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SAIL Supermicron Bioaerosol (SSB) Field Campaign Report

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February 2024

ARM

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Acronyms and Abbreviations

5G	fifth-generation technology standard for cellular networks
AMF	ARM Mobile Facility
ANL	Argonne National Laboratory
AOS	Aerosol Observing System
AOSMET	Aerosol Observing System meteorology sensor
ARM	Atmospheric Radiation Measurement
ASL	above sea level
ASR	Atmospheric System Research
DOE	U.S. Department of Energy
EMSL	Environmental Molecular Sciences Laboratory
FICUS	Facilities Integrating Collaborations for User Science
LANL	Los Alamos National Laboratory
PM	particulate matter
RMBL	Rocky Mountain Biological Laboratory
SAIL	Surface Atmosphere Integrated Field Laboratory
SAIL-AVP	Surface Atmosphere Integrated Field Laboratory-Aerosol Vertical Profiles
SFA	Science Focus Area
SSB	SAIL Supermicron Bioaerosol
TBS	tethered balloon system
UCRB	Upper Colorado River Basin
WIBS	Wideband Integrated Bioaerosol Sensor

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1.0 Summary

1.1 Science Goals

The Surface Atmosphere Integrated Field Laboratory (SAIL) Supermicron Bioaerosol (SSB) study was designed to complement the larger Atmospheric Radiation Measurement (ARM) SAIL science goals to understand aerosol processes and aerosol-cloud interactions in the Colorado River's East River Watershed Basin. Supermicron aerosol, particles larger than one micron in diameter, and bioaerosols, primary particles containing biological material, are important for understanding atmospheric processes and sources within high mountainous terrain. For example, they can interact with clouds and the water cycle such as by serving as nuclei for cloud droplets and ice crystals that can eventually result in precipitation events. These particles can also be recycled back to the surface via wet and dry deposition, where they can alter plant and microbial growth and/or be reemitted again, forming a positive feedback loop within the Earth system known as bioprecipitation.

Despite their importance within the Earth system in mountainous regions, the seasonal and diurnal cycles of supermicron aerosol and bioaerosols are largely unknown. For this reason, the SSB campaign characterized and quantified supermicron events and bioaerosol activity in real time at two locations at different elevations using in situ measurements during SAIL. In mid-latitude continental interior mountain ranges and especially at SAIL, supermicron and bioaerosol seasonal and diurnal cycles have not been observed using high-time-resolution aerosol measurements. Supermicron aerosol was measured at two locations from summer in 2022 to the following summer in 2023 to determine seasonality. The diurnal cycle and timing of bioaerosol events with large-scale meteorological events was measured for three months in the biologically active spring and summer seasons of 2022 and 2023 to examine the prevalence, duration, and type of bioaerosol events. Our supermicron and bioaerosol data can be united with the large-scale meteorological patterns measured by the second ARM Mobile Facility (AMF2), ecological studies by the Rocky Mountain Biological Laboratory (RMBL), and ongoing surface and subsurface hydrologic observations from the U.S. Department of Energy (DOE)'s Watershed Function Science Focus Area (SFA) to investigate the influence and role of bioaerosol events in the complex mountainous terrain within the East River watershed in southwestern Colorado.

1.2 Supermicron and Bioaerosol Guest Instrument Deployments

SSB guest instrument deployments were conducted by Los Alamos National Laboratory (LANL) during the deployment of the AMF2 as part of the SAIL campaign in the East River watershed of the Upper Colorado River Basin (UCRB). SBB measurements were collocated with the Aerosol Observing System (AOS) on Crested Butte Mountain and the AMF2 main site in Gothic, Colorado as shown in Figure 1.

We also deployed two particulate matter (PM) sensors at M1/AMF2 in Gothic (elevation 9,577 ft ASL) and S2/AOS on Crested Butte Mountain (elevation ~10,293 ft ASL) for a year to understand the differences in PM mass concentrations for three different size ranges (< 1 micron, 2.5 micron, < 10 micron) between the two sites where the AMF2 and AOS were located. These sensors were deployed outside of the AOS to limit the loss of supermicron particles by not having to use a long inlet or tubing to sample aerosol. We deployed LANL's bioaerosol sensor (Wideband Integrated Bioaerosol Sensor [WIBS-5/NEO]) for two seasons, summer (June-September) 2022 and spring (March-June) 2023, inside the AOS to directly compare with the other single-particle and aerosol number concentration instruments inside the AOS (Theisen et al. 2023).

Figure 1. Pictures of the two PM sensors mounted (a) on a platform at M1 in Gothic, Colorado, and (b) on the roof at S2 located midway up Crested Butte Mountain in the Crested Butte Ski Valley.

1.3 Data Processing and Availability

The PM sensor and WIBS data are available via open access on ARM Data Discovery. Processed PM sensor data available includes PM mass at three different sizes as well as particle size distributions. Uploaded WIBS data includes number concentrations, size distributions, fluorescence signals, and asymmetry parameter. Further information can be found on both in the metadata files associated with each data set.

2.0 Results

2.1 Supermicron

SSB collected supermicron data at 1-minute time resolution for one year during SAIL from June 14, 2022 to June 14, 2023 at M1 and S2. We observed differences in aerosol (particulate matter) mass concentrations at the two SAIL ARM sites. Figure 2 shows an example from one month exemplifying the continuous and high-time-resolution data and the observed similarities and differences between the two sites for PM of three different size ranges – PM_1, $PM_{2.5}$, and PM_{10}. M1 data is shown in blue and the main AMF2 facility at S2 data, where the AOS and radar were located, is shown in red. Similar trends in the timeseries of PM for all sizes was observed for the measurements made at the two locations. For all measured sizes, the mass concentrations were on average higher at M1, potentially due to the proximity of an unpaved road near the M1 site.

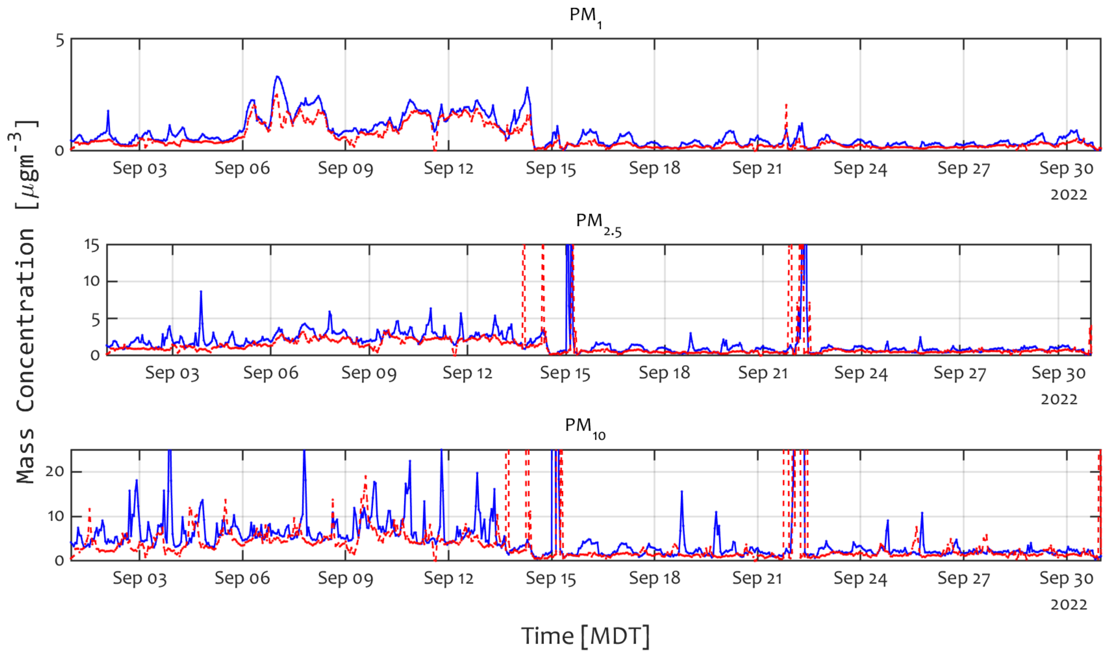

Figure 2. Time series of PM_1, $PM_{2.5}$, and PM_{10} at the two locations sampled at different elevations. M1 data is shown in blue and S2 data in red for the month of September in 2022. During the first half of the month, elevated concentrations were observed due to an event that has preliminarily been associated with a transported biomass burning plume.

Further comparisons showed similar trends with PM mass concentrations on average yet higher over the deployment period at M1 when compared to S2. Figure 3 shows the PM_{10} mass concentrations for particles < 10 µm in diameter from the PM sensor data collected from June 2022 to March 2023. PM mass concentrations were binned for each site and compared with a scatter plot.

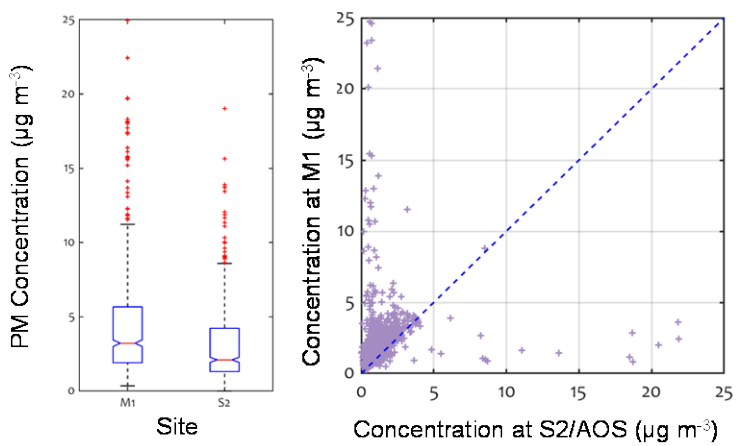

Figure 3. Box plots and scatter plot of PM_{10} mass concentrations at M1 and S2 from June 2022 to March 2023 as measured by the two PM sensors.

2.2 Bioaerosol

We observed supermicron and bioaerosol events with the WIBS during our first deployment in the biologically active summer season from June to September in 2022. Figure 4 (Shawon et al. 2024) shows the number concentration of non-biogenic and biogenic particles detected by the WIBS via fluorescence (Kaye et al. 2005) from mid-August to mid-September in 2022. During this period, multiple events were observed when bioaerosol concentrations were elevated for several days at a time.

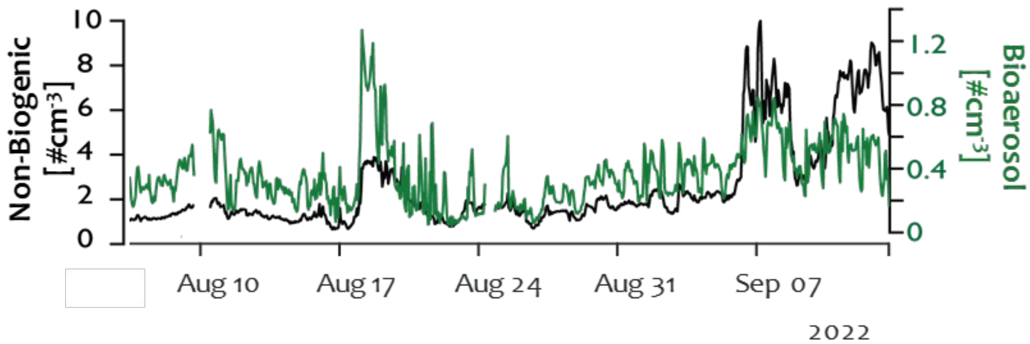

Figure 4. Time series of particles detected by WIBS with diameters greater than 0.5 micron during the initial WIBS summer deployment in 2022.

The WIBS was able to detect seven categories of biological particles based on their fluorescence patterns that are used to indicate the presence of different types of biological material in the particles (Perring et al. 2015, Hernandez et al. 2016). Figure 5 shows a time series from mid-August to mid-September in 2022 for the high-time-resolution data of the different detected particle types based on their excitation and emission wavelengths. Seasonal trends and diurnal profiles can be determined and are reported in Shawon et al. 2024. Additional information is reported by the WIBS and can be found in ARM Data Discovery on the size distribution (optical diameter) of biological and non-biological particles detected by the WIBS as well as an asymmetry parameter for all detected particles.

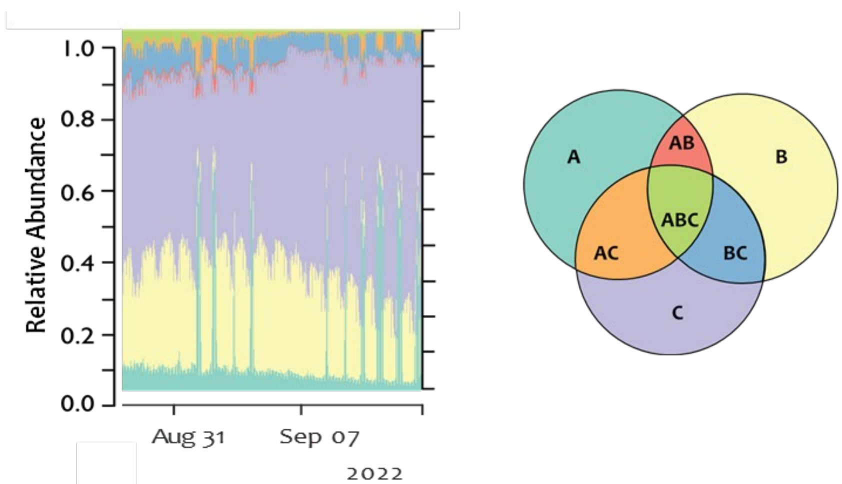

Figure 5. Time series during the initial summer deployment in 2022 of the seven different fluorescent particle types detected by the WIBS as defined by Perring et al. 2015.

Local meteorological patterns were evaluated for their impact on the bioaerosol number concentration and type measured during SSB. Trends with temperature, relative humidity, wind speed and direction, and precipitation are discussed in Shawon et al. 2024. For example, during 2022, approximately 50 precipitation events were defined based on observations by the AOS meteorology sensor. As shown in Figure 6, some resulted in an increase in bioaerosol detected by the WIBS, while others showed decreasing or no discernable trend.

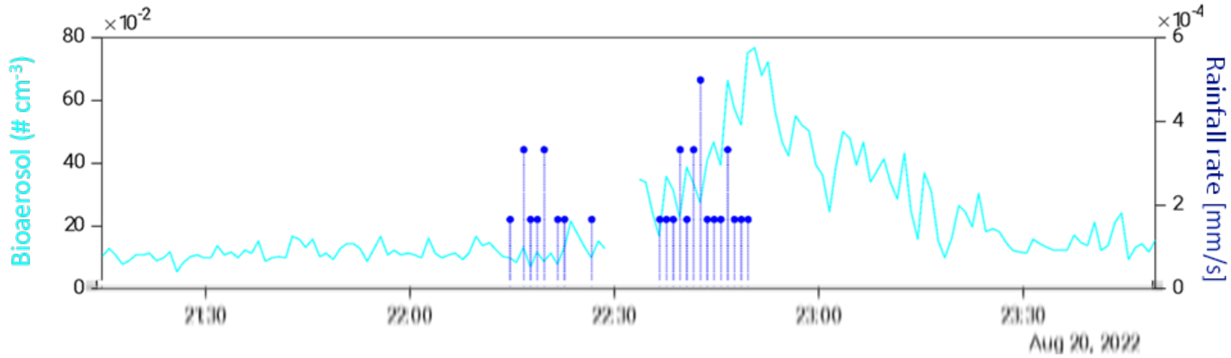

Figure 6. Time series of bioaerosol number concentration detected by WIBS and rainfall rate detected by the AOS meteorology sensor (AOSMET; Theisen et al. 2023).

2.3 Preliminary Findings and Future Work

SSB extended the core scientific capabilities of the AMF2 AOS by co-deploying a complementary suite of real-time supermicron and bioaerosol aerosol instrumentation. PM mass concentrations were measured outside of the AOS to limit the loss of supermicron particles. SSB directly enabled a more in-depth understanding of the extent that supermicron and bioaerosol can influence aerosol processes, aerosol-cloud interactions, and the hydrological cycle in complex mountainous terrain by studying the seasonality of supermicron events and the impact of bioaerosol during the biologically active season.

Preliminary analysis of SSB data includes observed supermicron dust events in the spring, transported biomass burning plumes in the warmer months, and seasonality in the bioaerosol types during the biologically active periods. Overall, PM concentrations were similar between the two sites with higher mass concentrations for all size cuts at the M1 location in Gothic, Colorado, likely due to the proximity of an unpaved road. On average, PM_{10} concentrations were low throughout the year, < 5 ug/m^3.

Further analysis will focus on diurnal profiles and seasonality of supermicron aerosol including variability between the two sites/elevations, developing a new categorization scheme for bioaerosol, comparing 2023 bioaerosol analysis and with 2022 results for understanding seasonal variability, and integration with column measurements such as those collected by the ARM tethered balloon system (TBS) during SAIL-Aerosol Vertical Profiles (SAIL-AVP).

3.0 Publications and References

3.1 Presentations

Aiken, AC, K Benedict, ASM Shawon, K Gorkowski, J Viegas, J Bilberry, H Powers, and D Feldman. 2022. "Surface Atmosphere Integrated Field Laboratory (SAIL) aerosol regimes and processes, including supermicron and bioaerosol events measured during the SAIL Supermicron Bioaerosol (SSB) campaign." Poster presented at the ARM/ASR Principal Investigator Meeting, Rockville, Maryland.

Aiken, AC, K Benedict, ASM Shawon, and K Gorkowski. 2022. "SAIL Aerosol Regimes and Processes." Invited presentation at the ARM/ASR PI Meeting, Rockville, Maryland.

Shawon, ASM, AC Aiken, K Benedict, K Gorkowski, J Bilberry, and J Viegas. 2022. "Exploring the Properties of Supermicron and Bioaerosol Events during the Surface Atmosphere Integrated Field Laboratory (SAIL) Campaign." Platform presentation at the American Geophysical Union Fall Meeting, Chicago, Illinois.

Aiken, AC. 2023. "Working with SAIL Aerosol Measurements." Invited Tutorial by the Workforce Development Coordination in ARM for the Open Science in the Rockies Short Course, American Meteorological Society (AMS) Annual Meeting, Denver, Colorado.

Shawon, ASM, K Benedict, D Feldman, and AC Aiken. 2023. "Meteorological Impacts on the Properties of Bioaerosol Particles during the SAIL Campaign". Platform presentation at the International Conference on Carbonaceous Particles in the Atmosphere, Berkeley, California.

Aiken, AC, K Benedict, ASM Shawon, J Viegas, J Bilberry, H Powers, and D Feldman. 2023. "Seasonal Aerosol Regimes and Processes Observed in Mountainous Terrain at Surface Atmosphere Integrated Field Laboratory (SAIL)*.*" Poster presented at the ARM-ASR Joint User Facility and Principal Investigator Meeting, Bethesda, Maryland.

Shawon, ASM, K Benedict, and AC Aiken. 2023. "Abundance, Properties and Seasonal Variation of Bioaerosol Particles Observed during the SAIL Campaign*.*" Presented at the American Association for Aerosol Research (AAAR), Portland, Oregon.

Aiken, AC, K Benedict, and ASM Shawon. 2023. "Supermicron and Bioaerosol Events and Impacts. SPLASH/SAIL/SOS (S^3)." Combined Workshop in Boulder, Colorado.

Aiken, AC, PJ DeMott, J Fan, M Skiles, JN Smith, K Benedict, ASM Shawon, D Dexheimer, S China, F Mei, M Zawadowicz, SAIL Aerosol Observing System mentors, and ARM site operations staff. 2023. "Aerosol Measurements for Integrated Mountainous Hydroclimate Processes in the Upper Colorado River Basin." Invited platform presentation at the American Geophysical Union Fall Meeting, San Francisco, California.

Aiken, AC, K Benedict, and ASM Shawon. 2023. "Supermicron and Bioaerosol Seasonal Regimes and Interactions within Mountainous Terrain." Platform presentation at the American Geophysical Union Fall Meeting, San Francisco, California.

Aiken, AC, K Benedict, ASM Shawon, and D Feldman. 2024. "Aerosol Interactions in Complex Mountainous Terrain." Platform presentation at the American Meteorological Society Annual Meeting, Baltimore, Maryland.

3.2 Planned Submissions

Shawon, ASM, et al. "Meteorological and Diurnal Variation of Bioaerosol Particles Sampled in the Summer within Mountainous Terrain in the Upper Colorado River Basin." In preparation for *Journal of Geophysical Research – Atmospheres*, 2024.

Aiken, AC, et al. "Local and Regional Supermicron Seasonality and Events of Interest in the East River Watershed of the Colorado River Basin." In preparation, 2024.

Shawon, ASM, et al. "Interannual Variability of Bioaerosol Sampled during Two Biologically Active Seasons in the Complex Mountainous Terrain of Colorado." In preparation, 2025.

3.3 Collaborations

- Co-deployed Facilities Integrating Collaborations for User Science (FICUS) TBS measurements and Environmental Molecular Sciences Laboratory (EMSL) analysis with SAIL-Aerosol Vertical Profiles (AVP).
- Coordinating science with other SAIL teams at LBNL and RMBL.

3.4 References

Hagan, DH, S Gani, S Bhandari, K Patel, G Habib, JS Apte, L Hildebrandt Ruiz, and JH Kroll. 2019. "Inferring aerosol sources from low-cost air quality sensor measurements: A case study in Delhi, India." *Environmental Science and Technology Letters* 6(8): 467–472, https://doi.org/10.1021/acs.estlett.9b00393

Hernandez, M, AE Perring, K McCabe, G Kok, G Granger, and D Baumgardner. 2016. "Chamber catalogues of optical and fluorescent signatures distinguish bioaerosol classes." *Atmospheric Measurement Techniques* 9(7): 3283–3292, https://doi.org/10.5194/amt-9-3283-2016

Kaye, PH, W Stanley, E Hirst, E Foot, K Baxter, and S Barrington. 2005. "Single particle multichannel bio-aerosol fluorescence sensor." *Optics Express* 13(10): 3583–3593, https://doi:10.1364/OPEX.13.003583

Perring, AE, JP Schwarz, D Baumgardner, MT Hernandez, DV Spracklen, CL Heald, RS Gao, G Kok, GR McMeeking, JB McQuaid, and DW Fahey. 2015. "Airborne observations of regional variation in fluorescent aerosol across the United States." *Journal of Geophysical Research – Atmospheres* 120(3):1153–1170, https://doi:10.1002/2014JD022495

Theisen A, O Mayol-Bracero, J Uin, S Smith, J Shilling, C Kuang, M Zawadowicz, A Singh, R Trojanowski, J Creamean, A Sedlacek, C Hayes, D Campos DeOliveira, and M Allain. 2023. *ARM FY2024 Aerosol Operations Plan.* U.S. Department of Energy, Atmospheric Radiation Measurement user facility, Richland, Washington. DOE/SC-ARM-TR-289, https://10.2172/2008425

4.0 Lessons Learned

4.1 Guest Instrument Data Connectivity

PM Sensors: We had some issues with the lack of connectivity for the PM sensors since they were designed to be deployed in areas supported by 5G, which was not available at either site. As a result, we have some data gaps (~10%). We are working to improve this with the vendor for future deployments in remote locations.

WIBS: To our knowledge, this was the first time the WIBS-5/NEO has been deployed in the AOS. The software from the vendor resulted in connection and restart problems after power outages. We worked with the vendor and the ARM Site Operations (LANL) and Site Data System (ANL) teams to enable the computer to retain the security packages necessary and remote access required to maintain continuous data collection.

4.2 Deployment – Weather and Terrain

Multiple scenarios were discussed with Site Operations to transport the WIBS during times of limited accessibility due to significant snow cover, difficult terrain, and high elevation (> 10,000 feet ASL). In 2023, snow delayed deployment of the WIBS to the AOS, located midmountain at a ski resort.

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