Aerosol Sampling System for WMO Global Atmosphere Watch

John Ogren <John.A.Ogren@noaa.gov>
NOAA Climate Monitoring and Diagnostics Laboratory
Boulder, CO 80305, USA
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1. Introduction

NOAA/CMDL operates five baseline stations that are part of the WMO/GAW network, as well as a number of regional aerosol monitoring sites. This document describes some of the essential features of those systems that are suitable for replication at other GAW sites. CMDL welcomes collaboration with GAW station operators desiring to initiate or upgrade aerosol sampling at their stations. The sampling systems described here are consistent with the recommendations for aerosol sampling systems prepared by the GAW Scientific Advisory Group for Aerosols (WMO #153, WMO/GAW Aerosol Measurements and Procedures: Guidelines and Recommendations).

2. Measurement System

The aerosol parameters that are continuously measured with the sampling system are light scattering coefficient, light absorption coefficient, and number concentration. An integrated impactor/filter sampling module samples particles for subsequent gravimetric and chemical analysis. This system provides measurements of four of the five core aerosol variables recommended for regional and global GAW stations, as well as two other variables recommended for global GAW stations:

- mass in two size fractions (core);
- major chemical components in two size fractions (core)
- light absorption coefficient (core)
- light scattering coefficient at various wavelengths (core)
- hemispheric backscattering coefficient at various wavelengths
- aerosol number concentration

Detailed specifications of the system are given in section 5 below. The instruments used by CMDL include:

- TSI model 3563 integrating nephelometer
- Radiance Research model PSAP absorption photometer
- TSI model 3010 or 3760 condensation nucleus counter
- NOAA/PMDL impactor/filter sampler.

The instrumentation is designed to be installed in a climate-controlled laboratory, with heating and air-conditioning as necessary to maintain a room temperature around 25 degrees Celsius. Some of the essential features of the sampling techniques used by CMDL are:

- an omnidirectional inlet that brings particles from 10 meters above ground level into the laboratory;
- control of relative humidity, to ensure that measurements of aerosol properties sensitive to relative humidity are made under stable conditions, and also to avoid condensation of water in systems that are operated in air-conditioned laboratories;
- control of particle size, to allow determination of the properties of sub-micrometer and super-micrometer particles.

Photographs of the aerosol sampling systems deployed at two of CMDL's baseline observatories are shown below.

Figure 2-1: NOAA/CMDL aerosol sampling system at Mauna Loa Observatory. The major components in the 19” instrument rack (from bottom) are the particle size-cut control box, condensation nucleus counter, light absorption photometer, analog/digital subsystem, and inlet heater controller. The tall instrument to the right of the rack is the integrating nephelometer for measuring aerosol light scattering coefficient. The power supply for the nephelometer and the personal computer that operates the system rest on top of the rack.

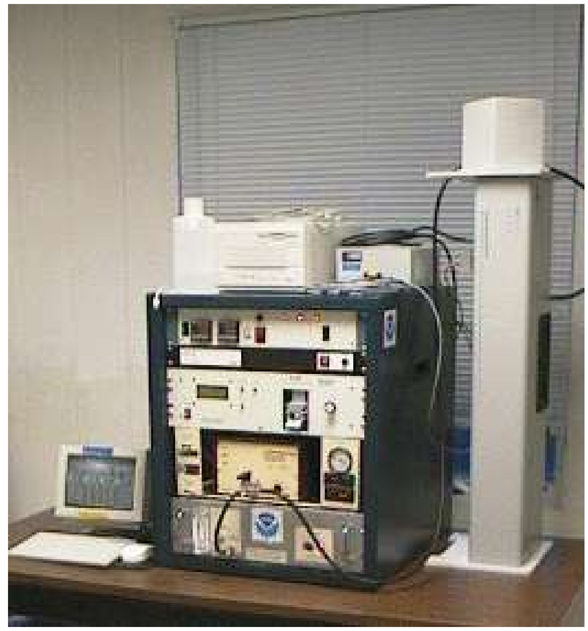

Figure 2-2: NOAA/CMDL aerosol sampling system at Trinidad Head Observatory. This system is more complex than the one at Mauna Loa, and includes a second nephelometer for measuring the dependence of aerosol light scattering on relative humidity, as well as a filter sampling unit. The two nephelometers are to the left of the instrument racks. The upper-right rack contains most of the components shown in the photo above from Mauna Loa, while the upper-left rack contains the filter sampling unit. The lower-left rack contains the humidity and particle size-cut control units, and the lower-right rack contains storage drawers and an uninterruptible power supply.

The sampling system uses a variety of pumps and blowers to pull air through different components. A high-capacity blower is used for the main stack flow, and diaphragm and/or carbon-vane pumps provide the vacuum for the instruments and filter samplers. In order to maintain acceptable noise levels inside the laboratory, the pumps and blowers are installed in a wooden box outside of the laboratory.

Figure 2-3: Pumpbox at Mauna Loa Observatory. The base of the 10-meter tower and the 10-cm stack bypass line are also seen in the photograph.

Figure 2-4: Pumpbox at Trinidad Head. Shelter from rain is provided by installing the pumpbox under the elevated instrument trailer at this site.

Figure 2-5: Pumpbox interior. Louvres (top) and a thermostat-controlled fan (bottom) prevent excess heat buildup. Time-delay relays (box at top left) provide a controlled recovery from power outages by spreading out the power surge when the pumps are started. The long cylindrical object is a filter that captures the graphite particles generated by the carbon-vane pump.

3. Inlet System

An elevated inlet provides air samples above the dust and flow disturbances at the surface. NOAA/CMDL uses a 10-meter tower to support a 20-cm diameter duct that brings air down to the laboratory. The inlet stack is made from polyvinyl chloride (PVC) sewer pipe, which is inexpensive and widely available. A metal hat prevents rain from entering the inlet stack, and a 5-cm diameter stainless steel tube extracts the sample flow from the centerline of the stack near its base. The stainless steel tube is wrapped with heating tape, and the tube is heated if necessary to reduce the relative humidity of the sample to 40%. The total stack flowrate is 1000 lpm and the flow through the stainless steel tube is 150 lpm; the excess 850 lpm is exhausted into the pumpbox by a high-capacity blower. The sample flow leaving the heated tube is split into four analytical lines (30 lpm each), with another 30 lpm flowing through a bypass line containing the temperature and RH sensor used to control the sample heater.

The characteristics of the site determine the details of the inlet system installation. It is preferable to bring the sample into the laboratory through the roof, to minimize bends in the flow. In some cases, however, it is necessary to bring the sample through the wall of the laboratory. The photographs below show some of the inlet system configurations used by CMDL. Note that the insulation has been removed from the sample lines in the photos; at most sites, the splitter and all downstream sample lines are heavily insulated to avoid a temperature drop, particularly at air-conditioned stations.

Figure 3-1: Inlet stack at Bondville station. The stack is cantilevered over the laboratory trailer so that the sample can be brought through the roof without any bends in the flow. Pumps and blowers are kept in the wooden box at the base of the stack. The 10-meter tower is supported by three guy wires and protected by a lightning rod.

Figure 3-2: Inlet stack at Gosan station (South Korea). Penetration through the roof was not allowed at this station, so sample air had to be brought in through a wall. This meant that the stack could be directly bolted to the tower.

Figure 3-3: Base of inlet stack at Gosan station. The tee-adapter directs the main stack flow to the blower in the pumpbox through 10-cm diameter PVC pipe. The 5-cm heated inlet tube is inserted into the main stack from the bottom, and extends to a point above the tee-adapter.

Figure 3-4: Lower part of inlet stack at Mauna Loa. The structure used to cantilever the stack away from the tower, which allows direct penetration of the inlet through the roof, is clearly visible. An access port is cut into the stack at the level of the top of the 5-cm stainless steel inlet, to allow filtered air checks of the entire system. The port is glued to the back of the white saddle adapter, seen just below and to the left of the pineapple.

Figure 3-5: Close up view of stack access port at Mauna Loa, with HEPA capsule filter installed on aerosol inlet.

Figure 3-6: Rain hat used at Mauna Loa. Galvanized steel was used at this arid site. Stainless steel is used at other sites.

Figure 3-7: Inlet splitter at Gosan station, showing penetration through wall of trailer. This installation was flawed because the base of the splitter was about 50 cm too low, leading to a tighter bend in the 5/8"-ID sample lines (black, conductive silicone tubing) than desired.

Figure 3-8: Inlet splitter at Mauna Loa, with direct penetration of sample inlet through the roof. Conductive silicone tubing (5/8" ID) is used for active sample lines, and polyethylene tubine is used for the spare and bypass lines. A temperature and RH sensor is inserted into the bypass line through the union tee just below the base of the splitter. Readings from this sensor is used to control the inlet heater, so that the RH of the air leaving the splitter is kept below 40%. Rotameters are used to measure the sample flowrate in the spare and bypass lines, which are maintained at a 30 lpm flowrate.

4. Data Acquisition System

Data acquisition and instrument control are done with open source software. NOAA/CMDL has written software in the C programming language for controlling the aerosol sampling system, and will freely provide this software to interested GAW stations. This software runs under the GNU/Linux operating system, which is freely available on the internet. The hardware requirements for running the CMDL aerosol software are modest (500 MHz Pentium-class CPU, 128 MB RAM, 12GB hard disk, USB port). CMDL has had good success using older laptop computers (IBM Thinkpad model T20), which are readily available used for about $500.

Measured data are normally transmitted over the internet once per day to a restricted ftp server at CMDL that allows anonymous, write only connections. Dial-up access over telephone lines is used where direct internet access is not available. The quantity of data transferred daily is around 150 kilobytes. Quick-look plots are generated automatically and available on the internet within 15 minutes after receipt of the data (see http://www.cmdl.noaa.gov/aero/qcplots.html). Daily review of these plots allow problems to be quickly identified, which helps avoid extended data loss caused by malfunctions. CMDL is willing to provide this level of automated processing to GAW stations that use the CMDL aerosol data collection software.

Incoming connections to the aerosol computer allow remote users to view the data (as text or time-series plots) for troubleshooting problems in real-time. The data acquisition software can also be upgraded remotely.

5. Specifications of NOAA/CMDL aerosol sampling system

<u>Inlet system:</u>	
Diameter, main stack, cm	20
Flowrate, main stack, lpm	1000
Flow velocity, main stack, m/s	0.53
Reynolds number, main stack	7070
Particle stopping distance, main stack (cm)	0.02
Diameter, heated inlet tube, cm	4.76
Flowrate, heated inlet tube, lpm	150
Flow velocity, analytical sample line, m/s	1.4
Reynolds number, heated inlet tube	4440
Particle stopping distance, heated inlet tube (cm)	0.04
Diameter, analytical sample line, cm	1.59
Flowrate, analytical sample line, lpm	30
Flow velocity, analytical sample line, m/s	2.5
Reynolds number, analytical sample line	2670
Particle stopping distance, analytical sample line (cm)	0.07
<u>Light scattering coefficient:</u>	
Method	Integrating nephelometer
Manufacturer and Model	TSI, Inc., Model 3563
Wavelengths (nm)	450, 550, 700
Noise level, 1-minute average (Mm^{-1}), 550 nm wavelength	0.2
Relative humidity (percent)	< 40
Particle size ranges measured (diameter, µm)	D < 10, D < 1
Angular integration ranges (degrees)	total scattering: 7-170 hemispheric backscatter: 90-170
<u>Light absorption coefficient:</u>	
Method	Light transmission through fiber filter
Manufacturer and Model	Radiance Research, Particle/Soot Absorption Photometer (PSAP)
Wavelength (nm)	565, adjusted to 550
Noise level, 1-minute average (Mm^{-1})	0.1
Relative humidity (percent)	< 40
Particle size ranges measured (diameter, µm)	D < 10, D < 1
<u>Particle number concentration:</u>	
Method	condensational growth followed by optical detection of single particles
Manufacturer and Model	TSI, Inc., Model 3010
Working fluid	n, butyl alcohol
Particle size range measured (diameter, µm)	D > 0.010
<u>Chemical sampler:</u>	
Collection methods	Impactor with 8 backup filters
Size ranges sampled (µm)	1 < D < 10 (impactor), D < 1 (filter)

Sample duration, typical (hours)	168 (impactor), 24 (filters)
Sample volume, typical (m^3)	300 (impactor), 43 (filters)
Filter medium	Teflon
Analytical methods	gravimetric, ion chromatography
Species determined	total mass, major ions (Na+, K+, NH4+, Mg2+, Ca2+, Cl-, NO3-, SO42-)