

**Atmospheric Aerosol Source-Receptor Relationships:
The Role of Coal-Fired Power Plants**

Statement of Work

Carnegie Mellon University

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Project Overview and Objectives:

The Pittsburgh Air Quality Study (PAQS) is comprised of three inter-related components: 1) ambient PM measurements, 2) source characterization, and 3) deterministic and statistical air quality modeling. This effort will permit clarification of the contribution of coal-fired power plants to fine ambient PM-2.5 (particulate matter with an aerodynamic diameter less than 2.5 μm). The resources from the Department of Energy (DOE) will be leveraged with resources from the Environmental Protection Agency (EPA) and other organizations. This document describes the scope of work for the DOE component of the project.

The DOE funds will support a large-scale ambient air quality study in the Pittsburgh region. The EPA-Supersites Program is contributing \$3.4 million towards this effort. EPA has funded the establishment of a central supersite and a set of satellite sites, a set of core ambient measurements related to understanding atmospheric processes, and the development and evaluation of new PM measurement techniques. The DOE funds will support advanced ambient measurements needed for model evaluation, examination of source-receptor relationships, and the development of the next generation of techniques for source apportionment.

The DOE funds will support characterization of several of the most important PM sources in the Pittsburgh region. Major point sources including coal-fired boilers will be investigated. A broad suite of measurement techniques will be used to characterize each source including standard PM composition, detailed organics speciation, size-resolved mass and composition, and composition and size on a single particle. We will utilize advanced measurement techniques such as single particle mass spectrometry to develop new approaches for source characterization and source attribution.

The DOE funds will support statistical and deterministic modeling using the ambient and source data to examine source-receptor relationships. A variety of statistical tools will be used including factor analysis and advanced statistical techniques using air mass back trajectories and neural network pattern recognition of single particle data. A state-of-the-art air quality model will be used to examine secondary PM in the region and potential control strategies. We will investigate the contribution of all sources to the Pittsburgh region because of the non-linear interactions among the contribution of coal-fired power plants and of the rest of the sources to ambient PM levels.

The main objectives of the DOE supported work are:

1. To achieve advanced characterization of the PM in the Pittsburgh region. Measurements include the PM size, surface, volume, and mass distribution; chemical composition as a function of size and on a single particle basis; temporal and spatial variability.
2. To obtain accurate current fingerprints of the major primary PM sources in the Pittsburgh region using traditional filter-based sampling and state-of-the-art techniques such as dilution sampling and single particle analysis using mass spectroscopy and LIBS.
3. To estimate the impact of the various sources (transportation, power plants, natural, etc.) on the PM concentrations in the area using both statistical and deterministic models.

4. To quantify the responses of the PM characteristics to changes in these emissions in support of the emission control decision making in the area (SIP development, etc.).
5. To develop and evaluate current and next generation aerosol monitoring techniques for both regulatory applications and for determining of source-receptor relationships.

Scope of Work:

The research is organized into seven inter-related activities: 1) project management, 2) ambient PM measurements, 3) source characterization, and 4) statistical modeling for source apportionment, and 5) deterministic air quality modeling, and 6) hypotheses testing, and 7) reporting. The scope of work for each of these activities is described below. Attached is the scope of work for each of the subcontractors participating in the research.

Activity 1. Project Management

The proposed work will be conducted under the direction of a project management team headed by Carnegie Mellon University. Carnegie Mellon University will be the prime contractor to the Department of Energy (DOE) and will form a team with DOE, RJ Lee Group, University of Maryland College Park, University of California at Davis, University of Delaware, Clarkson University, Ohio University, Brigham Young University, and Rutgers University. The project team will determine the direction of the research, finalize the work plan, and carry out the work.

Activity 2. Ambient Monitoring

The purpose of this activity is to create an extensive database of ambient PM measurements for source apportionment, examination of aerosol processes, and air quality model development and evaluation. The measurement campaign will last for 18 months (May 2001-October 2002) to include two summers and will consist of regular measurement periods and three 14-day intensive periods. The first intensive period is scheduled for July 2001; the second and third intensive periods are tentatively scheduled for January and September of 2002.

Table 1 provides a detailed list of all of the ambient measurements at the site, the frequency of the measurements during the baseline and intensive periods, and the investigator responsible for the measurements. These measurements will be made at a central site located next to the Carnegie Mellon University campus in a heavily urbanized area of Pittsburgh (pending final approval of the City of Pittsburgh). DOE funds will also be used to support the measurements at the satellite sites located in Holbrook, PA and Athens, OH. The final set of measurements and measurement frequency will be determined by the Pittsburgh Air Quality Study Science team.

Activity 2.1 PM Size Distributions

Carnegie Mellon University will measure the ultrafine aerosol size distribution (3 nm to 50 nm) at the central supersite. These measurements will be made continuously using Ultrafine Scanning Mobility Particle Spectrometer (TSI model 3936N25) for 0.003-0.150 μm . Carnegie Mellon University will measure of surface area concentrations at the central site using an epiphaniometer.

Activity 2.2 Size-resolved PM Mass and Composition

Carnegie Mellon University will make size-resolved PM mass (PM_x) and composition measurements using Micro-Orifice Uniform Deposit Impactors (MOUDI). Mass size distribution measurements will be made periodically during the baseline sampling period, tentatively on a 1 in 6 sampling schedule. Size-resolved samples collected by Carnegie Mellon University during the intensives will be analyzed for chemical composition including ions, metals, and OC/EC. These analyses will be performed in the Carnegie Mellon University Air Quality Laboratories.

Activity 2.3 Advanced Characterization of $PM_{2.5}$ Chemical Composition

Activity 2.3.1 Sampling Artifacts: Brigham Young University (Eatough group) will examine sampling artifacts in conventional sampling systems using the PC-BOSS diffusion denuder sampler during the intensive periods. The PC-BOSS will provide data for OC and EC as well as semivolatile organics lost from particles during sampling. In addition, analyses will be conducted for sulfate, nitrate, ammonium, and acidity.

Activity 2.3.2 Organic Aerosol Characterization: Rutgers University (Turpin Group) will perform advanced characterization of organic aerosol using Fourier Transform Infrared Spectroscopy (FTIR) and other techniques. High volume samples will be collected for analysis of organic mass, functional groups and carbon by polarity with the likelihood of further exploratory analyses on fractions. During the intensive periods size-resolved samples will be collected and at least qualitative functional group analysis by polarity.

Activity 2.4 Continuous and Semi-Continuous PM Composition

Activity 2.4.1 In situ OC/EC: Rutgers University (Turpin group) will design and construct an improved *in-situ* semi-continuous OC and EC analyzer. The new analyzer should reduce sampling times to 1 hour per measurement (a reduction of a factor of two over the existing instrument). The *in-situ* carbon analyzer collects $PM_{2.5}$ samples on a quartz fiber filter mounted inside a thermal-optical carbon analyzer. The analyzer will be deployed at the central site throughout the monitoring period.

Activity 2.4.2 Semi-continuous elements. The University of Maryland (Ondov group) will measure the concentration of 18 metals species (As, Cu, Mn, Ni, Cr, Cd, Se, Ag, Pb, Al, Fe, Zn, Ca, Bi, V, Ti, Be, and Ba) during two intensive periods at both the central supersite and one of the rural satellite site. Their semi-continuous system consists of a high-frequency aerosol sampler (HFAS) (dynamic aerosol concentrator) and a true simultaneous multi-element Graphite Furnace Atomic Absorption (GFAA) spectrometer. The initial target sample collection period is 10 minutes, but will depend on ambient concentrations and preliminary findings.

Activity 2.5 Single Particle Characterization

Activity 2.5.1 Single Particle Mass Spectroscopy.

The University of California at Davis (Wexler group) and the University of Delaware (Johnston group) will deploy a new, more portable, single particle instrument based on ion mobility spectrometry. The new instrument, APS-IMS, is a TSI Aerodynamic Particle Sizer with an Ion

Mobility Spectrometer attached. Over the size range of the APS, APS-IMS is able to size, count, and chemically analyze individual particles. It complements RSMS-II (another single particle mass spectrometer supported by EPA funds), whose size range is roughly 10 nm to 2 microns, because it operates over roughly the 500 nm to 15 micron size range. In addition, APS-IMS is likely to be better at speciating organic compounds than RSMS-II, because the ablation step occurs in the presence of a one-atmosphere carrier gas, effectively cooling the ablated ions so they can remain intact before analysis. The APS-IMS will be deployed during the intensive periods, and other times as the budget permits.

Activity 2.5.2 Laser-Induced Breakdown Spectroscopy (LIBS). The University of Maryland (Buckley group) will measure the elemental composition of single particles in the atmosphere by Laser-Induced Breakdown Spectroscopy (LIBS). Using atomic emission, the mass concentration of a number of elements (Be, Cd, Cr, Na, K, V, Ni, Si and Pb) and particle mass within the spark volume will be quantitatively measured. The LIBS system will be deployed during two of the intensive sampling periods and during 1 month of the baseline-sampling period.

Activity 2.5.3 CCSEM analysis. During the intensive periods, Carnegie Mellon University will collect samples on polycarbonate filters for analysis by the RJ Lee Group using computer controlled scanning electron microscopy (CCSEM).

Activity 2.6 Aerosol Optical Properties

Carnegie Mellon University will measure the aerosol scattering coefficient using an integrating nephelometer. The visual range will also be measured during the measurement periods and additional observations will be collected from the airports in the area and archived. Pictures (in electronic form) of the area surrounding the supersite will be taken every hour during the intensive sampling period and every six hours during the rest of the study period for the calculation of the visual range and documentation of the prevailing conditions.

Activity 3. Source Characterization

Activity 3.1 Emissions and Activity Survey

A survey of existing emissions information for the sources of primary PM and PM precursors will be conducted for the Pittsburgh region. Emissions of criteria pollutants from many of these sources are collected as part of the current EPA regulations. The existing source fingerprints for these source categories will be reviewed with respect to their applicability to the Pittsburgh area. An output of this survey will be the important source categories and a list of critical sources with limited profile data.

Activity data for all source categories will be collected throughout the sampling period with particular emphasis on the intensive sampling periods. Activity data for the major point sources is collected as part of the normal operations of the Allegheny County Department of Health Collects. PennDOT already has compiled average vehicle activity data on a monthly, daily, and hourly basis. We will collect activity data for important non-regulated sources such as wood combustion and meat cooking.

Activity 3.2 Source Sampling

Source sampling will be formed on three different types of sources in the Pittsburgh region: major point sources, mobile sources, and dust. We propose to perform detailed sampling on 5 major point sources in the Pittsburgh area, tentatively chosen as 2 coal-fired boilers (one with low NO_x burners), a coke plant, a steel mill, and an industrial manufacturing facility. The exact set of sources will be defined by the results of the emissions survey and access. More limited sampling may be performed on additional facilities depending on the results of the emissions survey. Mobile source emissions will be characterized by conducting a tunnel study. Dust samples will be collected and analyzed from various locations around western Pennsylvania.

For each source a variety of measurements are planned including standard filter based characterization, size-resolved measurements, and single particle measurements. The goal of these measurements is to develop accurate source fingerprints and emissions for source-receptor and deterministic modeling. The exact list of measurements will depend on plant access, access to a suitable sampling port, electrical power readily available, and provisions for placing equipment on the stack sampling platform –preferably this will be an elevator. The exact list of measurements will also depend on the decisions of the Pittsburgh Air Quality Study science team.

At appropriate sources we plan to collect integrated filter samples of PM_{2.5} to determine standard source profiles and where applicable mass emission rates. The filter samples will be analyzed for ionic species (e.g., nitrate, sulfate, ammonium), OC/EC, and trace metals using the previously described equipment. Florida International University (Rogge group) will perform detailed organic speciation of source samples as part of their work on the Pittsburgh Air Quality Study.

At appropriate sources we will perform an extensive suite of size-resolved measurements. Using the ultrafine SMPS, the regular SMPS, and the APS system, we will measure size distributions from 3 nm to 10 μm. Size-resolved mass and composition distributions will be measured using the MOUDI. MOUDI samples will be analyzed for major ions, trace elements, and OC/EC.

At appropriate sources single particle measurements will be performed using the RSMS-II single particle mass spectrometer, LIBS, and CCSEM to create a database of single particle fingerprints. The smog chamber in the Air Quality Laboratories at CMU could be used, if necessary, for the transfer of particles to the RSMS-II.

Fence line monitoring: For sources such as steel mills and coke plants that do not have a single well defined emissions point fence line monitoring will be performed to try to develop an integrated fingerprint for the source. This fence line monitoring will utilize semi-continuous measurement techniques, which hopefully will provide time resolution required to define accurate source fingerprints. We plan to use the semi-continuous OC-EC analyzer of Turpin and the semi-continuous metals technique of University of Maryland (Ondov group). The high temporal resolution of these instruments in conjunction with meteorology data should allow the measurement of adequate source profiles in this situation.

Combustion sources: Source profiles and emission rates on an energy basis will be measured for combustion sources such as coal-boilers. We plan to use a state-of-the-art dilution sampler to

characterize emission from combustion systems and other high temperature sources. The sampler is constructed out of stainless steel and teflon to minimize sample contamination. The dilution sampler enables the use of advanced aerosol characterization instrumentation such as a single particle mass spectrometer and sophisticated sampling trains to characterize the emissions.

We plan to collect samples with standard source sample trains such as the EPA method 5. Comparison of these standard measurements with samples collected with the dilution tunnel will provide valuable new information regarding the effects of dilution and sampling on source profiles and emission rates.

Tunnel sampling: An integrated fingerprint for the vehicles operating the Pittsburgh region will be determined using a full suite of measurements (filter-based, continuous, single particle, etc.) made in one of the tunnels in the Pittsburgh area. The emission rates for the measured components will be determined per unit fuel consumed, calculated using a carbon balance. The background concentrations needed to calculate the emission rates will be measured as part of the ambient study. Data on traffic density, composition, and speed through the tunnel will be obtained in collaboration with the Pennsylvania Department of Transportation (PennDOT). The tunnel sampling will depend on getting access to one of the tunnels in the Pittsburgh region.

Dust Sampling: Dust samples will be obtained from paved roads and soil in Western Pennsylvania, and size-resolved composition (e.g., PM_{2.5}, PM₁₀, PM_x) will be measured using both filter and impactor based approaches and single particle mass spectrometry.

Activity 4. Source Apportionment

Activity 4.1 Statistical Source Apportionment

Clarkson University (Hopke group) will apply advanced receptor models to identify the nature, location and contribution of the sources of particulate matter observed by the measurements made as part of the Pittsburgh Air Quality Study. We will apply several forms of factor analysis including Positive Matrix Factorization (PMF) and UNMIX in order to identify the composition and contributions of the sources. We will apply Potential Source Contribution Function analysis as well as Residence Time Weighted Concentration analysis to the determination of the locations of the likely major contributing sources. We will also apply the aforementioned factor analysis methods to the spatially distributed data both on a single species and multiple species basis and to compare these results with those obtained utilizing the back-trajectory based methods. The availability of highly time resolved data should permit greater source resolution and we will be trying to examine how much increased source specificity can be obtained from the increased time resolution in the data. We will also assist with the multivariate calibration that will permit the use of single particle mass spectrometry data to estimate ambient concentrations of particulate species. These analyses should provide a better understanding of the source/receptor relationships that lead to the observed particle concentrations in the Pittsburgh area.

Activity 4.2 Single Particle Based Methods for Source Apportionment

Single particle measurements provide an exciting opportunity to improve upon the currently available source-apportionment capabilities. Single particle measurements offer the possibility

to create source fingerprints with multiple dimensions (chemical composition and size of individual particles). The addition of APS-IMS capabilities to RSMS-II will allow improved identification of the sources of both inorganic and organic, and fine and coarse particles. Combining these fingerprints with similar ambient single particle measurements could improve the identification of the origin of each individual particle measured in the ambient atmosphere. This work will be done in conjunction with the Carnegie Mellon University, University of California at Davis, Clarkson University, and University of Maryland groups.

The ART2a neural network based algorithm will be used to categorize the particles into like composition classes, as the particles are analyzed in the field. Later, comparisons of the source-oriented and the ambient-particle compositions will be made with ART2a to identify source categories associated with the ambient particles that are detected.

Advanced methods for source apportionment will be developed by combining the single particle source fingerprints with classified atmospheric particles (characterized with support from EPA). The approach will be based on existing Factor Analysis and Chemical Mass Balance approaches. The approach will likely combine both composition and back trajectories. The hope is that these will be able to identify the source on a particle-by-particle basis. We also anticipate that this approach will yield insight into both sources and atmospheric processing that particles have undergone. Typical sources of the condensation nuclei that can be identified include organic nucleation, soot, biogenic materials, metals, and crustal material. The nuclei then undergo atmospheric processes such as condensation of vapors and cloud processing to increase their secondary mass content. Typical secondary materials that can be identified include sulfates, nitrates, and aromatic condensable organics. Both composition and back trajectories will be used to identify the likely source of the nuclei and the secondary species contributions on a particle-by-particle basis.

Activity 5. Three-Dimensional Deterministic Modeling

The model developed by the EPA-STAR funded Research Consortium on Ozone and Fine Particle Formation in California and in the Northeastern United States will be used to simulate the air quality in the Pittsburgh region. The model is an extension of the URM model. The model describes the evolution of the aerosol size-composition distribution (using 12 or more chemical components and 10 or more size sections) and for approximately 100 gas-phase species for every grid cell in the three-dimensional modeling domain. Aerosol chemical components simulated include: sulfate, nitrate, chloride, sodium, ammonium, elemental carbon, primary and secondary organic carbon, crustal elements, H^+ , water, and others. The model uses first principles to simulate spatially and temporally resolved emissions, gas-phase chemistry, advection, dispersion, aerosol dynamics and chemistry, cloud chemistry, and dry and wet removal processes. The model is also coupled to a sensitivity analysis module so it can calculate directly the sensitivities of PM concentrations to source strength.

Simulations will be performed for selected periods during the intensive sampling periods. The region around Pittsburgh will be described with high spatial resolution (5x5 km). The focus of these simulations will be on:

1. Model evaluation using the ambient PM measurements.

2. Estimating the lifetime and transport distances of PM reaching Pittsburgh.
3. Quantifying the relationships between total nitric acid and sulfate in Pittsburgh and the NO_x and SO₂ emissions in the modeling domain.
4. Investigating the sensitivity of the PM in the area to these NO_x, SO₂, and VOC emissions
5. Quantifying the contribution of primary organic aerosol sources to the OC in Pittsburgh
6. Estimating the contribution of primary and secondary biogenic aerosol to the organic PM in the study area.

Activity 6. Hypotheses testing:

The Pittsburgh Air Quality Study has been designed to test a wide range of complementary hypotheses. The subset of these hypotheses that specifically involve the measurements and analysis supported by this proposal are listed below. Additional hypotheses regarding atmospheric processes, instrument development, health effects, and exposure, not supported by this proposal, are not described here.

Hypothesis 1. *Aerosol nucleation (during oxidation of biogenic hydrocarbons or SO₂) can be a major source of aerosol number in both urban and rural areas.* The DOE supported measurements of the ultrafine aerosol number concentration at both the central site and the rural Holbrook site will allow quantification of the contribution of nucleation as a source of particle number. Measurements of precursor concentrations (SO₂, biogenics), aerosol surface area, and the temporal and spatial characteristics of the nucleation event will be used to identify the source of the ultrafine particles.

Hypothesis 2. *Biogenic primary and secondary aerosols are a major component of the organic aerosol in the Pittsburgh region.* Recently identified tracers for organic aerosol (see, e.g., Rogge et al., 1993c), detailed organic aerosol speciation, and deterministic modeling will be used to evaluate the importance of biogenic sources to ambient PM.

Hypothesis 3. *The response of PM_{2.5} to changes in sulfate is highly non-linear during the winter and linear during the summer and is controlled by the ammonia availability.* Theoretical analysis by Ansari and Pandis (1998) suggest that the response of the fine PM to sulfate concentration changes can be estimated using several parameters that can be directly measured (West et al. 1999). Using this framework, ambient data will allow the parametric investigation of the sensitivity of the PM concentrations to ammonia, sulfate, and nitric acid availability.

Hypothesis 4. *The secondary aerosol contribution to OC exceeds 50% during the peak PM days, but is around 20% on a yearly average basis (based on similar contributions estimated for the Western US).* The ambient and source data will be analyzed using the three approaches described by Strader et al. (1999) to examine the importance of secondary aerosol formation.

Hypothesis 5. *The regional contributions to the PM_{2.5} levels in the Pittsburgh region for some compounds exceed the local contribution, whereas for others the local exceeds the regional.* Comparison of the parallel measurements at the central site and the various rural satellite sites in Holbrook will be used to distinguish the regional and local contributions. The PM components that are enriched in the urban area will be quantified.

Hypothesis 6. *The high time resolution, semi-continuous measurements will permit resolution of plumes from individual stationary sources impacting the site, and resolution of local and regional sources.* Factor analysis (FA) methods will be used to analyze the high time resolution measurements of PM composition. Air trajectories will be statistically compared with the aerosol measurements.

Hypothesis 7. *Single particle instruments can directly determine the local air quality contributions from a broad range of sources.* Neural network and other pattern identification approaches will be used to classify single particle composition data collected using RSMS-II, LIBS, and CCSEM into particle classes. The single particle source characterization data will allow assigning particle classes to different sources.

Hypothesis 8. *Dilution sampling can be used to provide better source fingerprints of combustion systems than traditional methods.* Source characterization measurements collected with the dilution tunnel will be compared to those conducted using the standard EPA method-5 protocol.

Activity 6. Reporting

Carnegie Mellon University will submit all status, technical management and environmental reports in accordance with the reporting requirements checklist. The results of the study will be presented at technical meetings and published in international peer-reviewed journals.

Table 1. Ambient Measurements in the Pittsburgh Air Quality Study (Note: The stated measurement frequency for both the baseline and intensive sampling periods is the target measurement rate. The final rate for the filter measurements will be decided by the project science team and will depend on ambient concentrations, blank levels, and data quality.)

Measurement	Funder & Instrumentation	Frequency Baseline*	Frequency Intensives*	Investigator
Aerosol number distribution	EPA: SMPS ² , APS ³ DOE: U-SMPS ¹ & CPC ⁵	10 min	5 min	Pandis
Aerosol surface distribution	EPA: SMPS, APS DOE: U-SMPS & CPC, Epiphaniometer	10 min	5 min	Pandis
PM _{2.5} mass	EPA: FRM ⁶ , TEOM ⁷ , CMU Sampler ⁸ DOE: MOUDI ¹⁰	1 day 1 in 6 days	4-6 hr 1 day	Davidson
PM ₁₀ mass	EPA: CMU Sampler DOE: MOUDI	1 day 1 in 6 days	4-6 hr 1 day	Davidson
PM _x mass	DOE: MOUDI	1 in 6 days	1 day	Davidson
PM _{2.5} ions and elements	EPA: CMU Sampler/ IC ¹¹ & ICPMS ¹²	1 day	4-6 hr	Davidson
PM _{2.5-10} ions, elements	EPA: CMU Sampler/ IC & ICPMS	1 day	4-6 hr	Davidson
HNO ₃ vapor	EPA: CMU Sampler/ IC & ICPMS	1 day	4-6 hr	Davidson
NH ₃ vapor	EPA: CMU Sampler/ IC & ICPMS	1 day	4-6 hr	Davidson
Size-resolved ions and metals	DOE: MOUDI/IC and ICPMS	-	4-6 hr	Davidson
PM _{2.5} OC and EC ¹³	EPA: Organic sampler/thermal DOE: PC-BOSS system ¹⁴ DOE: In-situ carbon analyzer	1 day - -	4-6 hr 4-6 hr 1-2 hr	Robinson Eatough Turpin
PM _x OC and EC	DOE: MOUDI/thermal	-	4-6 hr	Robinson
Organic speciation	EPA: Organic sampler/GC-MS ¹⁶	2 weeks	4-12 hr	Rogge
Organic size-resolved characterization	DOE: LPI ⁹ /FTIR ¹⁷		24 hr	Turpin
Single Particle Chemical Composition	EPA: RSMS-II DOE: Filter/SEM ²¹ DOE: LIBS ¹⁸	Continuous - -	Continuous 4-6 hr Continuous	Wexler RJ Lee Buckley
Semi-continuous metals	DOE: HFAS/GFAA ²²	-	10-60 min	Ondov
Continuous nitrate	EPA: ICVC	Continuous	Continuous	Hering
Continuous sulfate	EPA: ICVC	Continuous	Continuous	Hering
Continuous carbon	EPA: ICVC	Continuous	Continuous	Hering
Bioaerosols	EPA: Epi-fluorescent microscopy, Molecular biology assays	1 day	Variable	Hernandez
Visibility	DOE: Nephelometer EPA: Photos/Visual Range	Continuous 6 hr	Continuous 1 hr	Pandis
Growth with RH	EPA: TDMA ²³ /RSMS-II	Variable	Variable	Pandis
CCN concentration	EPA: CCN Counter ²⁴	Variable	Variable	Pandis
RH, T, Wind	EPA	Continuous	Continuous	Davidson
UV and Solar		Continuous	Continuous	Pandis
Trajectories		1 day	4 hr	Kahl
VOCs	EPA: GC-FID ²⁵ , GC-MS	6 days	4-6 hr	Pandis
Hydrogen Peroxide	EPA: CSU Monitor	12 hr	1 hr	Collett
Organic Peroxides	EPA: CSU Monitor	12 hr	1 hr	Collett
O ₃ , NO, NO ₂ , SO ₂ , CO	EPA	1 hr	1 hr	Pandis
Fog and cloud composition	EPA: CSU Collector	Variable	1 hr	Collett

¹U-SMPS: Ultrafine Scanning Mobility Particle Spectrometer (TSI model 3936N25) for 0.003-0.150 µm

²SMPS: Scanning Mobility Particle Spectrometer (TSI model 3934L) for 0.01-1.0 µm

³APS: Aerodynamic Particle Sizer Spectrometer (TSI model 3320) for 0.5-1.0 µm

- ⁵ Ultrafine CPC: Ultrafine Condensation Particle Counter (TSI model 3025A) for 0.003-10 μm
- ⁶ FRM: Federal Reference Method $\text{PM}_{2.5}$ Sampler
- ⁷ TEOM: Tapered Element Oscillating Microbalance $\text{PM}_{2.5}$ Sampler
- ⁸ CMU Sampler: Carnegie Mellon University system
- ⁹ LPI: Low Pressure Impactor developed by Susanne Hering
- ¹⁰ MOUDI: Micro-Orifice Uniform Deposit Impactor
- ¹¹ IC: Ion Chromatography
- ¹² ICPMS: Inductively Coupled Plasma Mass Spectrometer
- ¹³ OC and EC: Organic Carbon and Elemental Carbon
- ¹⁴ PC-BOSS: Particle Concentrator-Brigham Young University Organic Sampling System.
- ¹⁶ GC-MS: Gas Chromatography-Mass Spectrometry
- ¹⁷ FTIR: Fourier Transform Infrared Spectroscopy
- ¹⁸ LIBS: Laser Induced Breakdown Spectroscopy
- ²⁰ RSMS-II: University of Delaware Single Particle Mass Spectrometer
- ²¹ SEM: Scanning Electron Microscopy
- ²² HFAS/GFAA: High Frequency Aerosol Sampler/Graphite Furnace Atomic Absorption Spectrophotometry
- ²³ TDMA: Tandem Differential Mobility Analyzer
- ²⁴ CCN Counter: Cloud Condensation Nuclei Counter manufactured by DH Associates
- ²⁵ GC-FID: Gas Chromatography-Flame Ionization Detector