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Calibrator for Airborne Aerosol Probes (CAAP) Field Campaign Report

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Acronyms and Abbreviations

AAF	ARM Aerial Facility
ARM	Atmospheric Radiation Measurement
CAAP	Calibrator for Airborne Aerosol Probes
CDP	cloud droplet probe
DMT	Droplet Measurement Technologies
DOE	U.S. Department of Energy
DSD	droplet size distribution
MP	Mesa Photonics
NPFTURBULENCE	Turbulent Layers Promoting New Particle Formation
OPC	optical particle counter
PNNL	Pacific Northwest National Laboratory
POPS	portable optical particle spectrometer
PSL	polystyrene latex
SBIR	Small Business Innovation Research
SGP	Southern Great Plains
UAS	uncrewed aerial system

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1.0 Summary

In this campaign, Calibrator for Airborne Aerosol Probes (CAAP), Mesa Photonics provided its U.S. Department of Energy (DOE) Small Business Innovation Research (SBIR) Phase II prototype of a portable, battery-powered monodisperse aerosol/droplet generator to field-calibrate two aerosol/cloud characterization instruments deployed on the DOE Atmospheric Radiation Measurement (ARM) Aerial Facility (AAF) ArcticShark uncrewed aerial system (UAS) during the flight campaign conducted at ARM's Southern Great Plains (SGP) atmospheric observatory and the Blackwell-Tonkawa airfield (Oklahoma) in May 2024. The CAAP campaign (May 20-24, 2024) partially overlapped with the main ARM AAF campaign, Turbulent Layers Promoting New Particle Formation (NPFTURBULENCE, May 7-27, 2024, Gannet Hallar, principal investigator). The main goal of the CAAP campaign was field validation of calibration of aerosol and cloud probes deployed on the ArcticShark UAS. The campaign also provided an opportunity to test and evaluate the Mesa Photonics' monodisperse aerosol/droplet generator prototype in the field, under real-life operational conditions.

The generator was used to produce monodisperse coarse-mode ammonium sulfate aerosols in a 1–10 µm size range, and monodisperse water droplets 35–40 µm in diameter. Calibration testing was performed for the following instruments deployed on the ArcticShark UAS: Droplet Measurement Technologies (DMT) cloud droplet probe (CDP; droplet size range 2–50 µm) and Handix Scientific portable optical particle spectrometer (POPS; particle size range 0.13–3 µm). We found that the CDP was completely out of calibration. The CDP was later sent to the manufacturer, who confirmed misalignment of the optics and repaired and re-calibrated the instrument. The POPS response was, in general, consistent with the size of the generated aerosol particles.

The main conclusion: **It is important to regularly field-calibrate atmospheric measurement instruments during field campaigns**. Many instrument calibration failures result simply from optical misalignments caused by physical impacts or vibrations that occur during shipping or transport to the field location. While in the field, the instruments operate under harsh conditions that can further degrade the quality of the manufacturer- or laboratory-performed calibration. Without frequent field calibration checks, it is difficult to determine if the instrument reports valid data. In this campaign, a calibration check performed a few days before the end of the three-week-long ARM AAF flight campaign revealed the CDP failure. It is unknown when the actual failure had happened and when the CDP data had become invalid. Fortunately, the CDP data were not relevant to the NPFTURBULENCE campaign.

The Mesa Photonics' monodisperse aerosol/droplet generator prototype was operating flawlessly during the one-week CAAP field campaign, with no hardware or software issues. The prototype demonstrated reliability, stability of the operational parameters, and ruggedness under field conditions, which confirms the validity of the design approaches implemented during the SBIR project. Mesa Photonics plans to make the instrument commercially available in the near future.

2.0 Results

One of the key factors contributing to high-quality field measurements is proper and timely calibration of the instruments used. Field calibration (as opposed to laboratory calibration) is critically important, especially for long-term field campaigns in remote areas.

The nature of this AAF-, UAS-centered field campaign introduced corrections to the CAAP goals and procedures. Due to limited access to the UAS, we only had one setup day and two days (a few hours each day) to validate the calibrations of the aerosol probes deployed on the ArcticShark. Validating the calibrations (as opposed to calibrating) is the correct term that describes the CAAP activities, because, for most instruments, recalibration is performed by the manufacturer. Therefore, the original plan of daily calibrations was reduced to one-time calibration testing of the two coarse-mode aerosol probes involved, and assessment of the calibration state of the instruments that existed at the end of the main NPFTURBULENCE campaign.

2.1 Generation of Aerosols

The Mesa Photonics' generator (including diffusion dryer) was used to produce monodisperse coarse-mode ammonium sulfate aerosols over a particle size range of ~1–10 µm by drying 40 µm monodisperse droplets of ammonium sulfate aqueous solutions. In some experiments, pure water droplets, 35 µm and 40 µm in diameter, were used. The droplet size distribution (DSD) of the emerging monodisperse droplets of pure water or ammonium sulfate solutions was periodically checked using the Mesa Photonics telecentric imaging module (part of the monodisperse aerosol/droplet generator). The DSD was checked on every change of the operational conditions (droplet size, solution concentration) and, additionally, a few times during each measurement. The measured droplet diameter was always within ± 1 µm of the set droplet diameter, with the DSD width being typically less than ± 2 µm (size distribution).

The size of the generated ammonium sulfate particles was derived from the precursor solution droplet diameter (40 µm) and ammonium sulfate concentration. Table 1 shows the solutions used and the resulting ammonium sulfate particle equivalent diameters. We note that the solvent purity affects the aerosol particle size, especially for smaller particles. The solvent (distilled water) purity was estimated based on previous experiments involving sizing of the residual aerosol particles produced by drying 40 µm pure water droplets. The estimated impurity content is $< 2 \times 10^{-5}$ by volume. For each aerosol particle size, the correction range for solvent impurity is shown in the fourth column (in parentheses).

Table 1. Ammonium sulfate aqueous solutions used to generate coarse-mode aerosols. The fourth column shows the equivalent aerosol particle diameter produced from 40 µm droplets with the possible contribution of solvent impurity indicated in parentheses. The last two columns show whether the aerosol/droplet size was used in CDP or POPS testing.

Sample #	Dilution of the ammonium sulfate 2M stock solution	Concentration, mM	Particle size (+ possible contribution of solvent impurity), µm	Used with CDP	Used with POPS
1	1:5000	0.4	1.24 (+0.23)		•
2	1:2500	0.8	1.56 (+0.16)	•	•
3	1:833	2.4	2.25 (+0.08)		•
4	1:500	4	2.67 (+0.06)	•	•
5	1:250	8	3.37 (+0.04)	•	•
6	1:100	20	4.57 (+0.02)	•	•

Sample #	Dilution of the ammonium sulfate 2M stock solution	Concentration, mM	Particle size (+ possible contribution of solvent impurity), µm	Used with CDP	Used with POPS
7	1:25	80	7.26 (+0.01)	•	•
8	1:10	200	9.85 (+0.00)	•	•
9	Pure water	-	35	•	
10	Pure water	-	40	•	

During the experiments, the size of the ammonium sulfate precursor solution droplets was validated by the telecentric imager; then the dried aerosol particle size was further verified using an optical particle counter (AlphaSense OPC-N3, 0.35-40 µm size range), either continuously (using a Y aerosol flow splitter) or by switching between the OPC-N3 and the instrument under test. Figure 1 shows a previously obtained OPC-N3 calibration plot, where OPC-N3 reading is plotted versus the size of monodisperse ammonium sulfate particles generated by the Mesa Photonics generator. The data closely follow the "ideal" response with a slope of unity.

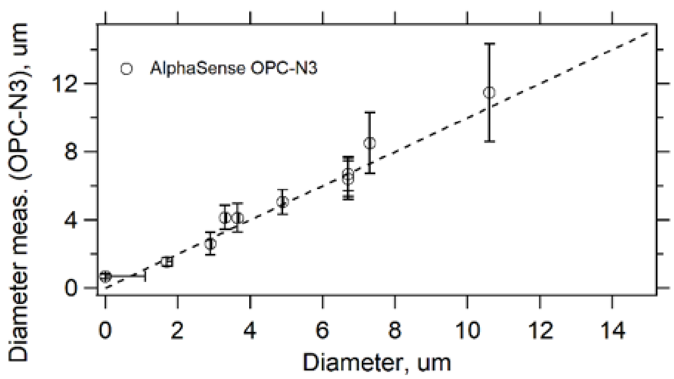

Figure 1. Calibration of the AlphaSense OPC-N3 optical particle counter using ammonium sulfate aerosols. Particle size measured by the OPC-N3 is plotted versus particle size set by the generator. Dashed line shows "ideal" response curve with a slope of unity.

2.2 Instrument Calibration Tests

Calibration tests were performed for the following instruments deployed on the ArcticShark UAS: DMT CDP (droplet size range 2–50 µm) and Handix Scientific POPS (particle size range 0.13–3 µm). Before the campaign, calibrations of both CDP and POPS were checked at PNNL. In addition, the POPS performance was tested in the beginning of the AAF campaign using polystyrene latex (PSL) monodisperse microspheres. Photographs in Figure 2 taken during the CAAP field campaign show the process of field testing of the calibration of the instruments mentioned above using the Mesa Photonics monodisperse aerosol/droplet generator.

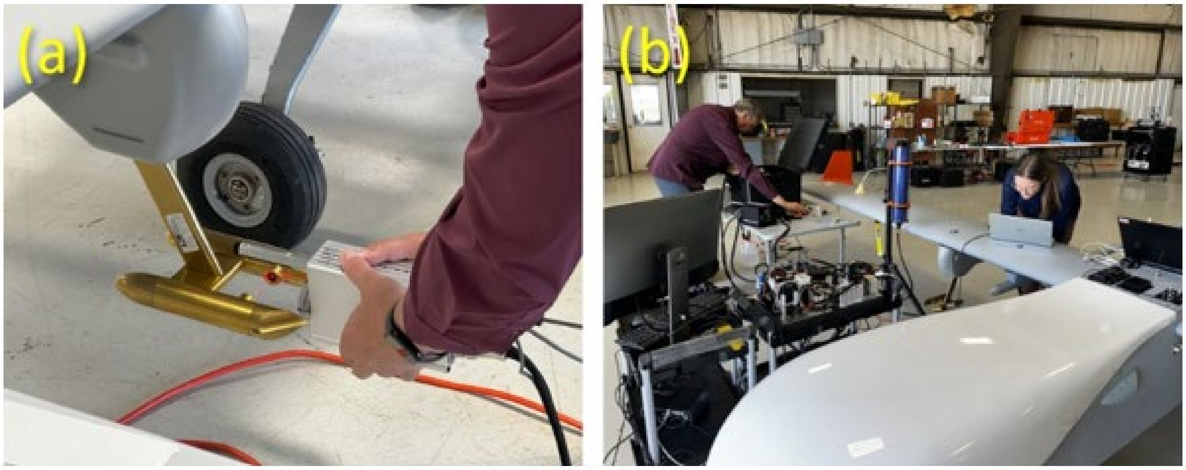

Figure 2. (a) Using the aerosol/droplet generator's detachable nozzle unit to present 40 µm monodisperse water droplets to the CDP. (b) Testing the calibration of the POPS using 1–10 µm monodisperse ammonia sulfate aerosols produced by the generator.

Although the CDP is primarily designed for DSD measurements in clouds, its droplet size range partially covers the coarse-mode aerosol particle size range. Therefore, the CDP could potentially be useful for coarse-mode aerosol measurements. During the testing, we found that the CDP was completely out of calibration: it did not detect 1–10 µm aerosol particles and, when presented with 35 µm and 40 µm water droplets, did not report anything except for sporadic particle counts in a size range below 10 µm. The CDP was later sent to the manufacturer, who confirmed misalignment of the optics, and repaired and re-calibrated the instrument.

The POPS was presented with ammonium-sulfate coarse-mode monodisperse aerosol particles of different sizes (~1–10 µm). Figure 3 shows the aerosol particle diameter measured by the POPS as a function of the particle diameter set by the generator. As follows from the figure, the POPS response was, in general, consistent with the size of the presented aerosol particles. The only deviation from normal behavior was observed during the first hour of POPS operation on day one (05/20/2024). When presented with 1.56 µm ammonium sulfate aerosol, the instrument was reporting 0.27 ± 0.03 µm particle size for the first 55 minutes of operation, and then the reading abruptly switched to 1.73 ± 0.28 µm. After this "warmup" glitch (shown in the figure with the open blue point) no problems with POPS performance were observed. The data in Figure 3 also show a slight overestimation of the particle size by the POPS closer to its larger size limit (3 µm). This minor inconsistency may possibly be caused by the POPS manufacturer's calibration approach based on using PSL microspheres.

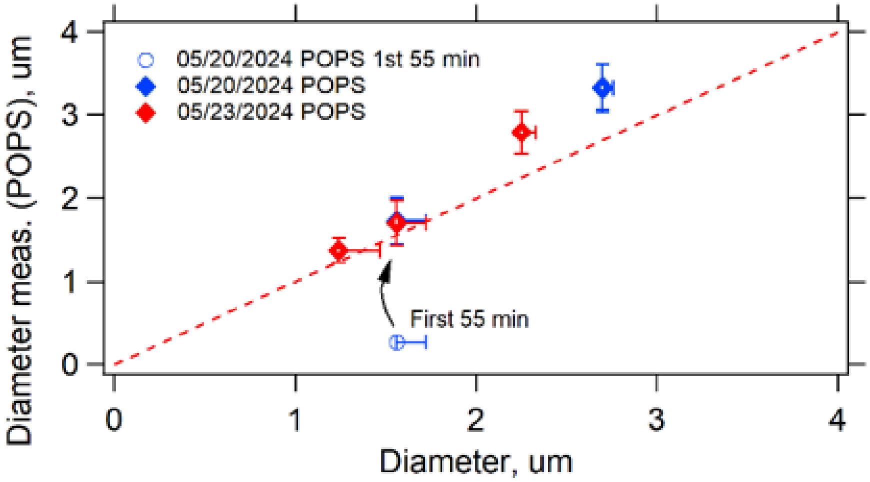

Figure 3. Ammonium sulfate aerosol particle size measured by the POPS as a function of particle size set by the generator. The open point shows the "warmup" glitch occurred during the first 55 minutes of operation. Dashed line shows "ideal" response curve with a slope of unity.

2.3 Conclusions

To repeat our most important findings:

- **It is important to regularly field-calibrate atmospheric measurement instruments during field campaigns.**
- The Mesa Photonics' monodisperse aerosol/droplet generator prototype operated flawlessly during the one-week CAAP field campaign, with no hardware or software issues.

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