High Resolution Source Attribution of PM Health Impacts with the CMAQ Adjoint Model

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What is Black Carbon?

- Component of PM$_{2.5}$ produced by incomplete combustion of fossil-fuel, bio-fuel, and open biomass burning.
- Light-absorbing particles
- Commonly called “soot”
- PM$_{2.5}$ mixtures with higher BC percentage may have greater effects on mortality (Cooke et al., 2007)
Where is it Coming From?

EPA AIRNow
June 07, 2011

MODIS
June 07, 2011
Co-benefits of Reducing BC

- Health effects of BC
- Effects on climate change.
- BC is short-lived climate forcer
  - “Reducing black carbon...now will slow the rate of climate change within the first half of this century” (UNEP, 2011).
  - “A small number of emission reduction measures targeting black carbon...could immediately begin to protect climate, [and] public health” (UNEP, 2011).

Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers (UNEP, 2011)
Adjoint Models

• Forward sensitivity analysis are source-based
• Adjoint method provides receptor-based sensitivities
• Adjoint method has 2 main advantages over FD:
  – Quickly calculate sensitivities with respect to all model parameters (sources) at the same time.
  – Don’t need multiple forward runs
Adjjoint Validation

• Validate adjoint by comparing Finite Difference sensitivities to Adjoint sensitivities.

• Finite Difference:
  – Run simulation --> store output values
  – Run simulation after perturbing parameter --> store output values
  – $FD = \frac{(\text{Perturbed output} - \text{base output})}{\text{perturbation}}$

• Adjoint:
  – Specify adjoint forcing (what drives adjoint model)
  – Run simulation
Black Carbon Analysis

AECJ Emissions

AECJ Concentrations
Black Carbon Analysis - Balt.

Health Impact Function: \( \Delta Mort = y_0 (1 - \exp^{-\beta \Delta X}) Pop \)

- \( y_0 = \) baseline mortality rate, 1.02 (Calculated from Maryland Vital Statistics)
- \( \beta = \) Concentration Response Factor, 0.005827 (calculated from Relative Risk from Annenberg et al. 2011. PM\(_{2.5}\) only)
- \( X = \) concentration (microgram per cubic meter for BC)
- \( Pop = \) population, 636,919 (Baltimore, MD. 2008 Maryland Vital Statistics)

\( J = \) Health Impact Function = 2.05

Adjoint model driven by: \[ \frac{\partial Mort}{\partial X} = \beta \cdot y_0 \cdot Pop \cdot \exp^{-\beta X} \]
Sensitivity of mortalities caused by black carbon in Baltimore, MD with respect to black carbon emissions. April 3, 2008, 7:00 PM Local to April 4, 2008, 7:00 PM Local
Black Carbon Analysis - NY

Health Impact Function: \( \Delta Mort = y_0 (1 - \exp^{-\beta \Delta X}) Pop \)

- \( y_0 \) = baseline mortality rate, 0.634 (Calculated from NY Vital Statistics)
- \( \beta \) = Concentration Response Factor, 0.005827 (calculated from Relative Risk from Annenberg et al. 2011. PM\(_{2.5}\) only)
- \( X \) = concentration (microgram per cubic meter for BC)
- \( Pop \) = population, 8,363,710 (NY, NY. 2008 New York Vital Statistics)

\( J = Health\ Impact\ Function = 36.96 \)

Adjoint model driven by: \( \frac{\partial Mort}{\partial X} = \beta * y_0 * Pop * \exp^{-\beta X} \)
Sensitivity of mortalities caused by black carbon in New York, NY with respect to black carbon emissions. April 3, 2008, 7:00 PM Local to April 4, 2008, 7:00 PM Local

\[
\frac{\partial J}{\partial E_{i,j,k}} \times \frac{E_{i,j,k}}{J} \times 100\%
\]
Summary

• Adjoint of CMAQ aerosol module has been developed and validated for black carbon.

• Sensitivities with respect to emissions have been obtained for single day simulations for Baltimore, MD and New York city.
  – Mortalities in Baltimore caused by exposure to black carbon most sensitive to emissions in Baltimore down through DC.
  – Mortalities in New York city caused by exposure to black carbon most sensitive to emissions in New York City and and into Newark and New Brunswick, NJ.
Future Work

• Expand Black Carbon simulation time period to 4 months.
  – Average over 4 day periods (atmospheric lifetime of BC).

• Run simulations for various regions and cities.
  – Requires gridded baseline mortality rates and gridded populations for cost functions consisting of a range of cells.