Modeling air pollution health impacts with \texttt{INMAP}

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https://github.com/spatialmodel/inmap
Reduced-complexity models

- Orders of magnitude faster than CTMs
- Much easier to use than CTMs
- Less accurate than CTMs
InMAP methodology

1. emissions
   InMAP reads annual total emissions from an arbitrary shapefile and allocates them to the model grid.

2. concentrations
   InMAP calculates annual average changes in PM$_{2.5}$ concentrations caused by the input emissions.

3. exposure
   InMAP estimates changes in human PM$_{2.5}$ exposure caused by the input emissions using census data.

4. health impacts
   Using epidemiological concentration-response functions, InMAP calculates the health impacts of the emissions.

5. economic damage
   Optionally, health damages can be converted to economic damages using a Value of Statistical Life metric.

6. environmental justice
   InMAP calculates how different demographic groups are exposed to PM$_{2.5}$ even when the groups live in adjacent neighborhoods.
InMAP (Intervention Model for Air Pollution)

\[
\frac{\partial C_i}{\partial t} = \nabla \cdot (D \nabla C_i) - \nabla \cdot (\vec{v} C_i) + \sum_{j=1}^{n} R_{i,j} + E_i - d_i
\]

http://inmap.spatialmodel.com

Performance evaluation
Comparison of total (primary plus secondary) area-weighted (black dots) and population-weighted (blue triangles) annual average predicted PM$_{2.5}$ concentration change for WRF-Chem (x axis) and either InMAP or COBRA (y axis) for 11 emissions scenarios.

Concentrations are normalized so that the largest value in each comparison equals one.

Comparison of WRF-Chem and InMAP performance in predicting annual average observed total PM$_{2.5}$ concentrations. The background colors in the maps represent predicted concentrations, and the colors of the circles on the maps represent the difference between modeled and measured values at measurement locations.

Applications
Applications: Effects of spatial resolution

Differences by race-ethnicity and resolution in: (a) average PM$_{2.5}$ exposure and (b) PM$_{2.5}$ exposure disparity (i.e., difference in average exposure for a population subgroup relative to whites).

Marginal damages of emissions ($/t·1) by emitted pollutant and emission location (log scale). The values do not represent the location where impacts occur, but instead represent the combined damages attributable to a source of one tonne of emissions at the location.

Cumulative damages by pollutant and distance of impacted population from sources of anthropogenic emissions. The black dashed line at 32 km from the source represents 50% of total damages.

Overall exposure and minority-white exposure disparity by source category. The source categories are ranked vertically according to the absolute value of the resulting exposure disparity, which is proportional to the area of each rectangle.

PM$_{2.5}$ concentrations resulting from emissions from each emitter group (maps on left); relationships among health impacts as attributed to emitters (left bar), end-uses (middle bar), and end-users (right bar).

Ongoing efforts

- Comprehensive chemical transport models are unwieldy but relatively accurate
- Reduced-complexity models are much faster but less accurate
- What if we could make a model that was as accurate as a comprehensive CTM but much faster?
Chemical mechanism surrogate model

Left: Time required for one million independent simulations using either CBM-Z using one CPU core, the neural network using one or eight CPU cores, and the neural network using one GPU. Right: Comparisons of CBM-Z and neural network simulated diurnal O\textsubscript{3} concentrations for representative initial conditions.

Conclusions

• InMAP and other RCMs are more practical for routine use than CTMs
• ...with a loss of accuracy that is an acceptable trade-off in many use cases.
• We are working on improving the accuracy.
Thank you

More information:

- https://github.com/spatialmodel/inmap
- http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0176131
- https://groups.google.com/forum/#!forum/inmap-users
- ctessum@uw.edu

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Supplemental Information
InMAP formulation

- Emission
- Advection + Mixing
- Reaction
- Deposition
- Exposure + Health Effects
Emission

- "VOC", "NOx", "NH3", "SOx", and "PM2_5"
- **Shapefile** format
- Annual total
- Can include stack "height", "diam", "temp", and "velocity" [m, m, K, and m/s].
Advection + Mixing

- Annual average wind speeds
- Parameters for wind "meandering" and sub-grid mixing
Reaction

- InMAP only considers chemistry related to PM$_{2.5}$ (no O$_3$)
- NH$_3$ $\leftrightarrow$ particulate NH$_4$
- NO$_x$ $\leftrightarrow$ particulate NO$_3$
- VOC $\leftrightarrow$ SOA
- SO$_x$ $\rightarrow$ particulate SO$_4$
- Primary PM$_{2.5}$ stays that way
Deposition

- Dry deposition (collisions with surfaces)
- Wet deposition (absorption into clouds + droplet scavenging)