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ARM FY2025 Aerosol Operations Plan

O Mayol-Bracero
S Smith
M Zawadowicz
J Creamean
C Hayes
M Salatti
O Enekwizu
S Petters
J Uin
J Shilling
A Singh
A Sedlacek
D Campos DeOliveira
O Enekwizu
M Petters
A Theisen

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DISCLAIMER

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O Mayol-Bracero, Brookhaven National Laboratory (BNL)
J Uin, BNL
S Smith, BNL
J Shilling, Pacific Northwest National Laboratory
M Zawadowicz, BNL
A Singh, BNL
J Creamean, Colorado State University
A Sedlacek, BNL
C Hayes, BNL
D Campos DeOliveira, BNL
M Salatti, BNL
O Enekwizu, BNL
M Petters, University of California, Riverside (UCR)
S Petters, UCR
A Theisen, Argonne National Laboratory

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Acronyms and Abbreviations

3D	three-dimensional
AAF	ARM Aerial Facility
ACSM	aerosol chemical speciation monitor
ACSM-CDCE	ACSM, Corrected for Composition-Dependent Collection Efficiency Value-Added Product
ACTRIS	Aerosol, Clouds and Trace Gases Research Infrastructure
AETH	aethalometer
AFC	ARM field campaign
AMF	ARM Mobile Facility
AMICE-2	Absorption Measurements in New Experiment for Establishing an Absorption Reference for Correction of Filter-Based Measurements
AMSG	Aerosol Measurement Science Group
AOD	aerosol optical depth
AODBE	Aerosol Optical Depth Best Estimate Value-Added Product
AOP	Aerosol Operations Plan
AOS	Aerosol Observing System
AOSMET	Aerosol Observing System meteorological instruments
APS	aerodynamic particle sizer
ARM	Atmospheric Radiation Measurement
AWARE	ARM West Antarctic Radiation Experiment
BNF	Bankhead National Forest
BNL	Brookhaven National Laboratory
CAMS	Center for Aerosol Measurement Science
CAPE-k	Cape kennaook/Grim, Tasmania
CAPS	cavity attenuated phase shift monitor
CAPS-SSA	cavity attenuated phase shift monitor-single-scattering albedo
CARGO-ACT	Cooperation and AgReements enhancing Global interOperability for Aerosol, Cloud, and Trace gas research infrastructures
CCN	cloud condensation nuclei
CLAP	continuous light absorption photometer
CoURAGE	Coast-Urban-Rural Atmospheric Gradient Experiment
CPC	condensation particle counter
CPCF	condensation particle counter, fine
CPCUF	condensation particle counter, ultrafine
CRG	ARM site code for CoURAGE campaign
CSU	Colorado State University

DAQ	data acquisition system
ENA	Eastern North Atlantic
EPCAPE	Eastern Pacific Cloud Aerosol Precipitation Experiment
FAIR	Findability, Accessibility, Interoperability, and Reusability
FY	fiscal year
GAW	Global Atmosphere Watch
GHG	greenhouse gases monitor
HTDMA	humidified tandem differential mobility analyzer
INP	ice nucleating particle, filters for ice nucleation particles
INS	ice nucleating spectrometer
IOP	intensive operational period
KCG	ARM site code for kennaook/Cape Grim campaign
MCPC	mixing condensational particle counter
ML	machine learning
NANOSMPS	nano scanning mobility particle sizer
NASA	National Aeronautics and Space Administration
NEPHDRY	nephelometer, ambient
NEPHWET	nephelometer, RH scanned
NOAA	National Oceanic and Atmospheric Administration
NOX	nitrogen oxide monitor
NSA	North Slope of Alaska
OPC	optical particle counter
OZONE	ozone monitor
PI	principal investigator
POPS	portable optical particle spectrometer
PSAP	particle soot absorption photometer
PTAAM	photothermal aerosol absorption monitor
PTI	photothermal interferometer
PTRH	pressure, temperature, and relative humidity
PTR-MS	proton transfer reaction-mass spectrometer
QA	quality assurance
QC	quality control
RH	relative humidity
RL	Raman lidar
RLPROF-FEX	Raman Lidar Vertical Profiles-Feature Detection and Extinction Value-Added Product
SAIL	Surface Atmosphere Integrated Field Laboratory
SGP	Southern Great Plains

SMPS	scanning mobility particle sizer
SP2	single-particle soot photometer
SP2-XR	extended-range SP2
TBS	tethered balloon system
TOF-ACSM	aerosol chemical speciation monitor–time of flight
TRACER	Tracking Aerosol Convection Interactions Experiment
UHSAS	ultra-high-sensitivity aerosol spectrometer
VAP	value-added product
WCCAP	World Calibration Center for Aerosol Physics
WP	work package

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Tables

1.0 Introduction

The U.S. Department of Energy's Atmospheric Radiation Measurement user facility (ARM) deploys at each of ARM's observatories a suite of aerosol and trace gas (further mention of aerosols will assume inclusion of trace gases) instrumentation that constitute the Aerosol Observing Systems (AOS; Uin et al. 2019). ARM currently deploys five AOSs, one each at:

- Southern Great Plains (SGP)
- Eastern North Atlantic (ENA)
- ARM Mobile Facilities (AMF1, 2, and 3).

Aerosol measurements at ARM's North Slope of Alaska (NSA) observatory have historically been made by the National Oceanic and Atmospheric Administration (NOAA) and provided to ARM through a collaboration. To complement these measurements, starting in financial year 2025 (FY25), ARM will monitor chemical composition and particle size by adding an aerosol chemical speciation monitor (ACSM), extended-range single-particle soot photometer (SP2-XR), and aerodynamic particle sizer (APS) at the NOAA facility in NSA.

As ARM's support for aerosol instrumentation increases, it is important for ARM to communicate plans and priorities for aerosol measurements to the community to maximize the benefit and planning around scientific activities and to advance confidence in ARM's aerosol measurements.

ARM is developing a yearly aerosol operations plan for every fiscal year (October 1-September 30). This started in FY24. The plan will be open and available through the ARM aerosol instrument webpages and will include:

- Review of the previous activities since the last plan
- Planned activities and their priorities for the upcoming FY
- Calibration timing and efforts
- Planned activities for data products and value-added products (VAPs).

Questions about the plan should be sent to Olga Mayol-Bracero through the mentor contact page: https://arm.gov/connect-with-arm/organization/instrument-mentors/list#aos.

2.0 AOS Instrumentation

Each AOS has a common set of standard instruments with additional instruments deployed as needed to ensure the best measurements at each site. The measurements include aerosol particle number concentration, size distribution, chemical composition, radiative and optical properties, hygroscopicity, concentration of trace gases, and supporting meteorological conditions. Table 1 lists instrumentation deployed at each ARM site and other instrumentation available for field campaigns such as during intensive operational periods (IOPs).

Table 1. Matrix of aerosol instruments and the observatories where they are deployed.

Instrument	AMF1	AMF2*	AMF3	SGP	ENA	NSA	IOP
Aerosol chemical speciation monitor-quadrupole (ACSM)							
Aerosol chemical speciation monitor-time of flight (TOF-ACSM)							
Aethalometer (AETH)						NOAA	
Aerodynamic particle sizer (APS)		CAPE-k					
Cavity attenuated phase shift monitor (CAPS)							
Carbon monoxide/nitrous oxide/water vapor (CO)		Y					
Continuous light absorption photometer (CLAP)						NOAA	
Cloud condensation nuclei (CCN)		Y					
Condensation particle counter (CPC, CPCF)		Y				NOAA	
Ultrafine condensation particle counter (CPCUF, CPCU)		Y					
Humidified tandem differential mobility analyzer (HTDMA)							
Impactor (1-10 µm)		Y				NOAA	
Nano scanning mobility particle sizer (NANOSMPS)							
Nephelometer, ambient (NEPHDRY)		Y				NOAA	
Nephelometer, RH scanned (NEPHWET)		Y					
Ozone (OZONE)		Y					
Scanning mobility particle sizer (SMPS)		Y					
Sulfur dioxide (SO2)							
Single-particle soot photometer (SP2)	IOP	CAPE-k	XR			XR	X
Ultra-high-sensitivity aerosol spectrometer (UHSAS)		CAPE-k					
Meteorological information (AOSMET)							
Filters for ice nucleating particles (INS/INP)							
Proton transfer reaction-mass spectrometer (PTR-MS)							X
Nitrogen oxide 3-channel [NO, NO2, NOy] (NOX)							X
Greenhouse gases [CO_2, CH_4] (GHG)							X
Y = part of the system							
Additions in FY25							
Removed from operations							

*The AMF2 AOS, except for the APS, SP2, and UHSAS, is not deployed in the current AMF2 deployment at CAPE-k (Cloud, Aerosol, and Precipitation Experiment at kennaook/Cape Grim, April 15, 2024-Sept 15, 2025) due to the overlap with the existing measurements at the Cape Grim, Tasmania aerosol stations.

2.1 Instrument Tiers

ARM operates a high-quality, research-grade AOS system and since 2024 started to invest in other tiers of aerosol measurements including aerosol nodes. Below are the definitions of the different instrument tiers: standard AOS, additional AOS, and aerosol nodes. Instrumentation outside the standard AOS could be operated during IOPs or field campaigns as requested.

2.1.1 Standard AOS

An ARM standard AOS system has high-quality, research-grade instrumentation. These are highly complex systems with a variety of instrumentation and sampling protocols. A standard AOS includes the following instruments, currently deployed at every AOS.

Table 2. Standard AOS instruments.

Aerodynamic particle sizer (APS)	Ozone (O3)
Cloud condensation nuclei counter (CCN)	Particle soot absorption photometer (PSAP)
Condensation particle counter (CPC/CPCF)	Scanning mobility particle sizer (SMPS)
Impactor	Ultra-high-sensitivity aerosol spectrometer (UHSAS)
Nephelometer (NEPH)	AOS meteorological system (AOSMET)

2.1.2 Additional AOS Instruments

Additional AOS instrumentation (Table 3) may be deployed full-time at certain sites or just during IOPs. These instruments are not the same across all AOSs and could be deployed standalone in some cases.

Table 3. Additional AOS instruments.

Aerosol chemical speciation monitor (ACSM/TOF-ACSM)	Humidified tandem differential mobility analyzer (HTDMA)
Aethalometer (AETH)	Nano scanning mobility particle sizer (NANOSMPS)
Carbon monoxide monitor (CO)	Proton transfer reaction-mass spectrometer (PTR-MS)
Ultrafine condensation particle counter (CPCU/CPCUF)	Sulfur dioxide monitor (SO2)
Cavity attenuated phase shift monitor (CAPS)	Single-particle soot photometer (SP2, SP2-XR)
Filters for ice nucleation particles (INS/INP)	

2.1.3 Aerosol Nodes

ARM is defining aerosol nodes to cover a range of possible aerosol systems for deployment, from lower-cost standalone systems to research-grade instruments deployed in a small shelter. The measurements deployed will depend on the scientific priorities of the field campaigns but may include, but are not limited to, size distributions, concentrations, and/or trace gases. Two tiers of aerosol nodes are being developed within ARM, known as the mini-AOS and micro-AOS. The key differences between these two types of nodes lie in their operational complexity, measurement capabilities, and physical footprint. As noted in the Engineering Development Section, ARM is currently investing in two mini-AOS for the extended AMF3 deployment to the Bankhead National Forest (BNF) in northwest Alabama. This system will initially consist of size distribution measurements from ~0.01 to 10 μm and, with deployment maturity of the mini-AOS, will include additional capabilities such as optical measurements. ARM is also deploying a micro-AOS using a Handix portable optical particle spectrometer (POPS) optical particle counter (OPC) during the upcoming urban AMF1 deployment, the Coast-Urban-Rural Atmospheric Gradient Experiment (CoURAGE; Maryland, December 1, 2024-November 30, 2025).

3.0 Outcomes from the 2024 Aerosol Operations Plan

The outcomes presented here correspond to accomplishments related to the FY24 Aerosol Operations Plan (AOP; Theisen et al. 2024) and the 2018 Aerosol Measurement Plan (Mather et al. 2018). Table 4 shows completed tasks in green shading and in-progress tasks in tan shading. A short overview of the completed tasks from this plan can be found in Appendix A with overviews of the in-progress tasks in Appendix B.

Two tasks were removed from the FY24 AOP. The establishment of a cloud condensation nuclei (CCN) scan strategy was a recommendation from the 2018 Aerosol Measurement Plan. Since the CCN instrument is not built to offer the flow-scanning capability, to do this will require modification of the hardware and software. This could have an impact on manufacturer's support; therefore, this task is not part of our plan in the near future and will require further discussion with the Aerosol Measurement Science Group (AMSG). The other task that was removed was the characterization of the humidigraphs. These instruments were aging in ARM, and many were at the point of needing replacement. Instead of replacing these systems, in FY24 ARM decided to retire all humidigraphs and RH-scanned nephelometers from operations.

Other changes for FY24 that impacted aerosol operations include ACSMs and humidified tandem differential mobility analyzer (HTDMAs). The Eastern North Atlantic (ENA) ACSM was removed from service and is kept as a spare. The AMF2 TOF-ACSM was installed at NSA. ARM will operate a maximum of two HTDMAs at a given time. Details of where these will be deployed are presented in Section 4.1.

Table 4. Outcomes from FY24 Aerosol Operations Plan (Theisen et al 2024). Green-shaded tasks are completed and tan-shaded are in progress.

#	Task	Priority	Year Planned
1	Improve and simplify access to aerosol data	1	2018
2	Improve documentation of measurements and data streams	1	2018
3	Identify candidate data products for other communities	1	2025
4	Reduce number of HTDMAs in field	1	2018
5	Refurbishment of ENA HTDMA	2	2024
6	Removal of ACSM at ENA	3	2024
7	Retirement of humidigraphs	3	2024
8	New instrumentation for AMF3 (SO2, APS, SP2-XR)	1	2024
9	Implement an inlet drying system (initially at SGP)	1	2025
10	Implement the new pressure, temperature, and relative humidity (PTRH) sensors in AOS02 and AOS03	2	2024
11	NSA additional instrument deployment	1	2024
12	Develop prioritization for ultrafine CPCs	3	2019
13	Implement second set of size distribution instruments	2	2019
14	Comparable size distribution output across instruments	1	2018
15	Absorption, scattering, and extinction closure	3	2023
16	Increase particle soot absorption photometer (PSAP) filter change at SGP	4	2023
17	New trace gas analyzer	2	2024
18	Develop plan to support detailed composition measurements	3	2019
19	Develop strategy for hygroscopic measurements	1	2023
20	Upgrade an ARM HSRL to support aerosol retrievals	1	2024
21	Support lidar/radiometer retrieval development	1	2025

4.0 ARM AOS Instrument Operations

4.1 FY25 Operations

4.1.1 Aerosol Observing System

ARM will continue operating AOSs at SGP, ENA, AMF1 (CoURAGE), and AMF3 (BNF) in FY25. Additional instrumentation will be added to the NOAA NSA facility at the end of FY24 (see Table 1 for the specific instruments). During the Cape kennaook/Grim, Tasmania campaign (CAPE-k) ending in September 2025, only a small subset of instrumentation (APS, SP2, and ultra-high-sensitivity aerosol spectrometer [UHSAS]) is being deployed at the AMF2 as the site is collocated with the Cape Grim Baseline Air Pollution Station. CAPE-k ARM aerosol data are available to users and ARM is actively working to ingest these data sets as appropriate. As ARM continues to expand and enhance capabilities, it must scale back in other areas.

AOS instrumentation will also be part of several ARM field campaigns (AFCs). Two of these are AFC10188 at ENA and AFC10203 at CoURAGE (CRG). The ENA AFC does not call out the AOS. The AOS will be operational and actively monitoring the site during that campaign. The CRG AFC calls out particularly the ACSM, CCN, and HTDMA.

4.1.2 Hygroscopicity Plan

4.1.2.1 Operations

To effectively operate the HTDMAs, ARM is implementing the following operational paradigm:

- Run a maximum of two HTDMAs at any given time for a total of 18 months per year.
- Run any HTDMA for at least six months consecutively to mitigate potential technical issues from instrument start up or shut down.
- Allow time and effort for switching from running one HTDMA unit to another. About a week of mentor and site operator effort is needed each time an HTDMA unit is shut down or started up. This time is required for instrument maintenance, changes to the sampling system, and data verification. This extra effort is offset by running the HTDMA units for a combined 18 months out of a year instead of 24.

For FY25, ARM will operate HTDMAs at AMF3 (BNF) and AMF1 (CoURAGE). Plans for FY26 will be developed depending on new AMF campaigns.

In limiting the operations of the HTDMA, the goal is to allow users to request different modes of operations as part of limited intensive operational periods (IOPs). Changes to the modes can be requested through the ARM field campaign process for a small field campaign (https://arm.gov/guidance/campaign-guidelines/small-campaigns). Potential HTDMA operational modes include:

- Extended humid size scans with higher resolution and/or longer scan times
- More or different dry size cuts (currently 50, 100, 150, 200, 250 nm)

- Ambient size distribution scans (up to 1000 nm) in between regular HTDMA growth factor measurements.

The operational modes listed above are contingent on the outcomes of laboratory tests and may be subject to change. Also, note that some of the listed operational modes are mutually exclusive.

Additionally, ARM currently deploys five dual-column CCN instruments. The instruments are operated with one column scanning over pre-defined supersaturation set points while the other column is kept at a constant supersaturation set point for reference. ARM will continue with CCN operations.

The HTDMA instrument currently does provide size-resolved hygroscopicity measurements, including kappa; however, the HTDMA measurements are in the subsaturated regime (RH at 85-90%) while the CCN operates in supersaturated mode.

4.1.2.2 Laboratory Effort

Only running a subset of the five total HTDMA units will leave some available for extended laboratory work. This opportunity will be used to better characterize HTDMA performance and capabilities, and to develop a list of possible operational modes (with associated benefits and costs) that extend the current measurement capabilities and could be requested by principal investigators (PIs).

ARM currently runs all its HTDMA units in a similar way. The ambient particles are dried and periodically size selected at 50, 100, 150, 200, and 250 nm. At each dry cut size the sample is then humidified to 85% or 90% RH and the resulting particle size measured. In theory, there are a few ways to potentially extend this mode of operation, but practical constraints such as instrument stability need to be assessed. Additionally, any benefits from new modes of HTDMA operation will likely include tradeoffs in some other area that need to be examined and eventually communicated to the users. Some of the extended capabilities that will be examined include:

- Ambient size distribution scans between regular humidified scans. This could provide a size distribution measurement in a wide range and potentially improve the HTDMA data inversion.
- Larger number and/or wider range of dry cut sizes. Depending on the number of cut sizes, this would impact the temporal resolution of the measurements.
- Different or more than one RH set point. As above, with more than one RH set point, this would lower the temporal resolution of the measurements.

Additional laboratory activities include:

- Characterizing instrument performance at different ambient conditions.
- Improving data inversion by using an external mixing condensational particle counter (MCPC).

The goal of this HTDMA work is to better quantify measurement uncertainty, refine the existing ARM HTDMA data products (such as the subsaturated kappa), and develop new value-added data products to facilitate wider use of ARM HTDMA data.

4.1.2.3 Data Products

ARM b-level HTDMA data includes variables for the growth factor and the hygroscopicity parameter kappa (at subsaturated conditions), calculated from the raw instrument data.

As noted in the FY24 Aerosol Operations Plan (Theisen et al 2024), ARM has started to produce a CCN-SMPS kappa product. A CCN and SMPS are deployed at all sites with the exception of NSA. The b1-level HTDMA data products also have a kappa that is based on the simple inversion that the HTDMA is performing in the software.

4.1.3 Ice Nucleating Particles

ARM has established routine ice nucleating particle (INP) filter collection and offline measurements at select sites since 2020. The filters are processed using an ice nucleating spectrometer (INS) at Colorado State University (CSU; also known as the ice spectrometer). For FY25, collections of duplicate filters integrated for 24 hours will occur approximately every six days at SGP (C1) and BNF (M1). ARM plans to establish similar measurements at NSA as time and effort permits in FY25. AMF collections of duplicate filters every six days currently include the Cloud And Precipitation Experiment at Kennaook (CAPE-k [KGC]) and two sites for the Coast-Urban-Rural Atmospheric Gradient Experiment (CoURAGE [M1 and S2]). Daily collections of single filters for 24 hours will occur during an approved CAPE-k IOP Jan-Mar 2025 and a subset will be processed for case study evaluation (PI: Kerri Pratt). INP filter samples will also be collected on the tethered balloon system (TBS) for six two-week deployments during CoURAGE and at BNF. Data from these sites and campaigns will be available on ARM's Data Discovery interface within 3-6 months after samples are shipped to CSU. We have caught up on the backlog of samples from all previous campaigns and sites.

4.2 Calibration

4.2.1 Calibration Schedule

Generally, the mentors calibrate the aerosol instruments at the beginning and end of mobile facility deployments with calibrations planned in between depending on the length of the deployment and scientific drivers for those campaigns. To align with needs expressed by the community for more routine calibration to better support field campaigns, IOPs, and long-term measurements in general, a new calibration plan for AOS instruments is being developed. The calibration plan is subject to change if other priorities and complications arise. The aerosol team will work with ARM communications on a communication plan to best convey changes to the community. The calibration plan for FY25 is shown in Table 5 with specific instrument-level calibration needs in Table 6. The aerosol mentor team will also work with site operators to define calibration procedures and transfer ownership of some calibration activities to site operations to improve the timeliness of calibrations and reduce the travel burden on the mentor team.

4.2.2 Intensive Operational Periods

As noted in Table 5, ARM will define periods at SGP, CoURAGE, CAPE-k, and BNF that are ideal for IOP operations in FY25. These periods are determined based on the mentor team's available effort and schedule for the coming years, deconflicted with planned IOPs as much as possible. During these periods, ARM will prioritize efforts to ensure that all instruments are operational, calibrated, and producing high-quality data. This will include shifting known activities (repairs, upgrades, etc.) that would take an instrument offline to either before or after this period and providing more frequent reviews of the data from the Data Quality Office and mentor. These periods do not exclude any other time of the year for IOPs but will be a period in which ARM makes a concerted effort to provide high-quality data with high uptime. In the case of BNF, the IOP periods may include TBS flights.

Table 5. Planned calibration activities for each of the ARM observatories.

Site	Oct 2024	Nov 2024	Dec 2024	Jan 2025	Feb 2025	Mar 2025	Apr 2025	May 2025	Jun 2025	Jul 2025	Aug 2025	Sep 2025
AMF1 (CoURAGE)				I	I					I	I	
AMF2 (CAPE-K)*	I			I	I							
AMF3 (BNF)						I	I		I		I	
ENA												
SGP												
NSA												

Calibration Trip

X - Every effort will be made to ensure all instruments are operating at a high quality

I - Ideal or planned periods for IOPs

* CAPE-k operators will be performing these calibrations

Table 6. Calibration frequency and needs for each instrument type.

Personnel	Instrument	Calibration Frequency	Equipment Needs
Mentor/Operators	ACSM	4x/year	CS, AS, FM
Operators	AETH, flows	1x/year	FM
Mentor/Operators	APS	4x/year	FM
Operators	CAPS	2x/year	AS
Mentor	CCN	2x/year	CS, AS
Operators	CO, MFC	2x/year	FM
Mentor/Operators	CPCf, CPCuf, SMPS	4x/year	CS
Mentor	HTDMA	2x/year	FM
Mentor	INS/INP, MFC	1/year	FM
Operators	NEPH	2x/year	Cal. gas

Personnel	Instrument	Calibration Frequency	Equipment Needs
Operators	OPC	4x/year	FM
Operators	OZONE, MFC	2x/year	FM
Operators	PSAP, Flow, MFC	2x/year	FM
Operators	SO2, MFC	2x/year	FM
Mentor	SP2	2x/year	CS, AS
Mentor (Operator for calibration check)	UHSAS	2x/year	AS

Cal SMPS (CS)
Atomizer system (AS)
Flow meters (FM)
Calibration material (CM) PSL, ammonium sulfate, nitrate, Fullerene soot

4.2.3 Improving Calibration Processes

In FY24 ARM started the procurement of instrumentation for the establishment of a gold-standard reference for size distribution (SMPS) and number concentration measurements (CPC). This equipment will be installed and tested at the Center for Aerosol Measurement Science (CAMS) at Brookhaven National Laboratory (BNL). These standards will then be compared against World Calibration Center for Aerosol Physics (WCCAP) standards every year. We are seeking to better facilitate these activities between involved organizations (i.e., ARM, CAMS, WCCAP).

Calibrations of ARM CPCs and SMPSs will start in FY25 with closure and intercomparison efforts in FY26/FY27. The goal is, in time, to expand calibrations to other aerosol properties related to the ARM AOS measurements (i.e., composition, optical, hygroscopicity). Table 7 presents the timeline for activities and deliverables in FY25. We expect that calibration activities will result in downtime of the instruments, and they will be planned accordingly as part of the future Aerosol Operations Plan for transparency.

Table 7. CAMS calibration activities for FY25.

Tasks	Deliverables	Planned End Date
Complete first-phase infrastructure preparations	CAMS calibration lab is set up and ready to receive reference instrument for SMPS calibrations.	Dec 2024
Procurement and installation of reference instrument for SMPS calibrations	Instrument has been installed at BNL and tested for proper operation. Staff has been trained on its operation. Certificate of performance from WCCAP for reference instrument.	Feb 2025
First calibrations of ARM SMPS instruments using reference instrumentation (starting with SGP), data analysis	ARM SMPSs from SGP have a certificate of performance from CAMS calibration lab.	April 2025
Preparation of lab for CPC calibrations	Calibration lab is set up and ready to receive reference instrument for CPC calibrations.	March/April 2025

Tasks	Deliverables	Planned End Date
Procurement and installation of reference instrument for CPCs calibrations	Instrument has been installed at BNL and tested for proper operation. Staff has been trained on its operation. Certificate of performance from WCCAP for reference instrument.	April/May 2025
First calibrations of ARM CPC instruments using gold standards (starting with SGP), data analysis	ARM CPCs from SGP have a certificate of performance from CAMS calibration lab.	June/July 2025
Documenting and sharing the results and lessons learned from the first CAMS calibrations	Calibration results, procedures, and lessons learned disseminated to relevant parties.	Sept 2025

4.2.4 Training Site Operations for Calibrations

To reduce travel costs while also maintaining reliable calibrations, the aerosol mentor team has been training site operators in necessary calibrations and maintenance. The first training was for the site operators of the CAPE-k deployment (APS, SP2, UHSAS, SMPS cal system) and was held in November-December 2023. The second training, on April 2024, was for the BNF and SGP site operators. A third training is planned for the AMF1 operators, and it will happen at the CoURAGE deployment. The past training events took place at BNL over the course of one week each time.

4.3 FY25 Engineering and Development

Besides routine AOS operations, the mentor team is focused on improving and expanding ARM measurements to better serve the research community. These efforts may revolve around improved understanding of the measurements, new instrumentation, new instrument development, or other needs as they arise. It is important that ARM prioritize these efforts and communicate those priorities to the community. Table 8 shows an overview of activities with further information below for Priority 1 activities.

Table 8. FY25 planned aerosol engineering and development activities.

Task	Priority	Planned End Date
Aerosol node development	1	June 2025
Aerosol flux measurement development	1	Nov 2024
Center for Aerosol Measurement Science (CAMS)	1	Dec 2027
Absorption Measurement Intercomparison and Calibration Experiment for advancing ARM’s absorbing aerosol measurements	1	Dec 2025
Training of AMF site operators on calibrations and instrument maintenance at BNL	1	Dec 2024
Develop and implement a plan for distributed aerosol measurements for urban AMF deployments	1	Dec 2025
Contracted deployment of a NOx system with the ARM AOS for CoURAGE	1	Dec 2025

Task	Priority	Planned End Date
Correction factors for the new PSAP filter media	2	Dec 2024
Refurbishing the ENA HTDMA	2	Nov 2024
Testing a new field-deployable calibration system	2	April 2025
Replacement of the aging NEPH systems	3	July 2025
Develop a data flagging approach for identifying MOSAiC AOS contamination events	3	Dec 2024
Evaluating UHSAS and OPC measurements	4	Dec 2025

4.3.1 Aerosol Node Development

As noted earlier, ARM is investing in the development of two aerosol nodes that will initially measure aerosol size distribution and number concentration but may be expanded to include additional measurements such as optical properties, CCN, INP, trace gases, and potentially more.

Progress update, August 2024

1. Milestone: Instrument Selection and Evaluation – 100% completed. Several instruments for fine-mode and coarse-mode size distribution were evaluated. Brechtel mSEMS (0.01 to 0.4 µm) and GRIMM OPC 11-d (0.27 to 10 µm) were selected to provide a complete size distribution for the AOS-mini.
2. Milestone: Infrastructure design and development (70-90% complete). The outline for the infrastructure design, detailed in the supporting document, encompasses the enclosure, sampling inlet, conditioning, and the data acquisition system (DAQ) has been prepared and was presented in the second design review in May 2024. Procurement of components is already underway; some components have already been received. ARM GRIMM OPC is sent to Durag for factory repair and calibration.
3. Milestone: AOS-Mini 1 System integration (ongoing). Integration of key components of the AOS-Mini 1 will begin after receiving all the procured items. AOS-Mini inlet system is already in BNL and laboratory work is underway to characterize the inlet with respect to flow requirement and transmission efficiency.

4.3.2 Aerosol Flux Measurement Development

ARM is deploying a single-particle flux system on the 40-meter tower at AMF3 to determine the viability of measuring aerosol fluxes. If the tests prove successful, additional heights will be deployed in subsequent years. Efforts for this will start in Q3 of FY24.

Progress update, August 2024 (only one milestone for FY24)

1. Milestone: Instrument survey, acquire test unit for lab evaluation, request instrument procurement. A design document is under preparation that underlines instrument selection, measurement, and infrastructural needs. As part of instrument selection, a series of discussion are underway with vendors for instrument feasibility for a tower-based flux measurement. Also, there are ongoing

conversations with subject-matter experts to assess current understanding of aerosol flux measurement and we are building a test system in the laboratory integrating the CPC and OPC with 3D wind vectors.

A summary report will be produced to capture instrument survey, some laboratory efforts, and overall infrastructural needs for a tower-based flux measurement.

4.3.3 CAMS

As noted in the Calibration Section (4.2), ARM will be improving existing calibration processes for aerosol instruments in the AOS. New calibration equipment is being procured, laboratory space at BNL is being prepared for this effort, and a detailed calibration plan for ARM instruments that measure particle number concentration and size will be developed.

4.3.4 CARGO-ACT

A dialogue between ARM and ACTRIS, looking for ways to collaborate, started in 2019. What emerged from that dialogue is a three-year project with the European Union named CARGO-ACT – Cooperation and AgReements enhancing Global interOperability for Aerosol, Cloud, and Trace gas research infrastructures. CARGO-ACT's goal is to deliver a clear roadmap for sustainable global cooperation between key organizations in Europe (ACTRIS) and in the United States (ARM, NOAA, National Aeronautics and Space Administration [NASA]) to provide all users with the best possible services (data, measurement facilities, reference instruments, reference standards, laboratories) for accessing and using information for monitoring climate- and air quality-relevant properties of aerosols, clouds, and trace gases. The project started in March 2024 and ARM contributes in different ways to the six work packages (WP). WP1 deals with data interoperability, WP2 has to do with the specification and documentation of common operation procedures and data quality methodologies, WP3 is the pilot implementations demonstrating service integration, and WPs 4 to 6 deals with governance, common data access, and strategies for how to bring more U.S. observation networks to the ACTRIS project. ARM aerosol operations (in situ and remote sensing) and calibration activities (as part of CAMS) are part of WP2. Deliverables for this year include (1) identification of opportunities for harmonized calibration and operation practices and data production software, (2) agreement on common vocabulary for describing instrument traceability and calibration, quality assurance and quality control, and (3) recommendations for common calibration and operation procedures.

4.3.5 Absorption Measurements in New Experiment for Establishing an Absorption Reference for Correction of Filter-Based Measurements (AMICE-2)

AMICE-2 will use in situ instruments (e.g., cavity attenuated phase shift monitor-single-scattering albedo [CAPS-SSA], photothermal interferometer [PTI], photothermal aerosol absorption monitor [PTAAM]) to establish a reference against which to calibrate and correct filter-based instruments recommended for replacement of the PSAP through AMICE-1 (conducted in summer 2025). AMICE-2 will also evaluate the use of prepared solutions to generate internally mixed aerosols with repeatable SSA as references for use in the field.

4.3.6 Distributed Aerosol Measurement for Urban Deployments

ARM will be deploying three ground-based POPS systems at the main and two supplemental sites for the CoURAGE campaign in Baltimore, Maryland. These are currently under development and plan to be ready for an operational start date of December 1, 2024.

4.3.7 New Trace Gas Analyzer

The AMF1 CO, N_2O, and H_2O trace gas analyzer had a failure during the Tracking Aerosol Convection Interactions Experiment (TRACER) and with limited support from the manufacturer, there is a need to replace the analyzer to reduce further downtime and unreliable measurements. Currently, the AMF1 CO, N_2O, and H_2O analyzer has been replaced by the ARM Aerial Facility (AAF) CO analyzer while the plane is not flying. The AMF1 analyzer will be sent to the manufacturer for refurbishment and repair, and returned to service at CoURAGE when this process is complete. A new trace gas analyzer (MIRO MGA-10) was evaluated in FY2024 to serve as a replacement for the aging CO, N_2O analyzer, along with consolidating the remaining trace gas measurements (O_3, SO_2) into a single instrument. Regrettably, this new analyzer did not pass acceptance testing, so we are currently exploring alternative options moving forward. A call for the deployment of a NOx system at CoURAGE was put out on sam.gov for proposals with the expectation to provide at least nine months of data for CoURAGE during the IOPs.

5.0 ARM AOS Data Products

5.1 FY24 Accomplishments and Ongoing Activities

Aerosol Optical Depth (AOD) and AOD Best Estimate (AODBE): ARM recently upgraded the MFRSR to include a new 1625-nm channel. This channel has significant interference from gas-phase species and a procedure for subtracting these interferences was developed and implemented in FY23. In FY 24, we processed and released AOD data for the TRACER, Surface Atmosphere Integrated Field Laboratory (SAIL), and Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE) campaigns that includes the new channel (seven channels total). AODBE evaluates the AOD measurements of several co-located instruments and provides a recommended AOD value and error range. We processed and released AODBE data for the ENA and NSA sites.

CCN Kappa: Kappa is a parameterized representation of an aerosol particle’s hygroscopicity widely used in models to calculate CCN concentrations and cloud properties. In the last two years, we have developed the CCN-SMPS kappa VAP and processed data for most sites. CCN kappa runs in near-real time and is currently available for all sites/campaigns.

CCN Profile: In previous years, we began implementing a VAP that estimates the CCN vertical profile using lidar data. We recently implemented changes in the VAP that allow it to be run for more sites and time periods. In FY24 we released processed and released data for ENA and additional data for SGP. We also worked to improve the QA/QC implemented in the VAP and have been evaluating the VAP output against available in situ data sets.

Merged Size Distributions: We recently developed a VAP that merges data from the SMPS and APS instruments into a single size distribution and a machine learning algorithm that performs QA/QC on the merged SMPS-APS data set. The merged size distribution VAP is now running routinely for sites that have both and SMPS and an APS. In FY 24, we released merged size distribution data with the machine learning QA/QC analysis for TRACER and EPCAPE. We also processed merged SMPS-UHSAS size distributions; however, upon investigating the data we noticed a systematic discrepancy between the SMPS and UHSAS particle counts over their common range. We therefore decided to postpone processing and releasing more SMPS-UHSAS merged size distribution data.

Additional VAPs: The ACSM, corrected for composition-dependent collection efficiency (ACSM-CDCE) VAP corrects the ACSM data for non-unity particle sampling. This VAP is now operational and running in real time. Data are available for all sites with an ACSM. The AOP VAP combines PSAP and nephelometer data to provide corrected in situ aerosol optical properties. The AOP VAP also runs in real time and is available for all sites with a PSAP and nephelometer.

5.2 FY25 Planned Activities

Detailed plans for specific data product development efforts in FY25 are as follows.

CCN Profile: In FY25, we plan to continue evaluating the performance of the CCN profile VAP against available in situ data. We will also develop a machine learning-based QA/QC evaluation of the data. Finally, we will evaluate the feasibility of using more values of the CCN supersaturation to retrieve the CCN vertical profile and explore the possibility of producing an altitude-dependent CCN spectrum across the range of measured saturation values.

HTDMA kappa: In FY24, we began developing a VAP that calculates kappa under subsaturated conditions using data from ARM's HTDMA instruments. This kappa calculation is less sensitive to errors in particle count than the CCN kappa, only relies on data from a single instrument, and provides a measure of kappa under subsaturated conditions. In FY25 we will finalize the development of this algorithm and produce HTDMA kappa data and compare data to the CCNC-SMPS-based kappa.

Merged Size Distribution Machine Learning: In FY24, we developed a machine learning (ML) algorithm that performs QA/QC labeling of the merged SMPS/APS size distribution data. We will continue to evaluate the performance of this algorithm with data from new sites and release ML-labeled merged-size distribution data.

AOD and AODBE: We have been working on extending the AOD VAP to additional sites that require more manual labor in evaluating the NASA Langley Research Center measurements and will continue to do so in FY25, including processing AOD data for new campaigns such as the ARM West Antarctic Radiation Experiment (AWARE) and the BNF site. In FY25 we will incorporate date from the new 1625 channel into the AODBE VAP, creating a seven-channel product, and process data for TRACER, SAIL, and EPCAPE.

Bundled Aerosol Data: At the request of ARM users and advisory groups, we will develop a VAP that bundles data from multiple aerosol instrumentation into a single file on a single time stamp. This VAP will simplify the user experience and reduce the amount of work for scientists wanting to use data from multiple instruments in their analysis.

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Appendix A

2024 Aerosol Operations Plan Completed Tasks

- **Improve and simplify access to aerosol data**

  We have made substantial improvements in aerosol data access and are also continually improving based on user feedback. Key improvements:

    - New Data Discovery interface
    - Additional metadata to improve the search capabilities
    - Spatial, temporal, and keyword search capabilities
    - Dedicated home page search by Category for "Aerosols"
    - Improved data details page with contact information, citations, data quality timeline, primary measurements, and data plots
    - Added recommendations for aerosol datastreams.

- **Improve documentation of measurements and datastreams**

  Metadata auditing for the aerosol datastreams is complete. The ARM Data Center metadata team improved the metadata keywords and classifications.

  The VAP web pages have been updated to provide improved short summary descriptions of VAPs including caveats that describe when the VAP is applicable and when caution should be used. The reference list has been updated and made easier to use to identify VAP point of contacts.

  CARGO-ACT work package 2 will also contribute to improve documentation regarding aerosol measurements (in situ and remote sensing).

- **Reduce number of HTDMAs in field**

  ARM has reduced the number of operating HTDMAs to two at a maximum. For FY25, this will include BNF and AMF1 (CoURAGE). Once CoURAGE is completed, the HTDMA at SGP will be brought online.

- **Removal of ACSM at ENA**

  In FY24, ARM retired from operations the ENA ACSM to add an ACSM to NSA.

- **Retirement of humidigraphs**

  To enable new scope, in FY24 ARM retired all humidigraphs and RH-scanned nephelometers from operations.

- **New instrumentation for AMF3**

  The AMF3 will be deployed at BNF in Alabama, starting September 2024. In addition to the aerosol node and aerosol flux measurement development, ARM added additional instrumentation to the AMF3 AOS. This includes an APS, SO2, extended-size-range SMPS (size range is extended from 10-500 nm to 10-800 nm), and SP2 (SP2-XR). The SO2 and APS are standard ARM instruments, but the SMPS and the SP2-XR are new additions that require ARM to develop new processes (ingest, data quality, calibration, etc.).

- **NSA additional instrument deployment**

  In September 2024, ARM started deployment of the following instruments: ACSM, APS, SP2-XR, and filters for INS at the NOAA facility alongside NOAA instrumentation.

- **Develop prioritization for ultrafine CPCs**

  We have "increased" the number density of the ultrafine CPC (CPCu or CPCuf) to four ARM sites (AMF1, AMF2, AMF3, SGP).

- **Implement second set of size distribution instruments**

  There are SMPSs and APSs in all five ARM deployments. The new SMPS at the AMF3 has the wide-range differential mobility analyzer that allows a measurement range of 10 to 800 nm. There is a sixth APS at NSA since September 2024.

- **Comparable size distribution output across instruments**

  The aerosol translator is leading an effort to create a merged size distribution VAP using a machine learning method. This is under testing and evaluation.

- **Absorption, scattering, and extinction closure**

  This was an optical closure analysis involving the Aerodyne CAPS (cavity attenuated phase shift spectroscopy) aerosol extinction monitor and the TSI nephelometer (aerosol scattering). The particle soot absorption photometer (PSAP, aerosol absorption) was to be the third element in this study, but due to the discontinuation of the filter media, it was not included. The study demonstrated that measurements of scattering coefficients and extinction coefficients for purely scattering particles agree to within 5-10 % in controlled laboratory experiments. This accuracy limits the extent to which closure between scattering, absorption, and extinction can be attained for an aerosol that contains absorbing components. The fact that numerous correction schemes have been, and are still being, proposed for filter-based measurements of aerosol light absorption (e.g., PSAP or aethalometer), which can vary considerably among themselves, indicates that this approach is unlikely to yield accurate results under any situation. For this reason, filter-based measurements are really only useful in identifying relative changes in absorption, not the actual absorption coefficients.

- **Increase PSAP filter change at SGP**

  On a nightly basis, every weekend, and during extended weekends, the PSAP filters at SGP face an excessive load, resulting in the loss of absorption measurements for several hours to an entire day each weekend, contingent on local conditions. To extend the operational window of the SGP PSAP, we increased the filter change frequency at minimally two changes per day—at the start and end of each shift.

- **New trace gas analyzer**

  We tested the MIRO Gas analyzer (MGA-10) as a potential replacement for ARM trace gas instruments and it is not a viable option for ARM field deployments. See Section 4.3.7.

- **Develop plan to support detailed composition measurements**

  ARM's plan is to operate the ACSMs and look at opportunities for expansion as they present themselves and as budgets align.

- **Develop strategy for hygroscopic measurements**

  Following the reduction in the HTDMA operations, the freed-up HTDMA units are undergoing performance evaluation before starting the tests on new operational modes. For more details regarding this plan please refer to Section 4.1.2.

- **Upgrade an ARM HSRL to support aerosol retrievals**

  ARM upgraded one high-spectral-resolution lidar (HSRL) to add a 532-nm wide-field-of-view channel and 1064-nm narrow-field-of-view channel along with off-nadir scanning. This system is deployed at SGP, alongside the Raman lidar (RL) which will allow for three-wavelength retrievals of aerosols optical and physical properties. ARM is in the process of upgrading its second HSRL to the same configuration for deployment at the AMF3 observatory in Bankhead National Forest where there will also be a RL deployed. ARM is also in the early phases of procuring an aerosol profiling lidar, similar to those deployed for ACTRIS. The plan is to incorporate aerosol microphysical retrieval into a VAP. ARM is working with the NASA Langley Research Center to receive their TIARA algorithm (Tikhonov Advanced Regularization Algorithm), which uses HSRL and RL to derive aerosol properties. In the last year, data analyst Peng Wu has developed an aerosol feature mask that identifies aerosol features using HSRL data.

Appendix B

2024 Aerosol Measurement In-Progress Tasks

- **Identify candidate data products for other communities**

  ARM has discussed getting data in the Global Atmosphere Watch (GAW) database and efforts are ongoing. Additionally, ARM held meetings with ACTRIS geared towards common practices, data products, and more. An outcome of these meetings is the three-year CARGO-ACT (Cooperation and AgReements enhancing Global interOperability for Aerosol, Cloud and Trace gas research infrastructures) project. The goal of this project is to make ARM, ACTRIS, NOAA, and NASA aerosol data more similar across the different networks to better serve the global research community, including modelers and satellite users. The ARM Data Center has provided the list of candidate data sets and the Findability, Accessibility, Interoperability, and Reusability (FAIR) implementation plan to CARGO-ACT.

- **Refurbishing of ENA HTDMA**

  The ENA HTDMA is being refurbished and will be one of the HTDMA units that are undergoing performance evaluation before starting the tests on new operational modes.

- **Implement an inlet drying system (initially at SGP)**

  Inlet drying systems have been installed in the SGP, AMF1, and AMF3 AOS systems. The AOS at AMF2 is planned for implementation next.

- **Implement new PTRH sensors in AOS02 and AOS03**

  A new PTRH sensor was developed and successfully deployed in AOS01. These sensors are in each sample line, as close to the instrument as possible to characterize the conditions of the sample air as it enters the instruments. This is being implemented in the AOS03 and will be implemented as well in AOS02.

- **Support lidar/radiometer retrieval development**

  A translator is currently preparing the Raman Lidar Vertical Profiles-Feature Detection and Extinction (RLPROF-FEX) VAP at SGP and improving the HSRL data to support multi-wavelength lidar retrievals of aerosols.

Appendix C

Download Metrics 1/1/2018-7/7/2023

Does not include aircraft data.

Table 9. Instrument download metrics, 2018-2023.

Instrument	Non-Infrastructure Downloads	Non-Infrastructure Users	Publications
CCN*	1072	333	15
CPC	772	259	20
SMPS*	771	230	23
AOSMET	514	205	4
UHSAS	519	190	7
NEPH	487	163	13
ACSM*	422	145	8
PSAP	398	135	9
AOS	395	180	30
CO	316	93	2
HTDMA	264	83	4
OZONE	177	71	4
SP2*	172	83	12
AETH	123	67	4
APS*	107	46	6
SO2	79	39	1
GHG	64	16	2
CAPS-PMEX	58	20	2
OPC	43	12	2
NOX	42	25	0
CLAP	39	19	1

*Numbers include VAPs, if available, which may pull in data from multiple products.

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