

# SCANNING MOBILITY PARTICLE SIZER™ (SMPS™) SPECTROMETER

BIBLIOGRAPHY

## APPLICATION: OUTDOOR AIR

### 2007

Spencer, Matthew T., Shields, Laura G., Prather, Kimberly A., 2007, "Simultaneous Measurement of the Effective Density and Chemical Composition of Ambient Aerosol Particles," *Environmental Science & Technology*, **ASAP Article 10.1021/es061425+ S0013-936X(06)01425-8**

Simultaneous measurements of the effective density and chemical composition of individual ambient particles were made in Riverside, California by coupling a differential mobility analyzer (DMA) with an ultrafine aerosol time-of-flight mass spectrometer (UF-ATOFMS). In the summer, chemically diverse particle types (i.e., aged-OC, vanadium-OC-sulfate-nitrate, biomass) all had similar effective densities when measured during the same time period. This result suggests that during the summer study the majority of particle mass for the different particle types was dominated by secondary species (OC, sulfates, nitrates) of the same density, while only a small fraction of the total particle mass is accounted for by the primary particle cores. Also shown herein, the effective density is a dynamic characteristic of the Riverside, CA ambient aerosol, changing by as much as 40% within 16 h. During the summer measurement period, changes in the ambient atmospheric water content correlated with changes in the measured effective densities which ranged from ~1.0 to 1.5 g·cm<sup>-3</sup>. This correlation is potentially due to evaporation of water from particles in the aerodynamic lens. In contrast, in the fall during a Santa Ana meteorological event, ambient particles with a mobility diameter of 450 nm showed three distinct effective densities, each related to a chemically unique particle class. Particles with effective densities of ~0.27 g·cm<sup>-3</sup>, 0.87 g·cm<sup>-3</sup>, and 0.93 g·cm<sup>-3</sup> were composed mostly of elemental carbon, lubricating oil, and aged organic carbon, respectively. It is interesting to contrast the seasonal differences where in the summer, particle density and mass were determined by high amounts of secondary species, whereas in the fall, relatively clean and dry Santa Ana conditions resulted in freshly emitted particles which retained their distinct source chemistries and densities.

### 2006

Geller, Michael; Biswas, Subhasis; Sioutas, Constantinos, 2006, "Determination of Particle Effective Density in Urban Environments with a Differential Mobility Analyzer and Aerosol Particle Mass Analyzer," *Aerosol Science & Technology*, **40(9):709–723**

Effective densities of atmospheric aerosols in various locations of the Los Angeles Basin were determined by a DMA-APM technique. Effective density was calculated by comparing voltage distributions of sampled atmospheric aerosols with PSL particles of known density. The five sites chosen for field experiments were: (1) Interstate-710 Freeway, impacted by heavy-duty diesel vehicles; (2) State Route CA-110, open only to gasoline vehicles; (3) Riverside, a receptor site known for secondary particle formation; (4) University of Southern California, a typical urban and industrial environment; and (5) Coast for marine aerosol. The size range selected for this study was from 50 nm to 414 nm. While 50 nm particles exhibited a single effective density multiple effective densities were measured for each of the other particle sizes as significant fractions of these particles are transported from background sources. Regardless of location, 322–414 nm particle effective densities were considerably lower than unity. The lowest effective densities (~0.1 g cm<sup>-3</sup>) were reported for I-710, confirming that diesel combustion aerosols are rich in chain agglomerates with large void spaces. Riverside exhibited high effective densities (~1.2–1.5 g cm<sup>-3</sup>) for 50–202 nm particles, which we hypothesize is due to transformations that occur during advection from Los Angeles. Measurements of diurnal variation of effective density at Riverside support this hypothesis. Overall, our results suggest that effective density declines as the particle mobility diameter increases irrespective of location. Fractal dimensions calculated from average effective densities were lowest for I-710 ( $D_f = 2.41$ ) and CA-110 ( $D_f = 2.54$ ) aerosols, presumably due to the influence of vehicular combustion emission on these sites. By contrast, average fractal dimensions at USC, Riverside and Coast were found to be 2.79, 2.83, and 2.92, respectively. High fractal



dimensions at these sites may be the effects of aging, moisture absorption and/or organic vapor condensation on the particles, which fills void space and makes particles more spherical.

Hogrefe, O.; Lala, G. G.; Frank, B. P.; Schwab, J. J.; Demerjian, K. L., 2006, "Field Evaluation of a TSI Model 3034 Scanning Mobility Particle Sizer in New York City: Winter 2004 Intensive Campaign," *Aerosol Science and Technology*, **40**(10):753–762

A new "single box" Scanning Mobility Particle Sizer (TSI SMPS Model 3034) was deployed and operated during a period of four weeks as a part of the PMTACS-NY Winter 2004 intensive study in Queens College, New York City. The SMPS 3034 is an alternative to a conventional multi-component TSI SMPS and houses a Differential Mobility Analyzer and butanol-based Condensation Particle Counter in one cabinet. The SMPS 3034 operates at a fixed 1 L/min sample flow rate (4 L/min sheath flow rate) and measures size distributions within a 10-487 nm size range. One size scan is produced every 3 minutes. Four other measurement systems (a conventional TSI SMPS with a Nano Differential Mobility Analyzer, an Aerodynamic Particle Sizer, a stand-alone Condensation Particle Counter, and an R&P Inc. Filter Dynamic Measurement System (FDMS) TEOM mass monitor) were operated side-by-side with the SMPS 3034. It is shown that total particle number concentrations measured by the SMPS 3034 are highly correlated with those from the conventional Nano SMPS, the Condensation Particle Counter and the FDMS TEOM monitor, and that the number median diameters measured by the SMPS 3034 and the Nano SMPS agree within 3 nm.

Zhu Y.; Kuhn T.; Mayo P.; Hinds W.C., 2006, "Comparison of daytime and nighttime concentration profiles and size distributions of ultrafine particles near a major highway," *Environmental Science and Technology*, **40**(8): 2531–2536

Previously we have conducted systematic measurements of the concentration and size distribution of ultrafine particles in the vicinity of major highways during daytime in Los Angeles. The present study compares these with similar measurements made at night. Particle number concentration was measured by a condensation particle counter (CPC) and size distributions in the size range from 7 to 300 nm were measured by a scanning mobility particle sizer (SMPS). Measurements were taken at 30, 60, 90, 150, and 300 m upwind and downwind from the center of the I-405 freeway. Average traffic flow at night was about 25% of that observed during the day. Particle number concentration measured at 30 m downwind from the freeway was 80% of previous daytime measurements. This discrepancy between changes in traffic counts and particle number concentrations is apparently due to the decreased temperature, increased relative humidity, and lower wind speed at night. Particle size distributions do not change as dramatically as they did during the daytime. Particle number concentration decays exponentially downwind from the freeway similarly to what was observed during the day, but at a slower rate. No particle number concentration gradient has been observed for the upwind side of the freeway. No PM<sub>2.5</sub> and very weak PM<sub>10</sub> concentration gradients were observed downwind of the freeway at night. Ultrafine particle number concentration measured at 300 m downwind from the freeway was still distinguishably higher than upwind background concentration at night. These data may be used to help estimate exposure to ultrafine particles in the vicinity of major highways for epidemiology studies.

## 2005

Bottenheim, Jan W.; Brickell, Peter; Brook, Jeffrey R.; Hayden, Katherine; Jayne, John T.; Leitch, W. Richard; Li, Shao-Meng; Lohmann, Ulrike; Lu, Gang; Rupakheti, Maheswar; Toom-Saunry, Desiree; Vet, Robert; Worsnop, Douglas R., 2005, "An intensive study of the size and composition of submicron atmospheric aerosols at a rural site in Ontario, Canada," *Aerosol Science and Technology*, **39**(8):722–736

Atmospheric sampling was conducted at a rural site near Egbert, about 70 km north of Toronto, Ontario, Canada from March 27 to May 8, 2003 to characterize the physical and chemical properties of the ambient aerosol in near real-time. The instrumentation included a tapered element oscillating microbalance (TEOM), an ultrafine condensation particle counter (UCPC), a scanning mobility particle sizer (SMPS), an aerodynamic particle sizer (APS), an aerosol mass spectrometer (AMS), and a particulate nitrate monitor (R&P 8400N) for aerosol measurements. Gas-phase non-methane hydrocarbon compounds (NMHCs) were measured by gas chromatograph-flame ionization detection (GC-FID). Filter samples were also collected for analysis of inorganic ions by ion chromatography (IC). Aerosol properties varied considerably depending upon meteorological conditions and air mass histories. For example, urban and industrial emissions advected from the south strongly influenced the site occasionally, resulting in higher particulate mass with the higher fractions of nitrate and organics. Cleaner northwesterly winds carried aerosols with relatively higher fractions of organics and sulfate. The AMS derived mass size distributions showed that the inorganic species in the particles with vacuum aerodynamic diameters between about 60 nm and 600 nm had mass modal vacuum aerodynamic diameters around 400-500 nm. The particulate organics often exhibited two modes at about 100 nm and 425 nm, more noticeable during fresh pollution events. The small organic mode was well correlated with gas-phase nonmethane hydrocarbons such as ethylbenzene, toluene, and propene, suggesting that the likely sources of small organic particles were combustion related emissions. The particulate nitrate exhibited a diurnal variation with higher concentrations during dark hours and minima in the afternoon. Particulate sulfate and organics showed evidence of photochemical processing with higher levels of sulfate and oxygenated organics in the afternoon. Reasonable agreement among all of the co-located measurements is found, provided the upper size limit of the AMS is considered. 30 Refs.

Fine, Philip M.; Fruin, Scott; Sax, Todd; Sioutas, Constantinos; Westerdahl, Dane, 2005, "Mobile platform measurements of ultrafine particles and associated pollutant concentrations on freeways and residential streets in Los Angeles," *Atmospheric Environment*, **39**(20) 3597–3610

Recent health studies have reported that ultrafine particles (UFP) (<0.1  $\mu\text{m}$  in diameter) may be responsible for some of the adverse health effects broadly attributed to particulate matter. In urban areas, UFP are produced by combustion sources, such as vehicle exhaust, and by secondary formation in the atmosphere. While UFP can be monitored, few studies have explored the impact of local primary sources in urban areas (including mobile sources on freeways) on the temporal and spatial distribution of UFP. This paper describes the integration of multiple monitoring technologies on a mobile platform designed to characterize UFP and associated pollutants, and the application of this platform in a study of UFP number concentrations and size distributions in Los Angeles. Monitoring technologies included two condensation particle counters (TSI Model 3007 and TSI 3022A) and scanning mobility particle sizers for UFP. Real-time measurements made of NO<sub>x</sub> (by chemiluminescence), black carbon (BC) (by light

absorption), particulate matter-phase PAH (by UV ionization), and particle length (by diffusional charging) showed high correlations with UFP numbers, ( $r^2=0.78$  for NO, 0.76 for BC, 0.69 for PAH, and 0.88 for particle length). Average concentrations of UFP and related pollutants varied strongly by location, road type, and truck traffic volumes, suggesting a relationship between these concentrations and truck traffic density. 38 Refs.

Johnson, Jason P.; Kittelson, David B.; Watts, Winthrop F., 2005, "Source apportionment of diesel and spark ignition exhaust aerosol using on-road data from the Minneapolis metropolitan area," *Atmospheric Environment*, **39**(11): 2111–2121

Air quality measurements were made on interstate highways in the Minneapolis metropolitan area. Gas and aerosol concentrations were measured on weekdays and weekends. By exploiting the difference in the relative volumes of heavy duty (HD) diesel and light duty (LD) spark ignition (SI) vehicles on weekdays and weekends, we were able to estimate apportioned fuel specific emissions. The on-road, apportioned, fuel specific particle number emissions factors, estimated from condensation particle counter (CPC) measurements were  $1.34 \pm 0.2 \cdot 10^{16}$  particles  $\text{kg}^{-1}$  for diesels and  $7.1 \pm 1.6 \cdot 10^{15}$  particles  $\text{kg}^{-1}$  for spark ignition vehicles. Estimates from the scanning mobility particle sizer (SMPS) measurements were  $2.1 \pm 0.3 \cdot 10^{15}$  particles  $\text{kg}^{-1}$  for diesels and  $3.9 \pm 0.6 \cdot 10^{14}$  particles  $\text{kg}^{-1}$  for SI vehicles. The difference between CPC and SMPS measurements is mainly due to different lower size detection limits of the instruments, similar to 3 and similar to 10 nm, respectively. On a weekly weighted basis and on weekdays, the majority of particle number was attributed to HD diesel traffic. Weekend production of particles can be primarily attributed to light duty SI automobiles. On a per vehicle basis, HD vehicles produced substantially greater numbers of particles. On a fuel specific basis, HD vehicles produce slightly higher concentrations of particles than light duty vehicles. The relative contribution of LD vehicles to particle number emissions increased as particle size decreased. The HD apportioned size distributions were similar to size distributions measured during other on-road and laboratory studies. The LD apportioned size distribution was bounded by laboratory and on-road size distributions. Our work is representative of summer, highway cruise conditions. It is likely that under cold start and high load operating conditions LD emissions will increase relative to HD emissions. 37 Refs.

Kuhn, Thomas; Biswas, Subhasis; Fine, Philip M.; Geller, Michael; Sioutas, Constantinos, 2005, "Physical and Chemical Characteristics and Volatility of PM in the Proximity of a Light-Duty Vehicle Freeway," *Aerosol Science & Technology*, **39**(4):347–357

Volatility properties of ultrafine particles were analyzed next to State Route 110 (Pasadena freeway CA), a light-duty vehicle freeway where heavy-duty traffic is prohibited. In addition, mass concentration and chemical composition of particulate matter (PM) were measured in coarse, accumulation, and ultrafine modes. On weekdays from 17 May to 4 June 2004, measurements were performed in two locations, one very close to the freeway (within 2.5 m from the curb) and one at a distance of about 50 m from the freeway. For measurement of mass and chemical composition, the study employed in each location a micro-orifice uniform deposit impactor (MOUDI) and a modified high-volume sampler. Both instruments sampled with the same size cutpoints: a coarse mode from 2.5 to 10  $\mu\text{m}$ , an accumulation mode from 0.18 to 2.5  $\mu\text{m}$ , and an ultrafine mode of particles less than 0.18  $\mu\text{m}$  in aerodynamic diameter. Alternately, a tandem differential mobility analyzer (TDMA) was used at the two sites. A heater between the two DMAs evaporated volatile material from the monodisperse aerosol, size selected by the first DMA. The second DMA analyzed the losses of volatile components. The ultrafine number concentrations next to the freeway were  $46,000 \text{ cm}^{-3}$  on average during the sampling period. The MOUDI ultrafine mass concentration, nitrate, and EC were higher next to the freeway than at the background site farther from the freeway. The other components analyzed in the ultrafine mode had similar concentrations next to the freeway and at the background site. Volatility ranged from about 65% volume losses of 120 nm particles heated to 110°C to 95% of 20 nm particles. The 20 nm aerosol was only internally mixed, whereas increasing nonvolatile fractions were found for 40 nm (6% next to the freeway), 80 nm (20%), and 120 nm (28%) aerosols.

Lawless, Philip A.; Noble, Christopher A.; Rodes, Charles E., 2005, "A sampling approach for evaluating particle loss during continuous field measurement of particulate matter," *Particle and Particle Systems Characterization*, **22**(2):99–106

A method for evaluating sample bias in field measurements is presented. Experiments were performed in the field and laboratory to quantify the bias as a function of particle size for the scanning mobility particle sizer and the aerodynamic particle sizer. Sources of bias and sample loss considered in this work were sampling line loss, instrumental differences and inlet efficiencies. Measurement of the bias and sample loss allow for correction of the data acquired in the field, so as to obtain more representative samples of atmospheric concentrations. Substantial losses of fine and ultrafine particle count were observed, with sampling line losses ranging from 10-50 %, dependent on particle size. Only minor line losses were observed for coarse particles (approximately 5 %) because the sampling line was oriented vertically. 32 Refs.

Rupakheti, Maheswar; Leitch, W.; Lohmann, Ulrike; Hayden, Katherine; Brickell, Peter; Lu, Gang; Li, Shao-Meng; Toom-Sauntry, Desiree; Bottenheim, Jan; Brook, Jeffrey; Vet, Robert; Jayne, John; Worsnop, Douglas, 2005, "An Intensive Study of the Size and Composition of Submicron Atmospheric Aerosols at a Rural Site in Ontario, Canada," *Aerosol Science and Technology*, **39**(8):722–736

Atmospheric sampling was conducted at a rural site near Egbert, about 70 km north of Toronto, Ontario, Canada from March 27 to May 8, 2003 to characterize the physical and chemical properties of the ambient aerosol in near real-time. The instrumentation included a tapered element oscillating microbalance (TEOM), an ultrafine condensation particle counter (UCPC), a scanning mobility particle sizer (SMPS), an aerodynamic particle sizer (APS), an aerosol mass spectrometer (AMS), and a particulate nitrate monitor (R&P 8400N) for aerosol measurements. Gas-phase non-methane hydrocarbon compounds (NMHCs) were measured by gas chromatograph-flame ionization detection (GC-FID). Filter samples were also collected for analysis of inorganic ions by ion chromatography (IC). Aerosol properties varied considerably depending upon meteorological conditions and air mass histories. For example, urban and industrial emissions advected from the south strongly influenced the site occasionally, resulting in higher particulate mass with the higher fractions of nitrate and organics. Cleaner northwesterly winds carried aerosols with relatively higher fractions of organics and sulfate. The AMS derived mass size distributions showed that the inorganic species in the particles with vacuum aerodynamic diameters between about 60 nm and 600 nm had mass modal vacuum aerodynamic diameters around 400–500 nm. The particulate organics often exhibited two modes at about 100 nm and 425 nm, more noticeable during fresh pollution events. The small organic mode was well correlated with gas-phase nonmethane hydrocarbons such as ethylbenzene, toluene, and propene, suggesting that the likely sources of small organic particles were combustion related emissions. The particulate nitrate exhibited a diurnal variation with higher concentrations during dark hours and minima in the afternoon. Particulate sulfate and

organics showed evidence of photochemical processing with higher levels of sulfate and oxygenated organics in the afternoon. Reasonable agreement among all of the co-located measurements is found, provided the upper size limit of the AMS is considered.

Westerdahl, D.; Fruin, S.; Sax, T.; Fine, P. M.; Sioutas, C., 2005, "Mobile platform measurements of ultrafine particles and associated pollutant concentrations on freeways and residential streets in Los Angeles," *Atmospheric Environment (Atmos. Environ)*, **39**(20): 3597–3610

Recent health studies have reported that ultrafine particles (UFP) (<0.1  $\mu\text{m}$  in diameter) may be responsible for some of the adverse health effects broadly attributed to particulate matter. In urban areas, UFP are produced by combustion sources, such as vehicle exhaust, and by secondary formation in the atmosphere. While UFP can be monitored, few studies have explored the impact of local primary sources in urban areas (including mobile sources on freeways) on the temporal and spatial distribution of UFP. This paper describes the integration of multiple monitoring technologies on a mobile platform designed to characterize UFP and associated pollutants, and the application of this platform in a study of UFP number concentrations and size distributions in Los Angeles. Monitoring technologies included two condensation particle counters (TSI Model 3007 and TSI 3022A) and scanning mobility particle sizers for UFP. Real-time measurements made of  $\text{NO}_x$  (by chemiluminescence), black carbon (BC) (by light absorption), particulate matter-phase PAH (by UV ionization), and particle length (by diffusional charging) showed high correlations with UFP numbers. Average concentrations of UFP and related pollutants varied strongly by location, road type, and truck traffic volumes, suggesting a relationship between these concentrations and truck traffic density.

## 2004

Abu-Allaban, M.; Gertler, A. W.; Rogers, C. F., 2004, "A Quantitative Description of Vehicle Exhaust Particle Size Distributions in a Highway Tunnel," *Journal of the Air and Waste Management Association*, **54**(3):360–366

During the period May 18–May 22, 1999, a comprehensive study was conducted in the Tuscarora Mountain Tunnel on the Pennsylvania Turnpike to measure real-world motor-vehicle emissions. As part of this study, size distributions of particle emissions were determined using a scanning mobility particle sizer. Each measured size distribution consisted of two modes: a nucleation mode with midpoint diameter less than 20 nm and an accumulation mode with midpoint diameter less than 100 nm. The nucleation and accumulation components in some distributions also exhibited second maxima, which implies that such particle size distributions are superpositions of two particle size distributions. This hypothesis was utilized in fitting the particle size distributions that exhibited second maxima with four lognormal distributions, two for the nucleation mode and two for the accumulation mode. The fitting assumed that the observed particle size distribution was a combination of two bimodal log-normal distributions, one attributed to the heavy-duty diesel (HDD) vehicles and another attributed either to a different class of HDD vehicles or to the light-duty spark ignition vehicles. Based on this method, estimated particle production rates were  $1.8 \times 10^{13}$  and  $2.8 \times 10^{14}$  particles/vehicle-km for light-duty spark ignition and HDD vehicles, respectively, which agreed with independently obtained estimates. 18 Refs.

Chan, W. R.; Khlystov, A. Y.; Mandiro, M.; Pandis, S. N.; Stanier, C. O., 2004, "A method for the in situ measurement of fine aerosol water content of ambient aerosols: The dry-ambient aerosol size spectrometer (DAASS)," *Aerosol Science & Technology*, **38**(S1):215–228

Hygroscopic growth of atmospheric particles affects a number of environmentally important aerosol properties. Due to the hysteresis exhibited by the aerosol hygroscopic growth, the physical state of particles and the amount of aerosol water are uncertain within a wide range of relative humidities (RHs) found in the troposphere, leading to uncertainties in optical and chemical properties of the aerosol. Here we report the design and tests of an automated system that was built to assess the amount of aerosol water at atmospheric conditions. The system consists of two scanning mobility particle sizers (SMPS) and an aerodynamic particle (APS) that measure the aerosol size distribution between 3 nm and 10  $\mu\text{m}$  in diameter. The inlets of the instruments and their sheath air lines are equipped with computer-controlled valves that direct air through Nafion dryers or bypass them. The Nafion dryers dehydrate the air streams to below 30% RH at which point ambient particles are expected to lose most or all water. The switch between the dried and the ambient conditions occurs every 7 min and is synchronized with the scan times of the aerosol spectrometers. In this way the system measures alternatively dried (below 30% RH) and ambient aerosol size distributions. A comparison of the ambient RH and the dried RH size distributions and the corresponding integrated volume concentrations provides a measure of the physical state of particles and the amount of aerosol water. The aerosol water content can be treated as a growth factor or as an absolute quantity and can be calculated as a time series or as a function of RH (humidigram). When combined with aerosol composition measurements, the DAASS can be used to compare hygroscopic growth models and measurements. 48 Refs.

Fine, Philip; Shen, Si; Sioutas, Constantinos, 2004, "Inferring the Sources of Fine and Ultrafine Particulate Matter at Downwind Receptor Sites in the Los Angeles Basin Using Multiple Continuous Measurements," *Aerosol Science and Technology*, **38**(S1):182–195

Recent studies that have found increased health effects of atmospheric ultrafine particulate matter (PM) have refocused attention on particle number rather than particle mass concentrations as a relevant measurement of PM pollution. As part of the Southern California Supersite program, ambient particle characteristics were measured over 13 months at three different sites in the eastern portion of the Los Angeles Basin: Riverside, Rubidoux, and Claremont, CA. The sites represent receptor locations that are influenced by local particle sources as well as advection from the more intense particle sources upwind closer to Downtown Los Angeles. An SMPS/APS tandem system was employed to collect continuous particle size distributions, from which particle number and mass concentrations were calculated. An aethalometer provided continuous particulate elemental carbon (EC) concentrations. Results show no meaningful correlation between particle number and mass, indicating that fine particle standards may not be effective in controlling ultrafine concentrations. Diurnal patterns show a morning traffic peak indicated by increases in particle mass, number, and EC. Afternoon periods in the warmer months are characterized by high number counts while mass and EC remain low, suggesting the formation of new particles by photochemistry. Particle mode diameters range from 30 nm up to above 100 nm, a result not seen in most other studies of particle size distributions in other urban or rural areas where mode diameters are generally less than 50 nm. Evidence is presented that the observed ultrafine particle concentrations and size distributions are influenced by long-range advection and photochemical processes as well as vehicular emissions, which have been previously assumed to dominate day-to-day ultrafine particle levels.

Froines, J. R.; Jaques, P. A.; Sioutas, C.; Teh, H. W.; Yu, R. C., 2004, "Quality control of semi-continuous mobility size-fractionated particle number concentration data," *Atmospheric Environment*, **38**(20):3341–3348

Fine and ultrafine particles have been postulated to play an important role in the association between ambient particulate matters and adverse health effects. As part of the EPA Supersite Program, the Southern California Particle Center & Supersite has conducted a series of monitoring campaigns that contribute to a better understanding of the sources, chemical composition and physical state of ambient aerosols. The Scanning Mobility Particle Sizer (SMPS) was deployed to semi-continuously measure mobility size-fractionated particle number concentrations. As part of the quality control efforts, we developed a two-stage graphic and statistical procedure to label and identify potentially discordant observations. The first stage considered the entire size-fractionated data by date-time as a whole to plot total concentration (TC) vs. coefficient of variation (CV), both in log scale. TC represents the magnitude of overall concentration for a size distribution; while CV represents the relative variability. This plot was used to partition all size distributions into four to five distinct regions. In each region, a generalized extreme studentized deviate (ESD) and a modified Z-score procedure were applied to identify potential discordant outliers. We have found that the majority of particle size distributions are concentrated within a 'normal' region, with TC ranging from  $10^2$  to  $10^5 \text{ cm}^{-3}$  and CV varying between 20% and 200%. Size distributions that are contaminated with discordant outliers are displayed distinctly from the 'normal' region and form four to five clusters in the LogTC-LogCV plot. The pattern of clusters in the plot is consistent among the four sampling sites in this study, suggesting the robustness of this technique. The generalized ESD and modified Z-score effectively identify discordant outliers and reveal that the pattern of clustering outliers are consistent within each distinct region. It has, thus, been concluded that the new approach is a useful quality control tool to identify potential discordant outliers in SMPS data. 18 Refs.

Hinds, W. C.; Shen, S.; Sioutas, C.; Zhu, Y., 2004, "Seasonal trends of concentration and size distribution of ultrafine particles near major highways in Los Angeles," *Aerosol Science & Technology*, **38**(S1):5–13

Ultrafine particles (diameter  $<0.1 \mu\text{m}$ ) have been suggested as a possible causative agent for the observed increases in mortality and morbidity with increases in particulate matter (PM) concentration. Zhu et al. conducted systematic measurements of the concentration and size distribution of ultrafine particles in the vicinity of Interstate 405 (mostly gasoline traffic) and Interstate 710 (large proportion of heavy-duty diesel traffic) in Los Angeles during the summer of 2001. The present study compares these measurements with those made at the same locations in the winter of 2001-2002. Particle number concentration and size distribution in the size range from 6 to 220 nm were measured by a condensation particle counter (CPC) and a scanning mobility particle sizer (SMPS). Measurements were taken at five distances downwind from the freeway. At each sampling location, concentrations of carbon monoxide (CO) and black carbon (BC) were also measured by a Dasibi CO monitor and an aethalometer, respectively. Average temperatures were about 7 degrees Celsius higher in summer than in winter. Wind directions are the same for both seasons, wind speeds are slightly higher in summer. Traffic densities were not statistically different between summer and winter for both the 405 and 710 freeways. The decay rates of CO and BC are slightly greater in summer than in winter for both freeways, suggesting a weaker atmospheric dilution effect in winter. Particle number concentration in the size range of 6-12 nm is significantly higher in winter than in summer. The associated concentration in that size range decreased at a slower rate in winter than in summer. The surface area concentrations in the size range of 6–220 nm are consistently higher in summer for all sampling locations. These results suggest that wintertime conditions favor greater particle formation, possibly due to increased condensation of organic vapors. These data may be useful to estimate exposure to ultrafine particles in the vicinity of major highways for epidemiological studies and to evaluate the adverse health effects of such particles.

Khlystov, A. Y.; Pandis, S. N.; Stanier, C. O., 2004, "Ambient aerosol size distributions and number concentrations measured during the Pittsburgh Air Quality Study (PAQS)," *Atmospheric Environment*, **38**(20):3275–3284

Twelve months of aerosol size distributions from 3 to 560 nm, measured using scanning mobility particle sizer are presented with an emphasis on average number, surface, and volume distributions, and seasonal and diurnal variation. The measurements were made at the main sampling site of the Pittsburgh Air Quality Study from July 2001 to June 2002. These are supplemented with 5 months of size distribution data from 0.5 to 2.5  $\mu\text{m}$  measured with a TSI aerosol particle sizer and 2 months of size distributions measured at an upwind rural sampling site. Measurements at the main site were made continuously under both low and ambient relative humidity. The average Pittsburgh number concentration (3–500 nm) is  $22,000 \text{ cm}^{-3}$  with an average mode size of 40nm. Strong diurnal patterns in number concentrations are evident as a direct effect of the sources of particles (atmospheric nucleation, traffic, and other combustion sources). New particle formation from homogeneous nucleation is significant on 30–50% of study days and over a wide area (at least a hundred kilometers). Rural number concentrations are a factor of 2-3 lower (on average) than the urban values. Average measured distributions are different from model literature urban and rural size distributions. 27 Refs.

Kittelson, D.; Watts, W.; Johnson, J.; Remerowki, M.; Ische, E.; Oberdörster, G.; Gelein, R.; Elder, A.; Hopke, P.; Kim, E.; Zhao, W.; Zhou, L.; Jeong, C.-H., 2004, "On-Road Exposure to Highway Aerosols. 1. Aerosol and Gas Measurements," *Inhalation Toxicology*, **16**(S1):31–39

On-road experiments were conducted to determine the sensitivities of rats to real-world aerosol. This article summarizes the on-road aerosol and gas measurements and provides background information for the companion paper on the rat exposures. Measurements were carried out over 10 days, 6 h/day, driving a route from Rochester to Buffalo. Aerosol instrumentation used in this study included two scanning mobility particle sizers (SMPS) to determine the aerosol size distribution from 10 to 300 nm, two stand-alone condensation particle counters to determine the total aerosol number concentration, and an electrical aerosol detector to determine the aerosol length concentration. A thermal denuder (TD) was used with one of the SMPS instruments to determine the size distribution of the non-volatile fraction. Filter samples were collected and analyzed for elemental carbon, and gas analyzers measured ambient levels of CO, CO<sub>2</sub>, and NO. Average daily total aerosol number concentration ranged from 200,000 to 560,000 particles/cm<sup>3</sup>. Past studies on urban highways have measured total number concentrations ranging between  $10^4$  and  $10^6$  particles/cm<sup>3</sup>. The average daily NO concentration ranged from 0.10 to 0.24 ppm and the corresponding CO<sub>2</sub> concentration ranged from 400 to 420 ppm. The average daily geometric number mean particle size determined by the SMPS ranged from 15 to 20 nm. The TD reduced the average SMPS number concentration between 87 and 95% and the SMPS volume between 54 and 83%, suggesting that most of the particles consisted of volatile material. The TD also increased the geometric number mean diameter from 15 to 20 nm to 30 to 40 nm.

Matsunaga, S.; Mochida, M.; Kawamura, K., 2004, "Variation on the atmospheric concentrations of biogenic carbonyl compounds and their removal processes in the northern forest at Moshiri, Hokkaido Island in Japan, *Journal of Geophysical Research. D. Atmospheres*, **109**(D4)

Biogenic aldehydes, hydroxycarbonyls, and dicarbonyls in gas and particle phases were collected with an annular denuder sampling system (ADSS) in a *Quercus crispula* and *Picea glehnii* mast mixed forest. Eighty samples were collected from 22 to 29 August 2002. The size distributions of aerosols were also observed concurrently with a scanning mobility particle sizer (SMPS). The gaseous concentrations of these carbonyl compounds ranged from the detection limit (approximately 1 pptv) to 154 pptv (630 ng/cu m, 4-oxopentanal), and the particulate concentrations ranged from the detection limit (approximately 3 ng/cu m) to 200 ng/cu m (4-oxopentanal). Although the production processes of these compounds are different from each other, the temporal variations of the gaseous concentrations were quite similar. In addition, the variation was also similar to that of the ambient temperature. Furthermore, gas-to-particle conversion was suggested to be an important removal process of these compounds. We could evaluate the importance of the gas-to-particle conversion as a removal process of the gaseous species by an ADSS measurement. In addition, the results of our experiment indicated that the conversion includes two processes. The first is an adsorption onto the aerosols which have already existed in the atmosphere. The next is dissolution into the water phases in the aerosols. The latter process was particular to water soluble compounds. The measurement allowed us to identify the most likely removal processes of biogenic semivolatile organic compounds (SOCs). In this study, we discuss about these processes of semivolatile and biogenic carbonyls in the forest atmosphere.

Philippin, S.; Scheer, V.; Vogt, R.; Wehner, B.; Wiedensohler, A., 2004, "Variability of non-volatile fractions of atmospheric aerosol particles with traffic influence," *Atmospheric Environment*, **38**(36):6081–6090

Emissions from vehicular traffic are considered to be a major source of anthropogenic submicrometer particles in the urban environment. In this study, volatile and non-volatile number and volume fractions were distinguished in particles sampled for three consecutive days (Friday, Saturday, and Sunday) close to a highway (HW) (A4) in Germany and for one day in the urban area of Aachen, Germany. A volatility tandem differential mobility analyzer (VTDMA) and a thermodenuder (TD) combined with two scanning mobility particle sizers (SMPS) were used to get insight into a size-resolved mixing state of volatile and non-volatile particle fractions. Operating the VTDMA at 280°C, the number size distribution of non-volatile particle cores was determined for initial particle sizes of 30, 50, 80, and 150 nm. The number size distributions from 10 to 400 nm of ambient and non-volatile aerosol particles were measured by using parallel a SMPS and TD/SMPS combination, respectively. Number size distributions measured near the HW showed a bimodal size distribution with a maximum number concentration at particle sizes between 10 and 20 nm. The TD/SMPS results for the HW site revealed that the nucleation mode disappeared after heating (completely volatile) and in total 10–20% by number of traffic-related particles were non-volatile. The VTDMA results revealed that only 22% of the 30 nm particles had a non-volatile core above the instrument detection limit of 10 nm. With increasing particle diameter, this non-volatile number fraction increased to ca. 60% for 50 nm particles and to approximately 100% for 80 and 150 nm particles. These findings mean that each particle in the upper Aitken and lower accumulation mode range contains a non-volatile core. With increasing traffic influence the number fraction of less-volatile particles representing mainly primary soot emissions increases to 62% for 50 nm particles and 71% for 80 nm particles.

Young, Li-Hao; Keeler, G. J., 2004, "Characterization of Ultrafine Particle Number Concentration and Size Distribution During a Summer Campaign in Southwest Detroit," *Journal of the Air & Waste Management*, **54**(9)

This paper presents results from a study conducted in southwest Detroit from July 20 to July 30, 2002, to characterize ambient ultrafine particles ( $dp < 0.1 \mu\text{m}$ ), and to examine the effect of local sources and meteorological parameters on the ultrafine number concentration and size distribution. The number concentrations of ambient particles in the size range of 0.01–0.43  $\mu\text{m}$  were obtained from a scanning mobility particle sizer (SMPS). Meteorological parameters including ambient temperature, relative humidity, wind speed, wind direction, rainfall, and solar radiation flux were also monitored concurrently atop a 10-m tower. On average, ultrafine particles ranged from  $1.4 \times 10^4$  to  $2.5 \times 10^4 \text{ cm}^{-3}$ , with significant diurnal and daily variations, and accounted for 89% of the total number concentration ( $0.01 < dp < 0.43 \mu\text{m}$ ). Time-series plots of the 5-min number concentrations revealed that peak concentrations often occurred during morning rush hour and/or around solar noon when photochemical activity was at a maximum. The morning traffic-related peak coincided with the  $\text{NO}_x$  peak, whereas the photochemical-related peak correlated with solar radiation flux. On some days, the noon peak concentration was many times higher than the morning peak concentration. Although the number size distribution varied considerably over the course of the study, it typically exhibited one to three modes, with diameters around 0.01, 0.05, and 0.09  $\mu\text{m}$ . Analysis of the influence of wind direction indicated that stationary sources could be one of the contributors to elevated ultrafine particle concentration. Overall, the data indicated that fossil fuel combustion and atmospheric gas-to-particle conversion of precursor gases are the major sources of ultrafine particles in the southwest Detroit area during the summer.

Zhou, Liming; Kim, Eugene; Hopke, Philip K; Stanier, Charles; Pandis, Spyros N, 2004, "Advanced Factor Analysis on Pittsburgh Particle Size-Distribution Data," *Aerosol Science and Technology*, **38**(S1):118–132

Positive matrix factorization (PMF) method was applied to particle size-distribution data acquired during the Pittsburgh Air Quality Study (PAQS) from July 2001 to August 2001. After removing those days with nucleation events, a total of 1632 samples, each with 165 evenly-sized intervals from 0.003 to 2.5  $\mu\text{m}$ , were obtained from scanning mobility particle spectrometer (SMPS) and aerodynamic particle sampler (APS). The temporal resolution was 15 min. The values for each set of five consecutive-size bins were averaged to produce 33 new size channels. The size distributions of particle number as well as volume were analyzed with a bilinear model. Three kinds of information were used to identify the sources: the number and volume size distributions associated with the factors, the time frequency properties of the contribution of each source (Fourier analysis of source contribution values) and the correlations of the contribution values with the gas-phase data and some composition data. Through these analyses, the sources were assigned as sparse nucleation, local traffic, stationary combustion, grown particles and remote traffic, and secondary aerosol in a sequence of decreasing number concentration contributions. Conditional probability function (CPF) analysis was performed for each source so as to ascertain the likely directions in which the sources were located.

Hirabayashi, Motohiro, 2003, "Size distribution of Ultra-Fine Particles in the Roadside Atmospheres," *JSAE Technical Paper No. 20035679, JSAE Autumn Conference, September 17–19, 2003, Tokyo, Japan*

Size distribution of ultra-fine particle was measured by using the Scanning Mobility Particle Sizer in the roadside of three places with different traffic conditions, in order to grasp the influence of exhaust ultra-fine particles to the atmospheric environment. The high-concentration, ultra-fine particles under the 50 nm diameter that is thought to originates in the vehicle exhaust, was observed in each roadside atmospheres. It was found that the heavy-duty vehicles have contributed largely for the particles under 50 nm diameter, and the contribution of exhaust soot is large for the particles above 50 nm diameter.

Nessler, R.; Bukowiecki, N.; Henning, S.; Weingartner, E.; Calpini, B.; Baltensperger, U., 2003, "Simultaneous dry and ambient measurements of aerosol size distributions at the Jungfraujoch," *Tellus, Series B: Chemical and Physical Meteorology*, **55B**(3):808–819

In a field campaign at the high-alpine site Jungfraujoch (JFJ, 3580 m asl), in-situ aerosol size distributions were measured simultaneously outdoor at ambient conditions (temperature  $T < -5$  C) and indoor at dry conditions ( $T = 25$  C and relative humidity RH  $< 10$  percent) by means of two scanning mobility particle sizers (SMPS). In addition, measurements of hygroscopic growth factors were performed with a hygroscopicity tandem differential mobility analyzer (H-TDMA). The measured growth factors, being a monotonic function of the relative humidity (RH), were fitted with a modified Koehler model. A comparison between dry and ambient size distributions shows two main features: First, the dry total number concentration is often considerably smaller (on average 28 percent) than the ambient total number concentration, and is most likely due to the evaporation of volatile material at the higher temperature. These particle losses mainly concern small particles (dry diameter  $D < 100$  nm), and therefore have only a minimal affect on the surface and volume concentrations. A slight correlation between ambient RH and the magnitude of particle loss was observed, but it was not possible to establish an empirical model for a quantification. Second, the dry number size distribution is shifted towards smaller particles, reflecting the hygroscopic behavior of the aerosols. To link the ambient and the dry size distributions we modeled this shift using the H-TDMA measurements and a modified Koehler model. The corrected dry surface and volume concentrations are in good agreement with the ambient measurements for the whole RH range, but the correction works best for RH  $< 80$  percent. The results indicate that size distribution data measured at indoor conditions (i.e., dry and warm) may be successfully corrected to reflect ambient conditions, which are relevant for determining the impact of aerosol on climate.

Noble, C. A.; Mukerjee, S.; Gonzales, M.; Rodes, C. E.; Lawless, P. A.; Natarajan, S.; Myers, E. A.; Norris, G. A.; Smith, L.; Oezkaynak, H.; Neas, L. M., 2003, "Continuous measurement of fine and ultrafine particulate matter, criteria pollutants and meteorological conditions in urban El Paso, Texas," *Atmospheric Environment*, **37**(6):827–840

Continuous measurements of aerosol size distributions were made in El Paso, TX, for a 21 day period in winter 1999. Size distribution measurements were performed at two urban locations in El Paso using two pairs of the scanning mobility particle sizer and the aerodynamic particle sizer. Complementary measurements also were performed for gas phase pollutants (CO, NO, NO<sub>2</sub>, O<sub>3</sub> and meteorological conditions. Throughout the study, the mean ultrafine particle (those smaller than 0.1  $\mu\text{m}$  in diameter) number concentration was 14,400 particles  $\text{cm}^{-3}$ . There was a significant correlation between CO and both ultrafine and accumulation mode (those between 0.1 and 1  $\mu\text{m}$  in diameter) particle count, with the Pearson correlation coefficient ( $r$ ) values of 0.81 and 0.87, respectively. The correlation between NO and both ultrafine and accumulation mode particle count is also significant, but not as strong as the correlation of CO and the particle concentrations. Most pollutants were found to vary on diurnal cycles and to follow one of two different trends, either vehicular traffic schedules or sunlight intensity. Wind direction was found to have an influence not only on pollutant concentrations, but also on the correlation between pollutants. With southerly winds, CO, NO and NO<sub>2</sub> concentrations were 25–140% greater than when the wind was coming from the north. Likewise, ultrafine and accumulation mode particle concentrations were approximately 100% greater for southerly than for northerly winds.

Palmgren, F.; Waahlin, P.; Kildesoe, J.; Afshari, A.; Fogh, C.L., 2003, "Characterization of particle emissions from the driving car fleet and the contribution to ambient and indoor particle concentrations," *Physics and Chemistry of the Earth, Parts A/B/C*, **28**(8):327–334

The population is mainly exposed to high air pollution concentrations in the urban environment, where motor vehicle emissions constitute the main source of fine and ultrafine particles. These particles can penetrate deep into the respiratory system, and studies indicate that the smaller the particle, the larger the health impacts. The chemical composition, surface reactivity and physical properties are also important. However, the knowledge about chemical and physical properties of particles and the temporal and spatial variability of the smallest particles is still very limited. The present study summarizes the first results of a larger project with the aims to improve the knowledge. The concentration and the emissions of ultrafine particles from petrol and diesel vehicles, respectively, have been quantified using Scanning Mobility Particle Sizer of ultrafine particles in the size range 6–700 nm and routine monitoring data from urban streets and urban background in Denmark. The quantification was carried out using receptor modeling. The number size distributions of petrol and diesel emissions showed a maximum at 20–30 nm and non-traffic at about 100 nm. The contribution of ultrafine particles from diesel vehicles is dominating in streets. The same technique has been applied on PM<sub>10</sub>, and about 50 percent contribution from non-traffic. The technique has also been introduced in relation to elemental and organic carbon, and the first data showed strong correlation between traffic pollution and elemental carbon. The outdoor air quality has a significant effect on indoor pollution levels, and we spend most of the time indoors. Knowledge about the influence of ambient air pollution on the concentrations in the indoor environment is therefore crucial for assessment of human health effects of traffic pollution. The results of our studies will be included in air quality models for calculation of human exposure. Preliminary results from our first campaign showed, that the deposition rate of particles in the apartment is negligible in the particle size range 100–500 nm. In the size range below 100 nm the deposition rate increases with decreasing particle diameter to a value of approximately 1/h at 10 nm. The penetration efficiency shows a maximum of 60 percent at 100 nm. More detailed studies of exchange of particles in outdoor/indoor air and the transformation are planned to take place during three next campaigns.

Weijers, E. P.; Kos, G. P. A.; Jongejan, P. A. C., 2003, "Ultrafine particle emissions along motorways. Emission factors, particle numbers and size distributions," *Technical Report, Energy Research Centre of the Netherlands ECN*, Petten (Netherlands), Report No. ECN-C--03-04

The aim of this study is the determination of emission factors for ultrafine particles and size distributions along motorways in the Netherlands. In the experimental campaign particle number concentrations and size distribution in the size range from 13 to 583 nm were measured by condensation particle counters (CPC) and a scanning mobility particle sizer (SMPS), respectively. The measurements were taken upwind and at various distances downwind of two Dutch motorways of which one site was situated about 20 km north of the city of Amsterdam (A9- motorway) in the open field, and the other within the Amsterdam agglomeration (A4, near the junction with the A10). At each sampling day, concentrations of particulate matter, CO and NO<sub>x</sub> were measured over 20 to 30 min after which the mobile measurement was driven to the next location at another distance. In this study the experimental data collected on eight days are discussed.

## 2002

Abu-Allaban, M.; Coulomb, W.; Gertler, A.W.; Gillies, J.; Pierson, W.R.; Rogers, C.F.; Sagebiel, J.C.; Tarnay, L., 2002, "Exhaust Particle Size Distribution Measurements at the Tuscarora Mountain Tunnel," *Aerosol Science & Technology*, **36**(6):771–789

On-road particle size distributions were measured at the Tuscarora Mountain tunnel on the Pennsylvania Turnpike in May 1999. The data were obtained using a scanning mobility particle sizer. The nucleation modes of the size distributions contained most of the particles on a number concentration basis and exhibited peak diameters ranging from 11 to 17 nm. This observation is consistent with previous calculations and measurements, indicating that significant numbers of ultrafine aerosol particles can be expected in close proximity to busy motorways. The experiment provided 4 case studies for which the tunnel inlet data could be used to correct data obtained at the outlet, allowing for estimates of particle production within the tunnel. Exhaust particle production rates per vehicle kilometer were estimated; the results are presented with the caveat that the measurements were affected by ambient dilution. The 4 case study nucleation mode sizes varied inversely with ambient temperature. The light-duty vehicle contributions to the ultrafine particle distributions were apparently dominated by the heavy-duty vehicle contributions.

Hand, Jenny L.; Kreidenweis, Sonia M., 2002, "A New Method for Retrieving Particle Refractive Index and Effective Density from Aerosol Size Distribution Data," *Aerosol Science & Technology*, **36**(10):1012–1026

As part of the Big Bend Regional Aerosol Visibility and Observation study (BRAVO) in July-October 1999, dry aerosol size distributions were measured over the size range of  $0.05 < D_p < 20 \mu\text{m}$  using a TSI differential mobility analyzer (DMA), a PMS LASAIR 1003 optical particle counter (OPC), and a TSI aerodynamic particle sizer 3320 (APS). Extensive calibrations were performed to characterize the response of the OPC and APS to particles of different size and composition. This paper describes a new method that was developed to align size distributions in the instrument overlap regions, allowing for the retrieval of aerosol real refractive index and effective density. To validate the method, retrieved particle real refractive index was compared with volume weighted model estimates based on measured PM<sub>2.5</sub> chemical composition. The study average retrieved real refractive index was  $m_r = 1.566 - 0.012$ , and the average computed PM<sub>2.5</sub> refractive index was  $m_r = 1.56 - 0.02$ ; the agreement is well within experimental uncertainties. The average value of computed PM<sub>2.5</sub> bulk density was  $1.85 - 0.14 \text{ g cm}^{-3}$ . The average value of retrieved effective density, a function of particle dynamic shape factor, was  $1.56 - 0.12 \text{ g cm}^{-3}$ . The comparisons of effective density to computed bulk density suggested an average particle dynamic shape factor of  $h = 1.2$ . Sensitivity studies showed that real refractive index could be retrieved with uncertainties on the order of 2-3%, and effective density was retrieved with uncertainties on the order of 20–30%.

Hitchins, J.; Morawska, L.; Gilbert, D.; Jamriska, M., 2002, "Dispersion of particles from vehicle emissions around high- and low-rise buildings," *Indoor Air*, **12**(1):64–71

Understanding the distribution of outdoor pollutants around a building envelope, generated by sources located in its vicinity, is important when choosing the location of building ventilation system intakes, as well as for quantifying the exposure of people living or working in the building. A systematic experimental characterization of the number concentration of submicrometer particles was undertaken around the envelope of six buildings (both low- and high-rise) at different distances from a road (the main pollution source). The concentrations were measured using two TSI Scanning Mobility Particle Sizing. PM<sub>2.5</sub> concentrations were also monitored around the low-rise buildings using two TSI DUSTTRAKS. For the three high rise buildings the concentration of fine and ultra-fine particles decreased in most cases to about 50-60% from the approximate ground level readings (between heights of 0 to 6 m), to full building height (from 24 to 33 m above the ground). Measurements of submicrometer particle number concentrations as well as PM<sub>2.5</sub> fraction in the envelope around low-rise isolated buildings did not show any significant trends from the front to the rear of the building. The sensitivity of PM<sub>2.5</sub> measurements to a small number of larger particles, possibly from sources other than vehicle emissions, was observed.

Sarnat, J. A.; Coull, B. A.; Koutrakis, P.; Long, C. M.; Schwartz, J.; Suh, H. H., 2002, "Using sulfur as a tracer of outdoor fine particulate matter," *Environmental Science & Technology*, **36**(24):5305–5314

Six homes in the metropolitan Boston area were sampled between 6 and 12 consecutive days for indoor and outdoor particle volume and mass concentrations, particle elemental concentrations, and air exchange rates (AERs). Indoor/outdoor (I/O) ratios of nighttime (i.e., particle non-indoor source periods) sulfur, PM<sub>2.5</sub> and the specific particle size intervals were used to provide estimates of the effective penetration efficiency. Mixed models and graphical displays were used to assess the ability of the I/O ratios for sulfur to estimate corresponding I/O ratios for PM<sub>2.5</sub> and the various particle sizes. Results from this analysis showed that particulate sulfur compounds were primarily of outdoor origin and behaved in a manner that was representative of total PM<sub>2.5</sub> in Boston, MA. These findings support the conclusion that sulfur can be used as a suitable tracer of outdoor PM<sub>2.5</sub> for the homes sampled in this study. Sulfur was more representative of particles of similar size (0.06-0.5  $\mu\text{m}$ ), providing evidence that the size composition of total PM<sub>2.5</sub> is an important characteristic affecting the robustness of sulfur-based estimation methods.



Shen, S.; Jaques, P. A.; Zhu, Y. F.; Geller, M. D.; Sioutas, C., 2002, "Evaluation of the SMPS-APS system as a continuous monitor for measuring PM 2.5, PM 10 and coarse (PM 2.5-10) concentrations," *Atmospheric Environment*, **36**(24):3939–3950

Respirable particulate matter (PM) has been linked to mortality and morbidity by a variety of epidemiological studies. This research has led to the creation of a new PM standard for particles with diameters  $<2.5 \mu\text{m}$  ( $\text{PM}_{2.5}$ ). Since the conclusion of these studies, many leaps have been made in the realm of continuous particle measurement. Because the literature is still dominated by 24-hour averaged data, the US Environmental Protection Agency still uses this time average as the basis of its federal reference method, despite the fact that PM varies on much shorter time intervals. The purpose of this work is to compare the Scanning Mobility Particle Sizer and Aerodynamic Particle Sizer tandem (SMPS–APS) to other continuous PM measurement devices and to time-integrated mass samplers. The instruments used for comparison include the DataRAM nephelometer, Micro-Orifice Uniform Deposit Impactor (MOUDI), and Partisol Dichotomous Sampler. The data was collected over 4–5 months at various sites in the Los Angeles basin. The results show excellent agreement between the SMPS–APS and the mass based MOUDI and Partisol samplers for  $\text{PM}_{2.5}$ . The DataRAM and SMPS–APS continuous monitors show robust correlation with each other when relative humidity  $<70\%$ . The coarse fraction ( $\text{PM}_{2.5-10}$ ) measured by the Partisol, however, does not track well with the same size range measured by the APS. Several sources of sampling error are discussed to account for this. Finally, mass concentrations collected in individual size ranges of the MOUDI were compared with those determined by the SMPS. While the size ranges from 0.32 to 10  $\mu\text{m}$  agree between samplers, the size ranges  $<0.32 \mu\text{m}$  are significantly different from MOUDI to SMPS, probably due to the differences between the aerosol sizing principles underlying each technique.

Wiegand, A., 2002, "Dirty air Down Under," *Environmental Protection*, **13**(9):22-25

In 1992, the Environmental Aerosol Laboratory (EAL) was established within the Faculty of Science at Queensland University of Technology, specializing in environmental science with particular emphasis on fine and ultrafine particles. The city of Brisbane in particular is expanding rapidly necessitating careful planning for the future. Smog chamber experiments combined with airshed (a large area over which air quality and movement can be considered) modeling are described. These are applicable in the planning of infrastructure with a view to the prevention of exposure of large populations to pollutants. Recent developments in computer technology including high-performance graphing and data analysis tools such as Origin Corp and tools for the study of the formation of ultrafine particles such as high resolution Scanning Mobility Particle Sizers (TSI Inc) have dramatically increased the capacity of researchers to conduct such modeling studies.

Zhu, Y. F.; Hinds, W. C.; Kim, S.; Shen, S.; Sioutas, C., 2002, "Study of ultrafine particles near a major highway with heavy-duty diesel traffic," *Atmospheric Environment*, **36**(27):4323–4335

An investigation to characterize the ultrafine particles emitted from heavy-duty diesel trucks, on Interstate 710 in Los Angeles, is presented. Particle number concentration and size distribution, from 6–220 nm, were measured by a condensation particle counter (CPC) and a scanning mobility particle sizer (SMPS). The output data were analyzed by the Aerosol Instrument Manager Software. Measurements were taken at 17, 20, 30, 90, 150 and 300 m downwind and 200 m upwind from the centre of the freeway. Wind speed and direction were measured at 1 min intervals and logged by computer. The black carbon (BC) concentrations were measured every 5 min with a dual beam Aethalometer and CO with a near-continuous monitor. Atmospheric dilution and coagulation are important in the changes in particle number concentration and in particle size distribution.

Zhu, Y.; Hinds, W. C.; Kim, S.; Sioutas, C., 2002, "Concentration and size distribution of ultrafine particles near a major highway," *Journal of the Air & Waste Management Association*, **52**(9):1032–1042

Motor vehicle emissions usually constitute the most significant source of ultrafine particles (diameter  $<0.1 \mu\text{m}$ ) in an urban environment, yet little is known about the concentration and size distribution of ultrafine particles in the vicinity of major highways. In the present study, particle number concentration and size distribution in the size range from 6 to 220 nm were measured by a condensation particle counter (CPC) and a scanning mobility particle sizer (SMPS), respectively. Measurements were taken 30, 60, 90, 150, and 300 m downwind, and 300 m upwind, from Interstate 405 at the Los Angeles National Cemetery. At each sampling location, concentrations of CO, black carbon (BC), and particle mass were also measured by a Dasibi CO monitor, an aethalometer, and a DataRam, respectively. The range of average concentration of CO, BC, total particle number, and mass concentration at 30 m was 1.7–2.2 ppm, 3.4–10.0  $\mu\text{g}/\text{m}^3$ ,  $1.3\text{--}2.0 \times 10^5/\text{cm}^3$ , and 30.2–64.6  $\mu\text{g}/\text{m}^3$ , respectively. For the conditions of these measurements, relative concentrations of CO, BC, and particle number tracked each other well as distance from the freeway increased. Particle number concentration (6–220 nm) decreased exponentially with downwind distance from the freeway. Data showed that both atmospheric dispersion and coagulation contributed to the rapid decrease in particle number concentration and change in particle size distribution with increasing distance from the freeway. Average traffic flow during the sampling periods was 13,900 vehicles/hr. Ninety-three percent of vehicles were gasoline-powered cars or light trucks. The measured number concentration tracked traffic flow well. Thirty meters downwind from the freeway, three distinct ultrafine modes were observed with geometric mean diameters of 13, 27, and 65 nm. The smallest mode, with a peak concentration of  $1.6 \times 10^5/\text{cm}^3$ , disappeared at distances greater than 90 m from the freeway. Ultrafine particle number concentration measured 300 m downwind from the freeway was indistinguishable from upwind background concentration. These data may be used to estimate exposure to ultrafine particles in the vicinity of major highways.

## 2001

Lawless, P. A.; Rodes, C. E.; Evans, G.; Sheldon, L.; Creason, J., 2001, "Aerosol Concentrations During the 1999 Fresno Exposure Studies as Functions of Size, Season, and Meteorology," *Aerosol Science & Technology*, **34**(1):66–74

Two 1999 Fresno exposure studies took place in February (winter season) and April/May (spring season) for periods of four weeks each. During that time, nearly continuous measurements of outdoor aerosol concentrations were made with a TSI Scanning Mobility Particle Sizer (SMPS) and a PMS optical particle counter (LASX). These instruments provide particle size distribution information from about 0.01 to 3  $\mu\text{m}$ . Although the primary concentration measurements were performed with integrated samplers, the SMPS/LASX combination provided useful information on the real-time variations of concentration and particle size distributions. This paper describes the agreement between the real-time instrumentation and the integrated measurements and examines some of the information available from the SMPS/LASX combination. In particular, two different types of aerosols contributing to  $\text{PM}_{2.5}$  were deduced from the instrumental data.

Morawska, L.; He, Congrong; Hitchins, J.; Gilbert, D.; Parappukkaran, S., 2001, "The relationship between indoor and outdoor airborne particles in the residential environment," *Atmospheric Environment*, **35**(20):3463–3473

The relationship between indoor and outdoor airborne particles was investigated for 16 residential houses located in a suburban area of Brisbane, Australia. The submicrometer particle numbers were measured using the Scanning Mobility Particle Sizer, the larger particle numbers using the Aerodynamic Particle Sizer and an approximation of PM<sub>2.5</sub> was also measured using a DUSTTRAK. The measurements were conducted for normal and minimum ventilation conditions using simultaneous and non-simultaneous measurement methods designed for the purpose of the study. Comparison of the ratios of indoor to outdoor particle concentrations revealed that while temporary values of the ratio vary in a broad range from 0.2 to 2.5 for both lower and higher ventilation conditions, average values of the ratios were very close to one regardless of ventilation conditions and of particle size range. The ratios were in the range from 0.78 to 1.07 for submicrometer particles, from 0.95 to 1.0 for supermicrometer particles and from 1.01 to 1.08 for PM<sub>2.5</sub> fraction. Comparison of the time series of indoor to outdoor particle concentrations shows a clear positive relationship existing for many houses under normal ventilation conditions (estimated to be about and above 2h<sup>-1</sup>, but not under minimum ventilation conditions (estimated to be about and below 1h<sup>-1</sup>). These results suggest that for normal ventilation conditions, outdoor particle concentrations could be used to predict instantaneous indoor particle concentrations but not for minimum ventilation, unless air exchange rate is known, thus allowing for estimation of the "delay constant".

Shi, J. P.; Evans, D. E.; Khan, A. A.; Harrison, R. M., 2001, "Sources and concentration of nanoparticles (less 10 nm diameter) in the urban atmosphere," *Atmospheric Environment*, **35**(7):1193–1202

Air at four sites was monitored and the nanoparticles size and concentrations determined using condensation particle counters (particles less than 7 nm) and ultrafine condensation particle counters (particles larger than 3 nm). A Scanning Mobility Particle Sizer was used to measure particle size distribution in the range 9.47–359 nm. An epiphaniometer was used to measure the particle Fuchs surface area. SO<sub>2</sub>, NO and NO<sub>2</sub> were determined using analyzers. A mini meteorological station was used to measure wind speed, direction, temperature, relative humidity, UVA and UVB in the measuring site. Results are presented graphically, tabulated and discussed.

Vette, Alan F.; Rea, Anne W.; Lawless, Philip A.; Rodes, Charles E.; Evans, Gary; Highsmith, V. Ross; Sheldon, Linda, 2001, "Characterization of Indoor-Outdoor Aerosol Concentration Relationships during the Fresno PM Exposure Studies," *Aerosol Science & Technology*, **34**(1):118–126

Particle size distributions were measured indoors and outdoors of a single, detached residence during the Fresno particulate matter exposure studies in winter (February 1–28, 1999) and spring (April 18–May 16, 1999). Data was collected for particle sizes ranging from about 0.01 to 2.5 µm. These data were used to investigate the temporal relationships between indoor and outdoor aerosol concentrations and to determine particle deposition rates and penetration factors for discrete particle sizes. Indoor/outdoor aerosol concentration ratios for particle sizes > 1 µm were diurnally variable with highest ratios occurring during daytime (6:00–18:00) due to resuspension from indoor activities. Daytime and nighttime (19:00–7:00) aerosol concentration ratios were very similar for particle sizes < 1 µm. Particle deposition rates were determined by measuring the decay in indoor aerosol concentrations after indoor levels were elevated by infiltration of native ambient aerosols. Deposition rates varied depending on particle size and were consistent with model results up to about 0.4 µm. The experimentally determined deposition rates were considerably higher than model results at larger particle sizes, suggesting the possibility of an additional indoor loss mechanism. Penetration factors were determined to be less than unity for all particle sizes and ranged from 0.5 to 0.9.

## 2000

Abt, E.; Suh, H. H.; Catalano, P.; Koutrakis, P., 2000, "Relative contribution of outdoor and indoor particle sources to indoor concentrations," *Environmental Science and Technology*, **34**(17):3579–3587

The effect of indoor particle sources on indoor particle size distributions and concentrations was previously investigated using real-time indoor and outdoor particle size distribution data collected in four homes in Boston in 1996. These data demonstrated the importance of indoor sources (i.e., cooking, cleaning, and movement of people) and air exchange rates on observed indoor concentrations. As part of the continued analyses of these data, a simple physical model was used to determine the source emission and infiltration rates for specific particle sizes. Decay rates were also estimated. Cooking, cleaning, and indoor work (characterized by movement of people) significantly increased PM<sub>(0.7–10)</sub> concentrations by 0.27, 0.27, and 0.25 µm<sup>3</sup> cm<sup>-3</sup> min<sup>-1</sup>, respectively. Cooking was the only variable significantly associated with generation of particles less than 0.5 µm in diameter. Outdoor particles (0.02–0.5 and 0.7–10 µm) were found to contribute significantly to indoor particle levels. Effective penetration efficiencies ranged from 0.38 to 0.94 for 0.02–0.5 µm particles and from 0.12 to 0.53 for 0.7–10 µm particles. Estimates for 0.7–10 µm particles decreased with increasing particle size, reflecting the influence of deposition losses from gravitational settling. The real-time particle size distribution data in conjunction with time-activity information provides valuable information on the origin and fate of indoor particles.

Abu-Allaban, M.; Gertler, A. W.; Rogers, C. F.; Gillies, J. A., 2000, "Measurement of ultrafine particle emissions in a highway tunnel," Recent advances in the science and management of air toxics : proceedings of the joint international specialty conference, exhibition and workshop of the Air and Waste Management Association, Abstract only; PP. 15, 300 pages, *Published by Air and Waste Management Association*, Edmonton, AB (Canada)

In May 1999, a six day experiment was conducted at the Tuscarora Mountain tunnel on the Pennsylvania Turnpike to measure particle number-size distributions and size-segregated particle chemistry at the entrance and exit of the tunnel. A Scanning Mobility Particle Sizer (SMPS) was used to measure the particle size distributions over a particle diameter range from 10 to 300 nanometers. The ultrafine particle chemistry was determined from afterfilter measurements using a Davis Rotating-drum Universal-size-cut Monitoring sampler. Heavy-duty diesel vehicles were found to contribute to the overall fleet composition by a fraction of 12 to 85 per cent. The SMPS data suggested that the aerosol was a mixture of three or more components. Diluted mobile source exhaust was usually present as a result of both heavy- and light-duty vehicle traffic. A non-mobile background aerosol was also observed. SMPS data from the tunnel exit showed characteristic size spectra for fresh vehicle exhaust for the heavy and light duty fractions. The size

spectra demonstrate dominant nucleation modes, smaller accumulation modes and elevated particle number concentrations. It was hypothesized that the nucleation mode peak diameter decreases somewhat with a decrease in the heavy-duty vehicle fraction. Sulfur was the most abundant element in the particles having diameters of 70 nanometers or less.

Bukowiecki, N.; Henning, S.; Hoffer, A.; Weingartner, E.; Baltensperger, U., 2000, "Cloud and aerosol characterization experiment in the free troposphere (CLACE) - a field experiment at the Jungfraujoch (3580 m ASL)," *Journal of Aerosol Science*, **31**(S1):S11–S12

The CLACE (cloud and aerosol characterization experiment in the free troposphere) aims to: examine cloud formation processes under different meteorological conditions; characterize organic aerosol compounds; compare particle size distributions measured under different ambient conditions; and determine hygroscopic properties of aerosols. Particle size distributions of the total and interstitial aerosol were measured with three different Scanning Mobility Particle Sizer (SMPS) systems operated with a closed loop.

Henning, S.; Weingartner, E.; Baltensperger, U.; Gaggeler, H. W., 2000, "Investigation of the interaction between aerosol and clouds at the Jungfraujoch (3580 m ASL)," *Journal of Aerosol Science*, **31**(S1):S13–S14

Two cloud and aerosol characterization field campaigns were conducted at the Jungfraujoch to study the effects of aerosol properties on cloud formation. A Scanning Mobility Particle Sizer was used to measure aerosol number size distributions of the total aerosol, and interstitial aerosol in two size classes (TSP and PM<sub>1</sub>). Assuming a pure ammonium sulfate particles with supersaturation equals 0.4% is needed to activate particles, a 50 nm diameter was observed for 50% scavenging DP50. 5 Refs.

Hitchins, J.; Morawska, L.; Wolff, R.; Gilbert, D., 2000, "Concentrations of submicrometer particles from vehicle emissions near a major road," *Atmospheric Environment*, **34**(1):51–59

As part of a program of study to assess the exposure risks related to particulate matter in the outdoor environment, number concentrations of particles from vehicle emissions were measured at increasing distances from a major road. Particles in the size range from 0.015 to 0.697 μm were measured with the Scanning Mobility Particle Sizer (SMPS) and in the size range from 0.5 to 20 μm, with the aerodynamic particle sizer (APS). In addition to number concentration measurements, an approximation of PM<sub>2.5</sub> fraction was obtained using a DUSTTRAK (simple photometer). The measurements conducted at distances from the road ranging from 15 to 375 m showed, that for conditions where the wind is blowing directly from the road, the concentration of fine and ultrafine particles decays to around half of the maximum (measured at the closest point to the road) at a distance of approximately 100-150 m from the road. For the wind blowing parallel to the road, the reduction to half of the concentration occurs at 50-100 m. There is no effect on total particle number concentration at a distance greater than 15 m from the road when the wind is blowing towards the road and away from the sampling points. Total number concentrations of larger particles measured were not significantly higher than the average values for the urban environment, and decrease with distance from the road, reaching about 60% at 150 m from the road for wind from the road. PM<sub>2.5</sub> levels also decrease with distance to around 75% for wind from the road and to 65% for wind parallel to the road, at a distance of 375m.

Hung, H. F.; Wang, C. S., 2000, "Characterization of ultrafine particles in Taipei aerosols," *Journal of Aerosol Science*, **31**(S1):S248–S249

The mass and number concentrations, and chemical compositions of atmospheric ultrafine particles in an urban environment were measured. Samples of ultrafine particles were taken from a third-floor balcony, a courtyard, the vicinity of a bus stop, and in an underpass. Results indicate that samples collected at the courtyard, which were mainly from vehicular exhausts, has higher mass concentrations of ultrafine particles and the main carbonaceous material was organic carbon. The results imply that the vehicular exhaust is the major source of ultrafine particles in the City of Taipei. 3 Refs.

Roberts, G. C.; Artaxo, P.; Andreae, M. O., 2000, "Chemistry and role of cloud condensation nuclei in the Amazon Basin," *Journal of Aerosol Science*, **31**(S1):S62–S63

The cloud condensation nuclei (CCN) interactions for cloud formation in the Amazon Basin is discussed. The aerosol measurements are carried out to study the chemical and physical properties of the CCN. Warm precipitating clouds in the Amazon Basin have been observed. The effect of organic material on CCN activity and the growth of cloud droplets are discussed. The number and mass size distributions for CCN activation are measured using a Scanning Mobility Particle Sizer and a multiple stage cascade impactor. The factors affecting the heat flux in the rainforests are presented. The modifications of CCN concentrations contribute to meteorological cycle and affect the climate in Amazon Basin. 8 Refs.

## 1999

Harrison, R. M.; Jones, M.; Collins, G., 1999, "Measurements of the physical properties of particles in the urban atmosphere," *Atmospheric Environment*, **33**(2):309–321

Measurements of the physical properties of particles in the atmosphere of a UK urban area have been made, including particle number count by condensation nucleus counters with different lower particle size cut-offs; particle size distributions using a Scanning Mobility Particle Sizer; total particle Fuchs surface area using an epiphaniometer and particle mass using Tapered Element Oscillating Micro-balance (TEOM) instruments with size selective (PM<sub>10</sub> and PM<sub>2.5</sub>) inlets. Mean particle number counts at three sites range from 2.86 × 10<sup>4</sup> to 9.60 × 10<sup>4</sup> cm<sup>-3</sup>. A traffic-influenced location showed a substantially higher ratio of particle number to PM<sub>10</sub> mass than a nearby background location despite being some 70 m from the roadway. Operating two condensation nucleus counters in tandem to determine particles in the 3-7 nm size range by difference showed significant numbers of particles in this range, apparently related to homogeneous nucleation processes. Measurements with the Scanning Mobility Particle Sizer showed a clear difference between roadside size distributions and those at a nearby background location with an additional mode in the roadside samples below 10 nm diameter. Particle number counts were found to show a significant linear correlation with PM<sub>10</sub> mass ( $r^2 = 0.44$ ;  $n = 44$  for 24 h data at an urban background location), although during one period of high pollution a curvilinear relationship was found. Measurements of the diurnal variation in PM<sub>10</sub> mass, particle number count and Fuchs surface area show the same general pattern of behavior of the three variables, explicable in terms of vehicle emission source strength and atmospheric dispersion, although the surface area growth was out of phase with the particle number and mass. It appears that particle number gives the clearest indication of recent road traffic emissions.

Holub, R. F.; Reimer, G. M.; Hopke, P. K.; Hovorka, J.; Krcmar, B.; Smrz, P. K., 1999, "Geo-aerosols': their origin, transport and paradoxical behavior: a challenge to aerosol science," *Journal of Aerosol Science*, **30**(S1):S111–S112

Aerosols in the range 3 to 200 nm in a cave and in an experimental mine were measured using Diffusion Particle Sizer (DPS) and Scanning Mobility Particle Sizer (SMPS). The areas were also sampled for volatile organics by means of TENEX adsorbers, and for the filterable inorganics and organics by means of porous membrane filters. Some of the filters were measured by means of electron microscope and gas chromatography to determine the concentration and composition of the inert aerosols. The concentration and composition of the radioactive aerosols was measured by means of standard nuclear counting equipment. Simultaneously, the outdoor inert and radioactive aerosols were also sampled. The results for both DPS (cave) and SMPS (mine) were basically the same. 5 Refs.

Ji P.; Khan, A. A.; Harrison, R. M.; Harrison, R. M.; Hamilton, R. S., 1999, "Measurements of ultrafine particle concentration and size distribution in the urban atmosphere," *Science of the Total Environment*, **235**(1–3):51–64

Particle size distributions were measured at three adjacent sites in Birmingham: a busy roadside (A38); 30 m away from the road and a nearby urban background site. Two Scanning Mobility Particle Sizers (SMPS), an electrical low pressure impactor (ELPI), a condensation particle counter and a thermophoretic precipitator were employed to measure and collect particles. Excellent agreement on the number weighted size distribution was found between the SMPS and ELPI, as well as with sizes measured by transmission electron microscopy. The average number concentration at roadside measured on four separate days was between  $1.6$  and  $1.9 \times 10^5 \text{ cm}^{-3}$  with similar size distributions and more than half of measured particles smaller than 30 nm. Traffic was the main source of ultrafine particles at the roadside. A 24-h average of  $2.68 \times 10^4$  plus or minus  $1.29 \times 10^4 \text{ cm}^{-3}$  was measured, which is close to that in Hughes et al. (Physical and chemical characterization of atmospheric ultrafine particles in the Los Angeles area. *Environ Sci Technol* 1998; **32**:1153-1161) in Pasadena, CA, USA. Total particle number concentration declined downwind of the traffic, faster than the mass concentration. Model calculations show that dilution with background air is the main mechanism for the rapid drop in particle number concentration and change in particle size distribution when moving away from traffic.

Morawska, L.; Thomas, S.; Gilbert, D.; Greenaway, C.; Rijnders, E., 1999, "A study of the horizontal and vertical profile of submicrometer particles in relation to a busy road," *Atmospheric Environment*, **33**(8):1261–1274

Epidemiological studies are consistently reporting an association between fine particulate pollution and ill-health. Motor vehicle emissions are considered to be the main source of fine particles in ambient urban air of cities which are not directly influenced by industrial emissions. The aim of this work was to assess the influence of a major arterial road on concentration levels of airborne fine particles in its vicinity. Measurements of over 500 particle size distributions in the particle size range 16–626 nm, were made using two Scanning Mobility Particle Sizers (SMPS). A subsequent comparison of the recorded values from differing locations is discussed, with reference made to topographic and climatic influences. Both horizontal and vertical profile measurements of fine particle number size distributions are described; the combination of the two yielding information as to the relative exposures of occupants of buildings in the vicinity of a major arterial route. With the exception of measurements in close proximity to the freeway (about 15 m), the horizontal profile measurements did not provide any evidence of a statistically significant difference in fine particle number concentration with respect to distance at ground level up to a distance of 200 m within the study area. The vertical profile measurements also revealed no significant correlation between particle concentration and height. However, for buildings in the immediate proximity to the arterial road (about 15 m) concentrations around the building envelope are very high, comparable to those in the immediate vicinity of the road, indicating undiluted concentrations drawn directly from the freeway. This finding has a significant implication for management of indoor air quality in the buildings located in the immediate vicinity of major roads.

Morawska, L.; Thomas, S.; Jamriska, M.; Johnson, G., 1999, "The modality of particle size distributions of environmental aerosols," *Atmospheric Environment*, **33**(27):4401–4411

Epidemiological studies are consistently reporting an association between fine particulate pollution and ill-health. Motor vehicle emissions are considered to be the main source of fine particles in ambient urban air of cities which are not directly influenced by industrial emissions. The aim of this work was to assess the influence of a major arterial road on concentration levels of airborne fine particles in its vicinity. Measurements of over 500 particle size distributions in the particle size range 16–626 nm, were made using two Scanning Mobility Particle Sizers (SMPS). A subsequent comparison of the recorded values from differing locations is discussed, with reference made to topographic and climatic influences. Both horizontal and vertical profile measurements of fine particle number size distributions are described; the combination of the two yielding information as to the relative exposures of occupants of buildings in the vicinity of a major arterial route. With the exception of measurements in close proximity to the freeway (about 15 m), the horizontal profile measurements did not provide any evidence of a statistically significant difference in fine particle number concentration with respect to distance at ground level up to a distance of 200 m within the study area. The vertical profile measurements also revealed no significant correlation between particle concentration and height. However, for buildings in the immediate proximity to the arterial road (about 15 m) concentrations around the building envelope are very high, comparable to those in the immediate vicinity of the road, indicating undiluted concentrations drawn directly from the freeway. This finding has a significant implication for management of indoor air quality in the buildings located in the immediate vicinity of major roads.

## 1997

Lee, W.-M. G.; Shih, P.-M.; Wang, C.-S., 1997, "The influence of relative humidity on the size of atmospheric aerosol," *J. Environ. Sci. Health, Part A: Environ. Sci. Eng. Toxic Hazard. Subst. Control*, **A32**(4):1085–1097

The relative humidity of ambient air is very often over 75% throughout the year in Taiwan. Thus, the influence of relative humidity on the growth of hygroscopic aerosols in the atmosphere is particularly important. In this study, a TDMA system (Tandem Differential Mobility Analyzer) equipped with newly developed a SMPS (Scanning Mobility Particle Sizer) was used to observe the sizes of submicron ammonium sulfate aerosols, from 63.8nm to 224.7nm, at five controlled relative humidities, 50%, 75%, 81%, 85% and 89%. It is the first time that the hygroscopic growths and deliquescence points of submicron aerosols of ammonium sulfate have

ever been closely observed by use of the SMPS. The experimental results showed that the abrupt size changes of aerosols at their deliquescence points can be more precisely observed than in previous studies. It was also shown that there was no apparent growth in an ammonium sulfate aerosol until relative humidities was over 75%. At relative humidities between 81% and 89%, the growth ratio of size was about a factor of 1.3 to 1.6 and the water content of ammonium sulfate aerosols by mass was about 47% to 66%.

## 1995

Weingartner E.; Keller C.; Stahel W.A.; Baltensperger U.; Burtscher H., 1995, "Field Study of Vehicle Emission Factors in a Road Tunnel," *Journal of Aerosol Science*, **26**(S1):669–670

Within the scope of measurements in the Gubrist tunnel, a 3'250 m long highway tunnel near Zurich, Switzerland, from 20.9 to 26.9.1993, continuous measurements of aerosol emissions were performed. These measurements were part of the Genemis-project, an EUROTRAK sub project.

## 1994

Zhang, Xinqiu; Turpin, Barbara J.; McMurray, Peter H.; Hering, Susanne V.; Stolzenburg, Mark R., 1994, "Mie Theory Evaluation of Species Contributions to 1990 Wintertime Visibility Reduction in the Grand Canyon," *Air & Waste Management Association*, **44**:153–162

Contributions of the major fine particle species to light scattering were evaluated using Mie theory from measurements of size-resolved chemistry and particle hygroscopicity obtained during the 1990 NGS Visibility Study at Hopi Point, Grand Canyon, from January 9, 1990 through March 31, 1990. It was found that scattering efficiencies of particulate carbon mass ranged from 1.5 to 8m<sup>2</sup> per gram of carbon particle mass (assumed equal to 1.4 times carbon mass), with an average value of 5.4 ± 1.5m<sup>2</sup>/g. Sulfur size distributions, which are available for the entire 80-day study, show that sulfate scattering efficiencies depend on both relative humidity and on median particle size, and that 'dry' (RH <60 percent) sulfur scattering efficiencies range from about 1.5 to 4.5 m<sup>2</sup> per gram of ammonium sulfate. This range reflects the wide variability in median sulfur particle size (0.07 to 0.66µm) that was observed during the study. For the 20-day period during which size distribution data for the major fine particle species are available, the contributions of soil dust, carbon, sulfates, and nitrates to scattering are 0.38, 5.0, 4.8 and 0.7 Mm<sup>-1</sup> respectively, and average daily percentage contributions are 4.2, 50.1, 38.5, and 6.9 percent. Sulfur mass median diameters >0.3µm were only found during periods of high relative humidity, but not all high humidity periods had large sulfur mass median diameters. Sulfate scattering efficiencies for >60 percent RH were smaller for instances of direct transport of <36 hr from Navajo Generating Station to Hopi Point than for the regional background. Scattering efficiencies for longer transport times resembled the regional background.

## 1993

Covert, David S.; Heintzenberg, Jost, 1993, "Size Distributions and Chemical Properties of Aerosol at NY Ålesund, Svalbard," *Atmospheric Environment*, **27A**(17/18):2989–2997

Physical and chemical parameters of the arctic aerosol were investigated at Ny Ålesund, Svalbard, in March and April 1989 in connections with the third Arctic Gas and Aerosol Project (AGASP III). The number size distribution of the particles was measured over the range of 0.02–1.0 µm. Filter samples were analyzed for elemental composition and two integral chemical properties, hygroscopic growth and volatility, were measured. Along with the latter measurements, the distribution of these properties at specific particle sizes, i.e., the degree of internal mixing was determined. Both clean, marine conditions and 'arctic haze' episodes were included in the series of measurements. The number size distribution indicated that the aerosol was well aged based on its narrowness and the relative low concentration of nuclei mode particles. It had a number mode at 0.22 µm diameter and geometric standard deviation of 1.4. Generally the particles exhibited uniform gygroscopic growth properties, i.e., they were largely internally mixed. The growth factor was 1.45 at 90% relative humidity. A volatile fraction varied from particle to particle, i.e. the particles were externally mixed with respect to volatility.

Li, Chih-Shan; Lin, Wen-Hai; Jenq, Fu-Tein, 1993, "Characterization of Outdoor Submicron Particles and Selected Combustion Sources of Indoor Particles," *Atmospheric Environment*, **27B**(4):413–424

Environmental tobacco smoke, mosquito-coil smoke, and joss stick smoke are the major indoor combustion sources in Asian countries. Field evaluations of the size distributions of outdoor submicron particles and selected combustion sources of indoor particles were conducted in an apartment in Taipei urban area. The size distributions of submicron aerosols were determined by a high resolution particle sizer, which could measure the particles in the size range of 0.017-0.886 µm. The particle sizer contains a differential mobility analyzer (TSI 3071) and a condensation particle counter (TSI 3022). The number concentrations of the indoor and outdoor submicron particles varied from 14,000 to 150,000 cm<sup>-3</sup> and from 10,000 to 45,000 cm<sup>-3</sup>, respectively. The changes of the size distributions and the number concentrations of submicron aerosols before, during, and after the aerosol generations were compared. The average number median diameters of environmental tobacco smoke, smoldering cigarettes, mosquito-coil smoke, joss stick smoke, the indoor typical conditions, and the outdoor typical conditions were 0.090, 0.085, 0.094, 0.084, 0.091 and 0.054 µm respectively. Regarding the surface area-weighted size distributions, the average surface median diameters of these conditions were 0.229, 0.219, 0.282, 0.188, 0.224 and 0.221 µm, respectively. In addition, the average volume median diameters were 0.338, 0.332, 0.398, 0.289, 0.330 and 0.340 µm, respectively. These indoor combustion sources did generate a significant number of the ultrafine and submicron particle which have higher deposition probabilities in the respiratory tract. Further health evaluations of the submicron particles from these combustion sources are needed.

## 1984

Hoppel, William A.; Larson, Reginald; Vietti, Michael A., 1984, "Aerosol Size Distributions at a Site on the East Coast of the United States," *Atmospheric Environment*, **18**(8):1613–1621

Aerosol size distributions covering the range from 0.006 to 2.2  $\mu\text{m}$  radius were measured with the NRL differential mobility analyzer and an optical particle counter during a 12-day period in June of 1979 at Wallops Island, VA. Changes in the size distribution were associated primarily with the history of the air mass as indicated by synoptic conditions. The coastal location made it possible to contrast continental and marine conditions. On one occasion a high pressure system moved from over the Great Lakes, across New England, and out to sea. Circulation around this high first brought to the site air which had moved down the east coast of the U.S., and later air from the east with increasingly longer trajectories over water. As the length of the trajectory over water increased, a decrease in small particles was clearly evident.



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