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Aerosol Properties Downwind of Biomass Burns Field Campaign Report

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Executive Summary

We determined the morphological, chemical, and thermal properties of aerosol particles generated by biomass burning during the Biomass Burning Observation Project (BBOP) campaign during the wildland fire season in the Pacific Northwest from July to mid-September, 2013, and in October, 2013 from prescribed agricultural burns in the lower Mississippi River Valley. BBOP was a field campaign of the U.S. Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) Climate Research Facility. The morphological information was both two-dimensional, as is typical of most microscopy images and that have many of the characteristic of shadows in that they lack depth data, and three-dimensional (3D). The electron tomographic measurements will provided 3D data, including the presence and nature of pores and interstices, and whether the individual particles are coated by or embedded within other materials. These microphysical properties were determined for particles as a function of time and distance from the respective sources in order to obtain detailed information regarding the time evolution of changes during aging.

In the process of the making these measurements, we provided insight into the results of measurements made with the Single-Particle Soot Photometer (SP2), which has produced important but, in some cases, unpredicted and surprising results. The issue is that the SP2, like an Aerosol Mass Spectrometer (AMS), destroys the particles being measured. A consequence is that unexpected results must be explained by making simplifying inferences about the particles producing these results, just as with an AMS one needs to reconstruct the measured particles by combining the fragments produced during the analyses. Making parallel Transmission Electron Microscope (TEM) measurements on the same sample sets provided complementary information regarding the online measurements.

Acronyms and Abbreviations

AMS	Aerosol Mass Spectrometer
ARM	Atmospheric Radiation Measurement Climate Research Facility
BBOP	Biomass Burning Observation Project
С	Celsius
CPC	Condensation Particle Counter
DOE	U.S. Department of Energy
G-1	Gulfstream aircraft
jpeg	Joint Photographic Experts Group
nm	nanometer
NW	northwest
OM	organic matter
SE	southeast
SP2	Single-Particle Soot Photometer
SW	southwest
TB	tar balls
TEM	Transmission Electron Microscope
UTC	Coordinated Universal Time
3D	three-dimensional

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1.0 Sampling

We conducted sampling during the wildland fire season in the Pacific Northwest from July to mid-September, 2013, and in October, 2013 from prescribed agricultural burns in the lower Mississippi River Valley. Urban plumes from seven cities in the northwest (NW) and southeast (SE) United States provided a contrasting set of samples and observations. We used an automated, two-stage aerosol impactor on the DOE Gulfstream (G-1) aircraft flying through smoke plumes as close to a fire as allowed by aviation rules, followed by one or two sets of three to six transects covering a transport time of two to four hours. We collected up to 16 TEM grid samples on lacy-carbon grids per flight. TEM samples were collected when crossing the smoke plume that resulted from biomass burning. In total, 443 samples were collected for both fine- and coarse-mode aerosol particles (0.3 and 1 μ m 50% cutoff aerodynamic diameters, respectively) from 33 flights.

2.0 TEM Image Analyses

Each sample grid contains several thousands of individual particles. We obtained ~ 10 TEM images of all fine-mode samples (e.g., Figure 1). Each image includes several hundred particles. The goal was to determine the mixing states of each sample and the formation and amounts of tar balls. A representative TEM image for each sample has been uploaded to the BBOP data storage site (443 images in total). Each image is in Joint Photographic Experts Group (jpeg) format and has 4008×2664 pixel resolution.



Figure 1. Examples of TEM images from the BBOP campaign. a) Sunnyside Fire, Oregon (7/23/13 am); b) Sunnyside Fire, Oregon (7/23/13 pm); c) Research flight #5 - fire near Goldendale, Washington (mile marker 28) (7/26/13); d) Research flight #10 - Pony Fire complex near Mountain Home, Idaho (8/13/13); e) Research flight #11 - Pony Fire complex (8/14/13); f) Research flight #19 - agriculture burns, western Idaho panhandle and Dead Canyon southwest (SW) of Pasco, Washington (9/11/13); g) Research flight #20 - Nashville plume; h) Research flight #25 - agricultural fire (10/14/13); and i) Research flight #27 - fire plume survey in box 2 and 3 west and south of Memphis (10/18/13). Scale bars: 2 μm.

3.0 Tar Ball Formation in the July 30B Sample: An Example

We focused on the July 30B flight to investigate the aging process of biomass-burning smoke (Figure 2). We sampled the Colockum Fire, which occurred southeast of Wenatchee, Washington, from 15:39:00 Coordinated Universal Time (UTC) to 18:15:00. For samples collected just above the fire (0-hour aging), organic matter (OM) with potassium inclusions dominated. The OM spread over the substrate, indicating that it had low viscosity when collected. As we collected more aged and dispersed particles, as seen from the SP2 data (Figure 3), we observed that the OM became more viscous. Most OM was solid and spherical, some on the way to becoming tar balls (TBs), in the smoke that aged for >2.5 hour. They, together with other biomass-burning particles, also occurred outside the smoke plumes, perhaps as a result of dilution.



Adachi-Buseck BBOP TEM series

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Figure 2. Particle evolution with distance from a flame (BBOP, July 30, 2013). The bold green arrow points downwind from the source fire. The numbered yellow spots indicate places where we collected particles, with image numbers matching those in the surrounding panels. The blue arrows between panels indicate the evolution sequence, with elapsed time for collection indicated on the right above the panels, except for panel 8 where it is in the upper left on the image. The small spots mark places where Condensation Particle Counter (CPC) results were obtained each minute.



Figure 3. Aerosol mass concentrations measured using the SP2 and TEM sampling periods (yellow and grey areas) on the July 30 flight. Red numbers indicate TEM samples that contain tar balls. They generally dominated when TEM samples were collected outside smoke (lower particle number concentrations).

4.0 Heating Experiment

We conducted heating experiments on biomass-burning samples, including TBs, using a standard TEM heating holder, which can heat samples up to ~1000 °C during TEM observation. The TBs started to shrink when the temperature was increased (Figure 4, Figure 5, and Figure 6). The TBs still existed at 650 °C, which is the highest temperature of the substrate we used, although they had lost much volume. In contrast, all the sulfate had evaporated by ~180 °C. The ns-soot did not change during heating, although its coating evaporated. The heating behavior at 600 °C is important because it is the filament temperature used by the AMS, suggesting that the TB detection efficiency in biomass-burning smoke may be low.



Figure 4. Evaporation of tar balls. The arrow indicates that tar balls shrank but did not completely evaporate when heated to 600 °C. Red arrows indicate tarballs.



Figure 5. TEM images of BBOP aerosol particles at ambient temperature (top) and after heating to ~600 °C (bottom). The sample contained organic particles, sulfate, ns-soot, and TBs. The TB (arrow) persists at ~600 °C but lost mass during the 15-minute heating. The fibers are the lacey-carbon substrate.



Figure 6. Volume remaining fraction of organic aerosol particles from wild fire, urban plume, and agriculture burns. Three TEM samples were measured for each flight (>100 particles for each flight). About 50% in volume was lost between 150 and 300 °C and ~30% of volume remained after 600 °C heating. No obvious differences were found between samples.

5.0 Ns-Soot Mixing States

One of the most abundant species in the BBOP plumes is ns-soot, and its mixing state, which varied considerably, is important for evaluating optical properties. Its coatings are relatively thin (Figure 7) relative to anthropogenic sources such as Mexico City and Los Angeles. Also, many ns-soot particles were partly coated and not compacted even when coated (Figure 8; also cf. right panel in Figure 9), similar to what we observed in southern Africa. We interpret the BBOP observations as indicating that the OM had a relatively high viscosity when it coated or embedded the ns-soot. As the result, the OM only coated parts of many particles.

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Ns-soot attached to tar balls



Ns-soot partially embedded



Ns-soot partially embedded and attached to tar balls



Ns-soot attached to tar balls



Ns-soot partially and fully embedded



Ns-soot partially embedded

Figure 7. Mixing states of ns-soot particles in samples collected on July 30. Ns-soot particles are coated or partly embedded within OM. Yellow arrows indicate ns-soot.



Figure 8. Ns-soot coated by high-viscosity organic matter. Note the small spheres of the ns-soot.



Figure 9. Examples of embedding as a variety of internal mixing. Left: 3D isosurface electron tomographic image of embedded ns-soot within OM and sulfate from an urban area (Mexico City). The individual ns-soot spherules can be seen embedded within the OM (from Adachi et al. 2010). Right: ns-soot embedded within OM. Scale bar = 250 nanometers (nm).

6.0 Wildfire versus Agricultural Burns

The mixing states of agricultural-burning smoke and wildfire smoke differed (Figure 10). Aerosol particles in the agricultural smoke had larger sulfate inclusions, whereas the wildfire particles included smaller and scattered potassium inclusions within OM. The agricultural smoke particles had lower viscosity than those from the wild fires and contained fewer TBs.





7.0 Presentations of Research Results

The following presentations of research results were made at scientific and professional meetings:

Adachi, K, PR Buseck, A Sedlacek, L Kleinman, and D Chand. 2015. "Evolution and micro physical properties of biomass-burning aerosol particles." Presented at 9th Asian Aerosol Conference, Kanazawa, Ishikawa, Japan, June, 2015.

Buseck, PR, K Adachi, D Chand, LI Kleinman, and AJ Sedlacek. 2014. "Transmission electron microscopy analysis of tarball formation and volatility from biomass-burning aerosol particles during the 2013 BBOP Campaign." Presented at American Geophysical Union (AGU) Fall Meeting, San Francisco, California, Abstract A52A-03, December 2014.

Kleinman, LI, AJ Sedlacek III, RJ Yokelson, TB Onasch, K Adachi, PR Buseck, D Chand, S Collier, MK Dubey, F Mei, JE Shilling, SR Springston, J Wang, NL Wigder, and Q Zhang. 2014. "Time dependence of aerosols in biomass burn plumes from BBOP." American Geophysical Union (AGU) Fall Meeting, San Francisco, California, Abstract A52A-01, December 2014.

Adachi, K, AJ Sedlacek, L Kleinman, D Chand, and P Buseck. 2014. "Transmission electron microscopy analysis of biomass-burning aerosol particles during BBOP Campaign." American Association for Aerosol Research (AAAR) Annual Conference, Orlando, Florida, October, 2014.

Adachi, K. 2014. "Mixing states of aerosol particles from various environment: transmission electron microscopy analysis." International Aerosol Conference 2014, Busan, South Korea.

Busek, PR, and K Adachi. 2014. "What information can TEM provide for aerosol research?" Pacific Northwest National Laboratory workshop, Pasco, Washington.

Sedlacek, AJ, L Kleinman, WP Arnott, K Adachi, P Buseck, E Lewis, T Onasch, M Pikridas, J Shilling, S Springston, J Wang, and R Yokelson. 2014. "Evolution of biomass burning aerosols in the near field." European Geosciences Union (EGU) General Assembly 2014, Vienna, Austria (*Geophysical Research Abstracts* 16:EGU2014-9226).

Sedlacek, AJ, LI Kleinman, K Adachi, WP Arnott, PR Buseck, S Collier, A Freedman, DA Jaffe, TB Onasch, M Pikridas, JE Shilling, SR Springston, J Wang, RJ Yokelson, NL Wigder, Q Zhang, and S Zhou. 2013. "Near-field evolution of biomass burning aerosols." American Geophysical Union (AGU) Fall Meeting, San Francisco, CA, Abstract A33D-0246, December 2013.



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