DOE/SC-ARM-TR-258

Miniaturized Optical Particle Counter (MOPC) Instrument Handbook

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November 2020

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

Acronyms and Abbreviations

AAF	ARM Aerial Facility
ACCESS	aerosol counting, composition, extinction, and sizing system
ARM	Atmospheric Radiation Measurement
ASCII	American Standard Code for Information Interchange
DAQ	data acquisition
DMA	differential mobility analyzer
ESD	electrostatic discharge
HEPA	high-efficiency particulate air
MCPC	mixing condensation particle counter
MIST	multiple instrument stackable tower
mOPC	miniaturized optical particle counter
netCDF	Network Common Data Form
NIST	National Institute of Standards and Technology
PMT	photomultiplier tube
POPS	portable optical particle spectrometer
PSL	polystyrene latex
STAP	single-channel tricolor absorption photometer
UAS	unmanned aerial system
UHSAS	ultra-high-sensitivity aerosol spectrometer
UTC	Coordinated Universal Time

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1.0 Instrument Title

The U.S. Department of Energy Atmospheric Radiation Measurement (ARM) aerosol counting, composition, extinction, and sizing system (ACCESS) includes a base module (9400), a filter sampler (9401), an advanced mixing condensation particle counter (MCPC, 9403), a miniaturized optical partical counter (mOPC, 9405), and a single-channel tricolor absorption photometer (STAP, 9406).

This handbook focuses on the mOPC, which measures the aerosol particle size distribution between 0.19 and 3 μm.

2.0 Mentor Contact Information

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4.0 Instrument Description

The miniaturized optical particle counter (mOPC), as shown in Figure 1, measures the number and size distribution of aerosol particles using a 405-nm-wavelength laser light. It operates at a twice per second sampling rate, although the software reported the data at 1Hz. Particles smaller than 190 nm can be detected, but with the detection efficiency, less than 100% are not reported by an mOPC. The sample flow rate (0.06 lpm) of an mOPC is measured by a precision laminar flow element on the inlet and controlled in real time by modulating the integrated sheath flow (1 lpm) and vacuum pumps.

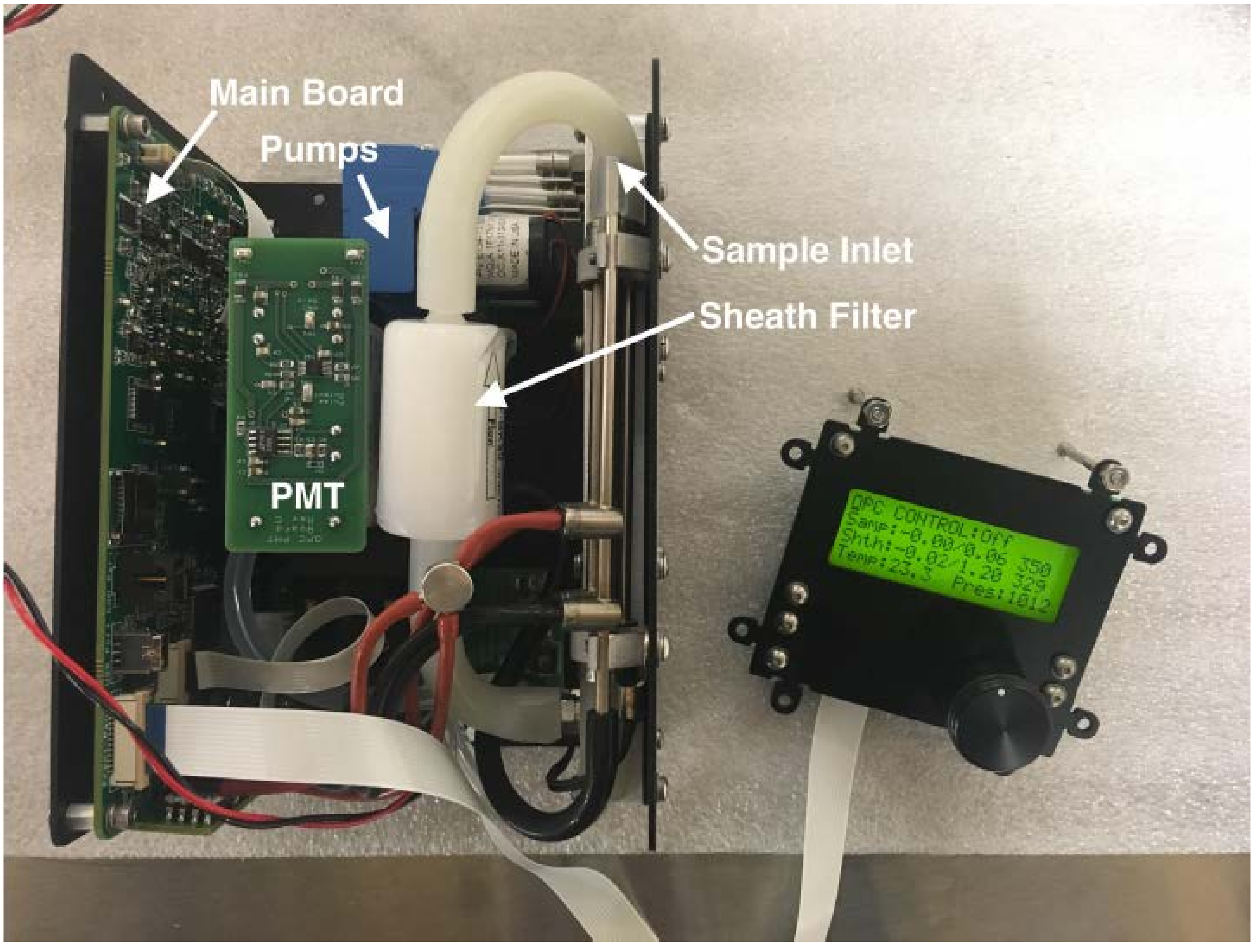

Figure 1. Major components of the mOPC (from the manufacturer's manual).

5.0 Measurements Taken

The mOPC is capable of a high-time-resolution size distribution measurement via the light scattering to rapidly capture aerosol properties' changes. Individual aerosol particles are surrounded by the filtered sheath flow and passed through the laser pathway. The laser light is focused with lenses and apertures to optimize the beam quality and photon density to maximize the photomultiplier tube (PMT) response, as shown in Figure 1. A light trap is used to capture the direct laser beam light and minimize background photons detected by the PMT. The amplitude of the scattered light pulse is proportional to particle size. The concentration is determined by dividing the number of particles counted over a time period by the sample flow rate. The unit is calibrated with size-selected ammonium sulfate and polystyrene latex spheres (PSL) to confirm sizing performance.

6.0 Links to Definitions and Relevant Information

mOPC webpage: https://www.brechtel.com/products-item/mopc/

6.1 Data Object Description

The raw data from the mOPC are recorded in *.dat file with appropriate headers specifying the data and units of measurement. The diameter array is written as one of the header rows in the file. The data file column definitions are included in Table 1.

The ARM archived data are available in both netCDF format and ASCII format.

Table 1. Data file column definitions.

Column	Headers	Definitions
1	YY/MM/DD	Year, Month, Day
2	H.R.:MN: S.C.	Hour, Minute, Second
3	opc_cntl	opc control (0=off, 1=on)
4	sample_sp	sample flow setpoint (lpm)
5	sheath_sp	sheath flow setpoint (lpm)
6	bin_time	time to accumulate bin data (0=0.5 sec, 1=1sec, 60=60sec)
7	total_conc	raw total counts divided by sample flow rate
8	sample_flw	measured sample flow (lpm)
9	sheath_flw	measured sheath flow (lpm)
10	sample_temp	sample flow temperature (℃)
11	sample_press	sample flow pressure (mbar)
12	lasr_brt	laser brightness reading (0-4095)
13	lasr_cur	laser current reading (0-4095)
14	pmt_base	pmt base offset voltage (0-4095)
15	pmt_offs	setting of pmt offset pot (automatically controlled)
16	sheath_pwr	sheath pump power level (0-400)
17	exit_pwr	exhaust pump power level (0-400)
18	sd_install	whether or not S.D. card is installed
19	opc_errs	opc error number
20	bin1	84 bins of raw count data

6.2 Data Ordering

The collected mOPC data are distributed through the ARM Data Center and are presently updated after each unmanned aerial system (UAS) daily flight.

6.3 Data Plots

Figure 2 shows the housekeeping plots that the ARM Aerial Facility (AAF) field crew use to check the instrument health during flight operation.

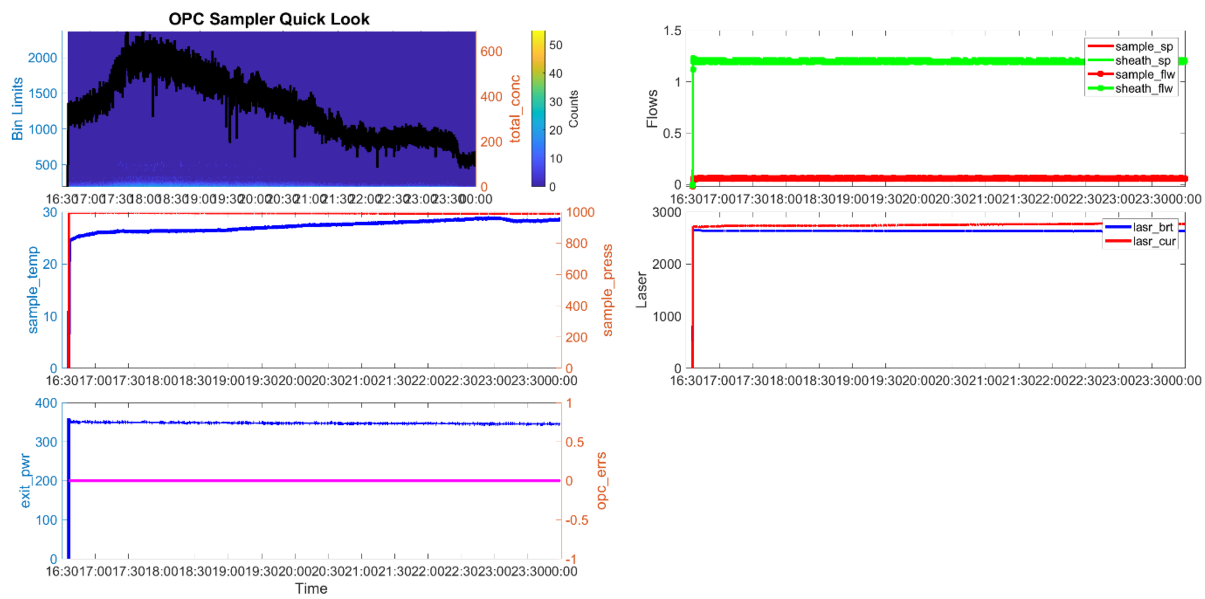

Figure 2. An example of the housekeeping data from mOPC.

6.4 Data Quality

The mOPC calibration is periodically verified by the instrument mentors. The verification includes using the mOPC to measure the size distribution of a PSL particle or monodisperse aerosol particles with a known mean particle diameter (electrical mobility) generated by a differential mobility analyzer (DMA) and comparing the measured geometric mean particle size to the DMA selection size. During the deployment, the mOPC readings are periodically compared with those from the portable optical particle spectrometer (POPS) and the ultra-high-sensitivity aerosol spectrometer (UHSAS) at the ground station, as shown in Figures 3 and 4. to check performance. Additionally, more information such as the size determination and the counting efficiency can be found in Mei et al. 2020 [1]. Calibration verification data are collected and maintained by the instrument mentors.

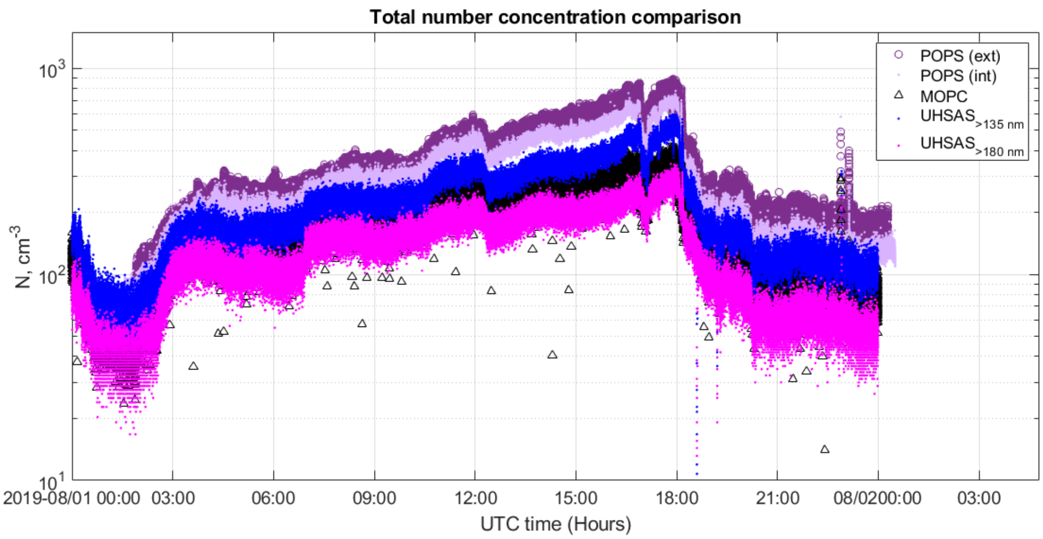

Figure 3. An example of the total number concentration integrated from mOPC, POPS, and UHSAS from the ground station.

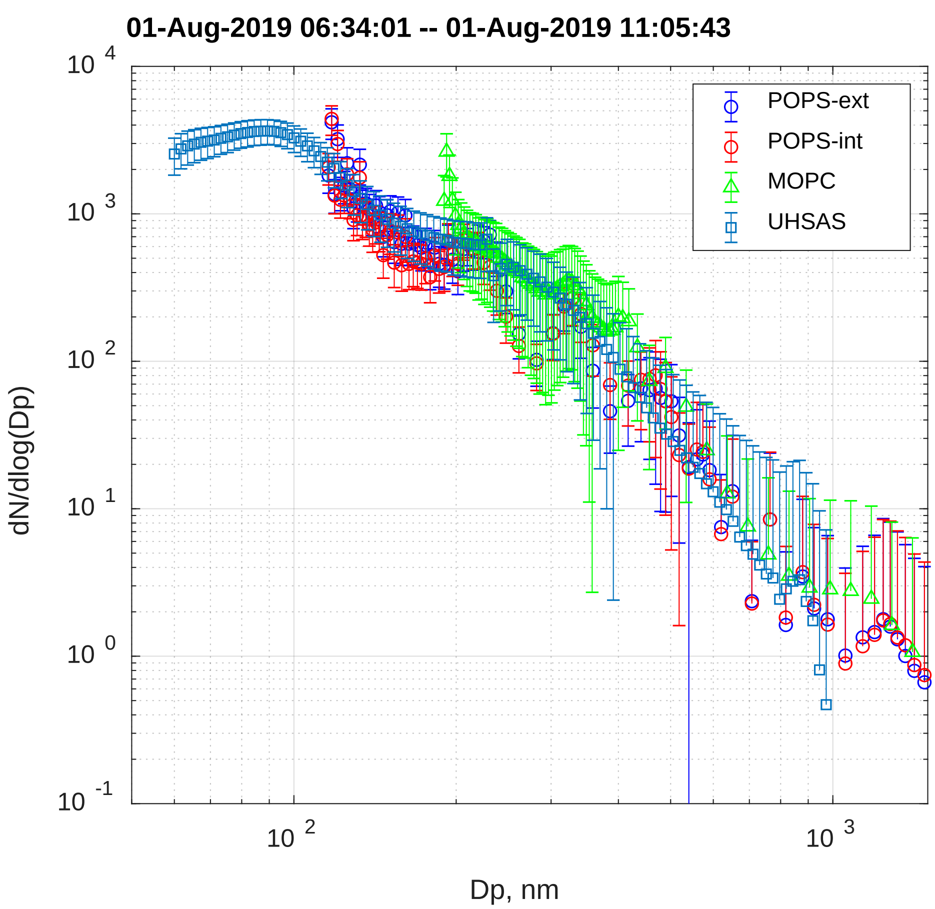

Figure 4. A comparison example of the size distributions from mOPC, POPS, and UHSAS from the ground station.

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 counts (dimensionless).

7.2 Range

Particle size can be measured from 190 to 3000 nm. Total particle number concentration (per unit time) can be measured from 0 to 5000 cm^{-3} based on the instrument manual.

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, usually 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 a scanning mobility particle sizer (SMPS) [2]. This applies to the instrument's normal operating mode where the total particle counts are below 5000 cm^{-3}, and no significant particle coincidence occurs.

7.4 Repeatability

Repeatability of particle sizing mainly depends on the inherent noise in the electronics' response that measures the pulse height of the scattered light. In general, the repeatability is within 1% [2]. This repeatability applies to the instrument's normal operating mode where the total particle counts are below 5000 cm^{-3} and no significant particle coincidence occurs.

7.5 Sensitivity

Aerosol particle size and concentration measurement are 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 4000 cm^{-3}. The instrument makes no corrections for particle coincidence, 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). If the ambient particle refractive index is known, corrections can be applied to the measurement data [2].

7.6 Uncertainty

Uncertainty for particle sizing is mostly determined by the instrument's sizing resolution, 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

The user's parameters include measurement range, number of size bins, upper and lower boundaries of each size bin, and sample flow rate.

7.8 Output Values

See section 6.1.

8.0 Instrument System Functional Diagram

See section 5.0 and the mOPC manual.

9.0 Instrument/Measurement Theory

See section 5.0 and the mOPC manual.

10.0 Setup and Operation of Instrument

General procedures:

1. Switch on the instrument and wait for the internal computer to boot up.
2. Start the measurement software by double-clicking on the “UAV reader” icon on the computer desktop screen. The software may be configured to start automatically in the future, in which case skip this step.
3. The instrument is now ready to operate automatically.

The mOPC employs an extremely sensitive detector capable of measuring extremely small electrical signals. To protect the detector, some good electrostatic discharge (ESD) practices are critical to maintaining and operating this device.

- Always be sure to ground yourself before handling the unit.
- Always be sure to connect the unit to earth ground.

Before each flight:

1. Check the instrument time: make sure it is synchronized with UTC.
2. Check the mOPC status.

a. Check the mOPC display tab, and make sure MOPC is on and communicate with the data acquisition (DAQ) computer.

b. Check that the flow is around 0.06 lpm.

3. Daily zero check – verify that the instrument is operating normally.

a. Turn on the instrument and let it warm up (approximately 600 seconds).

b. Attach the supplied HEPA zero filter assembly to the inlet screen assembly.

c. The particle concentration should go to zero in approximately 5 to 10 seconds. Leave the HEPA zero filter attached to the instrument for 30 seconds to ensure the zero reading is stable.

Deployment on a TigerShark or ArcticShark

The mOPC is installed on the multiple instrument stackable tower (MIST) in the main payload bay of the ARM ArcticShark UAS. The MIST itself is seated in the payload bay connected by four vibration isolators to reduce noise. Outside air is brought into the payload via a universal inlet installed on the nose of the UAS. The inlet is pumped actively via a scroll pump and controlled with a mass flow controller. The instrument is initialized by an onboard data acquisition system that operates the Brechtel LabVIEW software. The data is transmitted to scientists on the ground in real time.

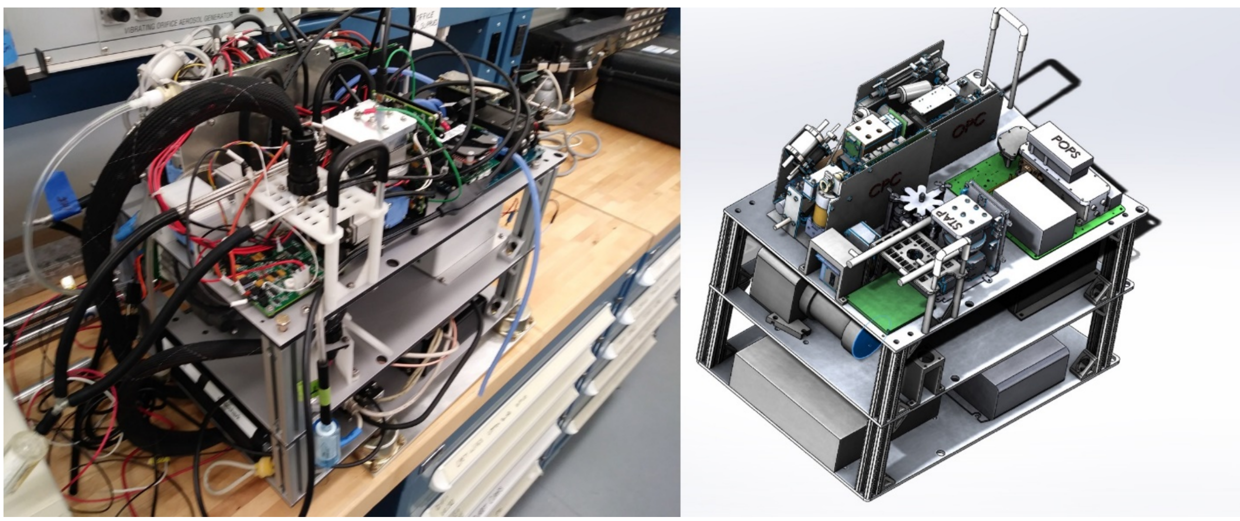

Figure 5. MIST instrument payload tower. Left: On laboratory bench. Right: Schematic with instrument placement clarified.

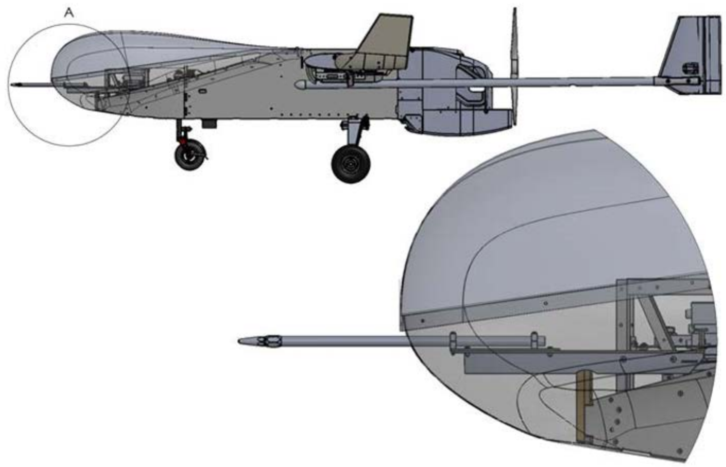

Figure 6. ArcticShark with nose inlet installed.

11.0 Software

For further details, consul the manufacturer’s manual.

12.0 Calibration

The mOPC 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 the 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 light detector electronics' responses 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 HEPA filter attached to the inlet.

A similar calibration verification done by instrument mentors was documented in Mei et al. 2020 [1].

13.0 Maintenance

Please consult the manufacturer's manual for cleaning the laser optics, cleaning the mirror, and laser alignment.

14.0 Safety

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

15.0 Citable References

[1] Mei, F, G McMeeking, M Pekour, R-S Gao, G Kulkarni, S China, H Telg, D Dexheimer, J Tomlinson, and B Schmid. 2020. “Performance Assessment of Portable Optical Particle Spectrometer (POPS).” *Sensors* 20(21): 6294, https://doi.org/10.3390/s20216294

[2] Bates, TS, PK Quinn, JE Johnson, A Corless, FJ Brechtel, SE Stalin, C Meinig, and JF Burkhart. 2013. “Measurements of atmospheric aerosol vertical distributions above Svalbard, Norway using unmanned aerial systems (UAS).” *Atmospheric Measurement Techniques* 6(8): 2115−2120, https://doi.org/10.5194/amt-6-2115-2013

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