

ARIES: **Aerosol Research and Inhalation Epidemiology Study**

Atmospheric measurements, exposure assessment, and health data in Atlanta are combined to test hypotheses concerning the health effects of PM_{2.5} and other air pollutants

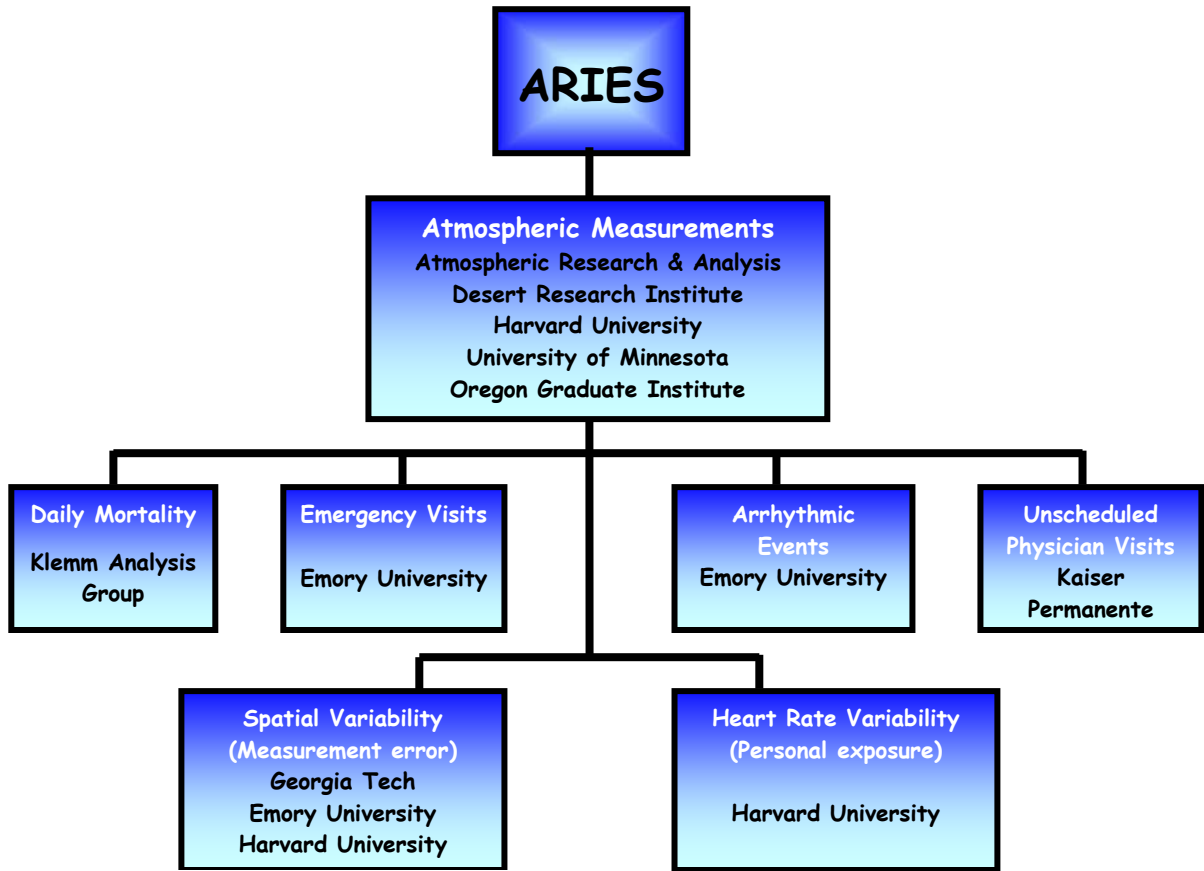


Figure 1. ARIES design

Background

Findings from numerous epidemiology studies have shown discernible associations between daily levels of suspended particulate matter and adverse health effects. Interpretation of these associations has been difficult and controversial because particulate matter can be an index (or surrogate) for one or more of its specific constituents or for a range of other

substances in air as well as for weather and seasonal patterns.

On the basis of the epidemiological evidence, the United States Environmental Protection Agency (EPA) promulgated new National Ambient Air Quality Standards (NAAQS) in 1997 for particulate matter 2.5 micrometers in diameter (PM_{2.5}) and smaller – also known as “fine PM.” These standards address long term (annual average) and short-term (24-hour average) concentrations of PM_{2.5}. Based on recent data, many areas

of the US approach or exceed the annual-average threshold for attainment of the annual PM_{2.5} NAAQS. The health-based particulate matter standards were recently reconsidered by the EPA, based upon a review of new health information, and the daily standard was lowered, while the annual standard was left unchanged. No consideration was given to regulating the specific materials in PM_{2.5} that either singly or in combination lead to adverse health effects. Clearly there was and continues to be a need for identifying precisely what it is in PM_{2.5} that harms people so that more highly focused mitigations schemes can be devised that better protect the population's health.

Objectives

The objective of ARIES is to investigate (via epidemiology and exposure studies) associations between air quality and human health and produce results for consideration of the health basis of the NAAQS and for subsequent development of State Implementation Plans (SIPs). As alluded to above, fine PM mass may be an indicator (but not necessarily a cause) of adverse effects associated with air pollution — other pollutants, or PM components that co-vary with PM mass, may be the underlying cause. What sets ARIES apart from prior studies is that its focus is not on PM mass alone but on an unprecedented range of potential agents in the air, including VOCs, aeroallergens, pollutant gases, and specific PM components. This comprehensive sampling approach enables a far more robust and explicit investigation of the relationship between human health and airborne pollutants.

Study Design

The study is fundamental by design, so that the results in terms of associations between air quality and health will, in principle, be generic and not limited to Atlanta. Nonetheless, the same design principles are being applied in shorter

duration studies elsewhere – in St. Louis, MO, Dallas, TX, and Birmingham, AL, in part to satisfy critics of a single-city approach. It is expected that the study will continue to generate hypotheses to be tested through mechanistic studies and will provide data to better focus toxicology studies. In short, ARIES can provide the underpinning of health-related studies for years to come.

ARIES is a multidisciplinary study in which atmospheric research, epidemiology, exposure assessment, health assessment, and modeling have been considered as parts of the whole from the study's inception (see Figure 1). A further unique aspect of ARIES is that it includes multiple epidemiological studies investigating similar health endpoints in the same study population, thus enabling consistency testing. To preclude “data mining” to support preconceived ideas, the initial analyses were conducted using *a priori* models based on a review of the literature as to what was most supportable at the time. A comprehensive daily monitoring program, described below, has provided epidemiologists with a characterization of aerosol (gas and particle) physical, chemical, and biological (aeroallergenic) properties that had not been available to them before. There are four components of ARIES:

- *Air Quality Characterization:* PM_{2.5} mass and composition, as well as related gas-phase and particle-phase pollutants, are measured every day at the Jefferson Street core monitoring station (shown below in Figure 2) with at least 24-hour time resolution. The air quality field measurements have included SO₂, CO, NO, NO₂, NO_y, O₃, HNO₃, NH₃, and VOCs in the gas phase; major ions, including acidity, elemental/organic carbon (EC/OC), speciated non-polar organic compounds, trace elements, water-soluble transition metals, and solvent-extractable carbon in the particle phase; pollen and mold; and particle

number and size distribution from nanometers to micrometers in diameter. See “ARIES at a Glance,” below for the periods during which specific variables have been measured. The core site measurements are supplemented by a smaller suite of measurements made at three other sites in the Atlanta metropolitan area as part of the Assessment of Spatial Aerosol Composition in Atlanta (ASACA) study.

- *Air Pollution Mortality:* daily mortality data continue to be collected from the three-counties comprising the Atlanta metro area and analyzed in a multi-pollutant time-series study.
- *Air Pollution Morbidity:* daily data on emergency department (ED) visits are collected from 31 hospitals in the Atlanta area. The focus is on ED visits for cardiovascular and respiratory endpoints. A parallel study is also being conducted to understand the influence of daily air quality on unscheduled physician visits at a large health-maintenance organization. Finally, another health component has evaluated the effect of air pollutants in a group of patients with more severe cardiac conditions (those with implanted defibrillators).

- *Exposure & Health Assessment:* a personal/indoor/outdoor exposure assessment study will help the epidemiologists assess how well ambient measurements can represent personal exposures for groups of individuals with recent heart attacks and with chronic obstructive pulmonary disease. This information may also have applications in validation of personal exposure models. The exposure assessment study is also examining associations between personal exposure to air pollution and cardiovascular responses in these participants. The representativeness of the ARIES central monitoring site has been assessed through

Revised 08/31/07

specialized studies of spatial variability utilizing data from the ASACA Study and from governmental air quality networks having stations in Atlanta.



Figure 2. ARIES Central Monitoring Site

Schedule

The first phase, including the full suite of data collection, began in August 1998 and ended in August 2000. ARIES was therefore one of the few studies that were in a position to provide valuable new monitoring and health data in time for EPA’s review of the PM standard. The second phase extended through the end of 2002, creating a 53-month data set. To add even more statistical power and explore interannual trends, most of the air quality and much of the health data collection are planned to continue through 2010.

Collaborations

EPA selected Atlanta as its first designated ‘Supersite’ and conducted an intensive one-month experiment at the ARIES site in August 1999. The cooperative structure of ARIES allows for and fosters collaboration with EPA in integrating these private and public sector experiments. Plans are underway to bring a mobile aerosol particle concentrator and animal exposure laboratory to the ARIES site to investigate toxicological properties of the Atlanta aerosol.

Results to Date

Many scientific papers describing ARIES research findings have been published. These are listed below, and

detailed findings can be found in the papers. Highlights from published findings include:

- Detailed characterization of PM_{2.5} shows carbonaceous matter contributes a significant fraction of the mass.
- There are discrete episodes of elevated ultrafine particle numbers that are believed to be related to anthropogenic emissions.
- PM_{2.5} composition varies hour-to-hour, day-to-day, and season-to-season. Sulfate comprises the largest fraction of PM_{2.5} in summer, while carbonaceous matter comprises the largest fraction in the spring, fall, and winter.
- Daily mortality results show that the best model fits for all-cause mortality in those aged 65 and older are observed for CO, NO₂, PM_{2.5}, coarse PM, SO₂, and ozone, followed by PM_{2.5} elemental carbon (EC) and PM_{2.5} organic carbon (OC).
- Emergency department (ED) visits for cardiovascular disease are associated with NO₂, CO, PM_{2.5} EC, and PM_{2.5} OC.
- ED visits for respiratory diseases are associated with PM₁₀, PM_{2.5}, PM_{2.5} water-soluble metals, ozone, NO₂, CO, and SO₂.
- Associations with cardiovascular ED visits are generally stronger in the cold months.
- Associations with respiratory ED visits, especially asthma, are generally stronger in the warm months.
- Adverse cardiac events in defibrillator patients are associated with coarse PM.
- Ambulatory care visits for child asthma are associated with EC and water-soluble metals; for upper respiratory infections, with SO₂; and for lower respiratory infections, with oxygenated hydrocarbons.
- To date, we see consistency (health endpoint vs. pollutant) across the health studies in the cardiovascular results. Respiratory results are more varied.

Publications

Hansen, D.A.; Edgerton, E.; Hartsell, B.; Jansen, J.; Burge, H.; Koutrakis, P.; Rogers, C.; Suh, H.; Chow, J.; Zielinska, B.; McMurry, P.; Mulholland, J.; Russell, A.; Rasmussen, R. Air Quality Measurements for the Aerosol Research and Inhalation Epidemiology Study. *J. Air Waste Manag. Assoc.*, **2006**, 56(10), 1445-1458.

Klemm, R.J.; Mason, R. M., Jr. Aerosol Research and Inhalation Epidemiological Study (ARIES): air quality and daily mortality statistical modeling - Interim Results. *J. Air Waste Manag. Assoc.*, **2000**, 50, 1433-1439.

Klemm, R.J.; Lipfert, F.W.; Wyzga, R.E.; Gust, C. Daily Mortality and Air Pollution in Atlanta: Two Years of Data from ARIES. *Inhalation Toxicology* **2004**, 16, Supplement 1, 131-141.

Marmur, A.; Park, S.-; Mulholland, J.A.; Tolbert, P.E.; Russell, A.G. Source apportionment of PM_{2.5} in the southeastern U.S. using receptor and emissions-based models: conceptual differences and implications for time-series health studies. *Atmos. Environ.*, **2006**, 40, 2533-2551.

McMurry, P. H.; Woo, K.S.; Weber, R.; Chen, D.-R.; Pui, D.Y.H. Size distributions of 3 to 10 nm atmospheric particles: implications for nucleation mechanisms. *Philosophical Transactions of the Royal Society of London*, **2000**, A358, 2625-2642.

Metzger, K.B.; Tolbert, P.E.; Klein M.; Peel, J.L.; Flanders, W.D.; Mulholland, J.A. Ambient air pollution and arrhythmic events in patients with implanted cardioverter defibrillators, 1993-2002. *Epidemiology*, **2004**, 15(4) 522-523.

Metzger, K.B.; Tolbert, P.E.; Klein M.; Peel, J.L.; Flanders, W.D.; Todd, K.; Mulholland, J.A.; Ryan, P.B.; Frumkin, H.. Ambient Air Pollution and Cardiovascular Emergency Department Visits. *Epidemiology*, **2004**, 15(1): 46-56.

Metzger, .KB.; Klein, M.; Flanders, W.D.; Peel, .JL.; Mulholland, J..A.; Langberg, J.J.; Tolbert, P.E. Ambient air pollution and cardiac arrhythmias in patients with implantable defibrillators. *Epidemiology*, **2007**, 18(5), 585-592.

Peel, J.L.; Tolbert, P.E.; Klein, M.; Metzger, K.; Flanders, W.D.; Todd, K.; Mulholland, J.; Ryan, P.B.; Frumkin, H. Ambient air pollution and respiratory emergency department visits. *Epidemiology*, **2005**, 16(2), 164-174.

Peel, J.L.; Metzger, K.; Klein, M.; Flanders, W.D.; Mulholland, J.; Tolbert, P.E.. Ambient Air Pollution and Cardiovascular Emergency Department Visits in Potentially Sensitive Groups. *Amer. J. Epidemiology*, **2006**, 165, (6) 625-633.

Peel, J.L.; Tolbert, P.E.; Klein, M.; Metzger, K.B.; Flanders, W.D.; Todd, K.; Mulholland, J.A. Further results from a time-series analysis examining the relationship between ambient air pollution and asthma emergency department visits in Atlanta, 1993-2000: ISEE-355. *Epidemiology*, **2003**, 14(5) Supplement: S70.

Sinclair, A.H.; Tolsma, D. Air Pollution and acute cardio-respiratory visits in an ambulatory care setting: Two year and preliminary four year results. *Epidemiology*, **2004**, 15(4) S25.

Sinclair, A.H.; Tolsma, D. Associations and lags between air pollution and acute respiratory visits in an ambulatory care setting: 25-month results from the Aerosol Research and Inhalation Epidemiology Study (ARIES). *J. Air Waste Manage. Assoc.*, **2004**, 54(9), 1212-1218.

Tolbert, P.E.; Klein, M.; Metzger, K.B.; Peel, J.; Flanders, W.D.; Todd, K. ; Mulholland, J.A.; Ryan, P.B.; Frumkin H. Interim results of the Study of Particulates and Health in Atlanta (SOPHIA). *J. Exposure Sci. Environ. Epidemiol.*, **2000**, 10, 446-460.

Tolbert, P.E.; Klein, M.; Peel, J.; Sarnat, S.; Sarnat, J. Multipollutant modeling issues in a study of ambient air quality and emergency department visits in Atlanta. *J. Exposure Sci. Environ. Epidemiol.*, in press.

Tolsma, D.; Sinclair, A.H. Ambient air pollution and acute primary care visits: 53-month follow-up analyses from the Aerosol Research and Inhalation Epidemiology Study. *Epidemiology*, **2005**, 16(5), S93.

Van Loy, M.; Bahadori, T.; Wyzga, R.; Hartsell, B.; Edgerton, E. The Aerosol Research and Inhalation Epidemiology Study (ARIES): PM2.5 mass and aerosol component concentrations and sampler intercomparisons. *J. Air Waste Manage. Assoc.*, **2000**, 50, 1446-1458.

Wade, K.S.; Mulholland, J.A.; Marmur, A.; Russell, A.G.; Hartsell, B.; Edgerton, E.; Klein, M.; Waller, L.; Peel, J.; Tolbert, P.E. Instrument error and spatial variability of ambient air pollution in Atlanta, Georgia. *J. Air Waste Manage. Assoc.*, **2006**, 56, 876-888.

Woo, K.S., Chen, D.R.; Pui, D.Y.H ; McMurry, P.H. Measurements of Atlanta aerosol size distributions: observations of ultrafine particle events. *Aerosol Sci. and Technol.*, **2001**, 34, 75-87.

Zheng, M., Cass, G.R.; Schauer, J.J.; Edgerton, E.S. Source Apportionment of PM2.5 in the southeastern United States using solvent-extractable organic compounds as tracers. *Environ. Sci. Technol.*, **2002**, 36, 2361-2371.

ARIES at a Glance

Sponsors

American Automobile Manufacturers Assoc.
 American Electric Power Service Corp.
 Alabama Electric Cooperative
 Allegheny Energy
 American Petroleum Institute
 BG&E/Constellation
 Central & South West Corp.
 Connectiv
 Detroit Edison
 Duke Energy Corp.
 Dynegy Midwest Generation
 EPRI
 First Energy Corp.
 Great River Energy
 LG&E Energy

Midwest Generation
 Minnesota Power
 National Rural Electric Cooperative Association
 NiSource/NIPSCO
 Oglethorpe Power Corp.
 Reliant Energy HL&P
 Salt River Project
 South Carolina Electric & Gas Co.
 Southern Company
 Tennessee Valley Authority
 TXU Electric
 U.S. Department of Energy
 Wisconsin Electric Power Co.
 WPS Resources
 Xcel

Component Funding (approximate distribution)

Air Quality	\$4.5 MM
Exposure Assessment	\$1.5 MM
Epidemiology	\$4.5 MM

Measurements by Collaborators

Single particle composition and size-resolved particle composition by NOAA
 Continuous PM_{2.5} mass and speciated monitoring at other sites by GIT (ASACA)
 PM density (experimental) by University of Minnesota
 EPA Supersite experiments

Ambient Measurements

Continuous (1-minute average) O₃, NO, NO₂, NO_y, HNO₃, NH₃, SO₂, CO, PM_{2.5} mass, sulfate, nitrate and ammonium, wind speed, wind direction, temperature, relative humidity, barometric pressure, solar radiation, precipitation
 Continuous (10-minute average) Particle-count (0.003 to 3.0 μm) (1998-1999)
 Discrete (24-hour average)
 PM_{2.5} mass, ions, water-soluble metals, trace elements, organic carbon, elemental carbon, speciated non-polar organic compounds (beginning 2006)
 PM_{coarse} mass, ions, water-soluble metals, trace elements
 Pollen and mold (>25 species) (1998-1999)
 VOCs, oxygenated VOCs and multi-phase VOCs
 Ammonia