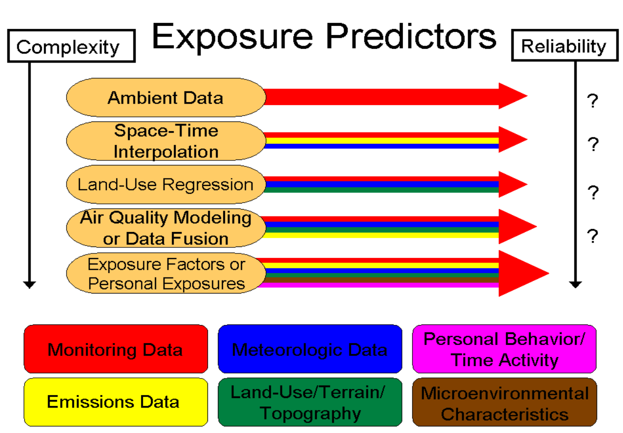
Overview of USEPA/NERL Cooperative Agreement Research Program on Air Pollution Exposure and Health

Halûk Özkaynak[1], Stefanie E. Sarnat[2], Jeremy A. Sarnat[2], Lianne Sheppard[3], Barbara Turpin[4]
Vlad Isakov[1], James Crooks[1], Paul Sampson[3], David Rich[4]
[1] US EPA, Office of Research and Development, RTP, NC USA
[2] Emory University, Atlanta, GA USA
[3] University of Washington, Seattle, WA USA
[4] Rutgers University, New Brunswick, NJ USA

Rationale

- Numerous health studies have used measurements from a few central-site ambient monitors to characterize exposures to air pollution. However, central-site ambient monitors do not account for the spatial and temporal heterogeneity of ambient air pollution and human activity patterns, nor the influence of infiltration indoors and contributions of indoor sources.
- Central-site monitoring becomes even more problematic for certain PM components and species (e.g., EC, OC, , coarse, ultrafine) that exhibit significant spatial heterogeneity.
- Novel approaches have recently been developed to improve exposure assessment for air pollution health studies. These approaches include enhanced estimates of ambient concentrations using both measurements and air quality models, identification of key factors that impact indoor-outdoor and personal-ambient relationships, and probabilistic personal exposure modeling (see Figure 1).

Figure 1. Tiers of exposure predictors applicable for air pollution health studies showing increasing levels of complexity



Background

- USEPA's National Exposure Research Laboratory (NERL) recently initiated a two-year Cooperative Agreement Research Program between EPA and three academic institutions: Emory University, Rutgers University and University of Washington.
- The overall goal of this "Air Pollution Exposure and Health Program" is to enhance the results from epidemiologic studies of ambient PM and gaseous pollution by using refined approaches for characterizing personal and population exposures.
- Under this EPA/NERL sponsored research, novel exposure assessment techniques are currently being evaluated in a complimentary and tiered fashion using several epidemiologic health studies, as summarized in Table 1and further described below.

Table 1. Summary of research performed under the EPA/NERL Air Pollution Exposure and Health Cooperative Agreements

Collaborators	Pollutants	Exposure Approach	Health Study	EPA Role
Rutgers/LBNL	(1)PM2.5 (2)PM2.5 species: EC,OC,SO4, NO3,NH3)	(1)Ambient Monitoring (2)SHEDS (3)Infiltration Model (LBNL) (4)SHEDS-Infiltration Hybrid	(1)NJ MI (2)NJ Birth Outcomes	(1)SHEDS (2)CMAQ*
Emory/Ga Tech	(1)PM2.5 EC (2)CO (3)NOx (4)Ozone	(1)Ambient Monitoring (2)Interpolation (3)CMAQ (4)Mobile Emissions Model (5)CMAQ+AERMOD (6)Air Exchange/Infiltration	(1)Atlanta ED (2)Atlanta ICD	(1)CMAQ (2)AERMOD (3)Data Fusion (4)EMI* (5)SHEDS*
U. Of Washington	(1)PM2.5 (2)NOx*	Assimilated Data from •Ambient •CMAQ+AERMOD** •Spatio-temporal models (GIS & physically-based)	(1)MESA-Air (2)WHI-OS	(1)CMAQ** (2)AERMOD**

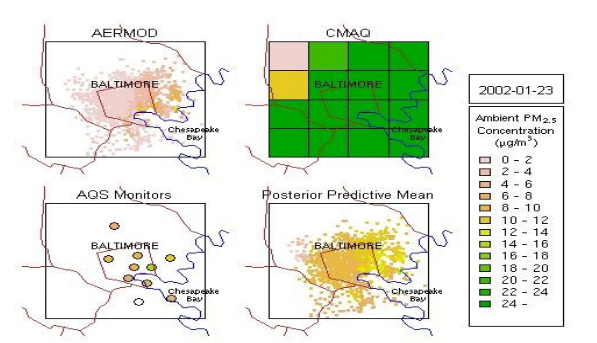
NOTES: * Being considered; ** For selected MESA Cities (e.g., Baltimore, New York City)

Initial Results

Enhanced Characterization of Ambient Concentrations and Exposures

- Measurements and modeling tools are being developed to provide more spatially and temporally resolved estimates of ambient air pollutant concentrations and exposures to ambient PM and co-pollutants. Specifically:
  - Under the University of Washington and Emory Cooperative Agreements techniques have been developed to improve the spatio-temporal resolution of ambient concentrations that account for the influence of various factors including meteorology and emissions from both regional and local sources using CMAQ and AERMOD models
    - In Baltimore, CMAQ $PM_{2.5}$ results, capturing the regional secondary aerosol formation processes, and AERMOD results, capturing local scale emissions of $PM_{2.5}$, were combined with ambient monitoring data from AQS using Bayesian techniques to produce space and time resolved surfaces of $PM_{2.5}$ concentrations (see Figure 2)
    - In Atlanta, model results compare favorably with AQS monitoring data (N≈9 for $PM_{2.5}$ and N≈5 for NO_x) . For $PM_{2.5}$, regional model CMAQ (N=100) alone provides a good agreement with observations, whereas for NO_x, the hybrid model CMAQ+AERMOD (N=225) is necessary to account for near source impacts (see Figure 3)

Figure 2. CMAQ and AERMOD model results predictions for daily $PM_{2.5}$ concentrations in Baltimore and statistical combinations of these with available monitoring data from AQS



EMORY UNIVERSITY

Hypothesis

- Accounting for finer spatial resolution in traffic emissions and differential pollutant infiltration yields different estimates of population exposures
- Refined estimates → greater power to detect epidemiologic associations

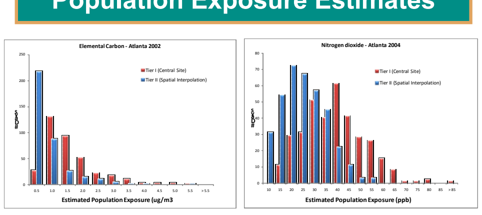
Objectives

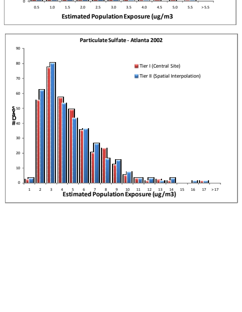
- Aim 1: Develop 5 exposure metrics to address various tiers of exposure refinement:
  Tier I = ambient fixed-site monitoring data
  Tier II = spatially-interpolated ambient monitoring data
  Tiers III – IV = modeled data (CMAQ, AERMOD)
  Tier V = infiltration surrogates to estimate exposures
- Aim 2: Compare estimates of population exposure using the 5 exposure metrics
- Aim 3: Use each exposure metric in epidemiologic analyses and compare effect estimates from models
  - Atlanta emergency department study, 93-04
  - Implantable cardioverter defibrillator study, 93-02

Methods/Approach

Comparing Tier I and II Exposure Estimates (Aims 1 and 2). Daily ambient nitrogen dioxide (NO_2), elemental carbon (EC) and sulfate (SO_4^{2-}) concentrations for 2002 were compared. Tier I estimates were measured at the Jefferson Street site in Atlanta. Tier II estimates were generated using log-transformed, normalized, and inverse distance square weighted ambient concentrations to 660 Atlanta census tracts (Ivy et al., 2008).

Tiers I and II: Comparing Population Exposure Estimates





For NO_2 and EC (spatially-variable pollutants), Tiers I and II yield substantially different estimates of population exposure, with Tier I distributions showing higher means and greater variability than Tier II distributions. For SO_4^{2-} (a spatially-homogeneous pollutant), Tiers I and II yield similar estimates of population exposure.

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Hypothesis

We hypothesize that modification of outdoor $PM_{2.5}$ mass/species concentrations to account for human activity patterns and particle penetration and persistence in indoor spaces will result in less exposure error and bias than the use of central site $PM_{2.5}$ alone, resulting in larger risk estimates, narrower confidence intervals, and better model fits.

Objectives

Hypothesis will be tested using the following:

---------- HEALTH STUDIES ----------

Triggering of Myocardial Infarctions in NJ
Time-stratified case-crossover design
5,864 MI's within 10 km of monitor in NJ

NJ Adverse Birth Outcomes Study
Cohort study, fetal growth restriction
88,678 births within 10 km of monitor in NJ

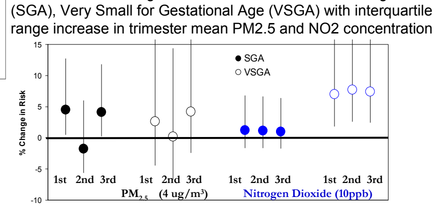
Methods/Approach

---------- EXPOSURE SURROGATES ----------

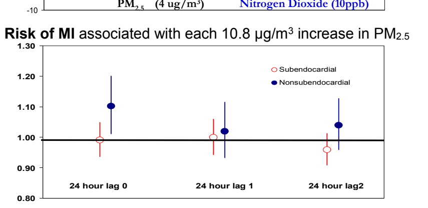
TIER 1: Central site PM2.5 mass, species
TIER 2a: SHEDS
probabilistic, PM of outdoor origin
incl. time activity, outdoor-to-indoor
TIER 2b: Aerosol Penetration and Persistence
physically-based, outdoor-to-indoor
incl. penetration, deposition,
and chemistry (APP)
TIER 3: Hybrid (SHEDS with APP) Approach

Tier I Results:

Birth: Percent change in risk of Small for Gestational Age (SGA), Very Small for Gestational Age (VSGA) with interquartile range increase in trimester mean PM2.5 and NO2 concentration



Risk of MI associated with each 10.8 μg/m³ increase in $PM_{2.5}$



UNIVERSITY OF WASHINGTON

Objectives

Specific Aim 1: To improve exposure models for use in epidemiological studies by developing methods for spatio-temporal prediction that integrate deterministic air quality model output, sub-grid scale predictions, and air quality monitoring data. (current work)
Specific Aim 2: To assess the effect of exposure model enhancements on health effect. (future work)

Aim 1 Hypothesis

Spatio-temporal model predictions can be enhanced by incorporating deterministic air quality model predictions.

Methods/Approach

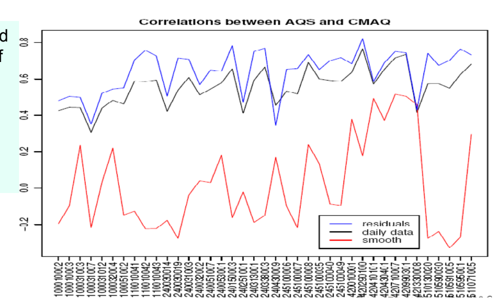
We have combined CMAQ predictions for 2002 in Baltimore with AQS data and assessed their relationship in exploratory analyses.
Work is underway to incorporate these predictions into a spatio-temporal concentration model of the form:

$$C(s_i,t) = \alpha\, m_{j(i)t} + \sum_{h=0}^{H} \gamma_{ih} f_h(t) + \sum_{\ell=1}^{L} \beta_\ell x_{i\ell} + \varepsilon(s_i,t)$$

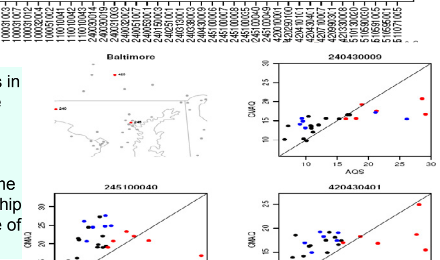
where $C(s_i,t)$ represents measured concentration at time t and location s_i, $m_{j(i)t}$ represents the CMAQ model predictions, $f_h(t)$ represent smooth empirical orthogonal temporal basis functions, and $x_{i\ell}$ are land use covariates, and $\varepsilon(s_i,t)$ is small-scale spatial error.

Example Results: Baltimore

There is good correlation of CMAQ predictions with AQS data on the daily time scale:



Because of differences in seasonal structure, the relationship between CMAQ predictions and AQS data is weaker at the 2-week average time scale and the relationship shows strong evidence of seasonality:

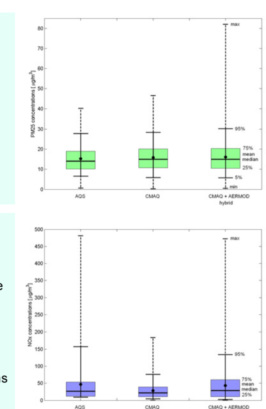


Key: red=summer, blue=winter

Figure 3. Comparison of CMAQ and CMAQ+ AERMOD model predictions of daily $PM_{2.5}$ and NO_x with monitored values from AQS

$PM_{2.5}$ is generally homogeneous across the Atlanta modeling domain but has significant temporal variations. CMAQ is capable of capturing this temporal variability. CMAQ explains most of the observed $PM_{2.5}$ total mass, and AERMOD predicts about 10% of observed total $PM_{2.5}$ mass due to direct emissions from stationary and mobile sources. The combination of CMAQ and AERMOD models shows an increased range in predicted $PM_{2.5}$ concentrations.

Unlike $PM_{2.5}$, NO_x has more significant spatial variation. AQS monitors are impacted by both regional and local emissions of NOx. CMAQ, representing the regional background, can explain the 25-75% range of NO_x concentrations. Combination of CMAQ and local scale modeling by AERMOD is needed to explain the upper end of the NO_x concentration distribution. AERMOD provides estimates of NO_x concentrations due to local sources, such as highways, airport, and industrial facilities.



Conclusions

Depending on the study design, uncertainties in estimating exposures to air pollution can influence the results derived from epidemiologic studies that rely upon available ambient monitoring data. These may be especially important for individual level studies examining health effects due to PM2.5 species and co-pollutants.

Future Plans

- Continue development, refinement and evaluation of alternative measurement and model based exposure metrics.
- Enhance SHEDS model by incorporating exposure factors (i.e., air exchange, penetration and removal rate) information for PM species.
- Apply and evaluate alternative exposure predictors using hospital and cohort health data bases.

References

Ivy, D., J. A. Mulholland, et al. (2008). "Development of ambient air quality population-weighted metrics for use in time-series health studies." J AIR WASTE MANAGE 58(5): 711-720.

Disclaimer

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