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ARM Aerosol Measurement Plan

J Mather
C Flynn
S Springston

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ARM CLIMATE RESEARCH FACILITY

DISCLAIMER

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J Mather, Pacific Northwest National Laboratory
S Springston, Brookhaven National Laboratory
C Flynn, Pacific Northwest National Laboratory

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Acronyms and Abbreviations

AAF	ARM Aerial Facility
ACE-ENA	Aerosol and Cloud Experiments in the Eastern North Atlantic
ACSM	aerosol chemical speciation monitor
ADC	ARM Data Center
AeroCom	Aerosol Comparisons between Observations and Models
AMF	ARM Mobile Facility
AMSG	Aerosol Measurements and Science Group
AOS	aerosol observing system
APS	aerodynamic particle sizer
ARM	Atmospheric Radiation Measurement
ASR	Atmospheric System Research
CACTI	Cloud, Aerosol, and Complex Terrain Interactions
CCN	cloud condensation nuclei particle counter
CLAP	continuous light absorption photometer
CO	carbon monoxide mixing ratio system
CPC	condensation particle counter
CY	calendar year
DOE	U.S. Department of Energy
DQO	Data Quality Office
E3SM	Energy Exascale Earth System Model
ENA	Eastern North Atlantic
FTE	full-time equivalent
FY	fiscal year
G-1	Gulfstream-1 aircraft
HR-TOF-AMS	high-resolution time-of-flight aerosol mass spectrometer
HSRL	high-spectral-resolution lidar
HTDMA	humidified tandem differential mobility analyzer
IMPROVE	Interagency Monitoring of Protected Visual Environments
LASIC	Layered Atlantic Smoke Interactions with Clouds
MAOS	mobile aerosol observing system
MARCUS	Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean
MET	surface meteorological instrumentation
MFRSR	multi-filter rotating shadowband radiometer
MOSAIC	Multidisciplinary drifting Observatory for the Study of Arctic Climate
NASA	National Aeronautics and Space Administration

NOAA	National Oceanic and Atmospheric Administration
NOx	nitrogen oxide monitor
PASS 3	3-wavelength photoacoustic soot spectrometer
PI	principal investigator
PILS	particle-into-liquid sampler
PSAP	particle soot absorption photometer
PTR-MS	proton transfer reaction mass spectrometer
RH	relative humidity
SGP	Southern Great Plains
SMPS	scanning mobility particle sizer
SO2	sulfur dioxide monitor
SP2	single-particle soot photometer
SPLAT	single-particle laser ablation time-of-flight mass spectrometer
TAP	tricolor absorption photometer
TOF	time-of-flight
UAS	unmanned aerial systems
UHSAS	ultra-high-sensitivity aerosol spectrometer

Contents

Tables

1.0 Introduction and Background

Over the past decade, the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility has been working toward developing a comprehensive (defined here as Tiers I-III in Appendix A) and consistent set of aerosol measurements across each of the ARM ground-based observatories. Along the way, the facility has deployed wide-ranging instruments including some for which ARM has had many years of operating experience and some which represent more cutting-edge capabilities. While there has been a clear motivation for this instrument suite, the adoption of these instruments has not been uniform. The reasons for this vary and include operational challenges, measurement complexity, and alignment with active research.

Table 1. Current distribution of aerosol instruments by ARM observatory. 1: Original first ARM Mobile Facility (AMF1) Aerosol Observing System (AOS) taken out of service as of 12/1/2015 and replaced by a mobile aerosol observing system (MAOS-A) (now called AMF1 AOS); 2: The 3-wavelength photoacoustic soot spectrometer (PASS-3) was removed from operation on 10/1/2015.

				MAOS		
Instrument	AMF2 AOS	AMF3 AOS	ENA AOS	MAOS-A/ AMF1 *1	MAOS-C	SGP AOS*2
ACSM/Q - Aerosol Chemical Speciation Monitor - Quadrapole			[green]	[green]		[green]
ACSM/TOF - Aerosol Chemical Speciation Monitor-Time of Flight		[green]				
Aethalometer				[green]		
APS - Aerodynamic Particle Sizer						[green]
CAPS - Cavity Attenuated Phase Shift Monitor		[green]	[green]			[green]
CO - Carbon Monoxide/Nitrous Oxide/Water Vapor	As of MARCUS [green]	[green]	[green]	[green]		[blue]
CCN - Cloud Condensation Nuclei	[green]	[green]	[green]	[green]		[green]
CPC - Condensation Particle Counter	[green]	[green]	[green]	[green]		[green]
µCPC - Ultra-Fine Condensation Particle Counter		[green]		[green]		[green]
GHG - Green House Gases (CO2, CH4))		[green]	[green]			[blue]
HTDMA - Humidified Tandem Differential Mobility Analyzer	[green]	[green]	[green]	[green]		[green]
1- 10-µm Impactor	[green]	[green]	[green]	[green]		[green]
n-SMPS - Nano Scanning Mobilty Particle Sizer						[green]
Neph, Amb - Nephelometer, Ambient	[green]	[green]	[green]	[green]		[green]
Neph, Dry - Nephelometer, Dry RH Scanned	Broken [red]	[yellow]	[green]	[green]		[yellow]
NOx - 3 Channel: NO, NO2, NOy					[green]	
O3 - Ozone	[green]	[green]	[green]	[green]		
PASS-3 - 3 Wavelength Photo Acoustic Soot Spectrometer *2				removed		
PILS - Particle Into Liquid Sampler					removed	
PSAP - Particle Soot Absorption Photometer	[green]	[green]	[green]	[green]		[green]
PTRMS - Proton Transfer Reaction Mass Spectrometer					[green]	
SMPS - Scanning Mobility Particle Sizer				[green]		[green]
SO2 - Sulfur Dioxide					[green]	[green]
SP2 - Single Particle Soot Photometer				removed		
TAP - Tricolor Absorption Photometer						[green]
UHSAS - Ultra High Sensitivity Aerosol Spectrometer	As of Marcus [green]	[green]	[green]	[green]		[green]
WXT520 – Weather Sensor	[green]	[green]	[green]	[green]		[green]

Legend	
Part of System	[green]
Not part of System	
Part of System, not yet Delivered	[yellow]
At site but not installed in AOS	[blue]
Broken	[red]

As shown in Table 1, we are approaching completion of the core measurement set. However, it is becoming clear that completing this matrix is not practical. At least in the near term, ARM cannot accommodate the cost of all these additional instruments at the same time as addressing issues such as data product development. Coupled with this, there is a concern that the current ground-based aerosol measurements are being underused and so may not be ideally matched to research needs. This concern is based on interactions with the science community and on data usage statistics where adoption of many ground-based aerosol measurements seems to be slow (Appendix B).

Most of this report deals with the in situ measurements contained with the ARM Aerosol Observing Systems (AOS); however, ARM also operates instruments that provide aerosol property information using remote-sensing techniques. In discussion of the draft highlights of this plan at the 2018 ARM/Atmospheric System Research (ASR) spring meeting, it was suggested that these remote-sensing instruments should be included more directly in discussions of aerosol measurement capabilities. To provide additional background for this plan, therefore, the deployments by site of remote-sensing instruments relevant to aerosol studies are listed in Table 2. There is some discussion of the lidars in Section 2.10 and we expect that follow-up work to this document will seek to provide further integration between the in situ and remote sensing classes of measurements.

Table 2. Active (lidar) and passive (spectral radiometers) remote-sensing instruments that can be applied to aerosol applications. Green shading indicates the instrument is deployed at the indicated site.

Instrument	AMF1	AMF2	AMF3	SGP	NSA	ENA
CSPHOT - Cimel Sun Photometer	■	■	■	■	■	■
HSRL - High-Spectral Resolution Lidar		■			■	
MPL - Micropulse Lidar	■	■	■	■	■	■
MFRSR - Multi-Filter Rotating Shadowband Radiometer	■	■	■	■	■	■
RL - Raman Lidar			■	■		■

The goal for this plan is to address issues that may be impeding the utility of ARM aerosol measurements, thereby enhancing the impact of those measurements. This plan involves a set of near-term goals intended to address issues that have been identified by the science community. For the most part, it does not attempt to identify priorities across measurement areas, though we expect that ARM will continue to work with the science community to refine this plan and to identify priorities to ensure that operation and development efforts have the greatest effect on the science community.

1.1 Steps toward this Plan

This plan began in a discussion between ARM and aerosol scientists at a breakout session at the 2016 ARM/ASR spring meeting. At that session, there was a call for feedback to the ARM Facility but it was noted that it is difficult to provide feedback without a more complete picture of ARM capabilities, relative costs, and other factors – particularly in such a constrained setting. Some of that information is provided in this report, but if further information is needed to advance the discussion, that can also be appended. The current distribution of instruments and the usage of ARM data have already been noted. Additionally, a categorization of instruments by cost and level of operational effort is provided in Appendix C as a reference for the plans laid out in the next section.

The 2016 breakout session led to a workshop organized by the ARM Aerosol Measurements and Science Group (AMSG) in early 2017 (McComiskey and Sisterson, 2018). The central goal of that workshop was to understand what the impediments were to using ARM data to address aerosol science goals – particularly those of interest to DOE but also for the wider atmospheric research community.

From the workshop introduction:

> *"A strategic planning workshop for the AMSG, sponsored by ARM, was held February 14-16 at Argonne National Laboratory in Chicago, IL, to evaluate the status of ARM's existing aerosol instrumentation, measurement strategies, and data products in the context of ARM and ASR science directions, the current and future needs of ARM data users, and budget. … The participants comprise experts in aerosol science, measurements, and deployment logistics from universities, national laboratories, and private industry. The outcomes of the workshop described in this report will aid in decision-making involving options for efficiently building on current ARM capabilities to address these science needs of the ASR and ARM communities within scope and budget."*

The AMSG workshop was organized around a set of measurement types and other measurement or data-related themes. The 10 themes identified below do not exactly match the categories that the workshop set out to examine but include planned categories as well as themes that emerged through the discussion.

Four categories deal with the overall aerosol measurement network:

1. Documentation and Communication
2. Deployment Strategies
3. System Configuration and Operation
4. General Data Product Issues/Harmonization.

Five categories deal with specific measurement areas[1]:

5. Number Density
6. Size Distribution
7. Hygroscopic Activity and Cloud Droplet Activation
8. Optical Properties
9. Aerosol Composition and Gas-Phase Aerosol Chemistry.

"Vertical profiles" is a cross-cutting theme that impacts several measurement themes but also includes operational considerations:

10. Vertical Profiles (captured under Deployment Strategies in the workshop report).

The discussion at the workshop focused particularly on issues within these 10 themes though there were activities geared toward assessing overall priorities and there was consensus on a number of these items. Where possible, ARM will be taking on these consensus items in the near term. In other cases, first steps

[1] Greenhouse gases were not considered as part of aerosol measurements through such instruments are sometimes deployed with aerosol observing systems.

to address these consensus items are identified. Where there was no consensus path forward, possible actions are proposed. It is expected that these priorities will evolve over time as ARM obtains additional input from the user community.

1.2 The Nature of this Plan

This plan seeks to identify near-term (FY2018-FY2019) actions and longer-term paths that will address issues identified in the 2017 Workshop and to a lesser extent other sources of input. In a few places where no clear consensus path forward emerged (for example for hygroscopicity and vertical profiles), ARM management has attempted to solicit additional input to form a preliminary strategy. This plan is intended to be a living document. That is, it is expected to evolve over time to continually align ARM capabilities with science needs. The hope and expectation is that this document will also motivate further discussion to continue to understand how ARM can better achieve that alignment. We encourage members of the user community to provide feedback and would particularly value input regarding what specific development is needed and how that will positively impact science outcomes.

The core of this document is the set of recommended activities described in the next section. These recommended actions attempt to reconcile user recommendations with operational constraints.

2.0 Measurement and Action Strategies by Measurement Theme

This section presents a wide variety of actions. Each is intended to improve the effectiveness of the ARM aerosol measurement network. Most of these actions emerged from the AMSG workshop and strong consideration to the priorities identified there are captured; however, logistic practicalities and competing priorities have also been taken into account to establish the strategy described. Prospective actions are organized according to the measurement identified above. In some cases, the AMSG have reached strong consensus on a path forward.

Seven activities in particular were identified as high-priorities and also align with logistic considerations. These seven items are highlighted in shaded text boxes and will be undertaken in FY2018. Other activities will also be taken on this year, but these seven are identified as the first priority.

Other tasks that ARM plans to take on in the next year, but which are slightly lower priority and/or are considered more difficult or uncertain, are identified with unshaded boxes.

In some cases, items were considered a high priority but there is not yet a clear path forward, so work will have to be done to define the scope of the activity. A summary of proposed actions including their priority and state of readiness is provided in Table 3 in the next section.

2.1 Documentation and Communication

There were no specific recommendations in this section; however, it is clear that issues in this category are impeding the effective use of ARM AOS measurements and there was a strong general recommendation from the AMSG to improve and simplify the ability to determine what data are available, where to find them, and their state.

There are approximately 60 individual instruments distributed across the five AOS systems (excluding greenhouse gas monitors and weather stations) and approximately 500 datastreams (accounting for multiple sites and data levels). Combining this with the fact that aerosol data products have been in a state of flux with the harmonization work leads to the aerosol datastreams being a complex landscape.

Following on the 2017 ARM Triennial Review, ARM is undertaking a broad review of Data Discovery as well as the underlying metadata and associated web pages and documents that provide supporting information about instruments and datastreams. These issues and this area will be a priority in FY2018 for ARM in general; however, given that aerosols represent the most complex array of instruments in terms of the diversity and number of measurements made, this area needs to be a particular priority.

2.2 Deployment Strategies

Two critical recommendations that emerged in this area were:

1. Develop a complete instrument set (as defined by Tiers I-III in Appendix A) at the Southern Great Plains (SGP) observatory.
2. Analyze the measurements from the Eastern North Atlantic (ENA) satellite site obtained during the Aerosol and Cloud Experiments in the Eastern North Atlantic (ACE-ENA) field campaign.

Additionally, it was proposed that the Oliktok Point, Alaska, AOS be moved to Barrow.

AOS instruments have been deployed over a number of years and for many reasons the sites have a range of capabilities, with the AMF2 having the fewest instruments (except for Barrow, where ARM does not operate an aerosol observing system) and the SGP having the most. No two sites have the same set of instruments. There has been a goal to raise all sites to include a complete set of instruments as defined by Tiers I-III in Appendix A. However, it has become apparent that ARM does not have the resources to support this full range of instruments and at the same time provide the data products, metadata, and documentation required to make optimal use of these measurements. This raises questions such as whether the current distribution of existing instrumentation is best suited to meet community science needs. Some of these issues will be addressed in this general deployment strategy section and some under specific measurement areas – where the issue is closely aligned with a specific area.

#1 Completing the instrument set at the SGP: A key recommendation from the AMSG workshop is to have at least one site that is as complete as ARM is able to support. Currently no ARM site has each type of aerosol instrument that ARM operates. The site that comes closest to achieving this is the Southern Great Plains observatory. The only instrument that is missing at the SGP from Tier I-III is an ozone analyzer. There was a strong recommendation to rectify this issue and deploy an ozone analyzer at the SGP. Given the low cost of this instrument, it was proposed to purchase a new unit rather than pulling one from another site. *Level of Effort: Low; Procurement cost: ~$15,000.*

#2 ENA satellite site analysis: There have often been challenges finding an appropriate location for aerosol measurements in conjunction with ARM deployments. This issue has perhaps most notably and persistently been raised in conjunction with the ENA site where there are known local aerosol sources. There have been suggestions that the AOS might be moved. It has also been proposed that prior to making such a move, ARM should perform limited measurements to evaluate prospective sites. In conjunction with the ACE-ENA field campaign, an ultra-high-sensitivity aerosol spectrometer (UHSAS), condensation particle counter (CPC), and weather station were deployed at an alternate site near the ARM observatory. As a next step toward evaluating this alternate site, it is necessary to analyze the alternate site in comparison with the ARM AOS observations to determine to what extent deployment at this alternate site mitigates local effects observed by the ARM AOS. This issue was not raised at the AMSG workshop but has been raised as a priority since the deployment of the temporary satellite instrument suite.

A notable disparity in the overall ARM aerosol measurement network is the lack of an AOS at Barrow where the National Oceanic and Atmospheric Administration (NOAA) operates a small set of aerosol instruments. There are no plans to implement a new AOS, which would cost over $1,000,000. Recognizing this, the AMSG has noted with a strong consensus that in the long term, it would be preferable to have an AOS at Barrow instead of Oliktok because Barrow better represents the background arctic state. It was recommended that AOS operations continue at Oliktok in the near term to characterize that site but that ARM consider moving that AOS to Barrow.

The plan for FY2018 is to continue operation at Oliktok. However, ARM is exploring the possibility of moving the AOS to Barrow as soon as FY2019. In considering such a move, future plans (as yet unsettled) for the AMF3 will have to be taken into account. Other options for Barrow, including the deployment of a reduced set of instruments, will also be considered.

In this and the following sections, strategies are described to improve ARM measurement capabilities across aerosol measurement areas. Progress toward these goals will be assessed periodically and if some areas prove to be impractical, revisions will be considered. Noted earlier in this section was a recommendation that at least one site include a full set of instruments. A counterpoint to this recommendation is that if the full set of measurements cannot be sustained while also making progress toward associated goals such as instrument characterization and data product development, it may be necessary to reduce the scope of some sites. In that case, the tiers identified in Appendix A would be used as a guide.

2.3 System Configuration and Operation

This section deals with the environment in which the instruments operate and the rules that govern their operation. The highest priority in this section, and a consensus item from the AMSG workshop, was the implementation of a drying system for AOS inlets. Two other issues identified by the AMSG are inlet sampling efficiency and setting guidelines for instrument temporal resolution. Additionally, as part of previously planned work, ARM will be adapting the MAOS-A system to become the new AMF1 AOS.

#3 Implementing an inlet drying system: In the current version of the ARM AOS, aerosol particle size measurements are measured at ambient relative humidity. This is problematic because measured size distributions are affected by both the dry size distribution and the humidity. This can be particularly problematic if the humidity is modified by differences in internal and external conditions. To measure an unambiguous size distribution, there was consensus that aerosols should be dried before measuring sizes and, if possible, that drying should be accomplished without heating, which could alter the composition of the aerosol by driving off volatile chemicals. *Level of Effort: ~0.2 FTE + ~10k materials*

Temporal resolution: It was identified as a strong recommendation by the AMSG to store measurements at the sample interval appropriate for each measurement rather than to integrate to a common time interval. The latter can be done in derived products but the sense was that we should keep and make available the full temporal resolution for each instrument. **This was not identified as a problem but as a guide for the future so there is no action required at present.**

Inlet characterization for large particles: Bullard et al. (2017) have conducted a detailed characterization of the AOS inlet (https://www.arm.gov/publications/tech_reports/doe-sc-arm-tr-191.pdf). This work included measurements of large particles; however, there were insufficient samples above about 1 micron so the evaluation does not sufficiently constrain sampling efficiency for larger sizes. A follow-on study has been proposed that would address this issue. The study relies on bringing both of ARM's Aerodynamic Particle Sizers (APS) into the laboratory for at least a few months. Currently only one of the instruments is operational. This work is proposed to occur in CY2019 (either during or after Cloud, Aerosol, and Complex Terrain Interactions [CACTI]). ***We propose this characterization work be conducted following CACTI so that a full size distribution can be carried out for that campaign (see section 6).***

It was not called out at the AMSG workshop, but there has been a pending task for the past year or so to modify MAOS-A to specifically include instruments that are part of AOS systems at other sites and modify some of the infrastructure to more closely resemble an AOS. *The goal is for the MAOS-A to become the AMF1 AOS. This work will be carried out between the Layered Atlantic Smoke Interactions with Clouds (LASIC; Ascension Island) and CACTI (Argentina) deployments of the AMF1 in mid-FY2018.*

An additional need in this area is to evaluate alternate neutralizers, required for the operation of the humidified tandem differential mobility analyzer (HTDMA) and scanning mobility particle sizer (SMPS). Normally, these instruments use a radioactive (Po-210 or Kr-85) neutralizer. This can be a challenge to deploy at some locations. Currently this is only an issue at ENA. As will be seen below, we propose to remove the HTDMA from ENA for the near term, so this is not currently a high priority and there are no immediate plans to take on this characterization; however, eventually, this will need to be done if we deploy the HTDMA or SMPS at sites where a radioactive neutralizer cannot be used.

2.4 General Data Product Issues/Harmonization

Data products specific to particular measurement areas will be mentioned in the associated sections below. This section pertains to data product effort that cut across measurement themes and is particularly focused on the aerosol product harmonization effort. The AMSG particularly emphasized the need to continue and complete this effort.

For the past three years, ARM has undertaken a harmonization of its core aerosol products. This project set out to define uniform data formats across the AOS systems, and to minimize manual processing by instrument mentors by implementing corrections and automated quality checks within the ARM infrastructure (ARM Data Center [ADC] and Data Quality Office [DQO]) to obtain well-characterized and consistent core data products. (https://www.arm.gov/news/features/post/46011). At the AMSG workshop, the group put a high priority on completing this work and, in fact, the harmonization of AOS optical properties to produce uniform products at the b1 level (conversion to calibrated geophysical units with automated quality checks) is complete. These products have been operationally released to provide uniformity. In a few cases, additional manual corrections are still being done and we will continue to review these processes to integrate this effort into the automated stream. There also remains work to do for a few of the more complex instruments, notably the aerosol chemical speciation monitor (ACSM), as well as harmonization across instruments (e.g., to create common methodologies for size distribution and hygroscopicity measurements across disparate instruments). Specific tasks have been identified to advance these areas and will be called out in the related measurement area in sections below.

One more general issue to consider here is that, based on preliminary discussions with scientists from other communities (especially global modeling and satellite observations), other data products may be useful for making ARM observations more valuable to a broader community f For example, calculating aerosol parameters comparable to quantities reported by commonly used aerosol parameterizations. **There is no immediate action here except for ARM to identify candidate data products and review with appropriate science stakeholders.**

2.5 Number Density

We operate fine particle (>10nm) CPCs at all sites and operate ultrafine particle (> 3nm) CPCs at three sites (SGP, AMF1, and AMF3). This was not identified as an area demanding attention so there are no immediate plans.

One question that should be considered; however, is whether the current locations of the three ultrafine CPCs makes the best use of those instruments. The proposal here is for the CPC mentor to recommend a prioritization of the CPCs by site for review by the AMSG and ARM management.

2.6 Size Distribution

Obtaining the complete size distribution was identified as a high priority by the AMSG, suggesting that the complete size distribution be deployed with each ARM AOS. The complete size distribution would be obtained through a combination of an SMPS (10-500 nm; or 2-150nm for the nano-SMPS), UHSAS (60- 1000 nm), and APS (500-20,000 nm). For the near term, this will be pursued with existing instrumentation. Because the complete size range is spanned by three different instruments, a second priority in this area is to develop a data product that merges the three data sets.

#4 Implementing a second full set of size distribution instruments. Currently the complete set of size distribution instruments is only available at the SGP: this includes both an SMPS and a nano-SMPS. Each site has a UHSAS but only the AMF1 has an SMPS and no other site has an APS, though ARM does have one spare APS. To create a second size distribution suite, the spare APS will be assigned to the AMF1, where there has been a specific request for large-particle measurements in support of CACTI, for the coming year.

Following CACTI, this pair of instruments could then be deployed to support another observatory and ARM will review options with the science community. That next deployment would have to wait until the inlet is characterized for large-particle losses (Section 2, System Configuration and Operations, above) because both of ARM's APS are required for that study.

To meet the full recommendation of the AMSG for full size distributions, additional SMPS and APS would be required at AMF2, AMF3, and ENA. These instruments each cost in the range of $50,000- $70,000 and carry with them additional ongoing mentor support expenses. As noted in the introduction, this is not possible without reduction in scope elsewhere.

#5 Comparable size distribution representation across instruments: There was also discussion in this area of the need for a merged data product. The three instruments that provide size distribution measurements do not do so in a consistent manner. To make the complete size distribution more useful to a broad community, a merged product would be valuable. A modest but important first step in creating this merged size distribution is to ensure that datastreams from each of the instruments contributing to the anticipated merged distribution provide representations of size in a consistent way. This task will create a consistent set of outputs, which represents a first important step toward a merged size distribution product.

2.7 Hygroscopic Activity and Cloud Droplet Activation

This is an important area for cloud-aerosol interactions and for understanding profiles of aerosol optical properties. However, it is also a complex area with three sets of instruments providing information: CCN counter, humidigraph (coupled with nephelometers), and the HTDMA. There was not a strong recommendation for any of these instruments or this area in general, but it was noted that characterization work is required and each of these instruments needs some development work to make them optimally useful to the science community.

CCN: There has been work done over the past year to assess alternate operational modes for the dual-column CCN (currently deployed at SGP, Oliktok, and AMF1). ARM needs to work with science stakeholders to identify an appropriate scan strategy and put that into operation.

Humidigraph: ARM currently operates two Recovery Act-era humidigraphs, at ENA and AMF1 and is preparing to deploy a newly engineered humidigraph design at the SGP. *An important task in FY2018 will be to test the new humidigraph and assess its performance relative to the older units.*

HTDMA: Each AOS currently has an HTDMA. The instruments are generally in good operating condition; however, each instrument is different, which complicates management. More importantly, the data do not appear to be seeing use (Appendix B). A hypothesis for this is that the data produced directly by the HTDMA are complex and not accessible by most users. If this is true, it suggests a need to accelerate the development of derived products that make the instrument more useful, but this effort would have to happen at the expense of something else.

We propose that until significant progress is made toward developing a well-characterized end-to-end datastream for the HTDMA, that the number of operational HTDMAs be reduced by at least one and possibly by 2-3 in the near term. We particularly propose taking off line the HTDMAs from the AMF2 and ENA in the near term – and applying effort to characterizing these instruments and pursuing the development of derived products through interaction with the user community.[2] *This change in near-term measurement scope will be reviewed with community stakeholders, and particularly with the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAIC) science team, who would be most impacted by this change. Additionally, resources should be applied to bring the array of HTDMAs into closer alignment with each other. Following the CACTI field campaign, the AMF1 HTDMA will be taken off line to upgrade that instrument. At that time, a review of readiness of the off-line systems and the overall state of the HTDMA characterization will be undertaken to consider if and where the HTDMAs should be deployed.*

The most critical need in this section is dialog between ARM and the science community to establish what measurements and data products are most needed in this area. For example, is there a need to operate each of the above instruments at each site? What are the critical data products needed from these instruments? Is it adequate to report size distributions as a function of humidity or is it important to provide derived growth factors? There is a lot of measurement capability in this area but it is not clear today how these measurements can be best leveraged to support the science community.

2.8 Optical Properties

ARM has been making optical property measurements for many years. The main challenge has been measuring absorbance, for which the primary mechanism has been the filter-based particle soot absorption photometer (PSAP). The top priority in this area for the AMSG is to manage the transition to a new type of filter media for PSAP-style instruments. The AMSG has also recommended that ARM invest in a new aethalometer to provide an alternative for the PSAP/continuous light absorption photometer (CLAP)/tricolor absorption photometer (TAP) class of absorbance-measuring instruments.

#6 Determine PSAP/TAP migration and replacement filter path: The PSAP has been used for many years to measure aerosol absorbance but is no longer available. The TAP is being examined as a possible successor to the PSAP. Both the PSAP and the TAP are filter-based measurements. The type of filter used for all the years of PSAP operation will no longer be available and the supply is projected to run out ~2020. To ensure continuity in measurements, it is critical that new filter media be evaluated in conjunction with the old-style filter while supplies remain. A consensus recommendation from the AMSG is to establish a migration path from the current PSAP/TAP filter media to a new filter type. An experiment plan is current being developed for review. *Level of Effort: ~0.25-0.5 FTE*

[2] There were several promising presentations related to HTDMA products at the 2018 ARM/ASR meeting from the mentor, Janek Uin, who proposed a strategy for the running and processing data from the HTDMA and from Levin et al. who reported on progress from an ASR project using the HTDMA. These, and possibly other activities, will be considered in forming plans for the HTDMA.

Meanwhile, independent of the filter issue, as evaluation of the TAP continues, there is interest in considering the 2-spot aethalometer as another source of absorbance measurements. This would require a modest investment to upgrade an ARM aethalometer. There would be value in including the aethalometer in the joint PSAP/TAP filter evaluation to further obtain overlapping measurements. ***ARM plans to upgrade an aethalometer to the 2-spot configuration in FY18 to support this activity.*** *Cost*: Approximately $20,000 for upgrade.

2.9 Aerosol Composition and Gas-Phase Aerosol Chemistry

As part of the Recovery Act project, ARM set out to provide a basic level of chemical compositional measurements at multiple sites through the Aerosol Chemical Speciation Monitor (ACSM) as well as detailed precursor information via a single set of more advanced instruments that could be rotated among sites. Over the past several years, there have been significant advances with the ACSM but the ARM methodology for providing the more detailed precursor measurements is in need of review. As part of this plan, ARM will continue to refine operations of the ACSM but will take a step back from the more detailed ground-based composition measurements. To supplement the ACSM, ARM would like to obtain feedback regarding the usefulness of filter-based measurements.

2.9.1 The Aerosol Chemical Speciation Monitor

There are two ACSM models, the original Quadrapole system and a more recent Time-of-Flight (TOF) version that offers improved sensitivity. There are three of the Quadrapole models, at SGP, ENA, and AMF1, and one Time-of-Flight version, currently at Oliktok.

#7 Implement improved quality controls in ACSM data products: The conclusion from the AMSG workshop was that the ACSM is maturing into a valuable instrument and data usage appears to support this; however, at the workshop, several important instrument issues were identified. Subsequent discussions among ARM staff, the science community, and the instrument vendor have resulted in improved speciation results. The mentor has undertaken manual reprocessing of historic data but will next implement automated processing to achieve these same results for future measurements. This will be a high priority for FY2018.

Another important near-term task for the ACSM is to complete the ingest for the ACSM-TOF so those data are more readily available. ***This work will also be a priority for this year.***

In addition to addressing the measurement artifacts, there is a proposal to conduct a thorough characterization of the ACSM through coordinated measurements with a high-resolution, time-of-flight, aerosol mass spectrometer (HR-TOF-AMS) using prepared samples under laboratory conditions. This task is considered valuable but will have to be considered with other priorities in out-years.

A consideration for the Time-of-Flight ACSM is whether Oliktok is the best location for the most sensitive instrument. A review of options for the optimum location for this version of the ACSM will be developed this year. Included in that assessment should be the possibility, noted in Section 1, that the Oliktok AOS may be moving to Barrow in the near future.

2.9.2 Detailed Composition Measurements

In addition to the ACSM, ARM has developed more comprehensive aerosol measurements through the MAOS as well as for the Gulfstream-1 (G-1) aircraft. The ground-based MAOS system has been deployed several times and has seen some success; however, there are some significant challenges. First, several of the more advanced instruments in the suite require significant attention for operation, data processing, or both. This is less of an issue for an aircraft deployment where data are collected for tens of hours than for a continuously operating ground-based site. Additionally, to meet science goals that explicitly depend on detailed composition measurements, the MAOS measurements have often needed to be supplemented with more advanced instruments (such as the HR-TOF-AMS or the single-particle laser ablation time-of-flight mass spectrometer [SPLAT]). In the end, it is not clear how much value the few ARM chemical composition instruments, notably the particle-into-liquid sampler (PILS) and proton transfer reaction mass spectrometer (PTR-MS), are really providing the science community – particularly considering their cost.

With these issues in mind, ARM is suspending operation of the MAOS-C as a separate facility and is suspending operation of the PILS, which requires a dedicated person for operation. The single-particle soot photometer (SP2) appears to be a notable exception that has provided significant value during multiple campaigns (though it continues to be labor intensive to process data, so long-term operation for months/years is prohibitive) and the PTR-MS and the nitrogen oxide monitor (NOx) are still under review in terms of operational outlook.

It was clear from the AMSG workshop that some detailed chemistry measurements are needed but it was not clear what the best mechanism to supply them is and whether this will ultimately be practical for ARM. There needs to be continued discussion with the science community to develop a strategy for how to address measurement needs in this area.

Options for ARM include:

- Providing a portable sampling shelter that would provide the infrastructure needed to host principal investigator (PI)-controlled instruments
- Maintaining several instruments that could be deployed in conjunction with an AOS or could be used by an appropriately experienced PI.

2.9.3 Filter Measurements

Given the challenges in obtaining composition information, it was proposed at the workshop, and has been proposed elsewhere, that ARM should pursue filter-based measurements. Over the past several years, ARM has accepted proposals for investigators to obtain filter samples for limited periods. This has primarily been in support of studies of ice nucleating particles but it illustrates one model for obtaining filter measurements at ARM sites. However, if this is an important activity, then ARM should explore whether it is practical to obtain these measurements on a more routine basis.

It was noted at the AMSG workshop that the Interagency Monitoring of Protected Visual Environments (IMPROVE) network, http://vista.cira.colostate.edu/Improve/improve-program/, represents a good example of a well-established filter-based measurement network that provides composition information using standard protocols. It appears that it would be relatively straightforward to implement IMPROVE measurements at one or more ARM sites. IMPROVE would provide supplies and carry out data processing while ARM would be responsible for the day-to-day management of the measurement systems. ARM will review the feasibility from a cost perspective but needs input from the community regarding the priority of this measurement[3]. *Cost: $37,500/site/year.*

2.10 Vertical Profiles

The AMSG workshop focused on the Aerosol Observing Systems, which are ground-based, in situ measurements. However, it was noted at the workshop and elsewhere, including the earlier ARM Absorbing Aerosol workshop, that profiles of aerosol are very important. This is true both for aerosol process studies and particularly for studies of aerosol-cloud interactions. ARM proposes continuing to use the Aerial Facility as a source of vertical profile information but also to pursue the application of multi-wavelength lidar as a mechanism to obtain more routine vertical profiles of aerosol information. There are three main options for obtaining vertical profiles, each with its own benefits and issues:

a) In situ measurements via aerial platform: manned aircraft, unmanned aircraft, and tethered balloons.

The ARM Aerial Facility (AAF) provides profile information about aerosol properties on an episodic basis.[4] ARM has well developed capabilities for aerosol measurements on manned aircraft and is developing capabilities for unmanned aerial systems (UAS) and Tethered Balloons (Schmid et al. 2014; Schmid and Ivey 2016). Manned aircraft activities are planned through approximately 2020 with the CACTI mission in FY2019 followed by the planned replacement of the G-1 aircraft in 2020.

For the past several years, ARM has been conducting small UAS and tethered balloon flights at Oliktok for approximately 3-5 intensive periods of approximately two weeks each spanning spring, summer, and fall. ARM has also been hosting UAS field campaigns at the SGP. Over the next several years, ARM will be expanding the measurement capabilities of these platforms and developing measurement capabilities for the newly acquired ArcticShark mid-sized UAS. These capabilities are expected to include aerosol sampling with the exception of the small UAS. The frequency of flights is expected to continue approximately as it has for the past several years.

b) In situ measurements via a fixed tower.

At present there are no plans in this category but this has been proposed as a potentially useful method for obtaining vertical profiles. Currently, ARM operates a 60-m triangular tower at the SGP Central Facility,

[3] At the Aerosol Measurements breakout at the 2018 ARM/ASR meeting there was a very positive response to pursuing IMPROVE measurements.

[4] ARM did conduct routine profiles of aerosol properties over the Southern Great Plains using a small Cessna aircraft between 2000 and 2007 (https://www.arm.gov/research/campaigns/aaf2000iap).

a 21-m walk-up scaffold at the Okmulgee SGP extended facility (E21), and a 40-m triangular tower at Barrow. None of these towers currently provides aerosol sampling although there are measurements of CO_2 fluxes on the 60-m tower at the SGP. Questions here include the utility of obtaining information at these relatively low heights and the practicality of implementing a sampling system on one or more of these towers. Of greater impact would be a tall tower (for example something > ~ 300 m), but that would be an expensive and logistically intensive undertaking. At present there are no plans to take on a tall tower at an ARM site. This does not mean that it could not be done – but it would take extensive planning.

c) Active remote sensing via lidar.

Researchers at NASA/Langley have developed a technique for obtaining vertical profiles of aerosol optical and physical properties using airborne multi-wavelength lidar (Müller et al. 2014). ARM has worked with this team to adapt this method to ground-based measurements using a modified high-spectral-resolution lidar (HSRL) and the ARM/Sandia Raman lidar. ARM does not have the capability currently of making these measurements continuously but collaborated with the University of Wisconsin and National Aeronautics and Space Administration (NASA)/Langley to carry out a demonstration of the technique in 2015 at the SGP (Ferrare et al. 2017). Providing this measurement, which produces information about particle size and number through the boundary layer, would require a capital upgrade to the HSRL. This seems like a good fit with ARM's broader capabilities and the most promising technique for obtaining some height-resolved aerosol information – so this is tentatively planned if it fits within ARM's limited capital budget[5]. However, we would like to hear from the science community regarding anticipated impact of these data.

Another facet to this lidar work is the possibility of using spectral radiometer measurements (e.g., from a multi-filter rotating shadowband radiometer (MFRSR) or sun photometer) to constrain the aerosol profile retrieval. This has the potential to improve the retrieval profiles of absorption coefficients or to enable the retrieval of some aerosol properties if it is not possible to deploy the full set of lidar channels deployed during the 2015 SGP measurement campaign. ARM proposes to carry out this evaluation in FY2018/19.

3.0 Summary

The preceding section described actions for each of 10 operations and measurement areas. These actions are intended to advance each of these measurement areas with the implicit assumption that each is important. Most of the tasks discussed are actions that ARM will be taking on over the next two years. These tasks are listed in Table 3. It may not ultimately be possible to accomplish all of these planned tasks, and in that case, the tasks to be taken on first will be determined by the task's priority ("P" in the table; 1 indicating the highest priority) and our readiness ("R"; with 1 indicating most ready) to accomplish the proposed task.

[5] Capital projects are those involving single-item investments exceeding $500,000 and require a special type of funding. ARM typically is allocated between ~$1,000,000 and $2,000,000 for capital projects in a given year depending on anticipated need.

Table 3. Summary of tasks. P = priority with 1 being the highest priority and R = readiness with 1 being the highest state of readiness (the scope is defined, funding is in place, ready to start now) and Y = year (18 = FY2018 and 19 = FY2019).

	Task	Theme	P	R	Y
1	Improve and simplify access to aerosol data	Documentation	1	2	18
2	Improve documentation of measurements and datastreams	Documentation	1	2	18
3	Complete SGP AOS by adding ozone	Deployment	1	1	18
4	Analyze ENA satellite site observations	Deployment	1	2	18
5	Develop measurement plan for Barrow	Deployment	2	3	19
6	Implement an inlet drying system (initially at SGP)	Configuration	1	2	18
7	Inlet characterization	Configuration	2	2	19
8	Convert MAOS-A to AMF1 AOS	Configuration	2	1	18
9	Complete harmonization of core data products	Data Products	1	2	18
10	Identify candidate data products for other communities	Data Products	2	3	19
11	Develop prioritization for ultrafine CPCs	Number Density	3	2	19
12	Implement second set of size distribution instruments	Size Distribution	2	1	19
13	Comparable size distribution output across instruments	Size Distribution	1	2	18
14	Establish CCN scan strategy	Hygroscopicity	3	3	19
15	Characterize humidigraph	Hygroscopicity	2	2	18
16	Reduce number of HTDMAs in field	Hygroscopicity	1	1	18
17	Develop strategy for hygroscopic measurements	Hygroscopicity	1	3	18
18	Determine PSAP/TAP filter migration path	Optical Properties	1	2	18
19	Upgrade an aethalometer to 2-spot configuration	Optical Properties	2	1	18
20	Implement improved ACSM quality controls	Composition	1	1	18
21	Implement ingest for the TOF-ACSM	Composition	1	2	18
22	Develop plan to support detailed composition measurements	Composition	3	3	19
23	Implement filter sampling via the IMPROVE network	Composition	3	2	19
24	Upgrade an ARM HSRL to support aerosol retrievals	Profiles	2	2	19
25	Support lidar/radiometer retrieval development	Profiles	3	2	19

As has been noted, to accomplish these tasks, there will be reduction in scope in a few operational areas, notably the MAOS-C and the HTDMA. As progress is made toward these tasks, ARM will periodically assess the sustainable level of instrumentation across the ARM observatories. There will also be instrument additions and moves targeted to advance specific measurement areas. Changes to the current measurement configuration identified in this plan are:

- Suspension of operation of the ENA HTDMA following ACE-ENA to make room for HTDMA characterization activities and to upgrade that instrument.
- Suspension of operation of the AMF2 HTDMA following the Measurements of Aerosols, Radiation, and Clouds over the Southern Ocean (MARCUS) campaign to make room for HTDMA characterization activities and to upgrade that instrument.
- Pairing the currently unassigned APS with the AMF1 SMPS for CACTI to meet the goal of a full size distribution at a second site. Following CACTI, the intent is that this SMPS/APS pair could be deployed at any site, not necessarily with the AMF1.
- Suspension of operation of MAOS-C as an integrated system. Operation of the SP2, sulfur dioxide monitor (SO2), proton transfer reaction mass spectrometer (PTR-MS), and NOx at an ARM site will be reviewed on a case-by-case basis. ARM is not currently considering deployment of the MAOS PILS due to high operational costs.

- Procurement of an ozone monitor and deployment to the SGP.
- Upgrade of a 2-channel aethelometer. Initially this will not be deployed as it is used for an absorption measurement evaluation. Following that evaluation, we anticipate that the instrument would initially be deployed to the SGP though we welcome input regarding the instrument's optimum siting.
- Relocation of the Oliktok AOS to Barrow, possible in CY2019.

Finally, we will continue to engage with the science community through breakout sessions at the ARM/ASR meeting, workshops, the AMSG, and the broader science community (e.g., through surveys and unsolicited feedback) with the goal of assessing science priorities and how ARM is advancing its capabilities to support those priorities.

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Appendix A

Aerosol Tiers

The following tiers were defined to consider how to distribute instruments across multiple sites in a tightly constrained budget environment. The specifics may be debated; however, tiers I-III are generally considered a complete aerosol observing system – in terms of the goals set out by the AMSG.

Tier I

UHSAS – to provide size distributions

CCN – to provide cloud propensity

Nephelometer and either TAP or PSAP at dry RH to provide optical properties (requires the impactor)

CO – for context with local effects and air parcel history

Met – for local effects

Package would take approximately 1 rack, 1 pump (carbon vane pump) and MAY be able to dispense with the drier.

Tier II

ACSM – for composition

O3 – for a measure of atmospheric processing

CPC – for particle counts (not in Tier 1 because its information is difficult to interpret and requires butanol)

SMPS – size distribution over smaller range than UHSAS and mobility size as opposed to scattering size

Tier III

APS – not in Tier I since not available AND inlet transmission efficiency unclear above ~3 um

HTDMA – Provides growth factors, but complicated, requires butanol and neutralizer source

f(RH) – provides growth factors for optical properties, but complicated and requires drying

CAPS – Interference from NO_2 and somewhat redundant to PSAP/nephelometer

Tier IV

SO2 – Sensitivity problematic at remote sites

NOx – Sensitivity problematic for long-term operation, expensive, requires separate inlet

SP2 – Black carbon, expensive to process

PTR-MS – Important, but expensive to process

Appendix B

Datastream Downloads (2014-2016)

Rank	Datastream	# Files	Rank	Datastream	# Files
1	MET	2,753,125	39	NOAAAOSAVG	171,357
2	SWATS	2,559,172	54	AOS	119,934
3	30EBBR	2,409,748	60	AOSACSM	89,138
4	SONDEWNPN	2,258,801	61	AIP1OGREN	89,010
5	30EBBR	2,228,801	63	AOSCPC	85,112
6	SIRS	1,055,536	64	AOSCCN100	83,732
7	30ECOR	1,027,586	65	TDMASIZE	83,603
8	MFRSRAOD1MICH	1,045,638	69	AIPAVG1OGREN	79,681
9	PBLHTSONDE1MCFARL	968,623	79	AOSCCN	65,219
10	LSSONDE	777,472	80	NDROPMFRSR	63,505
11	QCRAD		81	NOAAAOSCCN100	61,165
12	WACRSPECCMASKCO		83	AOSCCNAVG	58,923
13	MWRLOS		90	TDMAAPSSIZE	52,572
14	WACRSPECCMASKXPOL		101	TDMAHYG	43,266
15	MWRRET1LILJCLOU	399,505	109	AOSNEPHDRY	41,542
16	MERGESONDE1MACE		111	AOSMET	40,323
17	KAZRSPECMASKGECPOL		114	AIPFITRH1OGREN	37,150
18	SKYRAD60S		115	AOSCPCF	36,916
19	CSAPRRHI		120	AOSPSAP3W	34,172
20	GNDRAD60s	318,514	123	RLCCNPROF1GHAN	32,978
21	VCEIL25K		128	NIMFRAOD1MICH	28,994
22	RLPROF		155	AOSNOX	17,940
23	NOAAAOS	298,378	160	AOSSMPS	17,525
24	ARSCL1CLOTH		165	AOSNEPHWET	17,097
25	30MPLCMASK1ZWANG	276,186	170	AOSCLAP3W	16,182
26	1SMOS		173	AOSCO	15,642
27	CEIL		188	AOSUHSAS	12,928
28	RADFLUX1LONG		192	AOSOZONE	11,641
29	SWATSPCP		194	AOSPASS3W	11,519
30	5EBBR	243,925	195	AOSCPCU	11,399
31	30CO2FLX60M		204	AOSAETH	9,994
32	30CO2FLX4MMET		220	AOSSO2	7,869
33	CSAPRSUR		225	AEROSOLBE1TURN	7,607
34	15SWFANALSIRS1LONG		227	TDMACCMCOLL	7,296
35	THWAPS	186,700	265	CSPHOTAOT	4,529
36	DLPPI		278	AOSHTDMA	3,998
37	MFRSR		283	AOSCCN1COL	3,649
38	DLFPT				

Appendix C

Instrument Procurement and Operating Costs

Cost \ Effort	Low Effort	Moderate Effort	High Effort
< $25,000	CAPS, CPC, O3, PSAP, SO2, TAP, aethelometer		
$25,000-$50,000			
$50,000-$100,000	CO, SMPS, CCN100, UHSAS, APS		
$100,000-$200,000	CCN200,	NOx, ACSM, f(RH), HTDMA	SP2
>$200,000			PILS, PTR-MS

Appendix D

Summary of the Aerosol Measurements Breakout Session at the 2018 ARM/ASR Spring Meeting (also available, with presented slides, on the meeting website)

D.1 Summary of Presentations

The goal of this session was to continue an ongoing effort to improve the degree to which ARM is providing measurements and data products that meet the needs of the ARM aerosol science user community. The session focused on measurements from the ground-based Aerosol Observing Systems (AOS).

Jim Mather opened the session by providing an overview of the motivation for the session. The key issue is that there appears to be an underutilization of ground-based aerosol measurements based on file download statistics and publications. This issue, coupled with anecdotal reports of concerns about finding or using ARM aerosol measurements, led to the convening of a workshop in February 2017 by the Aerosol Measurement and Science Group (AMSG). Allison McComiskey, the science user co-chair of the AMSG, provided a summary of the 2017 AMSG workshop including recommendations for ARM to improve aerosol measurements. That report is available from the AMSG web page: https://www.arm.gov/about/constituent-groups/amsg.

Jim Mather followed Allison's talk with an overview of the steps ARM is planning to take to address the issues raised at the AMSG workshop. These steps are captured in more detail in a measurement plan that will be made available soon. This plan is meant to be a living document and the expectation is that feedback from the community will be used to update the plan on a periodic basis.

There did not appear to be concern about any of the proposed activities except for the creation of a unified size distribution from three ARM instruments: the SMPS, UHSAS, and APS. There were concerns that combining the output from these instruments could be misleading: they measure size differently, we would need to ensure that we were within the counting range of each instrument, and we should properly account for inlet losses, especially for large particles. However, the consensus seemed to be that there is a need for a unified size distribution and that it would be better for experts within the ARM/ASR community to construct the distribution than to force individual scientists to do this.

These talks on the work of the AMSG and plans by ARM were followed by a pair of talks by Jim Smith and Mark Flanner that provided perspectives on the aerosol measurement needs of the ASR Aerosol Processes Working Group and the climate modeling community respectively.

Jim broke down the measurement needs of the Aerosol Processes Working Group by listing specific measurement needs for each of four sub-groups: New Particle Formation, Aerosol Life Cycle and Properties, Radiative Properties of Absorbing and Carbonaceous Aerosols, and properties and processes associated with Secondary Organic Aerosols.

Mark Flanner followed with the large-scale modeling perspective. He noted that important characteristics of measurements for modelers include that they have good spatial coverage, good temporal coverage, or assist with process understanding. It is also important that data have quality labels to understand how the data should be used and that they be packaged in a convenient way. Finally, it would be helpful for data products to be constructed in such a way that they constrain parametric relationships.

D.2 Discussion

Following the presentations, there was quite a bit of discussion. In addition to concerns about constructing a unified size distribution mentioned above, topics included:

- A suggestion that ARM would benefit by setting up a science project associated with one or more sites that focused research attention on those sites.
- Options for obtaining vertical profiles including remote sensing (especially lidar and passive radiometry), Unmanned Aerial Systems, and towers. Generally, there seemed to be a lot of interest for obtaining vertical profiles (including absorption) but there was no clear path for doing so (though it seemed clear we should be making better use of our lidars)
- Interest was expressed in the full size distribution for study of Ice Nucleating Particles and interest in the HT-DMA because of its potential to provide information about hygroscopicity, CCN propensity, and species identification.
- There was interest in using filter measurements as a way of providing composition information. There seemed to be support for partnering with the IMPROVE network as well as for establishing our own filter-sampling protocol.
- The need to do a better job communicating capabilities and protocols (e.g., calibration).

D.3 Action Items

- Follow up with notes and questionnaire to meeting participants.
- Publish ARM Aerosol Measurement Plan.
- Provide a unified description of ARM aerosol measurements that span both in situ and remote-sensing capabilities.
- Reach out to European aerosol measurement community to get ideas for best practices – for example, with regard to synthesizing unified size distributions.
- Reach out to the global aerosol modeling community (e.g., E3SM and AEROCOM).
- Plan a follow-up workshop (could be virtual) with the AMSG and other scientists in FY2019 to continue moving this community discussion forward.

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