Characterizing Population Exposures and Co-Exposures to Ozone and PM2.5 for the City of Philadelphia Using a Source-to-Dose Framework

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by

Sheng-Wei Wang, Qing Sun, Anantharaman Chandrasekar, Vikram Vyas, Pamela Shade, Yu-Ching Yang, and Panos G. Georgopoulos

Computational Chemodynamics Laboratory (CCL)
Environmental and Occupational Health Sciences Institute (EOHSI)
170 Frelinghuysen Road, Piscataway, NJ 0885
Modeling Steps in the Source-to-Dose Analysis

• Estimating the ambient levels of ozone and PM2.5
  • Geostatistical analysis of fixed monitor data
  • Emission-based, regional air quality modeling (UAM-V, CAMx, MAQSIP, Models-3/CMAQ)

• Estimating local outdoor levels of ozone and PM2.5 (such as a census tract)
  • Application of an urban scale modeling
  • Spatial and temporal interpolation (STRF and BME)

• Estimating ozone and PM2.5 levels in microenvironments
  • Observed indoor/outdoor relationships
  • Microenvironmental modeling through mass-balance model

• Developing activity event sequences for each member of the sample population
  • Matching existing database with essential demographics
  • Study-specific information
Modeling Steps in the Source-to-Dose Analysis (Contd.)

- Calculating appropriate inhalation rates for the members of the sample population
- Combining inhalation rates and microenvironmental concentrations for each activity event to assess exposures
- Averaging exposure estimates over time-units (e.g. 1-hour average, 8-hour running average, etc.) characterizing the exposure metric of concern
The Philadelphia Region Case Study

- The case study focuses on a two-week episode between 11 July 1999 and 24 July 1999.
- 482 census tracts were selected in and adjacent to City of Philadelphia. Selection of the census tracts was based on population density and housing characteristics.
- 1990 Census data were used to obtain demographic and housing characteristics.
Calculation of Ambient Outdoor Concentrations

- US EPA’s Community Multiscale Air Quality (CMAQ) model was used to simulate spatial and temporal levels of O3 and PM2.5 for the 36km, 12 km and 4km resolution domains.
- The meteorological inputs were obtained from MM5 simulation.
- The emissions data were processed from the National Emissions Trends (NET) inventory using MCNC’s Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system.
Domain for Regional Meteorological and Air Quality Modeling
Predicted O3 Daily Maximum Concentrations (ppb) for 7/19/1999 for the 12 km resolution (left) and 4 km resolution (right) domains.
Predicted PM2.5 24 Hour Averaged Concentrations (ug/m3) for 7/19/1999 for the 12 km resolution (left) and 4 km resolution (right) domains.
Comparisons of 4km Resolution CMAQ O3 and PM2.5 Predictions with Observation Data for the NE-OPS Baxter Site in Northern Philadelphia
Spatiotemporal Interpolation for Obtaining Census-Tract Level Outdoor Concentrations

- The "Spatio-Temporal Random Field" (STRF) approach interpolates modeling output or monitor data in both space and time simultaneously.
- The "Bayesian Maximum Entropy" (BME) method uses prior information of hard data (measurements or modeling outputs), probability law descriptions, interval information, and physical laws.
Interpolated PM2.5 Outdoor Concentrations for 482 Census Tracts in Urban Philadelphia for 1:00 PM EDT, 19 July 1999 (using the STRF method)
Interpolated O3 Outdoor Concentrations for 482 Census Tracts in Urban Philadelphia for 1:00 PM EDT, 19 July 1999 (using the STRF method)
Calculation of Microenvironmental Concentrations – PM2.5

- For the indoor **non-residential** microenvironments, PM2.5 concentrations are determined by using observed indoor/outdoor relationships.
- For the indoor **residential** microenvironment, a single compartment, *steady-state mass balance equation* (Ozkaynak et. al., 1996) is used.

\[
C_{\text{residential}} = \left( P \times \frac{ach}{(ach + k)} \right) \times C_{\text{ambient}} + \frac{(E_{\text{smk}} \times N_{\text{cig}} + E_{\text{cook}} \times t_{\text{cook}} + E_{\text{other}} \times T)}{(ach + k) \times V \times T}
\]

where
- \( C_{\text{ambient}} \) = ambient outdoor PM concentration (\( \mu g/m^3 \))
- \( P \) = penetration factor (unitless)
- \( k \) = deposition rate (\( h^{-1} \))
- \( ach \) = air exchange rate (\( h^{-1} \))
- \( E_{\text{smk}} \) = emission rate for smoking (\( mg/cig^{-1} \))
- \( N_{\text{cig}} \) = number of cigarettes smoked during model time step
- \( E_{\text{cook}} \) = emission rate for cooking (\( mg/min^{-1} \))
- \( t_{\text{cook}} \) = time spent cooking during model time step (min)
- \( E_{\text{other}} \) = emission rate for other source (\( mg\ h^{-1} \))
- \( T \) = model time step (\( h \))
- \( V \) = residential volume (\( m^3 \))
Calculation of Microenvironmental Concentrations – O3

- The estimation of O3 concentrations in microenvironments are based on the general mass balance equation:

\[ \frac{dC_{in}}{dt} = (F_p)(v)(C_{out}) + S/V - (v + F_d)(C_{in}) \]

  where:
  - \( C_{in} \): indoor concentration (mass/volume)
  - \( F_p \): penetration factor (dimensionless fraction)
  - \( v \): air exchange rate (1/time)
  - \( C_{out} \): outdoor concentration (mass/volume)
  - \( S \): indoor generation rate (mass/time)
  - \( V \): indoor volume (volume)
  - \( F_d \): O\textsubscript{3} decay rate (1/time)
Calculation of Inhalation Rates

- CHAD database
  METs value for time spent in each microenvironment

- PM-SHEDS output: age/gender, particulate matter concentration in air

- ICRP databases: age/gender specific body mass

- ICRP databases: deposition fractions and efficiencies

Empirical physiological model:
Calculates inhalation rate using METs value (regression equations)

Metabolic model: simplified kinetic model for inhalation,
calculates deposition to 3 regions of lungs and total pulmonary burden,
time-dependent dosage for each microenvironment

HUMTRN 2

Plot results as a function of duration of exposure to particulate matter

Particulate matter deposition to nasal-pharyngeal, tracheobronchial, and pulmonary regions of lungs, total pulmonary burden; dose due to time spent in each microenvironment
95th Percentiles of 24 Hour Aggregated Total PM2.5 Doses from All Sources for 19 July 1999 (based on CMAQ outputs and STRF interpolation)
Comparison of 24 Hour Aggregated PM2.5 Doses from Outdoor Sources with Interpolated Outdoor PM2.5 Concentrations

95th percentiles of 24 hour aggregated PM2.5 doses from outdoor sources for 19 July 1999

Interpolated PM2.5 outdoor concentrations by using the STRF method for 1:00 PM EDT, 19 July 1999
Cumulative Distribution of PM2.5 Doses for 482 Census Tracts in Philadelphia

Philadelphia, July 11 – 24, 1999

Potential PM2.5 Dose (ug)

Percentiles

- Total PM2.5 Dose
- Total PM2.5 Dose Due to Outdoor Sources
- Total PM2.5 Dose Due to Indoor Sources
Regression Between 50th Percentiles of PM2.5 Doses and Outdoor Concentrations for 482 Census Tract Data in Philadelphia

- (a) total doses vs. outdoor concentrations
- (b) doses from outdoor sources vs. outdoor concentrations
- (c) doses from indoor sources vs. outdoor concentrations
- (d) doses from indoor source vs. number of smokers per census tract
95th Percentiles of 24 Hour Aggregated Total O3 Doses for 19 July 1999 (based on CMAQ outputs and STRF interpolation)
Comparison of 24 Hour Aggregated O3 Doses from Time Spent Outdoors with Interpolated Outdoor O3 Concentrations

95th percentiles of 24 hour aggregated O3 doses from time spent outdoors for 19 July 1999

Interpolated O3 outdoor concentrations by using the STRF method for 1:00 PM EDT, 19 July 1999
Cumulative Distribution of O3 Doses for 482 Census Tracts in Philadelphia

Philadelphia, July 11 – 24, 1999

- Total Ozone Dose
- Total Ozone Dose Due to Time Spent Outdoor
- Total Ozone Dose Due to Time Spent Indoor

Potential Ozone Dose (ug)

Percentiles
Regression Between 50\textsuperscript{th} Percentiles of O3 Doses and Outdoor Concentrations for 482 Census Tract Data in Philadelphia

- (a) total doses vs. outdoor concentrations
- (b) doses from time spent outdoors vs. outdoor concentrations
- (c) doses from time spent indoors vs. outdoor concentrations
Ratio of Normalized O3 Concentrations to Normalized PM2.5 Concentrations for 18 July 1999

Ratio = nO3/npm25, nO3 = (aO3 − 80)/80, npm25 = (apm25 − 65)/65
Cross-Covariance Between CMAQ Modeled O3 and PM2.5 Concentrations for 11 July 1999 to 24 July 1999
Future Work

• Application of this comprehensive source-to-dose modeling framework to other areas in the U.S.
• Incorporation of the commuting patterns into the framework
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