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Ultra-High-Sensitivity Aerosol Spectrometer Instrument Handbook

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ARM CLIMATE RESEARCH FACILITY

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Acronyms and Abbreviations

ccm	cubic centimeters per minute
cm^3	cubic centimeters
CPC	Condensation Particle Counter
DMA	Differential Mobility Analyzer
HEPA	high-efficiency particulate air
hh:mm:ss	hours:minutes:seconds
lpm	liters per minute
NIST	National Institute of Standards and Technology
nm	nanometer
PC	personal computer
PSL	polystyrene latex
SMPS	Scanning Mobility Particle Sizer
USB	Universal Serial Bus
UTC	Coordinated Universal Time
V	volt
yyyy-mm-dd	year-month-day

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Ultra-High-Sensitivity Aerosol Spectrometer

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Instrument manual available at http://www.dropletmeasurement.com/resources/manuals-guides

4.0 Instrument Description

The Ultra-High-Sensitivity Aerosol Spectrometer (UHSAS) (Figure 1) is an optical-scattering, laser-based aerosol particle spectrometer system for sizing particles in the 60 to 1000 nanometer (nm) range [1–3]. The instrument counts particles in up to 100 user-specified sizing bins. The instrument's laser illuminates particles, which scatter light. The system captures the peak light signals that are generated. These signals are used for particle sizing, since the amount of light scattered correlates strongly with particle size.

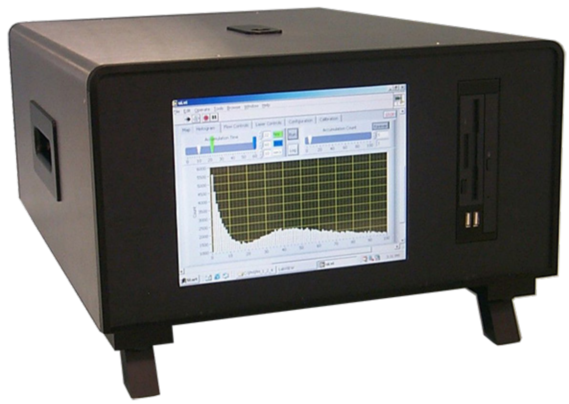

Figure 1. The Ultra-High-Sensitivity Aerosol Spectrometer. Image adapted from the manufacturer's website.

5.0 Measurements Taken

The main measurement output of the UHSAS is the aerosol particle size distribution as particle number concentrations (in counts or in cm^{-3}) per user-defined size bins. Additional measurements include sample flow rate, sample time, sample air pressure, and sample temperature.

6.0 Links to Definitions and Relevant Information

6.1 Data Object Description

The data from the UHSAS are recorded in column format with appropriate headers specifying the data and units of measurement. The data fields recorded include:

> Measurement date/time, sample accumulation time, raw light scatter signal, current drawn by the instrument, sample flow, laser reference signal, sample temperature, sheath air flow rate, instrument internal temperature, flow rate of purge air, ambient pressure, boundaries of the size bins of the particle size distribution, and particle concentration in each size bin.

Output data are recorded after every sample, typically every 10 seconds. A new data file is started every hour and every time the system is restarted.

This data object description is subject to change with future revisions of the instrument software.

6.2 Data Ordering

Data from the UHSAS can be ordered from http://www.arm.gov/instruments/uhsas. Data are organized by measurement location/campaign.

6.3 Data Plots

Figures 1 and 2 show typical data for the UHSAS. Figure 1 shows measured particle size distributions (particle counts per size bin) as a function of time. Figure 2 shows a comparison between the total particle number concentration (calculated from the measured size distribution) measured by the UHSAS and particle number concentration measured by a Condensation Particle Counter (CPC), as a function of time. Differences in measurements are mainly due to the different detection ranges of the two instruments. These plots were generated using the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility Data Quality Diagnostic Plot Browser (http://plot.dmf.arm.gov/plotbrowser/).

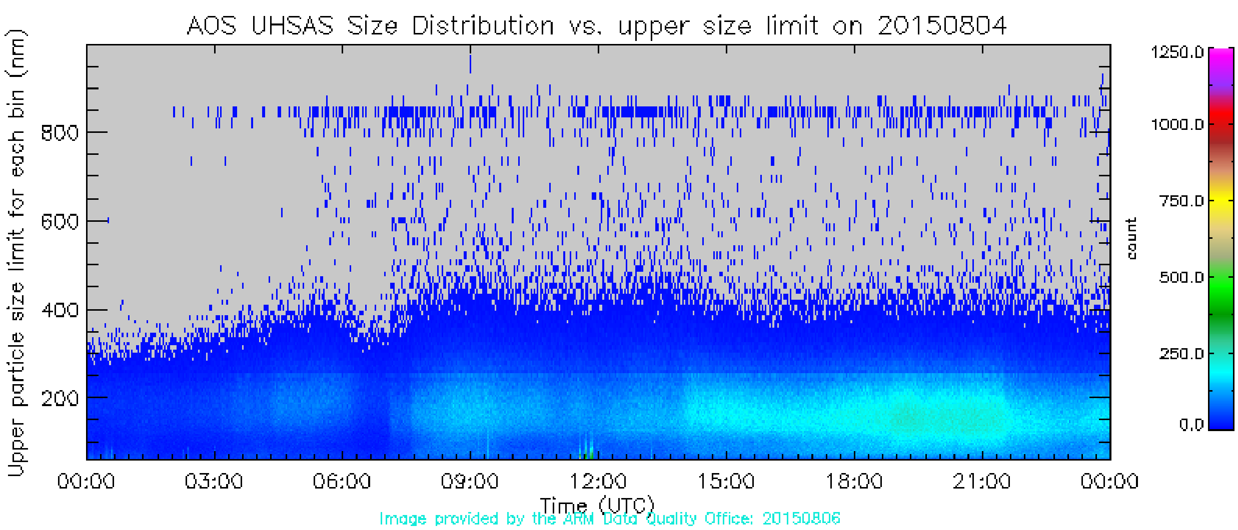

Figure 2. Aerosol size distribution as measured on August 4, 2015 by the UHSAS deployed at the ARM Eastern North Atlantic site on Graciosa Island, Portugal.

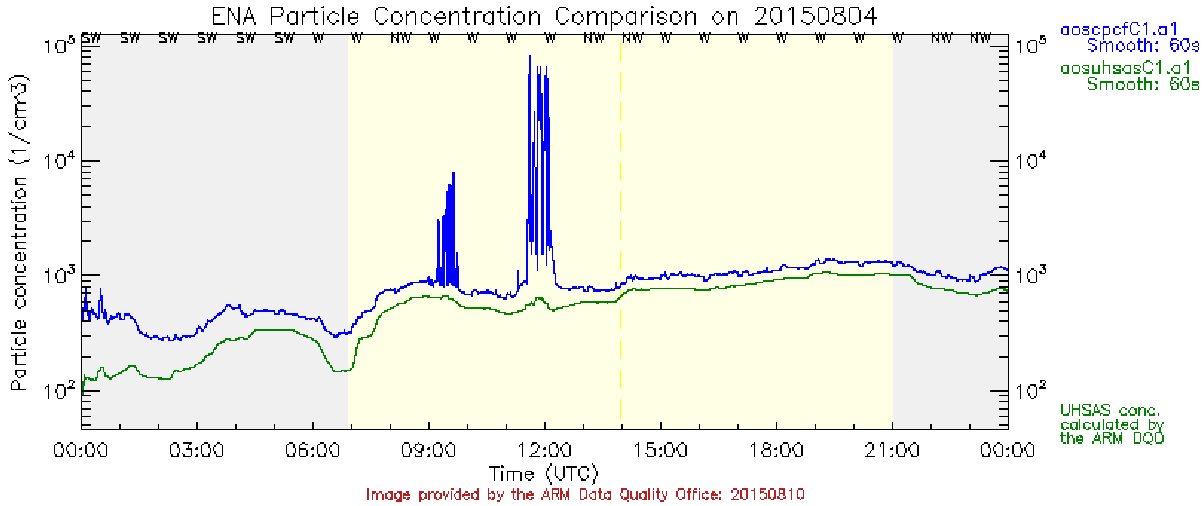

Figure 3. Comparison of total aerosol particle concentrations measured by the UHSAS and by a CPC on August 4, 2015 at the ARM Eastern North Atlantic site on Graciosa Island, Portugal.

6.4 Data Quality

Data quality evaluation involves the automatic generation of the following plots in collaboration with the ARM Data Quality Office (see also Figure 2 and Figure 3):

- Aerosol particle size distribution as a function of time. Low counts or noisy signal may indicate issues with the UHSAS optics block (misalignment, contamination) or air flows (low or unstable sample flow).
- Comparison of particle number concentration measurements from the UHSAS and from several co-located instruments such as CPC or Scanning Mobility Particle Sizer (SMPS). The total concentration as measured by the UHSAS should follow the same general trend as other instruments but show lower concentrations, since the lower particle size limit for the UHSAS is higher than it is for CPC or SMPS.
- Sample flow rate. Low or unstable flow rate indicates a blockage in the sample line or a failing pump.
- Laser reference voltage. A value more than 25% lower than the nominal value of 2.5 volts (V) indicates dirty optics or, less likely, misalignment of optical elements.

6.5 Calibration Data Base

During deployment the UHSAS calibration is periodically verified by the instrument mentors. This includes using the UHSAS to measure the size distribution of monodisperse (monomobile) aerosols with a known mean particle diameter (electrical mobility) generated by a Differential Mobility Analyzer (DMA) and comparing the measured mean particle size to the DMA selection size. Additionally, as particles selected by the DMA include those with more than one elementary charge the produced aerosol particle size distribution is not strictly monodisperse and includes multiple narrow peaks at well-defined positions corresponding to differently charged aerosol particles. The locations of those peaks, as measured by the UHSAS, are compared to locations theoretically predicted by the Millikan formula, which relates particle electrical mobility and diameter. Calibration verification data is collected and maintained by the instrument mentors. No corrections to the data are derived from calibration checks.

7.0 Technical Specification

7.1 Units

Units include aerosol particle size, nanometers (nm), aerosol particle number concentration, particles per cubic centimeter (cm^3), or raw number of counts (dimensionless).

7.2 Range

Particle size can be measured from 60 to 1000 nm. Total particle number concentration (per unit time) can be measured from 0 to 3000^{s-1} (3600 cm^{-3} for 50 ccm sample flow—the maximum number of particles per unit volume depends on the instrument's sample flow rate).

7.3 Accuracy

Accuracy of particle sizing depends mainly on the accuracy of the particle size look-up table that is calculated during instrument calibration with monodisperse calibration aerosols. The look-up table relates particle size to pulse height of scattered light for a calibration aerosol used, which is usually polystyrene latex (PSL). Ambient aerosol particles with a non-spherical shape or refractive index different from PSL can be thus sized incorrectly. In general, the instrument sizing accuracy is within 5% as seen from comparison experiments with an SMPS [1]. The above applies to the instrument's normal operating mode where the total particle counts are below 3000 $^{s-1}$ and no significant particle coincidence occurs.

7.4 Repeatability

Repeatability of particle sizing mainly depends on the inherent noise in the response of the electronics that measure the pulse height of the scattered light. In general, the repeatability is within 1% [1]. This applies to the instrument's normal operating mode where the total particle counts are below 3000 $^{s-1}$ and no significant particle coincidence occurs.

7.5 Sensitivity

Aerosol particle size and concentration measurement is sensitive to particle concentration (due to particle coincidence during counting at higher concentrations). The operating speed of the detector electronics sets the upper limit of total particle counts for reliable single particle detection at around 3000 $^{s-1}$ (3600 $^{cm-3}$ for 50 ccm sample flow). No corrections for particle coincidence are made by the instrument and a dilution system should be used when sampling aerosol particles at concentrations higher than the upper limit specified above.

Particle sizing is also sensitive to the particle refractive index if it differs from that of the calibration aerosol particles (PSL – polystyrene latex). If the ambient particle refractive index is known, corrections can be applied to the measurement data [1, 4].

7.6 Uncertainty

Uncertainty for particle sizing is largely determined by the sizing resolution of the instrument, which depends on the geometry of the optics system, i.e., the diameters of the laser beam and the particle jet. The manufacturer specifies the uncertainty of particle sizing as within 2.5% of particle size.

7.7 Input Values

Parameters set by the user include measurement range, number of size bins, upper and lower boundaries of each size bin, sample flow rate, sample accumulation time, and number of samples.

7.8 Output Values

The recorded data include measurement date/time, sample accumulation time, raw light scatter signal, current drawn by the instrument, sample flow rate, laser reference signal, sample temperature, sheath air flow rate, instrument internal temperature, flow rate of purge air, ambient pressure, boundaries of the size bins of the particle size distribution, and particle concentration in each size bin.

8.0 Instrument System Functional Diagram

The entire system can be divided into five separate subsystems (See Figure 4):

1. Main optical subsystem. Generates the laser light, detects the light scattered by particles, and provides a mechanical enclosure for the optical system and for delivery of the sample aerosol.
2. Flow system. Brings the sample aerosol through the optical interaction region, and controls and measures the flows.
3. Analog electronics system. Amplifies and processes the particle signals.
4. Digital electronics system. Analyzes particle signals, bins signals according to user-specified bin mappings, generates a histogram of particles in the specified bins, and communicates with the PC and system monitor/control functions.
5. Onboard personal computer (PC). Allows the user to control the instrument and collect and report data.

See the manufacturer's manual for detailed description of the instrument's subsystems.

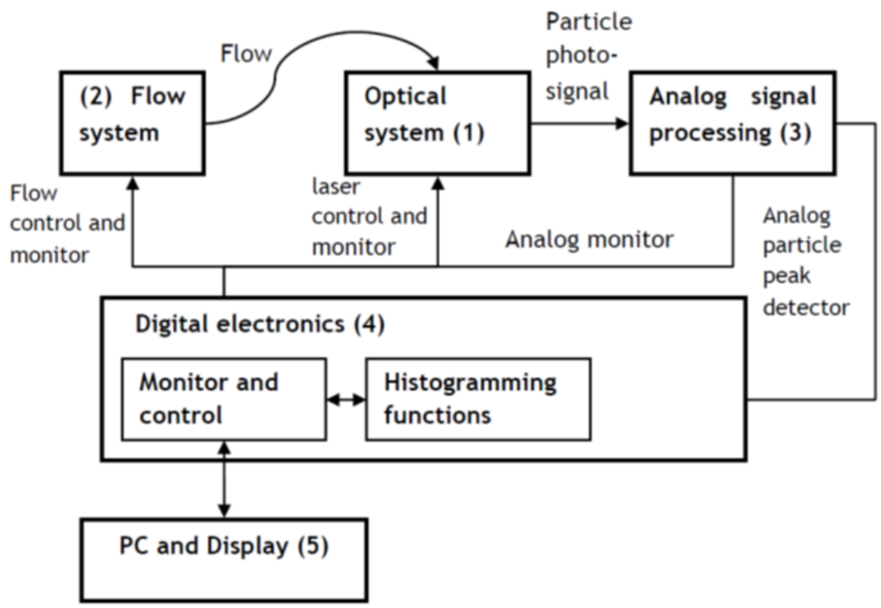

Figure 4. UHSAS block diagram. Adapted from the manufacturer's manual.

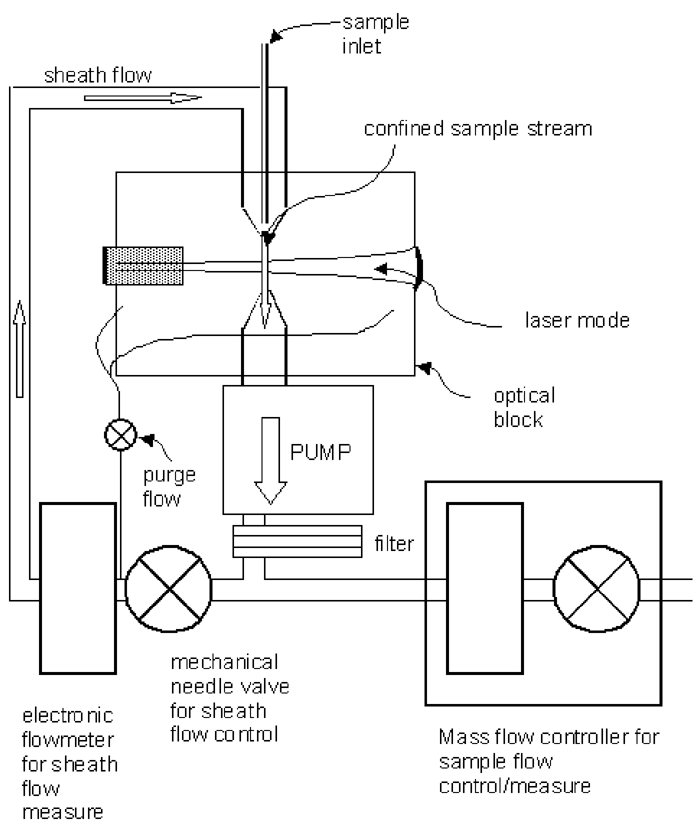

Figure 5. Schematic diagram of the UHSAS flow system. Adapted from the manufacturer's manual.

9.0 Instrument/Measurement Theory

The aerosol particles are drawn into the instrument's optical chamber and pass in front of a laser beam (see Figure 5). The instrument's infrared (1054 nm) laser illuminates particles, which scatter light. Four optical detectors capture the light signals generated by particles passing through the laser beam. These signals are used in calculations for particle sizing, since the amount of light scattered correlates strongly with particle size. Scattered light is collected in a direction perpendicular to both the particle flow and the laser beam.

10.0 Setup and Operation of Instrument

6. Connect a keyboard and a mouse to the Universal Serial Bus (USB) ports on the instruments (for initial setup only).
7. Switch on the instrument and wait for the internal computer to boot up.
8. Start the measurement software by double-clicking on the "Spectrometer" icon on the computer desktop screen. The software may be configured to start automatically, in which case skip this step.
9. Switch to the "Histogram" tab in the software main window. Click on "Run" and "Record" buttons in the upper left corner of the software window. If the software was started automatically, these buttons are likely to be already active, in which case skip this step.
10. The instrument is now ready to operate automatically.

For further details, consult the manufacturer's manual.

11.0 Software

Instrument control and data acquisition is performed by NI LabView-based software written by the manufacturer. Additional LabView-based software, written by Brookhaven National Laboratory, reformats and relocates the data files saved by the manufacturer's software.

12.0 Calibration

The UHSAS system is calibrated by the manufacturer before delivery to the user and during instrument maintenance at the manufacturer's facilities. The instrument mentors perform calibration verification that checks for conditions requiring a full calibration, typically once every 12 months or as needed, e.g., before deployment. No corrections to the data are derived from calibration verifications. In case of verification failure, the instrument would be size-calibrated by the mentors or sent to the manufacturer for maintenance

The manufacturer's calibration includes:

- Measuring the size distribution of National Institute of Standards and Technology (NIST)-traceable calibration aerosols PSL with known mean particle sizes.
- Calibrating the gain of the four internal pulse-height measurement ranges, i.e., recording the responses of the light detector electronics to aerosols with known particle sizes. Calibration values are recorded in the software and applied automatically.
- Calibrating the inlet flow rate with a precision flow meter. Calibration values are recorded in the software and applied automatically.
- Zero counts verification by operating the instrument with a high-efficiency particulate air (HEPA) filter attached to the inlet.

Calibration verification done by instrument mentors includes using the UHSAS to measure the size distribution of monodisperse (monomobile) aerosols with a known mean particle diameter (electrical mobility) generated by a Differential Mobility Analyzer (DMA) and comparing the measured mean particle size to the DMA selection size. Additionally, as particles selected by the DMA include those with more than one elementary charge, the produced aerosol particle size distribution is not strictly monodisperse and includes multiple narrow peaks at well-defined positions corresponding to differently charged aerosol particles. The locations of those peaks, as measured by the UHSAS, are compared to locations theoretically predicted by the Millikan formula, which relates particle electrical mobility and diameter.

13.0 Maintenance

For action when cleaning the laser optics (when laser reference voltage falls below ~1.9 V):consult the manufacturer's manual.

14.0 Safety

The UHSAS is a Class I Laser Product. During normal operation, the user is not exposed to laser radiation.

15.0 Citable References

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