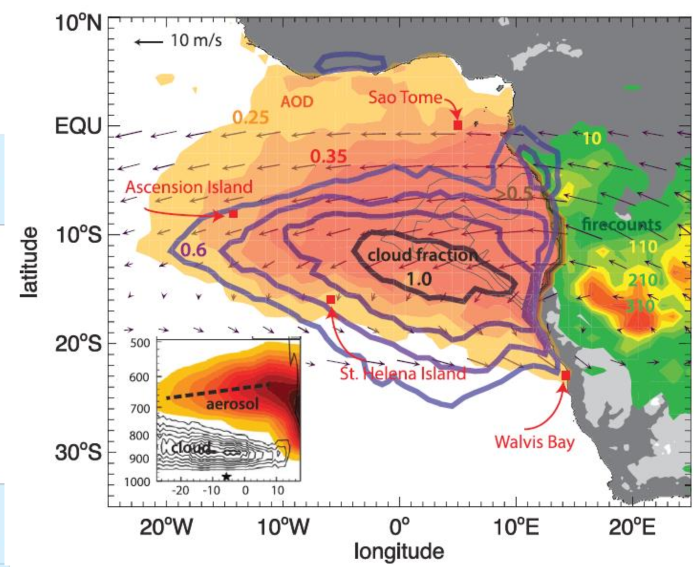


- **Coatings and Mixing with Brown Carbon (BrC)**
  - Enhances Absorption → "How much?"
  - Changes the optical properties, e.g. Absorption Angstrom Exponent (AAE)
  - How is hygroscopicity (and the ability to form cloud droplets) affected?

Cappa et al., Science, 2012
Liu, Aiken et al., Nature Comm., 2015

Layered Atlantic Smoke Interactions with Clouds (LASIC)

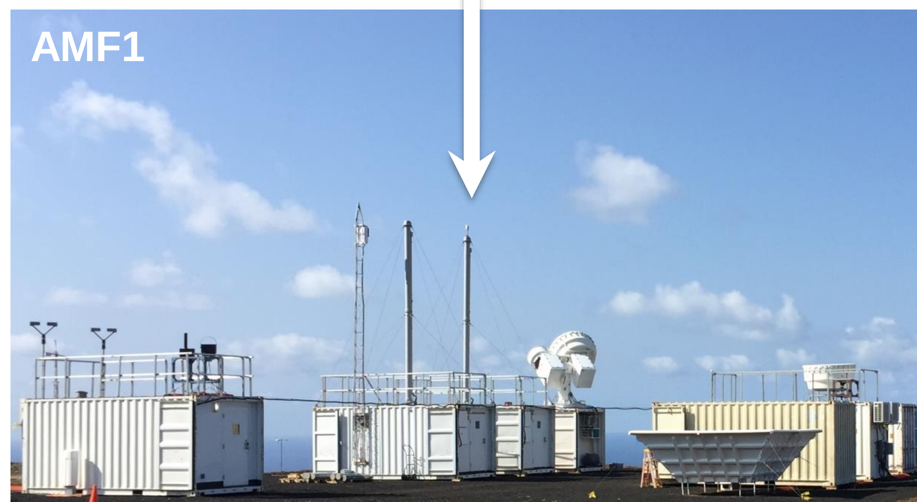
- **Southern Africa and Biomass Burning (BB)**
  - Largest source of BB Emissions Globally
  - Land Clearing Wood and Grassland Fires
  - BB Season is from June to November
- **LASIC Measurements**
  - Ascension Island in the Southern Atlantic Ocean
  - June 2016 – Oct. 2017
  - Two Southern African BB Seasons



P. Zuidema, BAMS, 2016

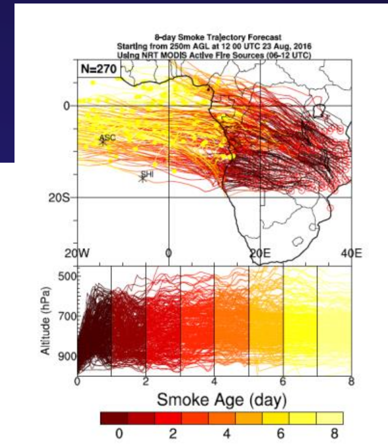
ARM Mobile Facility (AMF1) at LASIC

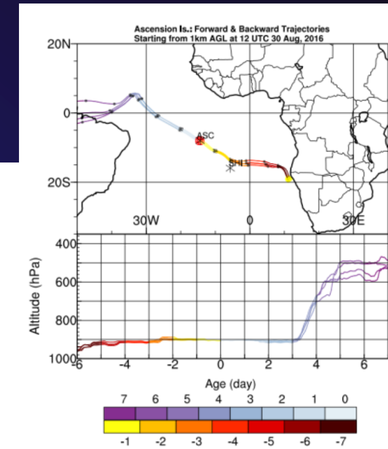
- **Aerosols and Trace Gases in the Aerosol Observing System (AOS) and Mobile AOS (MAOS)**
  - Surface: Particle number, size, optical properties, Black Carbon (BC) content, non-refractory chemical composition, hygroscopicity and water uptake properties, Nitrogen Oxides, Combustion tracers
    Organic Compounds
  - Column: Sunphotometer
- **Atmospheric Profiling**
  - Microwave, High Frequency, and 3-Channel Radiometers
- **Clouds**
  - Lidar, Cloud Radars (K- and W-band), Total Sky Imager, Ceilometer
- **Radiometers**
- **Surface Meteorology**

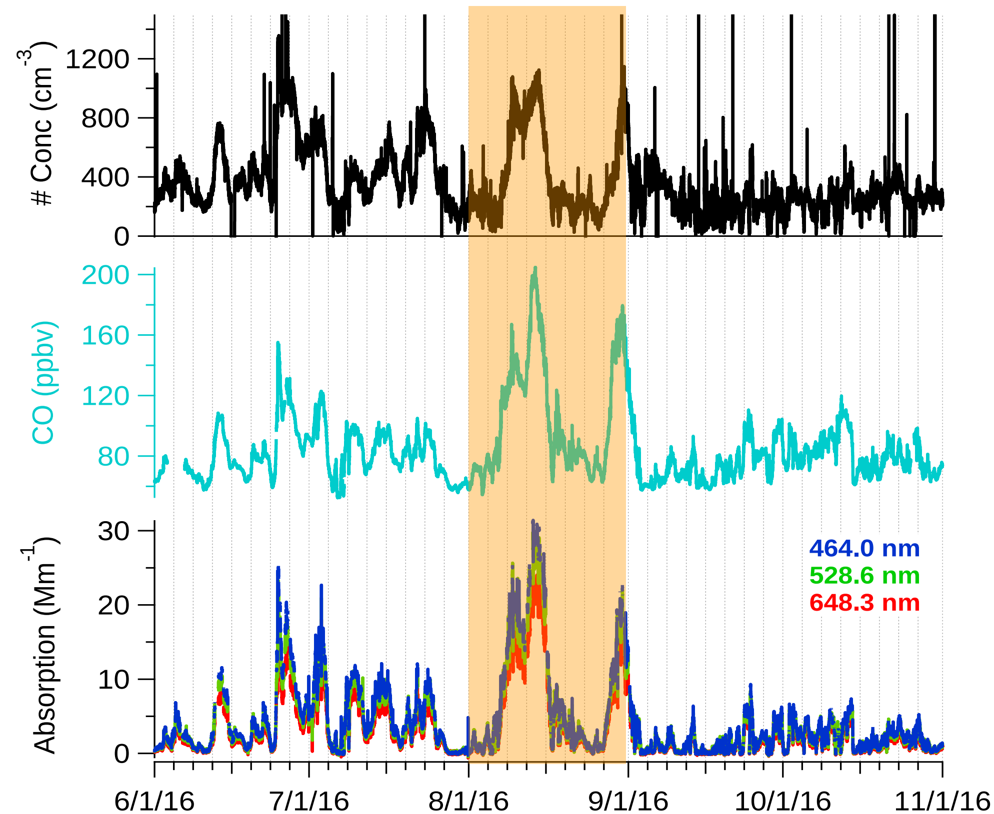


Early Results from LASIC

- **June – October, 2016**
  - 5 months of 1 minute data
  - Submicron aerosol (<1 µm diameter)
  - Largest plumes in August
  - BB trajectory analysis (Adebiyi/U. Miami)
- **Aerosol Number, CO, and Particulate Absorption**
  - Similar trends in the time series
- **3 Wavelength Absorption**
  - Spans the visible range
  - Signals reach 30 Mm^{-1} in August
  - Peak Biomass Burning season in Southern Africa

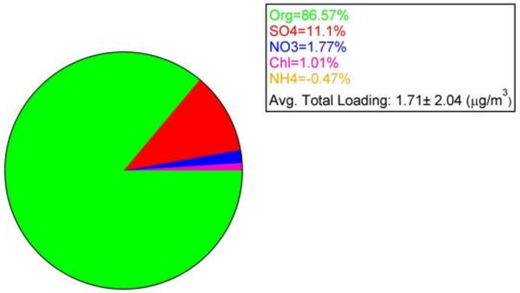






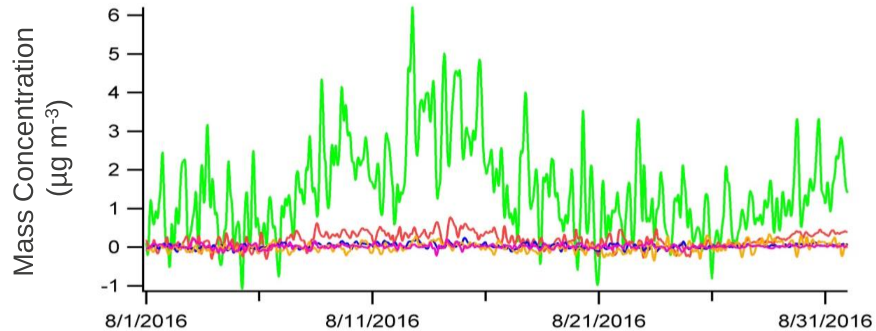
LASIC August Biomass Burning Plumes

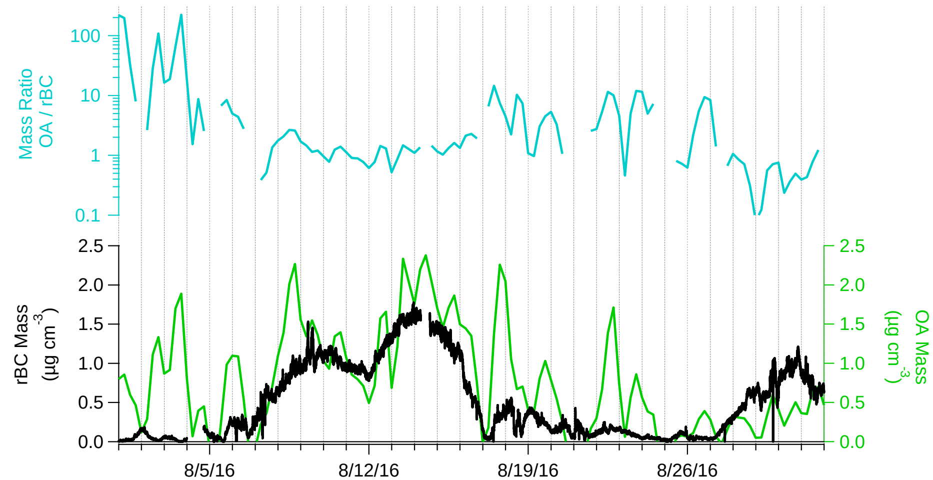
- **Non-Refractory Aerosol Mass**
  - Dominated by Organics (OA)
  - Average Total Mass: 1.7 µg m^{-3}

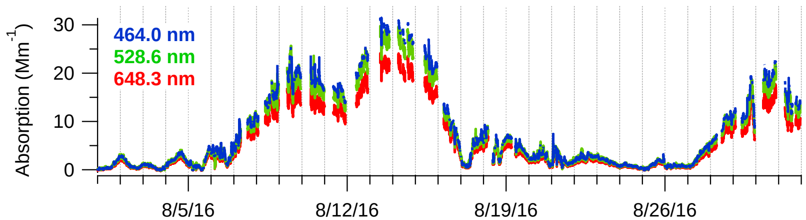


  - Preliminary (PMF) Analysis
    - Most of the Organics are Aged/Oxidized
    - Aged BB ~ *S. Zhou et al., ACPD, 2016*

- **Bulk Chemical Information**
  - rBC and OA dominate the submicron mass and are of similar magnitudes in the BB plumes







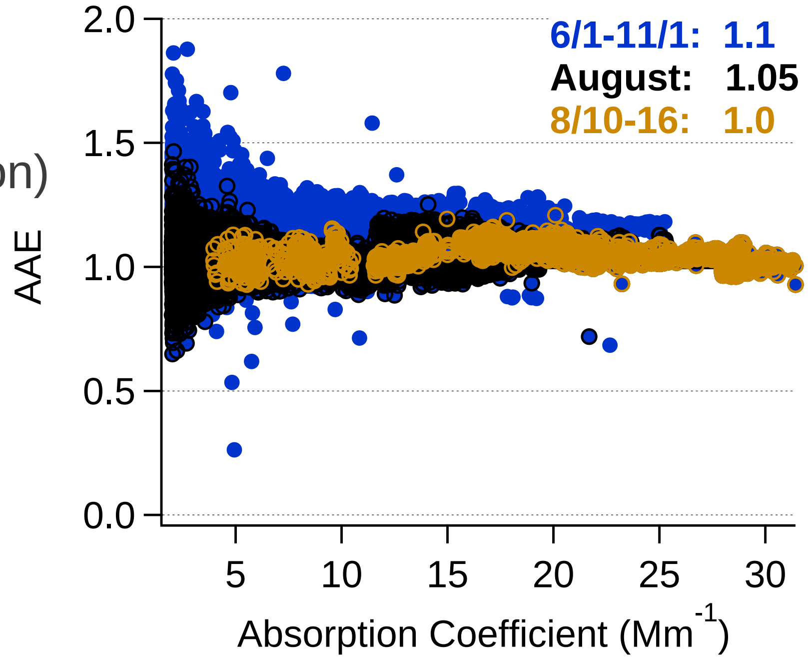
Aerosol Optical Properties: Absorption Angstrom Exponent (AAE) and Single Scatter Albedo (SSA)

- **AAE indicates most of the absorbance is from BC**
  - Values ~1 (higher values indicate the presence of BrC)
  - Where is the Brown Carbon signature?

$$\frac{\beta_{\lambda}}{\beta_{\lambda_0}} = \left(\frac{\lambda}{\lambda_0}\right)^{-AE}$$

- **Low SSA ranges ≤ 0.85**
  - Indicates a mixture (internal/external)
  - Not pure BC
  - Lower in the plumes (higher BC fraction)

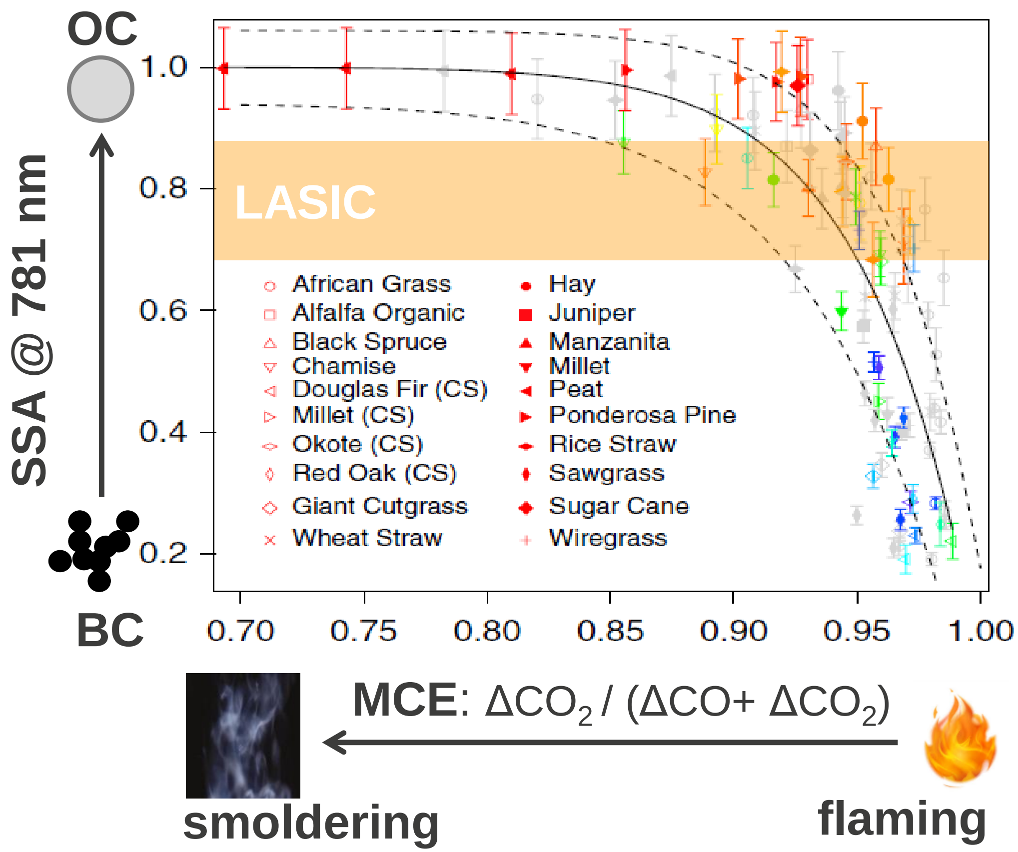
$$SSA = \frac{\beta_{sca}}{(\beta_{sca} + \beta_{abs})}$$



Single Scatter Albedo (SSA) Parameterized by Fire-Integrated Modified Combustion Efficiency (MCE)

- **FLAME-IV Lab data**
- **Particle Optical properties correlate with fire properties**
  - MCE: combustion
  - SSA: particle type
  - Parameterization to determine SSA from MCE

S. Liu, A.C. Aiken, et al., GRL, 2014

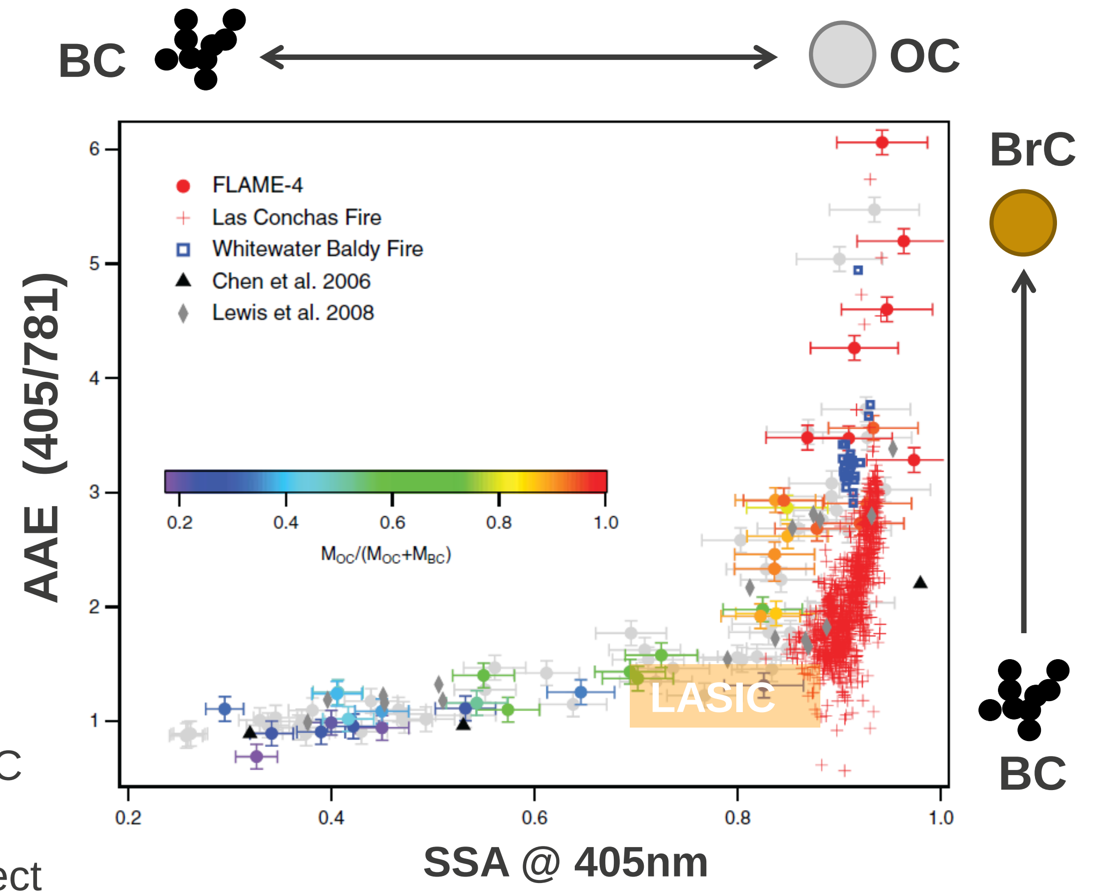


- **Grasses (Savannas)**
  - More flaming - Lower SSA

Saleh, R. et al., Nature Geoscience, 2014

Laboratory and Near-field Biomass Burning Data

- **SSA**
  - Bare BC ~ 0.4
  - OC ~ 1.0 (non-absorbing)
- **AAE**
  - BC ~ 1.0 (λ independent)
  - BrC > 1
- **Ambient US Forest Fires**
  - SSA ~ 0.85 – 0.95
  - AAE ~ 1 – 4
- **Preliminary LASIC BB**
  - Lower SSA and AAE
  - Absorption dominated by BC
  - Higher BC fraction than US Biomass Burning (more direct absorption per particle)



S. Liu, A.C. Aiken, et al., GRL,2014

BB Research and DOE

- **Known: Large Variability in BB Emissions measured in the atmosphere**
- **Need: Better understanding of BB aerosol sources and processing**
  - Characterization of the emission at the source (optical, chemical, physical, hygroscopic)
  - Refine chemistry and physical changes occurring in the atmosphere
  - Better constraint on absorption (including brown carbon) and overall optical properties

- **Field Measurements**
  - Sample regional and source-specific differences (optical, chemical, physical, hygroscopic)
    - e.g. Cappa et al., Science 2012, Liu et al., Nature Commun. 2015 - BC enhancement
  - Capture dynamic processes – internal, external mixing, photochemistry, etc.
  - Closure studies
  - Need for ambient aerosol *in situ* measurements – ground (statistics), air (vertical profiles), and improving the link between them

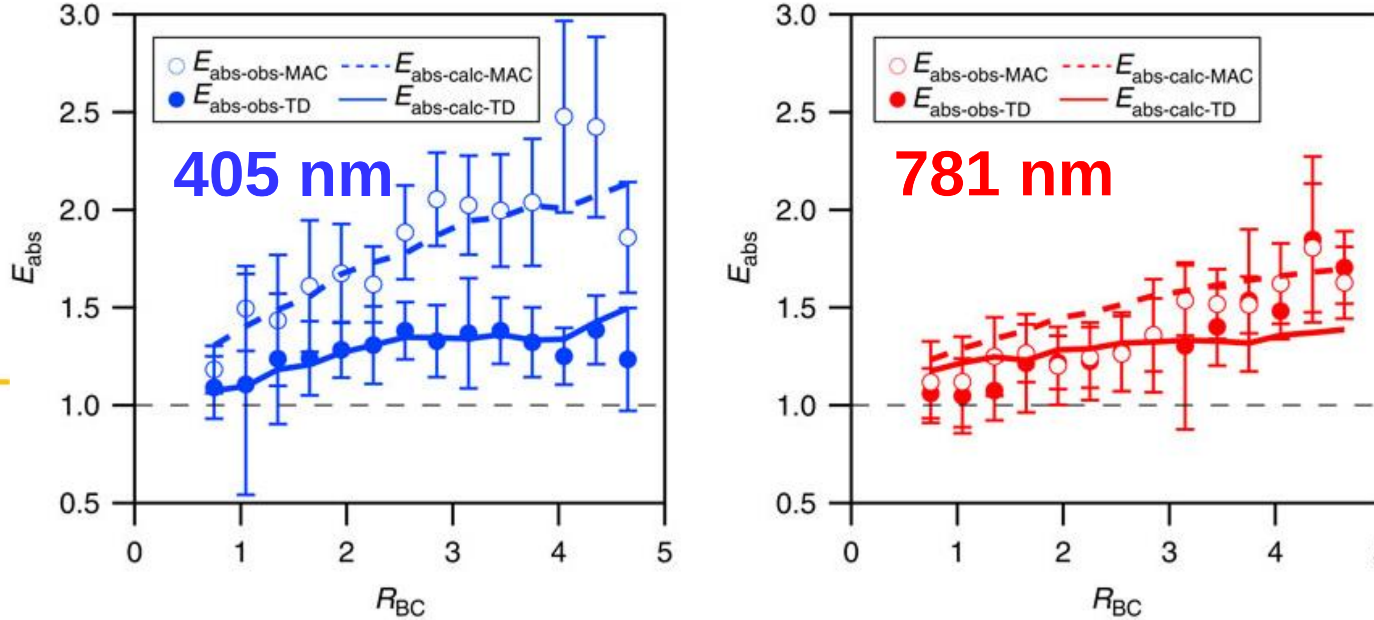
- **Laboratory Studies**
  - Controlled study of field observations, e.g. SAAS, BC, FLAME, etc.
  - Collaborative studies hosted at DOE facilities, e.g. PNNL environmental chamber

Backup Slides

BC Coatings and Enhancements – Detling/ClearfLo (UK) Differences – Regions/Sources

http://www.clearflo.ac.uk/

Detling Site:
Downwind of London and Continental European Outflow



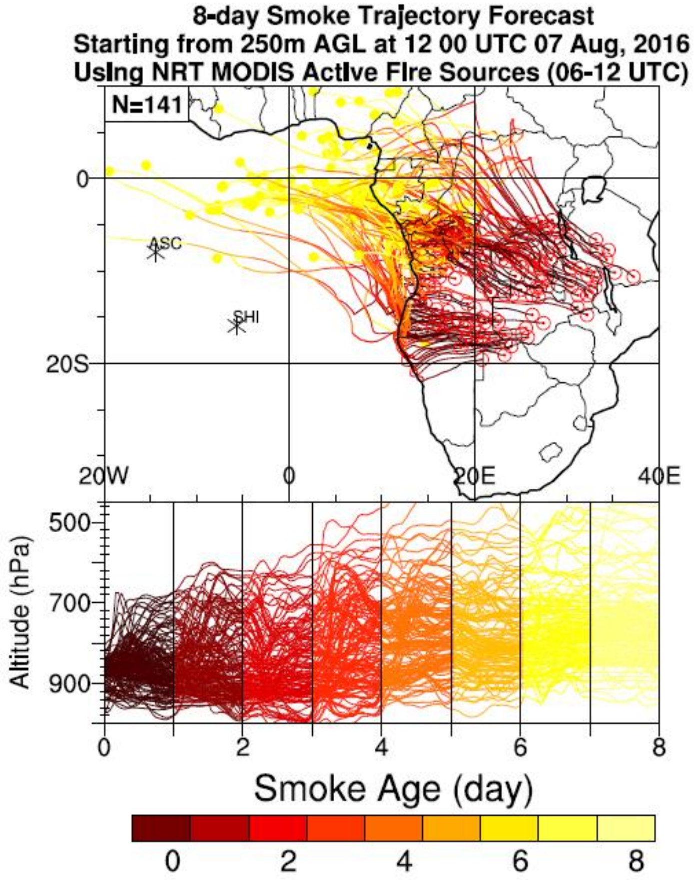
- **Winter measurements and Closure Study (Mie Theory): Regional and continental European emissions from wood burning and diesel**

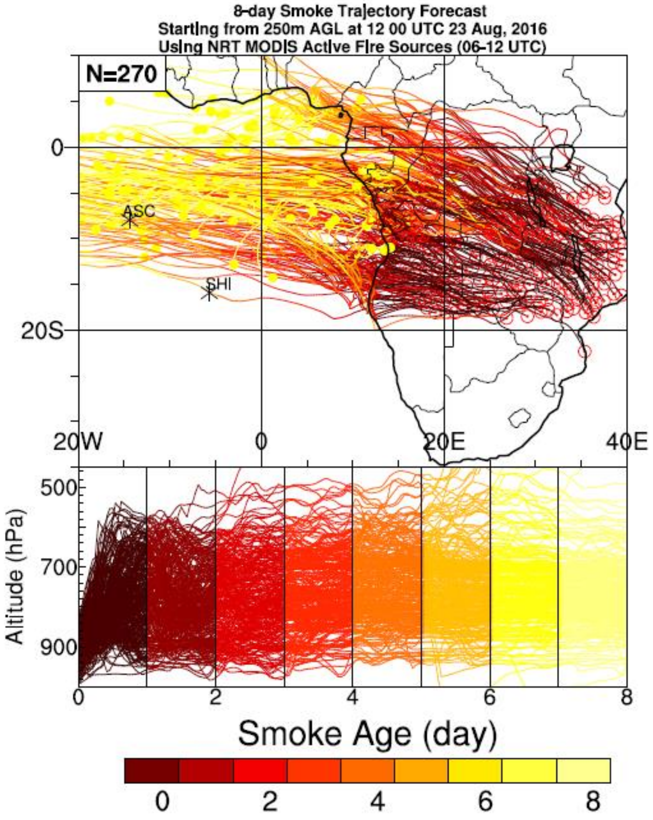
S. Liu, A.C. Aiken, K. Gorkowski, M. Dubey et al., Nature Comm, 2015.

- **In contrast to CA measurements – no significant enhancement**

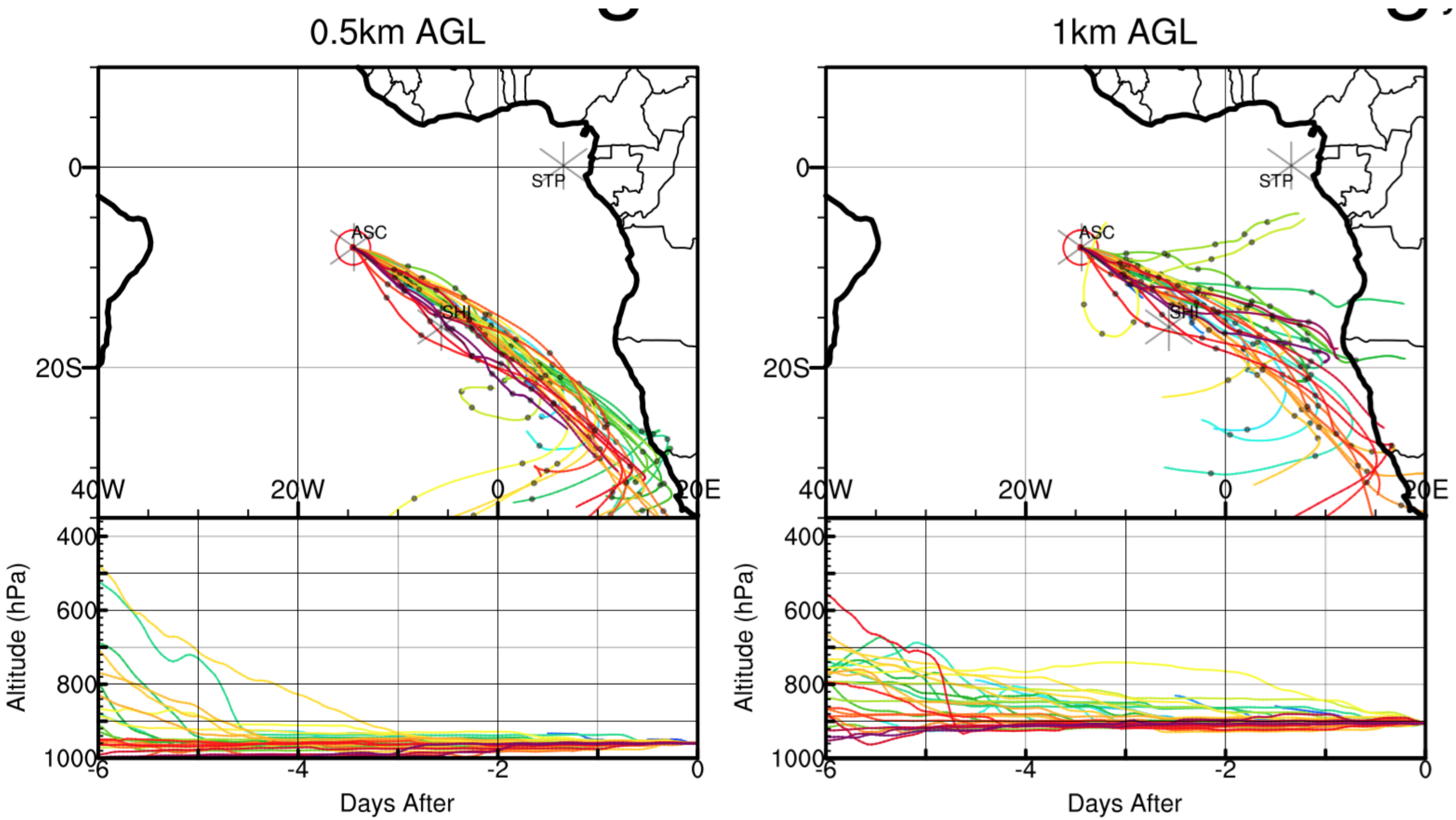
Cappa et al., Science, 2012.

Smoke Trajectories





August 2016 Back Trajectories



Back Trajectories of 3 August Plumes Observed