Determining the Effects of Grid Resolution on Marginal Damages of BC Emissions as Quantified by Adjoint Sensitivities

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Component-Specific Health Impacts

Percent increase in health effects estimates for cardiovascular hospitalizations (A) and respiratory hospitalizations (B) (Bell et al., 2009)
Where is it Coming From?

Daily Average PM$_{2.5}$ AQI
Tuesday, June 07, 2011

MODIS
June 07, 2011

EPA AIRNow
June 07, 2011
Adjoint Models

• Forward sensitivity analysis are source-based
• Adjoint method provides receptor-based sensitivities
• Main advantage of adjoint method over FD:
  – Quickly calculate sensitivities with respect to all model parameters (sources) at the same time.
Cost Function for National Premature Deaths

\[ J = \sum_{i=1}^{N} \text{Mort}_i \times (1 - e^{-\beta \times C_{av,i}}) \]

\[ \frac{\partial J}{\partial C_{i,t}} = \frac{\text{Mort}_i}{T} \times \beta \times e^{-\beta \times C_{av,i}} \]

- \( \text{Mort} \) = gridded annual premature deaths in the US
- \( C_{av} \) = gridded annual average concentration
- \( T \) = number of timesteps in a year
- \( i \) = grid cell index
- \( N \) = total number of grid cells for which cost function is calculated
- \( \beta \) = concentration response factor, 0.005827 (Krewski et al., 2009)
- \( t \) = timestep index
Forward Model Simulations

Forward simulations run from Dec. 21, 2006 to Dec. 31, 2007

Annual average BC concentration

Gridded annual premature deaths associated with exposure to BC

12,600 (8,600 - 16,500) total premature deaths
Sensitivity of BC Health Impacts - Definitions

- 12 1-week adjoint simulations performed for the first week of each month
- $\frac{\partial J}{\partial E_{i,k}} = $ Resulting sensitivities averaged and scaled to yearly
- $\frac{\partial J}{\partial E_{i,k}} * E_{i,k} = $ Contributions: semi-normalized sensitivities with respect to emissions scaling factors
- $\frac{\partial J}{\partial E_{i,k}} * \frac{E_{i,k}}{J} * 100\% = $ Contribution percentage: fraction of contribution from sectoral emissions in a single grid cell to sum of sectoral contributions
- $\frac{E_{i,k}}{\sum E_{i,k}} * 100\% = $ Emission percentage: fraction of sectoral emissions in a single grid cell to sum of sectoral emissions.
Cost Function (number of premature deaths attributed to exposure to BC in continental US) = 12,600 (8,600 - 16,500) mortalities in 2007
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12km BC Health Impact Analysis

Sectoral Emissions

- Onroad Diesel
- Nonroad Mobile
- Nonpoint
- Rail
- Onroad Gasoline
- Non-EGU
- Fire * 0.5
- EGU
- Non-US Nonroad / Nonpoint

Gg/year

Sectoral Contribution

Contribution of Emissions to Mortalities

SON JJA MAM DJF

Contribution of Emissions to Premature Deaths

SON JJA MAM DJF

0 10 20 30 40 50

0 500 1000 1500
Effects of Grid Resolution on Estimates of Premature Deaths

Percent difference between all-cause mortality estimate at 12 km resolution and regridded to coarser resolutions
(Punger and West, 2013)

Percent difference in mortality between regridded resolution and fine model resolution (Li et al., submitted)
# of Premature Deaths

12km: 12,600
(8,600 - 16,500)

36km: 9,500
(6,500 - 12,500)
Effects of Grid Resolution on Spatial Distribution of Premature Deaths

# of Premature Deaths: 12km regridded - 36km

# of Premature Deaths
12km regridded to 36km: 10,200 (7,000 - 13,400)
36km actual: 9,500 (6,500 - 12,500)
Effects of Grid Resolution on Spatial Distribution of Contributions

12km - 36km, 1 month simulation

# of Premature Deaths
12km: 12,600 (8,600 - 16,500)
36km: 9,500 (6,500 - 12,500)
Sectoral Resolution Analysis

12km - 36km Percent Contribution

More Deaths in 36km

More Deaths in 12km

- Onroad Diesel
- Nonroad Mobile
- Nonpoint
- Rail
- Onroad Gasoline
- Non-EGU
- EGU
- Fire
- Non-US Nonroad / Nonpoint
- Dust
- Non-US Onroad
- Commercial Marine
- Non-US Point

Percent
Conclusions

- Premature death estimates at coarser resolution lower than at 12km resolution.
- Coarser resolution adjoint simulations underestimate contributions from emissions in urban centers.
  - Overestimate contributions from emissions along I-95 corridor.
- Contributions from point sources have positive bias at coarser resolutions.
- Benefits of source attribution of BC health impacts at 12km (over 36km) using adjoint sensitivities do not outweigh the extra computational cost of simulation.
  - Results for 12km sectoral breakdown of contributions within uncertainty range of 36km analysis.