DOE/SC-ARM/TR-090

ARM

CLIMATE RESEARCH FACILITY

Tandem Differential Mobility Analyzer/ Aerodynamic Particular Sizer (APS) HANDBOOK

June 2010

U.S. DEPARTMENT OF ENERGY | Office of Science

Work Supported by the U.S. Department of Energy
Office of Science, Office of Biological and Environmental Research

DISCLAIMER

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1.0 General Overview

The tandem differential mobility analyzer (TDMA) is a single instrument that cycles through a series of complementary measurements of the physical properties of size-resolved submicron particles. In 2008, the TDMA was augmented through the addition of an aerodynamic particle sizer (APS), which extends the upper limit of the measured size distribution into the supermicron range. These two instruments are operated in parallel, but because they are controlled by a common computer and because the size distributions measured by the two are integrated in the produced datastreams, they are described together here. Throughout the day, the TDMA sequentially measures submicron aerosol size distributions and size-resolved hygroscopic growth distributions. More specifically, the instrument is operated as a scanning DMA to measure size distributions and as a TDMA to measure size-resolved hygroscopicity. A typical measurement sequence requires roughly 45 minutes. Each morning additional measurements are made of the relative humidity (RH) dependent hygroscopicity and temperature-dependent volatility of size-resolved particles. When the outside temperature and RH are within acceptable ranges, the hydration state of size-resolved particles is also characterized. The measured aerosol distributions complement the array of aerosol instruments in the Aerosol Observing System (AOS) and provide additional details of the light-scattering and cloud-nucleating characteristics of the aerosol.

2.0 Contacts

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3.0 Deployment Locations and History

Table 1 lists the deployment locations and history for the TDMA and APS.

Table 1. Deployment locations and history.

Serial Number	Property Number	Location	Date Installed	Date Removed	Status
1 (TDMA)		SGP/C1	2005/10/01		operational
70815064 (APS)		SGP/C1	2008/07/01		operational

4.0 Near-Real-Time Data Plots

Not yet available.

5.0 Data Description and Examples

5.1 Data File Contents

Please note: The combined TDMA-APS size distribution data is not yet available, as described below, but will be soon. Instead, size distribution data is available from the TDMA only and is described here: http://www.arm.gov/data/datastreams/tdmasize. Note also the "Data Object Design" documentation link on the right-hand side of that page. This provides detailed information on the currently available size distribution data.

5.1.1 Primary Variables and Expected Uncertainty

Table 2. Primary variables and expected uncertainty.

Variable Name	Quantity Measured	Dimension	Units
DMA-only size distribution	0.012–0.74 μm diameter dry particle number size distribution—dN/dlogDp	120[1] size bins	cm^{-3}
APS-only size distribution	0.4– ~15 μm diameter dry particle number size distribution—$dN/dlogD_p$	215[1] size bins	cm^{-3}
DMA+APS size distribution	0.012– ~15 μm diameter dry particle number size distribution—$dN/dlogD_p$	215[1] size bins	cm^{-3}
Hygroscopic growth factor distribution	Size-resolved particle hygroscopicity	120[1] growth factor bins	cm^{-3} (normalized2)

1. The size distributions are interpolated onto fixed diameter or growth factor arrays. Although the total number of size bins may be fixed, the number within the instrument size ranges may vary. Values of -999 are recorded in all size bins outside of the range of the instrument(s).
2. The hygroscopic growth factor distributions are arbitrarily normalized such that the sum of the values of each distribution is 100. The distributions are normalized because the absolute values are meaningless and because it facilitates averaging and comparing distributions.

5.1.1.1 Definition of Uncertainty

We define uncertainty as the range of probable maximum deviation of a measured value from the true value within a 95% confidence interval. Given a bias (mean) error B and uncorrelated random errors characterized by a variance σ^2, the root-mean-square error (RMSE) is defined as the vector sum of these,

$$RMSE = \left(B^2 + s^2 \right)^{1/2} .$$

(B may be generalized to be the sum of the various contributors to the bias and σ^2 the sum of the variances of the contributors to the random errors). To determine the 95% confidence interval we use the Student's t distribution: $t_{n;0.025} \approx 2$, assuming the RMSE was computed for a reasonably large ensemble. Then the *uncertainty* is calculated as twice the RMSE.

5.1.2 Secondary/Underlying Variables

This section is not applicable to this instrument.

5.1.3 Diagnostic Variables

This section is not applicable to this instrument.

5.1.4 Data Quality Flags

Size distribution

- A value of 0 indicates no flag.
- A value of 1 indicates that the distribution is somewhat unusual and may be inaccurate. These distributions are used in the calculated products available in other files.
- A value of 2 indicates that the distribution is highly unusual and is likely inaccurate. These distributions are not used in the calculated products available in other files.

- *Number concentration out of range flag—column 2*
  - A value of 1 indicates that the integrated number concentration was less than 300 cm-3 or greater than 30,000 cm-3.
  - A value of 2 indicates that the integrated number concentration was less than 100 cm-3 or greater than 100,000 cm-3.

Why? Though particle nucleation events can sometimes result in concentrations exceeding 30,000 cm^{-3}, these are rare. More often, very high concentrations reflect an instrumentation problem such as a major leak, a stuck valve, or arcing in the DMA. Aerosol concentrations over the remote ocean are typically around 100–200 cm^{-3}. Such low concentrations are rarely observed at continental locations such as SGP, though they can occur following extended periods of rain.

- *Volume concentration out of range flag—column 3*
  - A value of 1 indicates that the integrated volume concentration was less than 0.5 μm3/cm3 or greater than 40 μm3/cm3.
  - A value of 2 indicates that the integrated volume concentration was less than 0.2 μm3/cm3 or greater than 80 μm3/cm3.

Why? As with the expected number concentration range, unusual events such as nearby fires (high) or long rainy periods (low) can result in flagged distributions, but more frequently these indicate measurement error.

- *Unexpected volume concentration distribution slope flag—column 4*
  - A value of 1 indicates that the ratio of the differential volume concentrations (dV/dlogDp) at 0.6 μm and 0.5 μm is greater than 1.0.
  - A value of 2 indicates that the ratio of the differential volume concentrations (dV/dlogDp) at 0.6 μm and 0.5 μm is greater than 3.0.

Why? Most volume distributions are bimodal, with a submicron peak referred to as the accumulation mode and a supermicron peak referred to as the coarse mode. The 0.75 μm diameter upper limit of the DMA size range is generally between the accumulation mode peak and the inter-mode minimum. If there is even a very small leak (false count rate) in the DMA there will be a positive bias in the slope of the retrieved volume distribution near the upper limit of the size range. That region of the distribution is especially sensitive because the count rate is very low. Figure 1 below demonstrates the impact of even a false count rate of 1 particle per second throughout an entire measurement. To put that rate in perspective, a leak rate of 1% of the total flow would result in a false count rate of roughly 1,000 per second.

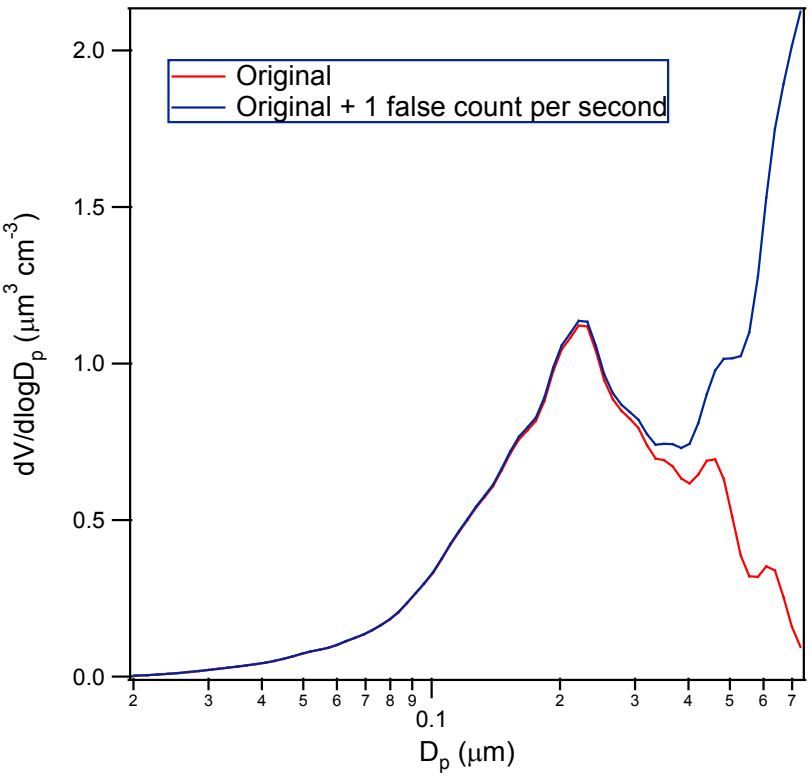

Figure 1. Original count versus original count plus one false count per second.

- *Poor correlation between up and down scan distributions flag—column 5*
  - A value of 1 indicates that the correlation between the measured up and down scan distributions was less than 0.9.
  - A value of 2 indicates that the correlation between the measured up and down scan distributions was less than 0.3.

Why? Each recorded distribution is actually the average of a pair of distributions measured sequentially. The first of these distributions is measured as the high voltage applied to the DMA is exponentially increased from just a few volts up to close to 10,000, and the second is measured as the high voltage is ramped back down. These two distributions are generally almost identical. Instrumentation problems or unusually abrupt changes in the sampled aerosol can cause significant differences. The similarity between the two is quantified, with a value of 1.0 indicating that the two independent distributions are identical. It is very uncommon for size distributions to be flagged when the instrument is functioning properly.

Hygroscopic growth factor distribution

- Relative humidity out of range flag—column 2
  - A value of 1 indicates that the inter-DMA relative humidity was less than 83% or greater than 93%.
  - A value of 2 indicates that the inter-DMA relative humidity was less than 78% or greater than 96%.

Why? The inter-DMA RH is controlled to 90%. A correction is applied to all distributions to adjust the distribution to that which would be expected if the RH were 90.00% to facilitate comparison of data time series. Not surprisingly, uncertainty in the correction increases as the RH adjustment increases. Though uncommon, the instrument RH sometimes does not fully stabilize following measurement of a size distribution, during which there is no flow between the two DMAs and, consequently, no RH control. Figure 2 below shows an example time series of the controlled RH over a 12-hour period. As is generally true, even the dips in RH during the size distribution measurements on this day would not result in significant deviations in RH, because the first hygroscopic growth measurement begins about two minutes after the end of the size distribution measurement to provide sufficient time for the RH to again stabilize.

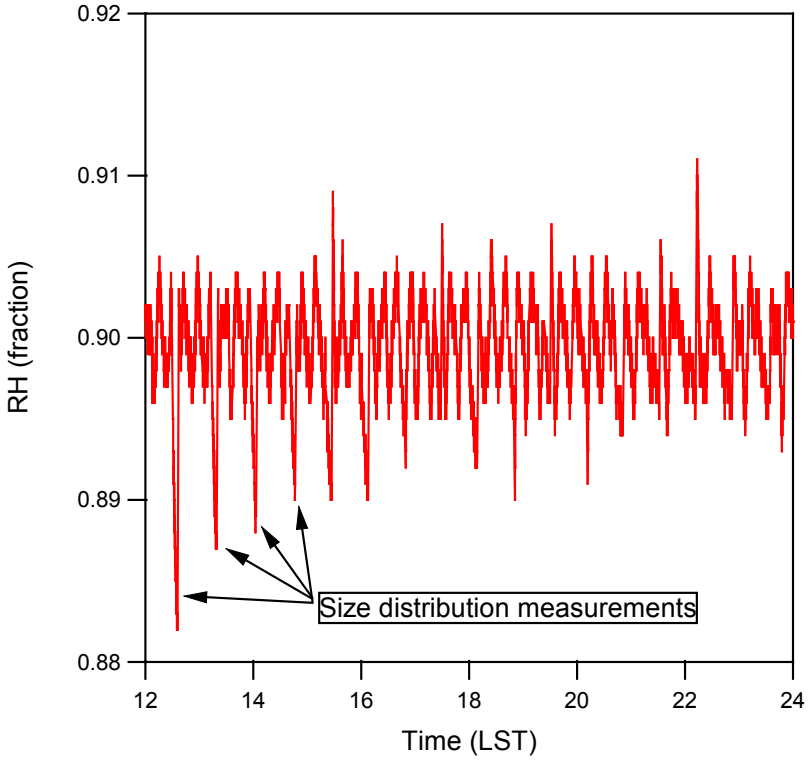

Figure 2. An example time series of the controlled RH over a 12-hour period.

- *Excessive number of peaks in distribution flag—column 3*
  - A value of 1 indicates that the distribution has more than six peaks.
  - A value of 2 indicates that the distribution has more than nine peaks.

Why? Different particle types have different hygroscopicities. It is conceivable that significant concentrations of five or more distinct particle types could be present in the ambient aerosol. Even then, the inherent resolution of the DMAs may not be sufficient to record five or more distinct modes. Moreover, common hygroscopic compounds such as nitrate and sulfate have very similar hygroscopicities, and common non-hygroscopic particle types such as soot, primary organic carbon, and dust (by definition) have very similar hygroscopicities. As a result, most growth factor distributions possess one, two, or at most three distinct modes. The inversion algorithm used produces smooth, plausible distributions even when the raw data are questionable.

An unusually high number of peaks in the inverted distribution often indicates the original data were very noisy and possibly inaccurate.

- *Tails of distribution too high flag—column 4*
  - A value of 1 indicates that dN/dlogDp at the first or last growth factor bin is greater than 5% of that of the maximum in the distribution.
  - A value of 2 indicates that dN/dlogDp at the first or last growth factor bin is greater than 15% of that of the maximum in the distribution.

Why? Only under unusual circumstances will particles shrink when brought from a low RH environment to a high RH one. Furthermore, very few particle types have hygroscopic growth factors exceeding two, with the most common example being sea salt particles. Because SGP is so far from the coast and because chemical transformation of sea salt particles that might make it all the way there tend to reduce their hygroscopicity, the concentration of such highly hygroscopic particles is very low. Thus, the size range scanned with the downstream DMA corresponds to a hygroscopicity range that extends beyond the range of expected particle hygroscopicities, and the measured distributions are expected to approach zero at the ends. Tails at the edges of a measured distribution are typically the result of false counts. Measurements of the smallest (0.013 μm) and largest (0.6 μm) particles are most often flagged because the true count rate may be on the order of one per 30 seconds.

- *Poor correlation between up and down scan distributions flag—column 5*
  - A value of 1 indicates that the correlation between the measured up and down scan distributions was less than 0.4.
  - A value of 2 indicates that the correlation between the measured up and down scan distributions was less than 0.0.

Why? As is described for the size distribution flags, significant differences between back-to-back measurements suggest the averaged distribution may be erroneous. The thresholds for flagging are quite a bit lower for the hygroscopicity measurements because count rates are considerably lower than with the size distribution measurements. Even so, far more hygroscopicity distributions are flagged for this than are size distribution measurements.

- *Location of peak in distribution out of range flag—column 6*
  - A value of 1 indicates that a peak in the distribution was located at a growth factor less than 0.98 or greater than 2.1.
  - A value of 2 indicates that a peak in the distribution was located at a growth factor less than 0.93 or greater than 2.3.

Why? As discussed above regarding flagging because of tails on the distribution, peaks located to the left of 1.0 suggesting the particles shrank or to the right of ~2 could reflect instrument error. It should be noted that drift in instrument response should not result in displacement of peaks outside of the expected range, because these checks follow application of zero and span corrections based on the automated nightly calibrations.

- *Insufficient number of particles counted flag—column 7*

– A value of 1 indicates that fewer than 15 particles were detected during the measurement.
– A value of 2 indicates that fewer than 5 particles were detected during the measurement.

Why? The control software is designed to minimize the time spent on measurements of particles for which high concentrations result in smooth and reliable distributions, while extending measurements at those particle sizes for which low count rates could compromise the accuracy of the distribution. Rather than attempt to prescribe the per-size measurement times in advance, the software repeats the measurement at a given size until either a minimum number of particles are detected or a maximum number of measurements are made. For the 0.013 and 0.6 µm measurements in particular, repeated measurements spanning a total of up to 10 minutes may occasionally still result in a total of ~10 detected particles. The exceedingly low false count rate of the instrument makes interpretation of these distributions possible, but they are still very noisy.

5.1.5 Dimension Variables

This section is not applicable to this instrument.

5.2 Annotated Examples

As noted above, the size distribution of smaller particles is measured by the DMA, and that of larger particles by the APS. A single distribution spanning the combined size range of the two measurements is produced through a data inversion algorithm. Figure 3 below shows the March 2009 time series of the combined DMA+APS size distribution. The number size distributions shown in Figure 3 were used to calculate the volume size distributions shown in Figure 4 to more clearly show the distributions measured by both the DMA and the APS.

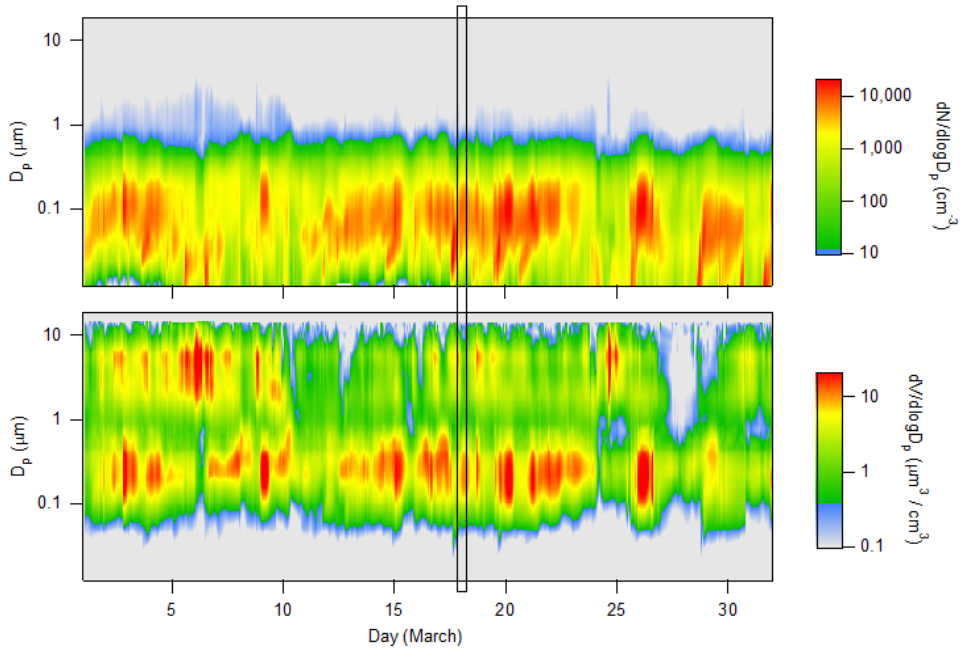

Figure 3. The March 2009 time series of the combined DMA+APS size distribution.

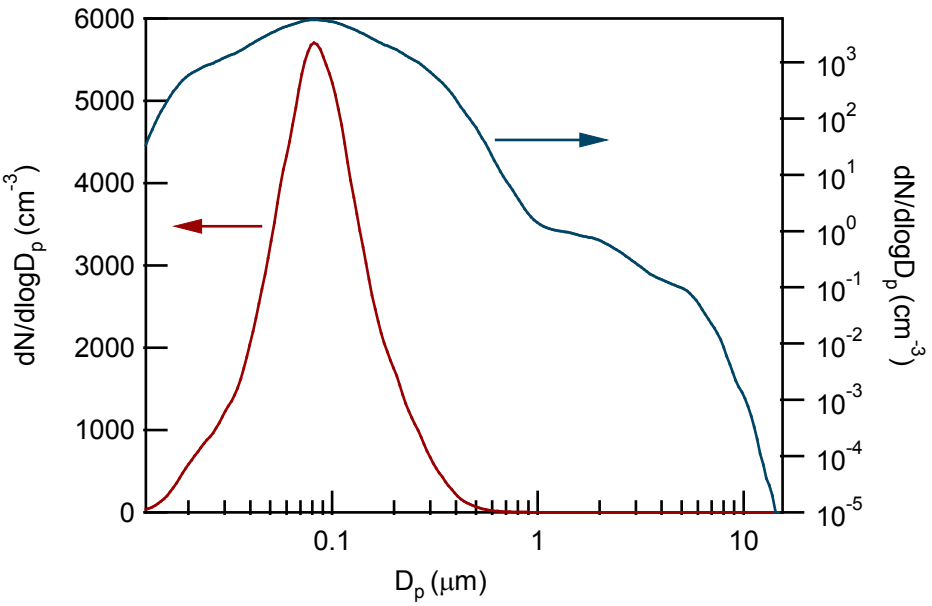

Figure 4. The number size distributions in Figure 3 were used to calculate the volume size distributions to more clearly show the distributions measured by both the DMA and the APS. The x-y graphs show example number and volume size distributions measured at the time identified with the black rectangle in Figure 3's time series. The number size distribution is presented using both linear and logarithmic y-axes to further highlight the contributions from both the DMA and APS.

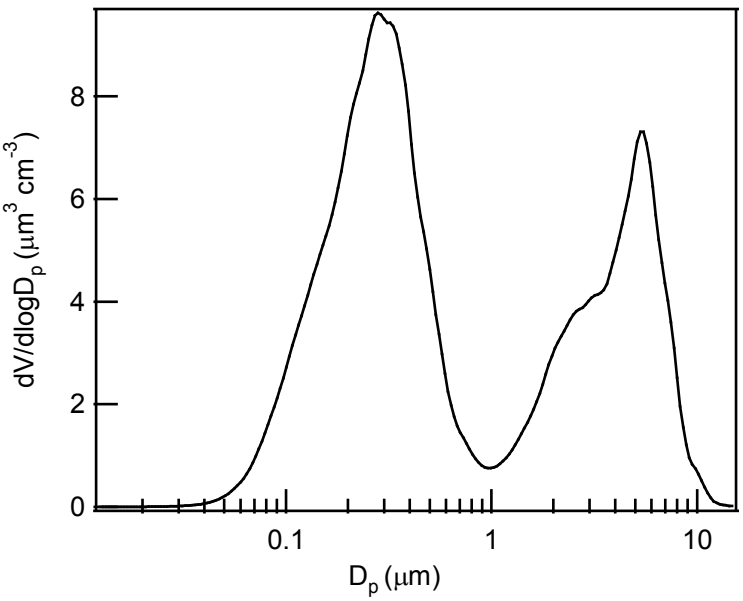

Figure 5. Size-resolved hygroscopicity distributions of 0.013, 0.025, 0.05, 0.1, 0.2, 0.4, and 0.6 μm diameter particles are recorded during each measurement sequence.

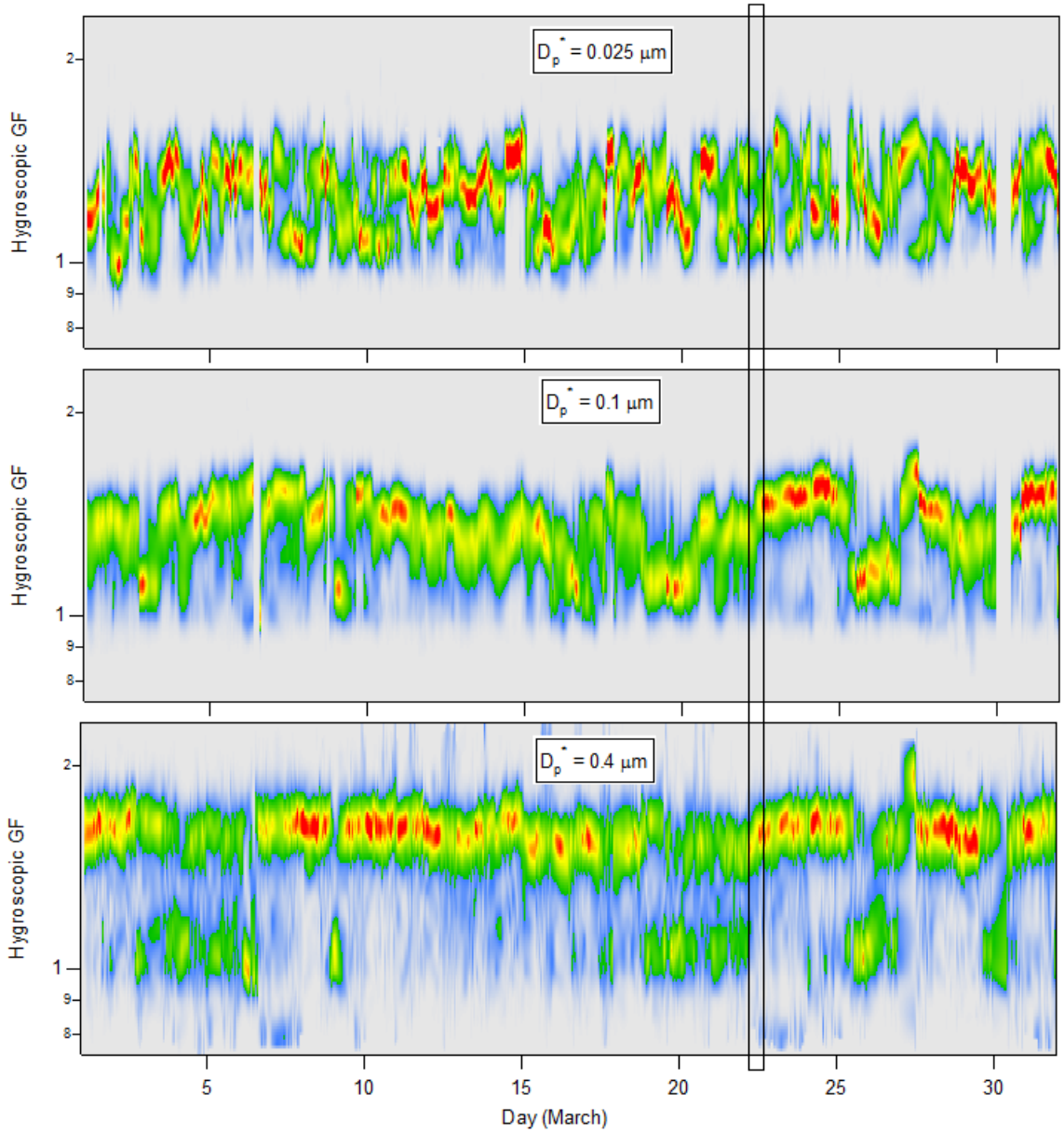

Figure 6. The time series show hygroscopic growth distributions for a subset of dry sizes recorded during each measurement sequence.

As is typical for this sampling site and others, the hygroscopic growth distributions of the larger particles vary less than those of the smaller ones. The dominant mode in the 0.4 µm particle time series has a hygroscopic growth comparable to that of ammonium sulfate particles. The less hygroscopic mode that is sometimes present in that same time series is thought to be made up of dust particles.

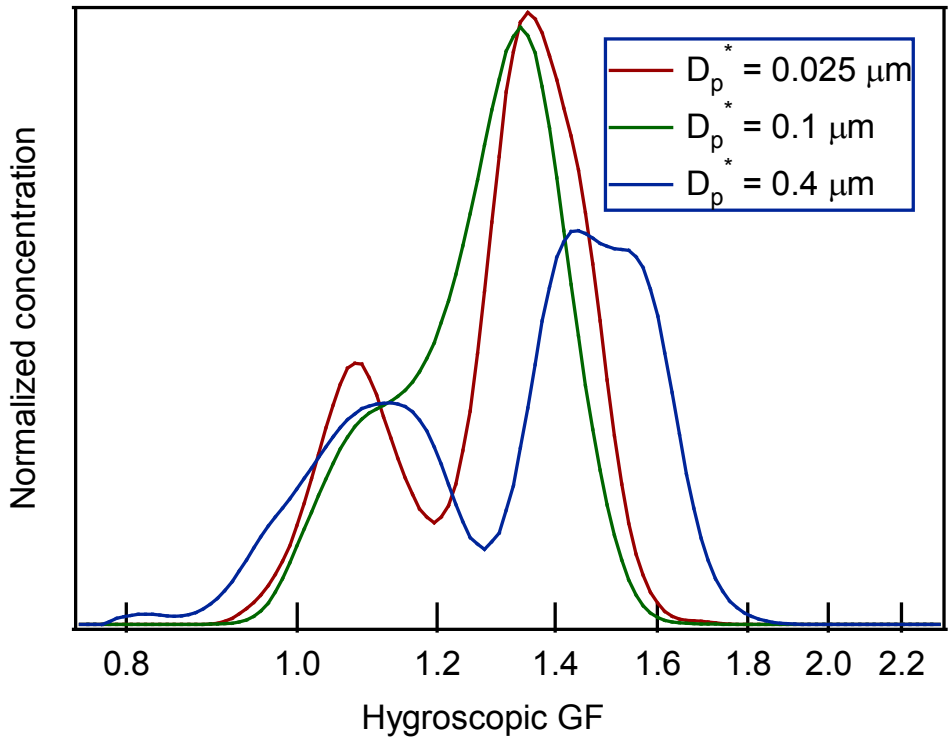

Figure 7. The x-y graph shows example hygroscopic growth factor distributions measured at the time identified with the black rectangle in Figure 6.

5.3 User Notes and Known Problems

As described below, the particle size separated by a DMA is a function of the ratio of the applied high voltage to the sheath flow rate. The applied high voltage is ramped from about 7V when separating 0.012 μm diameter particles to over 8000V when separating 0.75 μm diameter particles. Any offset error in the high voltage influences sizing at the small diameter end of the size distribution substantially more than at the large diameter end. The high voltage is monitored and a correction is applied in the data inversion to account for any offset, but error is introduced when this is done, primarily because the high voltage ramp is not exponential as must be assumed in the data inversion. Furthermore, such high voltage offsets shift the dry diameters at which hygroscopic growth factor distributions are measured. We have been unable to determine the cause of these offsets and instead have made adjustments when observed.

The TDMA is calibrated every night shortly after midnight by injecting a polydisperse pure ammonium sulfate aerosol that has known hygroscopicity. The details of the approach are provided below. The polydisperse calibration aerosol is generated using an atomizer, which produces a distribution having a peak just under 0.1 μm. The smallest and largest sizes measured with the TDMA are at the ends of the generated aerosol distribution where concentrations are very low. As a result, the distributions measured at these ends of the range are often too noisy to permit reliable assignment of representative low and high RH growth factors. The impact of this is sometimes evident in time series of the normal (not calibration) distributions measured at these sizes and shifts in calibration corrections cause shifts in the corrected distributions. We have taken several steps to minimize this problem, but its impact is still sometimes observed.

5.4 Frequently Asked Questions

Why are there gaps of an hour or two in the measurements each morning?

Though the TDMA system most often cycles between measurement of a submicron size distribution and measurements of a series of hygroscopic growth factor distributions, additional measurements are made many mornings. Specifically, the nightly calibrations are completed beginning shortly after midnight. Those measurements can require up to two hours. Later in the morning, the RH-dependent hygroscopicity of 0.05 and 0.2 μm diameter particles is measured. Each of those two measurements requires about an hour. If the ambient RH and temperature are within prescribed ranges, a series of measurements are made that quantify the ambient hydration state using the DMA system that is located outside of the trailer in a weatherproof and reflective enclosure. Intermittently, the size-dependent volatility of 0.05 and 0.2 μm particles is also measured each morning. The sequence of measurements for each of the two sizes requires about one hour.

Why isn't instrument RH reported?

There are actually five RH probes in the instrument, and their output is continuously recorded, as are instrument temperature, all flow rates, and all high voltages. These data are archived with the instrument mentor but have not been uploaded to the ARM Data Archive simply because it is unlikely many users would be interested in the housekeeping parameters.

How can I infer particle composition from the measured hygroscopicity?

Hygroscopicity is uniquely dependent upon composition. Unfortunately, composition cannot be uniquely determined from hygroscopicity. The most commonly employed approach to inferring composition is to assume the particles are composed of only two components, only one of which contributes to the observed hygroscopicity. Ammonium sulfate or ammonium bisulfate is often assumed to be mixed with a non-hygroscopic core. Using empirical expressions relating solute concentration to water activity and solution density, it is possible to iteratively determine the sulfate mass or volume fraction of a uniform population of particles.

Why are the hygroscopicity distributions normalized?

Unlike size distributions for which concentration is critically important for assessing the impact of the aerosol on cloud properties or radiative transfer, hygroscopicity is an intensive property, and as such, is independent of concentration. Normalizing the distributions makes it much easier to examine the size-dependence by viewing multiple distributions on the same graph even if the initial amplitudes of the distributions of the largest and smallest particles might be three orders of magnitude smaller than those closer to 0.1 μm.

Why does the size distribution in the supermicron range have a persistent point on the right-hand side of the mode?

The supermicron size distribution is measured by the APS. Unlike the DMA that scans through particle size, the APS detects particles of all sizes simultaneously. Each detected particle is binned according to its recorded time of flight between two lasers. Though the relationship between particle size and size bin

is monotonic (in contrast to that of the OPC it replaced), errors in quantification of the size-dependent slope of that relationship can result in bin boundaries wider or narrower than assumed, which results in spikes or dips in the recorded distribution, respectively. A thorough calibration of the APS is planned to reassign bin boundaries, after which the distributions will be reprocessed, which is expected to reduce or eliminate the persistent shape currently observed.

What exactly is dN/dlogDp and dV/dlogDp?

An inherent difficulty in presenting size distributions is the influence of the variable widths of the size bins. Reported concentration for each bin is dependent upon both the desired average concentration of particles in the size range and the width of the bin. Simply creating a size distribution by showing the concentration of particles in a set of irregular width bins would result in an irregular shape even if particle concentration varied smoothly with size. Thus, the concentrations are normalized by the bin width, but rather than dividing concentration by the difference between the upper and lower size boundaries for each bin, they are normalized by dividing by the difference in the logarithm of the upper and lower size boundaries simply because size distributions often span a size range of several decades. So, $dN/dlogD_p$ is simply the concentration (dN; cm^{-3}) of particles in a size bin divided by the difference in log_{10} of the upper and lower size boundaries ($dlogD_p$; unitless). The volume size distribution is simply calculated as the product of the dN/dlogDp in each bin and the volume of spherical particles with the midpoint diameter in the bin $\left(\frac{\pi}{6} D_p^3 \right)$.

Why do the normal measurement sequences (size distribution + hygroscopicity distributions) not all take the same amount of time even though the same measurements are made?

The variability comes from the measurement times of the series of hygroscopic growth factor distributions. The control software is designed to minimize the time spent measuring growth factor distributions at those particles sizes for which concentrations are high (e.g., 0.1 μm) and counting statistics rarely compromises the recorded distributions, while increasing measurement times for those particle sizes near the tails of the size distribution for which low count rates can hamper interpretation of the data. Rather than prescribing the (unknown) optimal size-dependent sampling times, individual voltage scans are made as quickly as possible for all particle sizes, but the software does not advance to the next particle size until either a specified minimum number of particles are counted or a specified maximum number of scans are completed. Thus, the lower the concentration of particles at one or more analyzed sizes, the longer the measurements will be and, consequently, the longer the total measurement sequence will be.

6.0 Data Quality

6.1 Data Quality Health and Status

The following links go to current data quality health and status results.

- DQ HandS (Data Quality Health and Status)
- NCVweb for interactive data plotting using.

The tables and graphs shown contain the techniques used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

6.2 Data Reviews by Instrument Mentor

Monthly reports on the data and instrument performance are provided by the mentor and can be found at www.db.arm.gov/IMMS/

6.3 Data Assessments by Site Scientist/Data Quality Office

All DQ Office and most Site Scientist techniques for checking have been incorporated within DQ HandS and can be viewed there.

6.4 Value-Added Procedures and Quality Measurement Experiments

A number of VAPs created using only the TDMA are planned. The software needed to generate the VAPs has been created, and it is hoped the VAPs will be available in the near future. At this time the only VAP in production integrates the measured size distributions and size-resolved hygroscopicity distributions to infer CCN spectra, which are simply descriptions of the concentration of CCN as a function of supersaturation. Cumulative and differential spectra are created, and parameterizations of the cumulative spectra are being generated and will soon be available.

Please see http://www.arm.gov/xdc/xds/tdmadap for further information on the CCN dataset.

7.0 Instrument Details

7.1 Detailed Description

7.1.1 List of Components

1. Aerodynamic particle sizer. The TSI model 3321 APS measures the aerodynamic size distribution of particles having diameters between roughly 0.5 and 20 μm. Sizing uncertainty is greatest near the tails of this size range. The APS accelerates the aerosol sample flow through a nozzle with a small orifice at its end. The aerodynamic size of a particle determines its acceleration, with larger particles accelerating less due to increased inertia. Consequently, downstream of the nozzle, large particles have a lower velocity than small ones. As particles exit the nozzle, they cross through two partially overlapping laser beams in the detection area. Light scattered as each particle crosses through the overlapping beams is detected, and particle size is inferred from the time interval between pulses.
2. Tandem differential mobility analyzer. The TDMA consists of multiple components that collectively measure size-resolved concentration, hygroscopicity, volatility, and ambient hydration state of submicron particles. The size-resolution and size range of each of the measurements are specified in the accompanying readme file that details the format of the archived data files.

7.1.2 System Configuration and Measurement Methods

TDMA Operation

1. Normal Operation

- Size distribution measurement

Figure 8 shows the flow schematic for the TDMA system. During normal operation, a sample flow of 3 liters per minute enters from the stack and is immediately dried to a relative humidity < 20% in a bundle of Nafion tubes surrounding by a vacuum in the purge flow. The dried aerosol is then brought to a steady state charge distribution in a bipolar neutralizer that contains a small amount of a radioactive alpha source. The flow then passes through a bipolar neutralizer to bring the aerosol to a predictable charge state before entering the first DMA. Further downstream, the air enters a variable Nafion where the relative humidity is maintained at 90% and then enters the second DMA. Once the sample exits the second DMA, it enters the final drying Nafion where the sample is dried to a relative humidity < 20% before entering the CNC.

2. Ambient State Operation

During this flow scheme the sample enters an upstream DMA outside the AOS trailer. Prior to entering this DMA, the sample flow passes through a bipolar neutralizer to bring the aerosol to a predictable charge state. Upon exiting the AS-DMA the sample is dried to a relative humidity < 20% before traveling into the AOS trailer where it is alternately exposed to a humidifying Nafion, then a nafion with a relative humidity that matches that of the AS-DMA before entering the downstream DMA. Upon exiting the downstream DMA, the sample flow is dried before entering the CPC.

- Volatility Tube Measurements

  During volatility measurements the flow travels through the DMA system normally, except it is diverted through a volatility tube prior to entering the second DMA.

- Calibration Scans

  Every night at midnight the TDMA system is calibrated using Sodium Chloride. During this operation, compressed air is fed to a TSI atomizer giving a distribution of NaCl that is dried immediately upon exit and fed into the TDMA system in normal configuration mode.

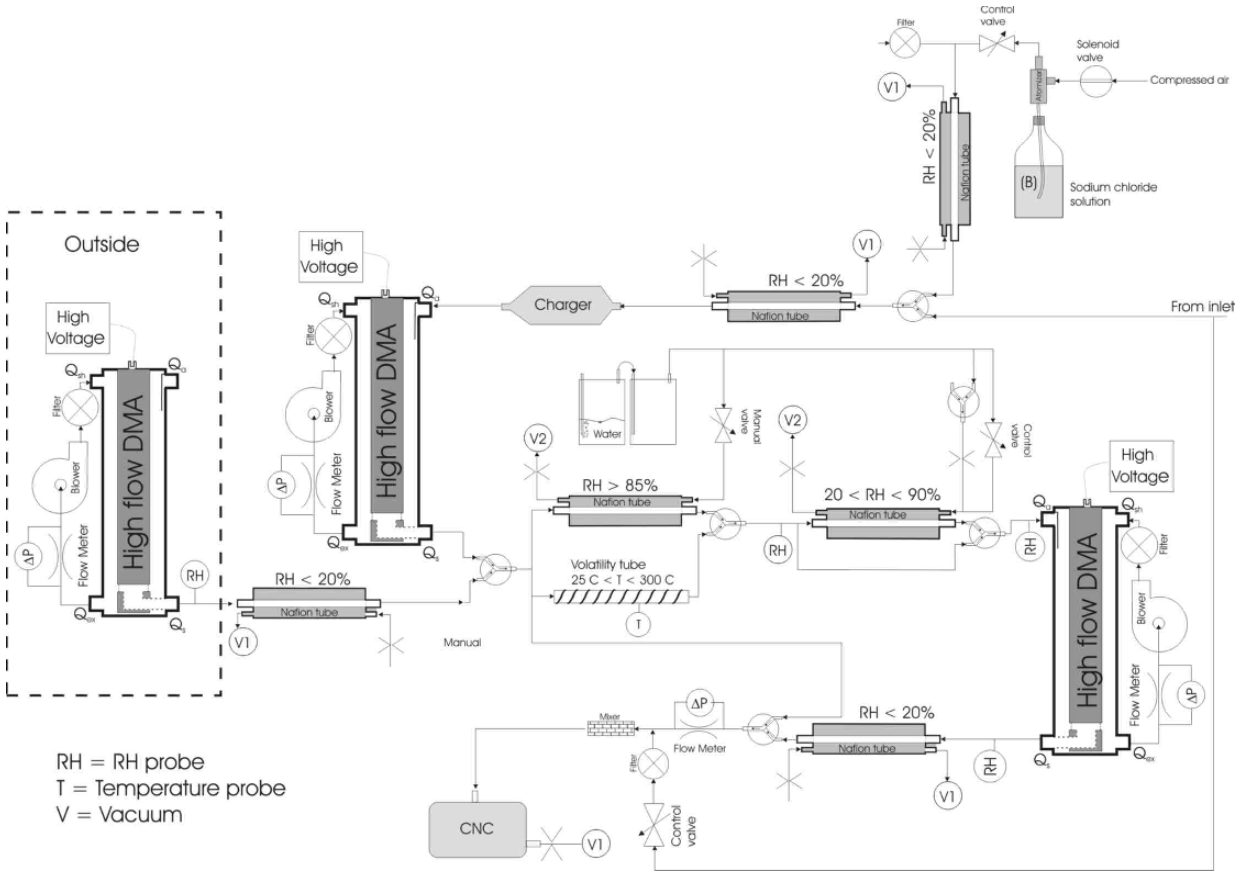

Figure 8. The flow schematic for the TDMA system.

3. APS Operation

Figure 9 shows the flow schematic for the TSI model 3321 APS. The APS pulls its flow from the stack prior to the TDMA system. The flow is accelerated through a nozzle with small particles having a higher rate of acceleration than larger ones. The particles pass through two beams, and size is calculated via the peak-to-peak time of flight.

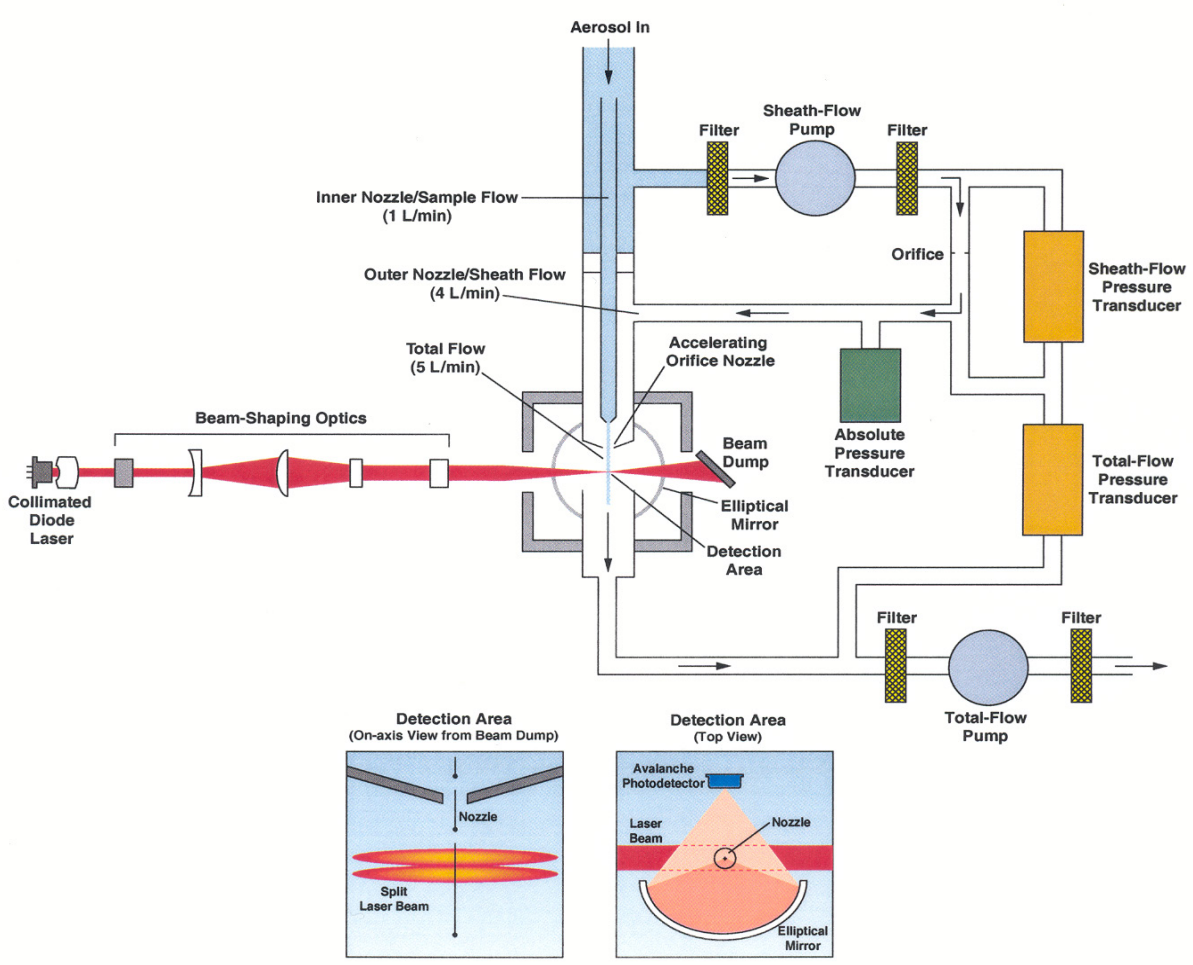

Figure 9. The flow schematic for the TSI model 3321 APS.

7.1.3 Specifications

APS:

Particle size range:	0.5 to 20 mm aerodynamic diameter
Size resolution:	0.02 mm at 1.0 mm, 0.03 mm at 10 mm
Size bins in distribution:	52
Upper concentration limit:	10,000 cm-3 with coincidence correction
Sample time (current configuration):	600 s
Aerosol flow rate:	1 L/min
Sheath flow rate:	4 L/min

TDMA:

Particle size range:	0.013 to 0.75 mm electric mobility diameter
Size resolution:	0.0026 mm at 0.05 mm, 0.013 mm at 0.2 mm
Size bins in distribution:	75
Sample time:	Approximately 45 minutes for complete sequence
Aerosol flow rate:	1.2–2.8 L/min, dependent upon measured size
Sheath flow rate:	10 x aerosol flow rate

7.2 Theory of Operation

This section is not applicable to the instrument.

7.3 Calibration

7.3.1 Theory and Procedures

TDMA: The TDMA system is calibrated every night at midnight. During this time, multiple items are addressed in the system. First, the CPC is drained and replenished of butanol, and all the flow meters are tared to remove any variance caused by signal drift. Next the system is checked for leaks by going through normal scans with the high voltages being alternately turned off. Any particle leaks that would affect normal daily measurements would be picked up during this process and shown on the calibration tab for the next day. The atomizer is then turned on, and a distribution of NaCl is sent through the system with the second DMA being held at a relative humidity < 20%. All particles should have a growth factor of 1 during this process and are plotted on the dryscan plot under the calibration tab. The final calibration measurement performed as above, except the downstream DMA is brought to a relative humidity of 90% and the growth factor of the resulting distribution is plotted against the expected growth factor for NaCl at that humidity. During normal day-to-day operations the plots should line up with their respective setpoints.

7.3.2 History

Calibration data are available from TAMU upon request.

7.4 Operation and Maintenance

7.4.1 User Manual

This section is not applicable to the instrument.

7.4.2 Routine and Corrective Maintenance Documentation

Daily Maintenance

You may be required to stop the TDMA system from time to time when asked to perform some of the maintenance procedures below.

1. To stop the program, press the “stop” button at the top left-hand area of the labview program.
2. Next, press the “play” button. The program will begin to run again, but before it runs, the power will shut off.
3. When the power shuts off quickly press the “stop” button again. This prevents the power from coming up. This should be sufficient for most of the procedures below.

If attempting perform electrical work or some other major work all switches must be turned off. The computer must also be shut down and the instrument unplugged from the wall to ensure that there are no sources of electricity.

1. Check that there is sufficient Butanol in reservoir at the top of the instrument just under the computer. Butanol should be added to the lowboy if level has drained to a 1/4 of the container.

   To add Butanol, stop the instrument using the method described above. Once the instrument has been stopped, take the cap off the top of the Butanol container and add Butanol until container is about 3/4 full. Put the cap back on the container loosely, and start the instrument again by pressing the "play" button in the labview program.
2. Check to make sure that the water level in the humidifier is above the heater. If not, stop instrument using the method described above. Add water to where the top of the bottle begins to curve inward. Adding water beyond this level could cause humidification problems. Screw cap back on, and start the instrument again by pressing the "play" button in the labview program.
3. Check the amount of Butanol in the waste Butanol container below the instrument. If full, stop the instrument using the method described above. Disconnect the container, and empty the waste container in an approved manner. Reconnect the container with the cap screwed on loosely, and start the instrument again by pressing the "play" button in the labview program.
4. Check the amount of water in the excess water container below the instrument. If full, stop the instrument using the method described above. Disconnect the container, and empty the water container. Reconnect the container, and start instrument again by pressing the "play" button in the labview program.

Weekly Maintenance

As long as the daily maintenance procedures above are followed there should not be any weekly maintenance.

Monthly Maintenance

Every 6–8 months the vacuum pumps will need to be rebuilt when the vacuum becomes insufficient for maintaining critical flow in the instrument. The atomizer solution will be replaced at least once a month.

Annual Maintenance

Planned annual maintenance is listed below. Any other maintenance is done on an as-needed basis.

- Replace pump if needed.
- Replace all purge flow filters on Nafion tubes.
- Replace CPC dilution flow filters.
- Replace sheath flow filters on the DMAs.
- Inspect instrument for any visible defects in wiring, and inspect overall appearance of components to determine if preventative replacement of components is necessary.

7.4.3 Software Documentation

This section is not applicable to the instrument.

7.4.4 Additional Documentation

This section is not applicable to the instrument.

7.5 Glossary

See the ARM Glossary.

7.6 Acronyms

AOS	aerosol observing system
APS	aerodynamic particle sizer
AS-DMA	ambient state differential mobility analyzer
CPC	condensation particle counter
DMA	differential mobility analyzer
NaCl	sodium chloride
TAMU	Texas A&M University
TDMA	tandem differential mobility analyzer

Also see ARM Acronyms and Abbreviations.

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