# Enhancing Air Pollution Exposure Assessment in the 21st Century by Measurement and Modeling

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## Introduction

Exposure assessment is a fundamental element of the risk assessment process and must inform risk management decisions. (Sheldon 2008) To be effectively utilized in air pollution risk assessment and management, exposure science must provide an understanding of human contact with air pollutants at regional, urban, local, and personal scales. For ubiquitous pollutants, like ozone and fine particulate matter, regional scale exposure assessments use data from ambient monitoring networks to represent exposures of interest (either population estimates of the mean or high end exposures). However, pollutants with greater spatial variability in ambient concentrations (such as coarse particulate matter and some particulate matter components or toxic air pollutants) or with significant indoor air sources (such as some air toxics or coarse PM) require more refined estimates of exposure at urban, local, or personal scales. In addition, there is a temporal scale (from minutes to years) component to exposure that is impacted by factors such as emissions, meteorology, and human activities, which requires using a source to dose framework to reduce impact of air pollution exposure. (Lioy 1999)

Exposure assessments may be conducted using measurement data, modeling results, or through a combination of measurements and models. Models are required to estimate exposure when measurement data is insufficient due to spatial or temporal gaps (e.g., for refined local scale assessments) or if an estimate of exposure is required when no measurements exist (e.g., to evaluate alternative risk management options). However, the advanced modeling tools needed for exposure assessments in the future require measurement data for both their development, including exposure information to evaluate models the estimate exposures and dose for similar conditions.. This article discusses why current and future air quality management issues require enhanced exposure assessment approaches, the role of exposure assessment in past monitoring studies, what measurements are needed to enhance exposure models, and new measurement and modeling approaches for estimating human exposures to air pollution.

## The Role of Exposure Assessment in Addressing Air Quality Management Issues

To address today's complex air quality issues we require an improved understanding of exposure because many of these issues involve pollutants with a greater degree of spatial variability. For example, there are questions regarding the possibility of establishing a NAAQS for specific particulate matter components or size fractions. Many particulate matter species exhibit a great degree of spatial variability, especially when associated with size fractions in excess of PM2.5. As a result, monitors sited to represent community average exposures may not adequately characterize exposures. Other air quality issues involve near source risks, such as near a roadway, which require a more refined exposure assessment. Again, because these issues require a more precise estimate of exposure to either inform risk assessment or manage risks, current ambient air monitoring networks will probably not be able to properly characterize exposures.

Therefore, target measurement studies will be needed in conjunction with the application of modeling tools to provide the require exposure assessment information.

The Role of Exposure in Air Pollution Monitoring Studies

Up until recently, very few air monitoring studies have been designed specifically to improve the estimates of exposure from models. Some notable recent examples are the Detroit Exposure and Aerosol Research Study (DEARS) (Williams 2008), the Camden Exposure Study (Wang 2009), and the Relationship of Indoor, Outdoor, and Personal Air (RIOPA) study (Weisel 2005). This is partially due to the fact that, historically, most air pollution measurement programs were primarily focused on measuring air quality concentrations and not exposure. Examples include the Particulate Matter Supersites Program and the Southern Oxidants Study. This was acceptable since most monitoring studies were directed toward understanding atmospheric processes that could impact compliance with ambient or source emissions standards. Further, the personal monitoring studies that were conducted were usually not linked to general air quality monitoring data to determine the degree of uncertainty between such measurements and identify or define the influence of confounders. In the recent reviews of the NAAQS, and in the research agenda established by the NRC for particulate matter in 1998 (NRC 1998), issues surrounding relationships between ambient air monitoring and actual human exposures have been elevated and brought to the attention of the scientific community. As a result, a number of panel studies and air pollution personal monitoring studies have been conducted in recent years to map exposures of various population subgroups to air pollutants, e.g. fine particle and ozone, in indoor and outdoor environments. Over the past 10 years, these studies have yielded information about the key air pollution variables selected for use in "observational" exposure studies and how they can be linked to human behavior and activity patterns that can lead to higher risks for either acute or long term health outcomes. For some ambient air pollutants, e.g. ozone and $PM_{2.5}$, the ambient monitors could be adequate surrogates for most common outdoor exposure – response situations; however, this would not be the case for others, e.g. coarse particles, and air toxics.

Measurements Needed to Enhance Exposure Models

To assess and manage risks associated with current and emerging complex air quality issues will require the development and application of advanced modeling tools developed though exposure science research. Today's modeling tools will evolve into the next generation of models only if targeted measurements are available to better inform their evolution. More refined modeling estimates of ambient air pollution concentrations will require more refined information on neighborhood emission densities and meteorological processes, as well as an improved understanding of the impact of urban topography on the dispersion of air pollution. This type of information will only be obtained through targeted measurement studies. Furthermore, highly-resolved spatial and temporal measurements will be required to evaluate fine scale distributions of levels in ambient air using air quality and exposure modeling tools. The outputs from fine scale models can be linked with human exposure models to produce estimates of actual human exposures needed for risk assessment and risk management. However, while the number of exposure measurement studies has increased, the amount of measurement data available to develop and evaluate human exposure models is still very limited.

Figure 1 presents a hierarchy of exposure metrics needed to enhance exposure science and its assessment. The shape of the figure provides an indication of the relative value of each metric in estimating actual exposures, with those metrics toward the bottom providing being further removed from human exposure. The top three metrics are of relative equal value to indicate that a combination of data on air pollutant concentrations in microenvironments (e.g., indoor at home, school, or work, or in-vehicle), time spent and activities in microenvironments, and personal monitoring is needed to inform human exposure estimates. The challenge ahead is to define the key variables needed to decrease the uncertainty of human exposure to dose models. Initial attempts by Georgopoulos (2005) to complete air pollution source to dose models used ambient air quality data to test the performance of the modeling results obtained from emissions and estimates from the regional scale Community Multiscale Air Quality (CMAQ) model. The use of regional scale modeling, national activity pattern data, i.e. Consolidated Human Activity Database (CHAD), and general inhalation rate and lung deposition information was adequate for the situation that was evaluated, e.g. the Philadelphia metropolitan area. However, for more focused analyses (e.g., local scale hot spots, near industrial source/roadway situations) the level of detail that needs to be collected in the observational exposure studies must be enhanced to address the influence of local scale conditions and activities on human contact with the air pollutants of concern in the local area. In addition, measurement data are needed to improve the understanding of the infiltration of outdoor pollutants (e.g., PM species) into places where individuals spend time (e.g., at home, at work, in-vehicle) and indoor/other (e.g. consumer products, coarse PM, ozone reaction products) sources of the same pollutants. These types of data are necessary for future applications of exposure models to partition outdoor, indoor, transportation and possibly occupational contributions.

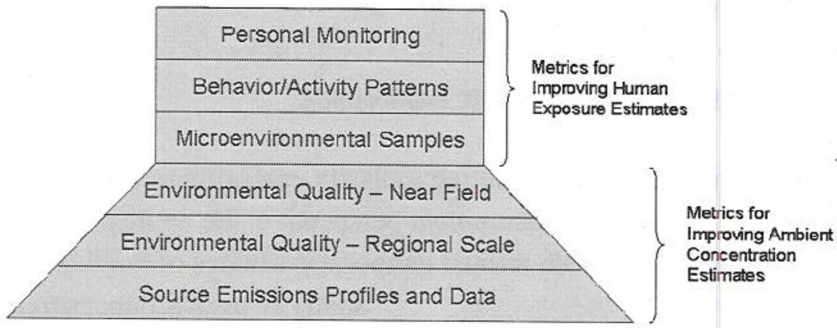


**Figure 1. Heirarchy of exposure metrics (adapted from Lioy, JEAEE 1999)**

Future air pollution exposure studies should collect measurements and other exposure related information that is matched with the needs of models. This is not a trivial issue since the results from many measurement studies have failed to minimally achieve this goal. Included would be the introduction of real time monitors to examine the range and variability in local levels, and simple devices, such as passive monitors to obtain detailed analysis of spatial distributions over time (Zhu 2008). Real time monitors can also provide insights regarding infiltration (Allen 2007) into microenvironments. Real or near real time air pollution measurements at personal and local scales should also be used in parallel with near real time measurements of personal activities and movements (e.g., GPS) to quantify the impact of those personal activities and movements on exposures to air pollution.

New Approaches for Exposure Assessment

New measurement and modeling tools are emerging to improve exposure assessment now and in the future. From the measurement perspective, the application of new continuous monitoring methods will yield more refined temporal estimates of ambient concentrations. In addition, more spatially resolved measurements of pollutants can be made with the emergence of lower cost passive measurement methods (Ott 2008) and remote sensing. New monitoring devices are also emerging to enhance measurements of actual personal exposures (http://www.gei.nih.gov/exposurebiology/program/sensor.asp) and technologies, such as GPS and web-based applications, can improve the understanding of human activities. New modeling approaches are also emerging to improve exposure assessment. The integration of regional-scale and-local scale dispersion models is providing more spatially refined estimates of ambient concentrations (Isakov 2009, Georgopoulos 2005)). However, the performance of these integrated models will still need to be evaluated with the results of much more detailed monitoring studies Spatial and temporal gaps in monitoring data are also being filled through the integration of modeling results with measurement data (McMillan 2009). Finally, advanced human exposure modeling tools are also being developed and linked to air quality dispersion models.

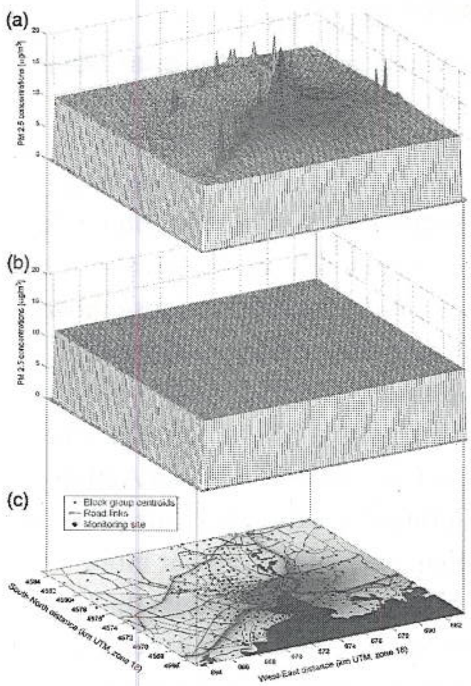


**Figure 2. Combined results (level a) from integrated of regional scale modeling (level b) and local scale modeling (level c). (Isakov, JAWMA 2009)**

Summary

The air quality management issues of the 21$^{st}$ century will present challenges to air quality and exposure communities. To meet these challenges, exposure assessment approaches must be enhanced through improved integration of measurements and models at regional, urban, local, and personal scales. Ambient air measurements must inform the development of new air quality modeling tools, which in turn, must be able to inform human exposure models. In addition, exposure related variables should be included in targeted measurement studies to inform the development of enhanced human exposure models. Advances in both measurement and modeling technologies will support the evolution of better exposure assessments. Though the challenges are significant, these advances are needed to support the risk assessments and risk management programs for protecting public health.

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