Biomass Burning Observation Project (BBOP): Near Field Evolution of BB Emissions

Scientific Objective:
To understand and quantify the role of BB aerosols in climate forcing by investigating the near-field evolution of their optical, chemical, hygroscopic, and microphysical properties.

Key Results
Rapid near-field changes observed in:
- Aerosol chemical properties
- Aerosol microphysical properties
- Aerosol optical properties

Dependence on burn conditions
Identification of 3 types of BBOA
Tar balls represent large contribution
Gulfstream-1 (G-1) Platform

Chemical & Physical Particulate Measurements

- **NR-PM**: SP-AMS, TEM
- **rBC**: SP2, **SP-AMS**, TEM
- **Size**: UHSAS, PCASP, FIMS

Optical Measurements

- **Extinction**: 1-λ **CAPS PMex** (630 nm)
- **Scattering**: 3-λ Nephelometer (450, 550, 700 nm)
  - 1-λ **PAS** (355 nm)
- **Absorption**: 1-λ **PAS** (355 nm)
  - 1-λ **PTI** (532 nm)
  - 3-λ PSAP (462, 523, 648 nm)

Trace Gas Measurements

- **VOCs**: PTRMS
- **CO₂, CO, O₃, SO₂, N₂O, NO, NO₂, NOₓ**
120 flight hours – Mix of Sources

**WildFires:** (17 fires)
- Shrub, Forest
- **MBO** (3 flights)
- **SEAC⁴RS:** Joint mission Aug., 6

**Agricultural Burns:** (> 24 burns)
- cotton, rice, soybean, sorghum

**Urban:** Seattle, Portland, Spokane, Nashville, Memphis
Near-Field Changes in Aerosol Properties

Colockum Tarps Fire

1-deg x 1-deg

Challenge: far-field modeling based on near-field measurement

Rapid Chemistry Occurring

Wind Direction

Rapid Increase in Light Absorption

$\lambda = 355 \text{ nm}$
Aerosol Measurements at Fixed Site (July 25 – Aug. 25, 2013)

Mt. Bachelor Observatory (MBO; 2.7 km)

G-1 flight tracks

MBO: Transported (6 – 48 hrs/Regional)
G1: Near Field (< 1 - 10 hrs)

Zhou et al., ACP 2017
Collier et al., ES&T, 2016
Regional BBOA Enhancement Driven by Burn Efficiency
BBOA Chemistry is Driven by Atmospheric Aging

OA enhancement = $\Delta \text{Org} / \Delta (\text{CO}+\text{CO}_2)$

MCE = $\Delta \text{CO}_2 / \Delta (\text{CO}+\text{CO}_2)$

Low MCE $\rightarrow$ greater POA and oxygenated VOCs emissions (greater SOA formation)

MBO and G1 data overlap $\rightarrow$ Aging has little influence on BBOA enhancement

Collier et al., ES&T, 2016
Three Types of Biomass Burn Organics (BBOA)

\[ \sum_{\text{BBOA}} \approx 70\% \text{ of OA mass} \]

Three types of BBOA
- Fresh \( \text{BBOA-1} \):
  - O/C = 0.35
- Aged \( \text{BBOA-2} \):
  - O/C = 0.65
- Aged \( \text{BBOA-3} \):
  - O/C = 1.06

BBOA-3 has very low volatility

BBOA Photochemical Aging
- Night: BBOA-1 = 52\%, BBOA-2 = 12\%, BBOA-3 = 27\%
- Day: BBOA-1 = 37\%, BBOA-2 = 20\%, BBOA-3 = 38\%

BBOA-1 ~POA
BBOA-2 ~SOA

Zhou et al., ACP 2017
Types of Spherical Carbonaceous Solids

**Soot**


**Tar balls (BrC particles)**

BBOP

**Tar Balls (TBs)**

- Spherical shape
- Particle diameter between 200 - 500 nm
- High viscosity
- Lack of crystallinity and absence of graphitic fine structure
- Composed primarily of carbon and oxygen
- Low volatility
- Recognized through TEM and SEM
Formation and Evolution of Tar Balls

BBOP demonstrated that Tar balls are extremely processed primary particles.

Tar ball formation need not involve rapid heating as suggested in laboratory studies.

Sedlacek et al., 2017 (prep)
High Tar ball *number fractions* (>50%) have been reported in previous studies. However, there are uncertainties due to loss of other (volatile) particles during analysis.

- BBOP yielded the first determination of Tar ball *mass fraction* in a wildfire plume.
- This is the quantity models need.

Tar balls could help resolve discrepancies between retrieval and inventory comparisons.

Sedlacek et al., 2017 (prep)
Constraint on Optical Properties of Tar Balls

Previous reported values of TB refractive index:

- $m = 1.67 - 0.27i$ (Alexander et al., 2008)
- $m = 1.84 - 0.21i$ (Hoffer et al., 2015)
- $m = 1.56 - 0.02i$ (Hand et al., 2005)
- $m = 1.80 - 0.007i$ (Chakrabarty et al., 2010)
- $m = 1.75 - 0.002i$ (Chakrabarty et al., 2010)

$m = 1.56 - 0.02i$, based on SSA consistency between calculations and BBOP field measurements.
Refractory Properties of Tar Balls

Tar balls resistant to heating

Fraction of TB Volume Remaining vs Substrate Temp (ºC)

Mass Fraction Remaining (%)

Tar ball
Substrate
Ns-soot

25 C
150 C
300 C
450 C
600 C

Adachi et al., 2017 (in review)

Zhou et al., 2016

Sedlacek et al., 2017 (prep)

Are Tar Balls = BBOA-3?
Near-field measurements of optical properties ➔ validity in models
  • Can models based on near-field measurements be applied to the far field?

Dependence of aerosol properties on combustion ➔ improved model estimation

BBOA-1, BBOA-2, BBOA-3 (= TB?) ➔ different classes of light-absorbing aerosol
  • Current models assume non-absorbing OA.
  • How spectral classes of absorbing OA are required for accurate modeling?

Tar Balls are a major component of some wildfires ➔ model incorporation
  • Implications for budgets and closure (top-down/bottom-up comparisons).
  • Are TBs “Dark Matter” not detected by current in situ instruments?
  • Are laboratory-generated TBs the same as ambient TBs?

Closing Thoughts
Big Thanks to all that made BBOP a success!

BBOP-Memphis

P. Arnott  F. Mei
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P. Daum     J. Thomlinson
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ARM
Climate Research Facility

IGAC
International Global Atmospheric Chemistry

ASR
Atmospheric System Research
BBOP: Aerosol Optical and Chemical Properties

BrC Absorption Increase with Age

POA

POA + SOA

Plume Age

Particulate Nitrate Increase with Age

Near Source

Downwind

NO$_3$ = 0.8%

NO$_3$ = 3.9% (5x)

OA Oxidation Increase with Age: SOA

O:C Ratio

Downwind distance (km)

ΔOrg/ΔCO Constant despite Chemistry

Sedlacek, Arnott, Onasch

Kleinman, Onasch
Coagulation Near Source Drives Particle Growth

Wang and Kleinman
BBOA Evolution in Regional Air Masses

- BBOA-1 = primary
- BBOA-2 & BBOA-3 = more aged, secondary

Cumulative Solar Radiation (W m\(^{-2}\))

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<th>f(_{\text{BBOA-1}})</th>
<th>r = -0.88</th>
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<td>0.6</td>
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<table>
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<th>f(_{\text{BBOA-2 + BBOA-3}})</th>
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<td>0.75</td>
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No net OA mass enhancement due to photochemical aging

- Night (\(\sum\text{SR}<500\ \text{W m}^{-2}\)):
  - \(r^2 = 0.88\)
  - \(s = 0.283 \pm 0.014\)
  - CO (bkg) = 79 ppbv

- Day:
  - \(r^2 = 0.94\)
  - \(s = 0.279 \pm 0.006\)
  - CO (bkg) = 69 ppbv

- Evidence of BBOA photochemical aging
- Photochemical production of BB SOA.
- Offsetting SOA formation and POA evaporation
  ~ constant OA/CO with aging
**Refractory Properties of Tar Balls**

**Field Measurements**

TBs resistant to heating

![Tar ball images at different temperatures](image)

- 25 C
- 150 C
- 300 C
- 450 C
- 600 C

Adachi et al., 2017 (in prep)

**Laboratory Studies**

Pyrolysis of pine twigs

Lab-generated TBs similar

AMS shows unsaturated hydrocarbons

**Are TBs a low-volatility PMF factor?**

- Sedlacek et al., 2017 (prep)

**Are lab-generated TBs the same as ambient?**

- Zhou et al., 2016

- Zhu et al., 2016

- Adachi et al., 2017 (in prep)