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Passive Cavity Aerosol Spectrometer Probe Aboard Aircraft (PCASP-AIR) with Signal Processing Package 200 Instrument Handbook

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ARM

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Acronyms and Abbreviations

AAF	ARM Aerial Facility
ADC	ARM Data Center
ARM	Atmospheric Radiation Measurement
DMT	Droplet Measurement Technologies
ID	inside diameter
IWG	interagency working group
netcdf	Network Common Data Form
PADS	Particle Analysis and Display System
PCASP	passive cavity aerosol spectrometer probe
PMS	Particle Measuring Systems
PSL	polystyrene latex sphere
SPP	signal processing package
WCM	Water Content Measurement

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1.0 Instrument Title

Passive cavity aerosol spectrometer probe aboard aircraft (PCASP-AIR) with Signal Processing Package-200 (SPP-200)

2.0 Mentor Contact Information

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3.0 Vendor/Developer Contact Information

Droplet Measurement Technologies (DMT)
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4.0 Instrument Description

Figure 1. The PCASP is in the gray canister positioned on the starboard side of the aircraft under the wing.

The passive cavity aerosol spectrometer probe (PCASP) is an airborne, optical spectrometer that uses the intensity of scattered laser light to measure an aerosol size distribution from 0.1−3.0 µm.

5.0 Measurements Taken

- Aerosol particle number concentration
- Aerosol particle size distribution

6.0 Links to Definitions and Relevant Information

Vendor's website: https://www.dropletmeasurement.com/product/passive-cavity-aerosol-spectrometer-probe/

Cai, Y, JR Snider, and P Wechsler. 2013. "Calibration of the passive cavity aerosol spectrometer probe for airborne determination of the size distribution." *Atmospheric Measurement Techniques* 6(9): 2349–2358, https://doi.org/10.5194/amt-6-2349-2013

6.1 Data Object Description

The file format for this probe is netcdf and can be opened by a number of software packages.

Table 1. Data objects names and descriptions provided in the PCASP-AIR data set.

#	name	type	dimension(s)	long_name	units	missing_value
0	base_time	int		Base time in Epoch	seconds since 1970-1-1 0:00:00 0:00	<Att Not Defined>
1	time_offset	double	time	Time offset from base_time	<Set at Runtime>	<Att Not Defined>
2	time	double	time	Time offset from midnight	<Set at Runtime>	<Att Not Defined>
3	time_bounds	double	time, bound	Time cell bounds	<Att Not Defined>	<Att Not Defined>
4	optical_diameter	float	optical_diameter	Optical diameter	µm	<Att Not Defined>
5	optical_diameter_bounds	float	optical_diameter, bound	Optical diameter bounds	µm	<Att Not Defined>
6	high_gain_signal	float	time	Average voltage registered by the high-gain signal	V	-9999
7	mid_gain_signal	float	time	Average voltage registered by the mid-gain signal	V	-9999
8	low_gain_signal	float	time	Average voltage registered by the low-gain signal	V	-9999
9	sample_flow_rate	float	time	Sample flow rate	(cm^3)/s	-9999
10	laser_ref	float	time	Laser power	V	-9999
11	auxs5	float	time	Channel reserved for internal use	V	-9999
12	sheath_flow_rate	float	time	Sheath flow read	(cm^3)/s	-9999
13	instrument_temperature	float	time	Instrument electronics temperature	degC	-9999
14	avg_transit	float	time	Average time it took for the particles to pass through the laserbeam	µs	-9999
15	fifo_full	short	time	Fifo full error flag, If value=1, data buffer on instrument was full. Data are likely missing	unitless	<Att Not Defined>
16	reset_flag	short	time	Probe reset flag	unitless	<Att Not Defined>
17	rejected_particles	int	time	An output channel on light-scattering instruments that indicates how many particles have been detected but rejected for counting because they were oversized.	count/s	-9999
18	spp_samples	float	time	Number of samples measured. Nominal is 10	count/s	-9999
19	**size_distribution**	int	time, optical_diameter	Particle size distribution, 30 bins	count/s	-9999
20	lat	float		North latitude	degree_N	-9999
21	lon	float		East longitude	degree_E	-9999
22	alt	float		Altitude above mean sea level	m	-9999

6.2 Data Ordering

Data from the PCASP can be ordered from https://adc.arm.gov/discoverybeta/#/results/instrument_class_code::pcasp-air. Data are organized by measurement location/campaign.

6.3 Data Plots

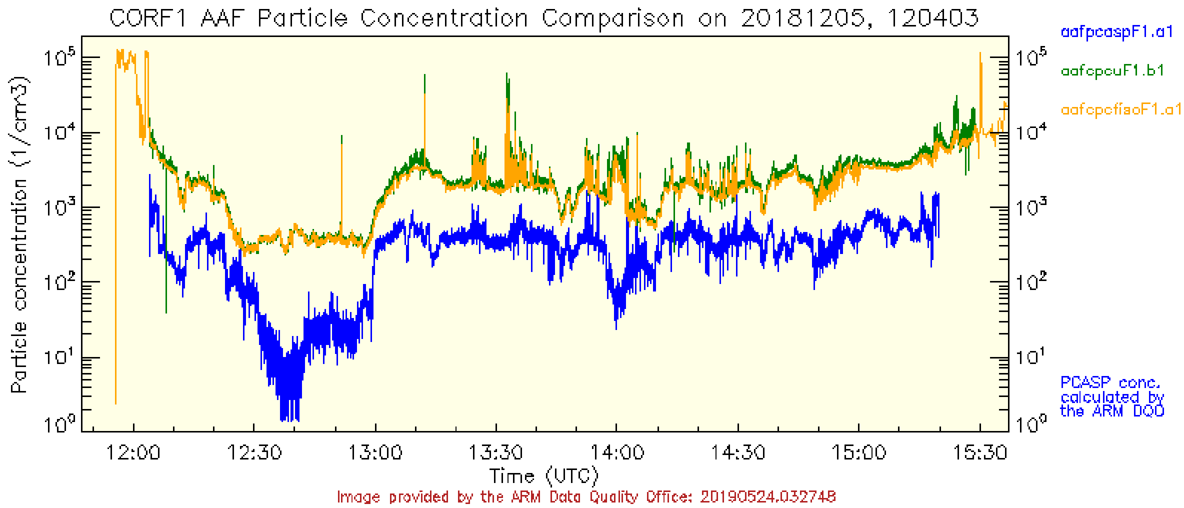

Figure 2. Time series plot of PCASP data products produced by the Data Quality (DQ) office, https://dq.arm.gov/dq-plotbrowser/

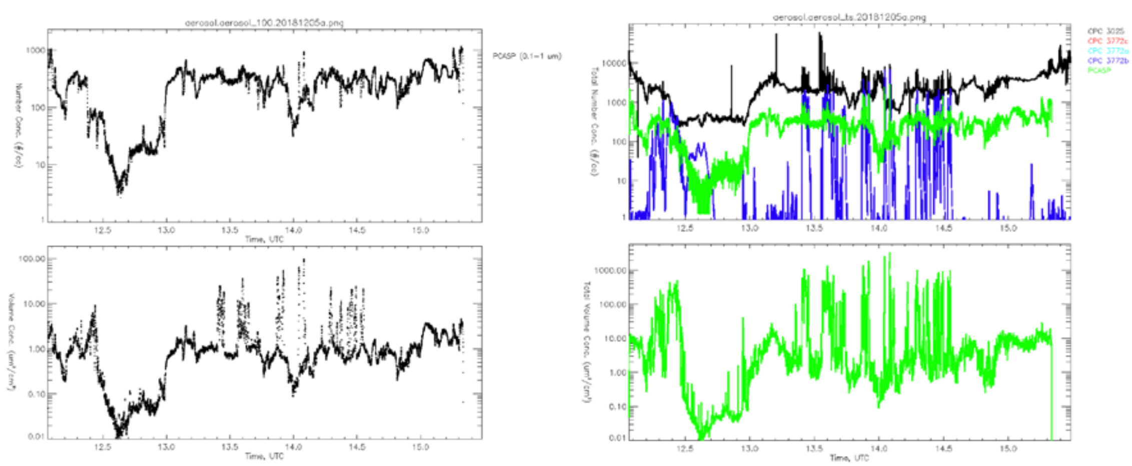

Figure 3. Time series plot of PCASP data products found on the Data Management Facility (DMF) Quick looks browser. The data in these plots are developed in the field and do not reflect the final, processed data found in the ARM Data Center (ADC). https://www.dmf.arm.gov/ql.php?path=%2Fdata%2Fhome%2Famatthews%2F

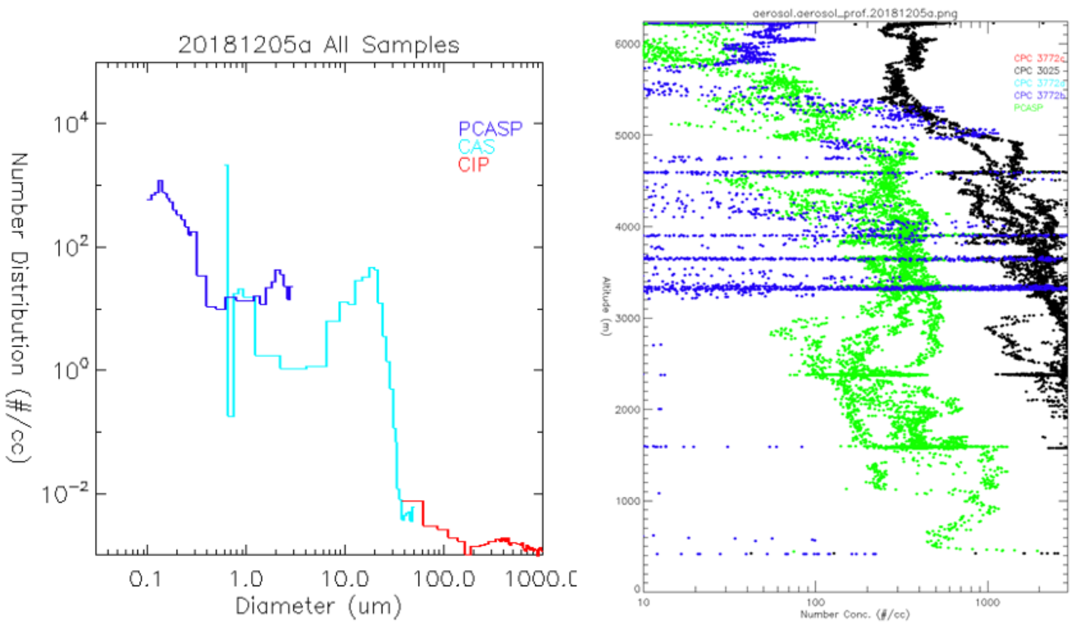

Figure 4. Time series plot of PCASP data products found on the DMF Quick Looks browser. The data in these plots are developed in the field and do not reflect the final, processed data found on the ADC. https://www.dmf.arm.gov/ql.php?path=%2Fdata%2Fhome%2Famatthews%2F

6.4 Data Quality

There are no current data quality reports at this time. Good data quality is ensured by a comparison with other measurements. The total number comparison from the PCASP shall not be greater than the total number concentration measured by in the in-cabin condensation particle counter 3772 and the in-cabin ultra-high-sensitivity aerosol spectrometer.

The measurements taken from this probe should not be used when the aircraft is ‘in cloud’, as shattering of hydrometeors on the PCASP inlet can affect the aerosol measurements. To determine if the measurement was made in cloud, data users can use the ‘cloud flag’ provided in the met-air data set, also known as the IWG or ‘interagency working group’ file. A WCM-2000 (Water Content Measurement) multi-element water content system measurement of total liquid water content above 0.1 g/m^3 is another indication of in-cloud conditions.

This instrument is regularly calibrated in the field and laser power is monitored during each flight to ensure consistent quality.

6.5 Instrument Mentor Monthly Summary

Mentor summary April 2020: PCASP-AIR is in storage while the Atmospheric Radiation Measurement (ARM) Aerial Facility (AAF)’s new research aircraft undergoes modifications.

6.6 Calibration Database

For calibration and laser alignment, the probe is sent to the vendor. Calibration is required post-shipping and at the start of each deployment using PSL-generated aerosol and aligning the 45-degree mirror. During campaigns generally, only PSL aerosol calibrations are necessary. Calibration results are tracked by the AAF's director of engineering.

7.0 Technical Specification

Details follow.

7.1 Units

1. Optical_diameter (bins), μm
2. Gain_Signals (dimensionless)
3. Sample_flow_rate, cm^3/s
4. Laser_ref, V
5. Sheath_flow_rate, cm^3/s
6. Instrument_temperature, C

7.2 Range

0.1−3.0 µm

7.3 Accuracy

±20% (Diameter)

±16% (Concentration)

7.4 Repeatability

This instrument is extremely stable and drifts minimally between calibrations. Contact mentor for more information.

7.5 Sensitivity

Particle detection is directly correlated to the laser power, because the sensitivity of detection is related to the scattering of the laser beam. The recommendation is to clean the optics when the reported laser reference voltage in the housekeeping data drops below a certain threshold. The laser reference voltage for good operation should be between 6 to 10 volts.

7.6 Uncertainty

The PCASP was developed as an aerosol particle measurement instrument, but it requires an assumption that the particle is spherical with a refractive index 1.58. The uncertainty in the size distributions increases when sampling mixed composition aerosols. Particles will not be correctly sized due to their different refractive index and non-spherical shapes.

Another consideration is that as concentrations increase, the probability also increases of more than a single particle coinciding in the beam or being missed during the electronic reset time. Corrections are applied to account for these losses but still lead to concentration uncertainties.

Uncertainties in the size measurement lead to root-sum-squared inaccuracies in surface area and volume a factor of two and three higher, respectively.

7.7 Input Voltage

- Probe power requirements:
  - 115 VAC, specified on ordering
  - 50-60 Hz
  - < 120 W.
- Anti-ice power requirements:
  - 28 VDC
  - 215 W.

7.8 Input Current

Variable by wattage required.

7.9 Input Values

Scattered light derived from particles intersecting a beam is collected and focused onto a photodetector and then amplified, conditioned, digitized, and classified into one of 32 size channels.

7.10 Output Values

Channels 1-32 are channels of accumulated counts. The size of the particle is determined by measuring the light-scattering intensity and using Mie scattering theory to relate this intensity to the particle size.

8.0 Instrument System Functional Diagram

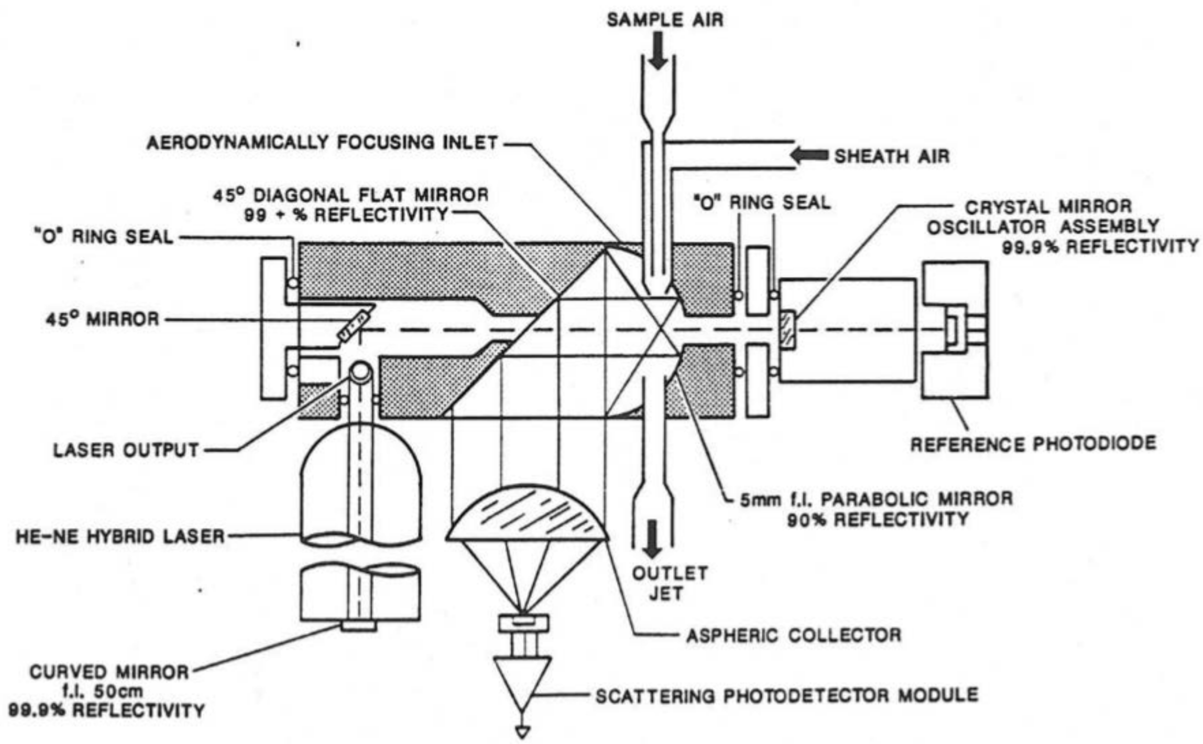

Figure 5. Schematic of the optical system from the PCASP manual by DMT.

9.0 Instrument/Measurement Theory

The PCASP has two parts: an optical bench and signal processing electronics. The optical bench collects light that is scattered by individual particles passing through a laser beam. It then converts the photon pulses to an electron voltage pulse via an avalanche photodetector. The SPP-200 amplifies, filters, digitizes, and categorizes this voltage pulse before transmitting the digital value for processing by an external data system.

While the PCASP detects and reports particles from a nominal range of 0.1 to 3.0 μm, the scattered light intensity over this size range covers more than six orders of magnitude. The amplification is therefore divided into a high-gain, mid-gain, and low-gain stage. The high-gain stage amplifies the signal detector voltage by a factor of 45 greater than the mid-gain stage, and the mid-gain stage amplifies by a factor of 17 greater than the low-gain stage. When the high-gain section voltage saturates, the processor automatically looks at the mid-gain section for a pulse. If the mid-gain section also reaches saturation, the low-gain is monitored for a pulse. If all gain stages saturate, an “ADC Overflow” counter is used.

Particle size is measured by using Mie scattering theory to relate the scattered light intensity to particle size. This assumes the particle is spherical and its refractive index is known. The sizing results and housekeeping information are then transmitted in the probe’s serial-stream data in a histogram form.

Derived measurements are as follows:

1. Concentration number of particles per unit volume [#/cc] $C = \sum_{i=1}^{i=32} \frac{n_i}{V}$
2. Surface area per unit volume [SA/cc] $C = \pi \sum_{i=1}^{i=32} \frac{n_i d_i^2}{V}$
3. Particle volume total per unit volume [µm³/cc] $V = \frac{\pi}{6} \sum_{i=1}^{i=32} \frac{n_i d_i^3}{V}$
4. Arithmetic average diameter of particle size [µm] $D_A = \frac{\sum_{i=1}^{i=32} n_i d_i}{\sum_{i=1}^{i=32} n_i}$

Where,

n_i, number of particles detected in size channel i

d_i, diameter of particles represented in channel i

i, number of channels detected by the PCASP instrument

V, sample volume for a sampling period, $V_a = F_{std} \cdot \frac{P_{std}}{P_a} \cdot \frac{T_a}{T_{std}} \cdot t$

Where, F_{std} = mass sample flow (cc/s), T_a= ambient temperature (K), T_{std}= standard temperature (273.15 K), P_a= ambient pressure (mbar), P_{std}= standard sea-level pressure (1013 mbar), and t= time (s)

Volumetric flow is set at the factory to a value of 1 cm³/sec for standard pressure and temperature regardless of ambient conditions. If this is not the case, the pump has likely failed.

10.0 Setup and Operation of Instrument

The PCASP is mounted to the wing of the aircraft in a Particle Measuring Systems (PMS) canister attached to a pylon.

11.0 Software

The Particle Analysis and Display System (PADS) was developed by DMT for interfacing with its instrumentation. It is a Microsoft Windows-based, LabVIEW software package, offering display and analysis features. Data acquired with PADS can be stored to a file for later analysis. The program stores configuration information as a file header, so users can easily determine the system settings at the time of data acquisition. PADS can set the channel-size thresholds, sample rate, and default setting for the instrument pump used upon startup. Examples of data that PADS can record and display include the following:

- Particle concentrations and size distributions (the latter in tabular and histogram form)
- Common particle statistics such as median volume diameter and effective diameter
- Housekeeping and auxiliary variables
- Time traces of user-selectable parameters.

12.0 Calibration

The PCASP is calibrated with the use of monodispersed polystyrene latex spheres (PSLs) with a refractive index of 1.58. These PSLs are available through DMT or Duke Scientific. The PSLs are nebulized via an aerosol generator. After vendor calibration, the instrument is returned with a set of calibration histograms that can be used to compare the probe's calibration with later calibration verifications.

13.0 Maintenance

The following is a description of cleaning and aligning routine to bring the laser up to the desired power level. The laser reference voltage for good operation should be between 6 to 10 volts, which can be monitored from the housekeeping data:

The laser output coupler is positioned in the sample cavity, attached to the front end plate of the probe. To clean it, remove the 45° mirror, held in place with three 4-40 screws. Clean only the tip itself at the center of the laser capillary tube using a slightly dampened Q tip with acetone. Use the Q tip only once in a sweeping motion across the coupler. While the mirror is removed, inspect the mirror surface for contamination, and clean using the same method described above. Align the red dots when reinstalling the mirror.

Maximize laser power before proceeding to the next surface. The laser is aligned by tightening the three screws to the outer O-ring that the mirror sits on. Be sure it is aligned with the three dots. If continued cleaning and aligning does not bring the laser power up to the desired level, the laser may have low power and need replacement. In most cases though, low power is a cleaning problem and/or alignment problem unless reassembling has resulted in significant misalignment because of mechanical tolerances.

To align the sample stream of air with the laser beam, adjustments can be made to the inlet tube. The Sample aerosol exits the optical Sample chamber through the exit tube. The airflow passes through the diaphragm pump, the desiccant, and the filter before being split into two separate airstreams, the Sample and Sheath. One flow segment passes through the Sample valve and mass flow meter and is then exhausted. The second flow segment is developed as the filtered Sheath airflow. This flow is controlled by a needle valve, and it passes through a mass flow meter before returning to the Sample inlet as filtered Sheath air. When adjusting the Sample or Sheath airflow, there will be a slight lag that exists before the new equilibrium is reached. Airflow corrections, particularly for altitude, should be applied for the most accurate flow measurements. The PADS will automatically make corrections to reported mass flow for use in the concentration calculations.

A leak check should be made whenever the probe is out of its cylinder. This check can easily be performed by closing off the sample flow valve or plugging its outlet. As soon as equilibrium is achieved (10−20 seconds), there should be essentially few, if any, counts registering in any channels. This "zero count" test can also be performed by supplying filtered air to the inlet jet. The presence of significant count events suggests either a plumbing leak or an electronic noise problem. A simple leak can be corrected by tightening all plumbing connections. A serious leak may require the use of a leak detector and pressurization of the optics chamber.

Located between the pump and the filter is a 12” piece of 1/4” ID Tygon tubing containing desiccant between two cotton plugs to remove entrained moisture. This drying material and the filter should be replaced periodically or once every other year to reduce clogging. We recommend replacing the desiccant before campaigns in humid locals.

14.0 Safety

The probe weighs 40 pounds and is 40” long by 7” in diameter. Always lift and install the probe in the canister in teams of two to avoid dropping the instrument. When calibrating with PSL, wear gloves and safety glasses, and clean up the workstation when done. The laser is a HeNe multi-mode classical passive cavity, wavelength 0.6328 μm, classified as a class II laser. When working with the instrument outside the pylon, this laser is considered safe because of the blink reflex, limiting exposure to 0.25 seconds. Still, work with caution and minimize risk by energizing with this probe within a canister that will block visible light lasers.

15.0 Citable References

Vendor’s website: https://www.dropletmeasurement.com/product/passive-cavity-aerosol-spectrometer-probe/

Cai, Y, JR Snider, and P Wechsler. 2013. “Calibration of the passive cavity aerosol spectrometer probe for airborne determination of the size distribution.” *Atmospheric Measurement Techniques* 6(9): 2349–2358, https://doi.org/10.5194/amt-6-2349-2013

Droplet Measurement Technologies. 2012. Passive Cavity Aerosol Spectrometer Probe (PCASP-100X) Operator Manual. DOC-0228, Rev C.

www.arm.gov

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