Modeling air pollution health impacts with 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

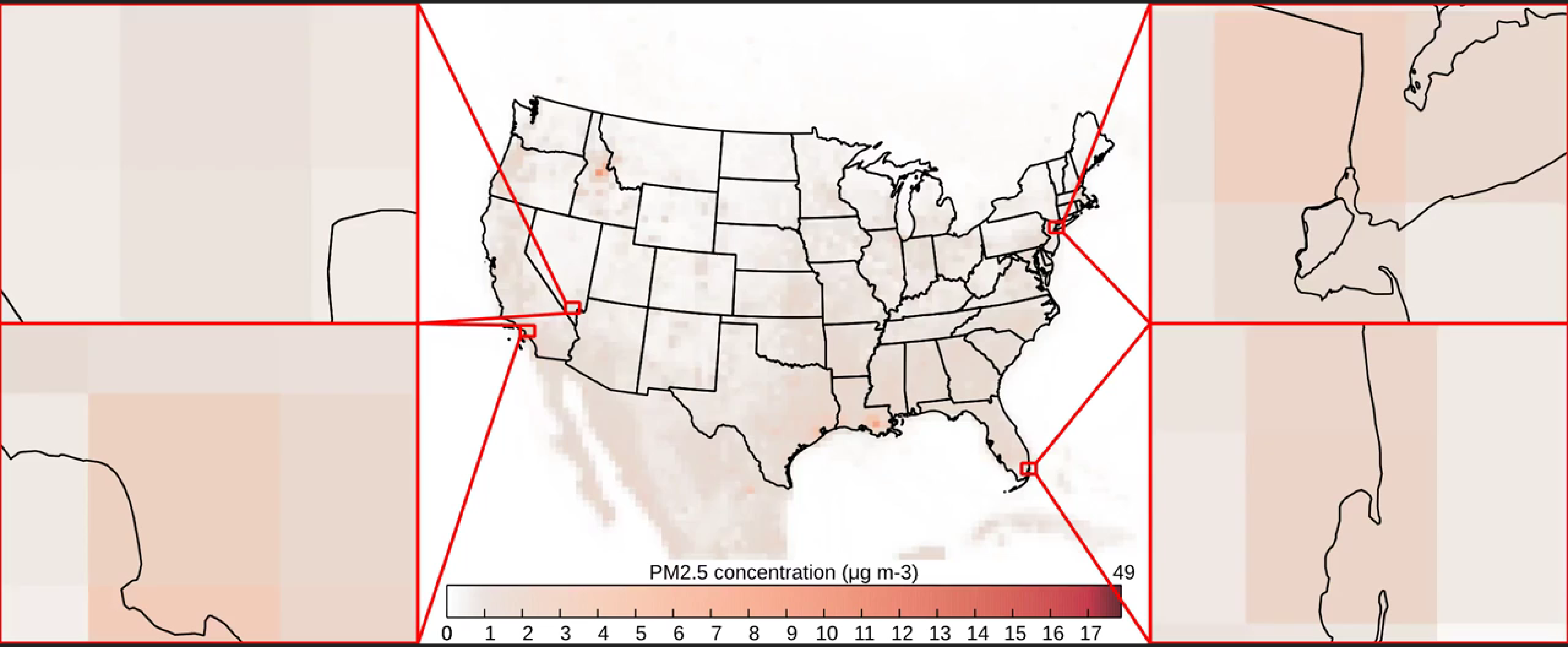
InMAP calculates how different demographic groups are exposed to $PM_{2.5}$ even when the groups live in adjacent neighborhoods.

InMAP (Intervention Model for Air Pollution)

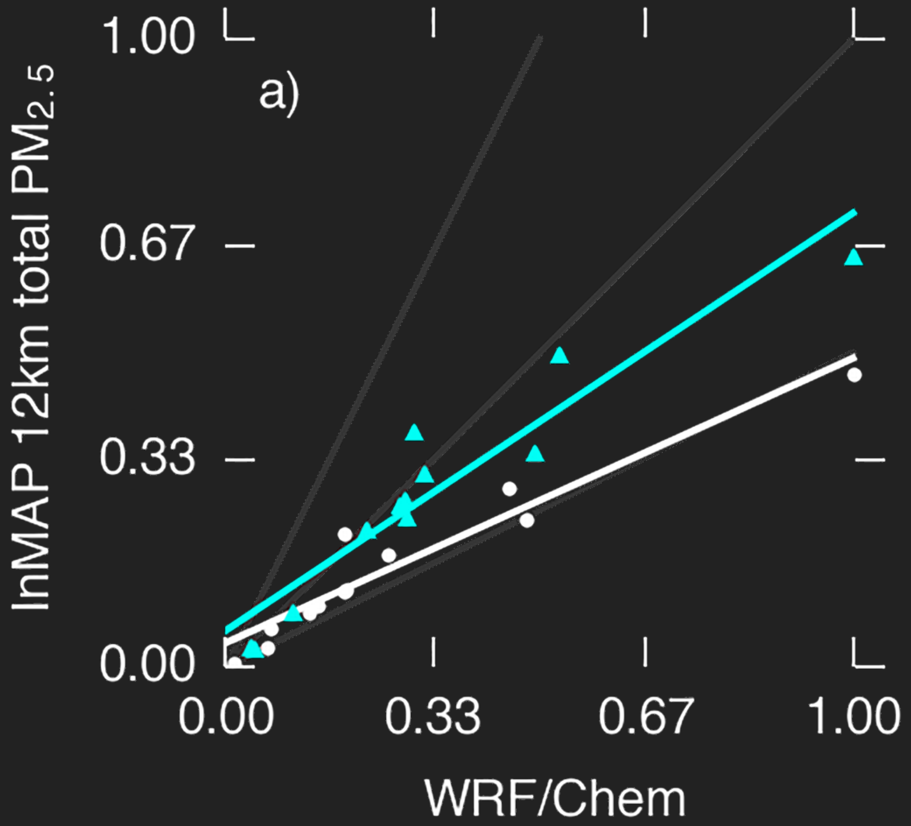
$$\frac{\partial C_i}{\partial t} = \nabla \cdot (D \nabla C_i) - \nabla \cdot (\vec{v} C_i) + \sum_{j=1}^{n} R_{i,j} + E_i - d_i$$

http://inmap.spatialmodel.com

Tessum, C. W.; Hill, J. D.; Marshall, J. D. InMAP: A model for air pollution interventions. *PLoS ONE* **2017**, *12* (4), e0176131 DOI: 10.1371/journal.pone.0176131.


PM2.5 concentration (µg m-3)
49
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

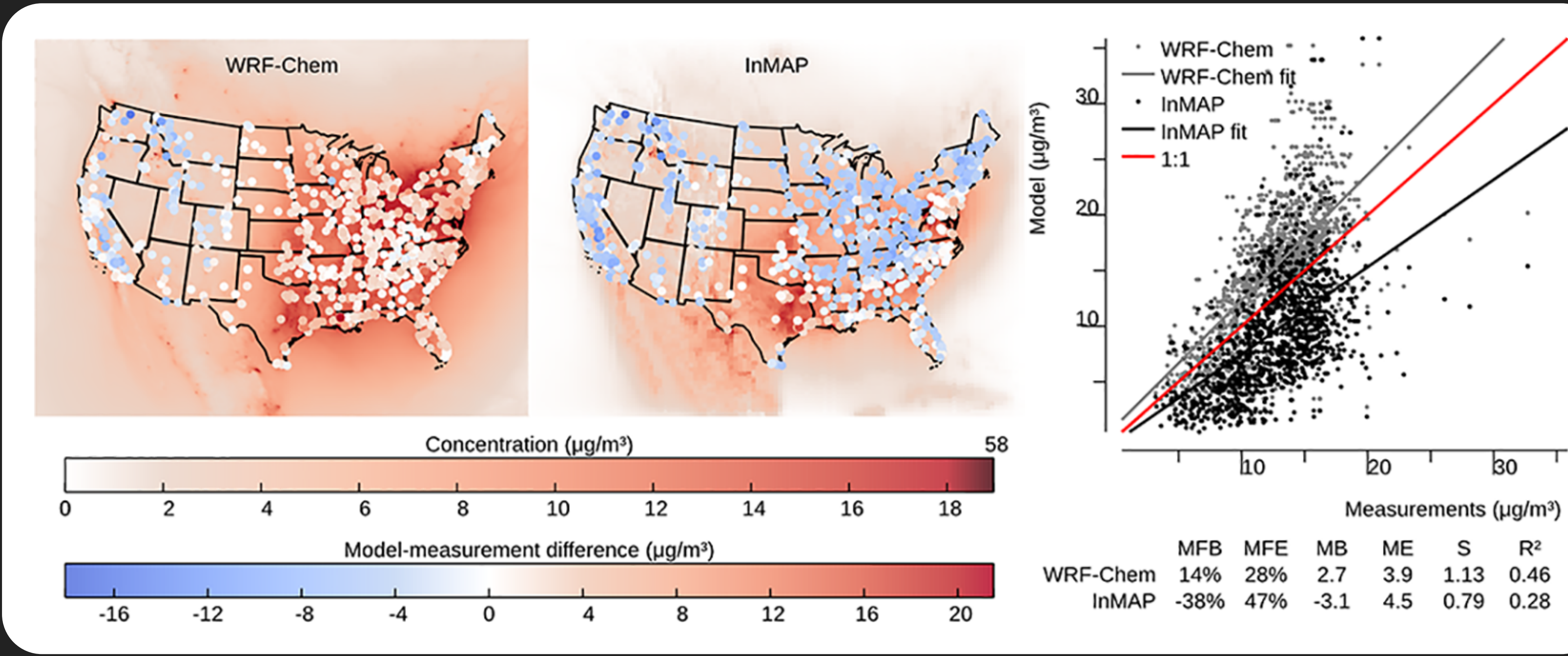
Performance evaluation



	MFB	MFE	MR	R^2	S
Area:	-46%	48%	0.65	0.92	0.45
People:	-17%	20%	0.86	0.90	0.66

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.

Tessum, C. W.; Hill, J. D.; Marshall, J. D. InMAP: A model for air pollution interventions. *PLoS ONE* **2017**, *12* (4), e0176131 DOI: 10.1371/journal.pone.0176131.

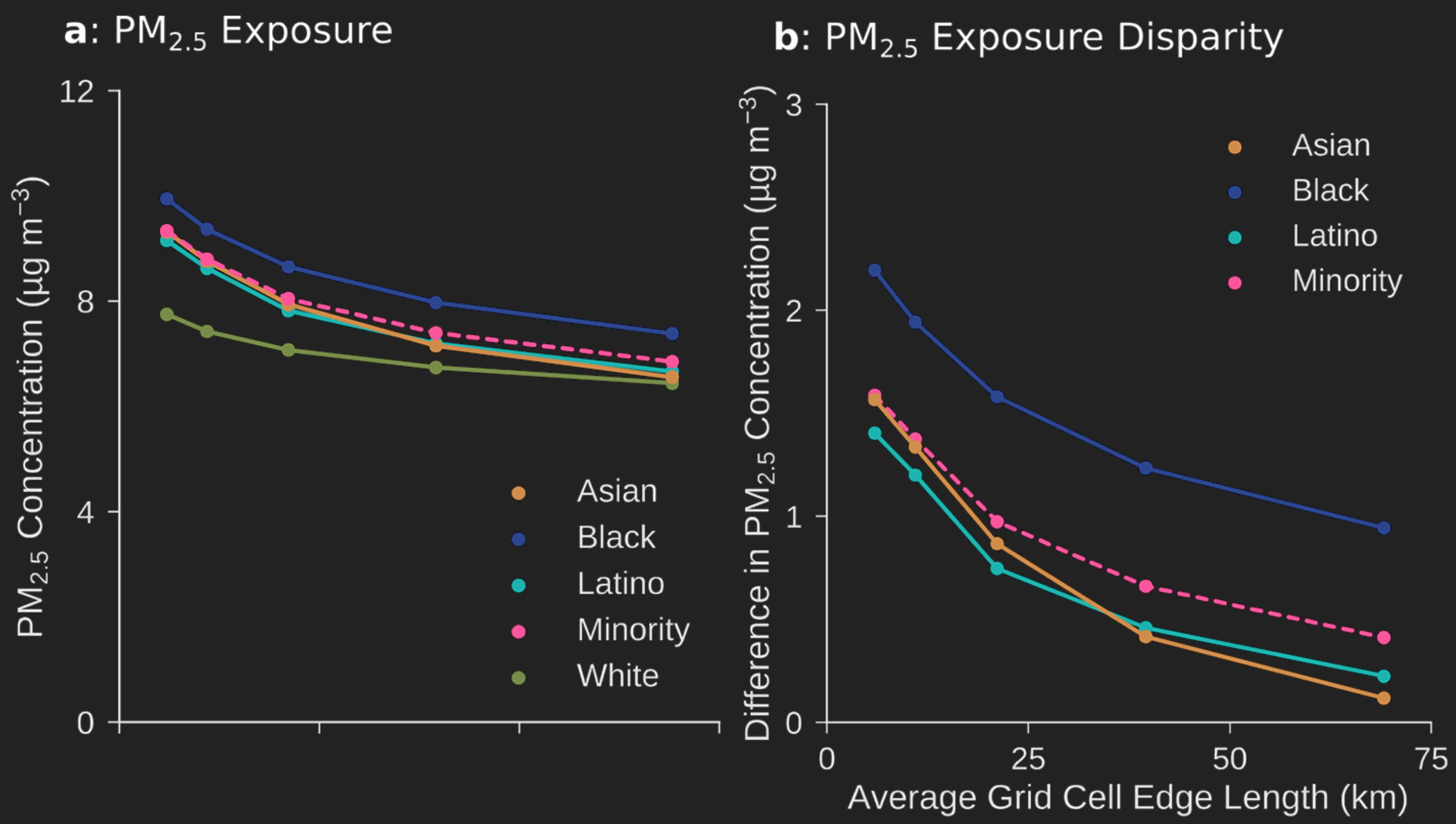


Comparison of WRF-Chem and InMAP performance in predicting annual average observed total $PM_{2.5}$ concentrations. The background colors in the maps represent predicted concentrations, and the colors of the circles on the maps represent the difference between modeled and measured values at measurement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

Tessum, C. W.; Hill, J. D.; Marshall, J. D. InMAP: A model for air pollution interventions. *PLoS ONE* **2017**, *12* (4), e0176131 DOI: 10.1371/journal.pone.0176131.

Applications

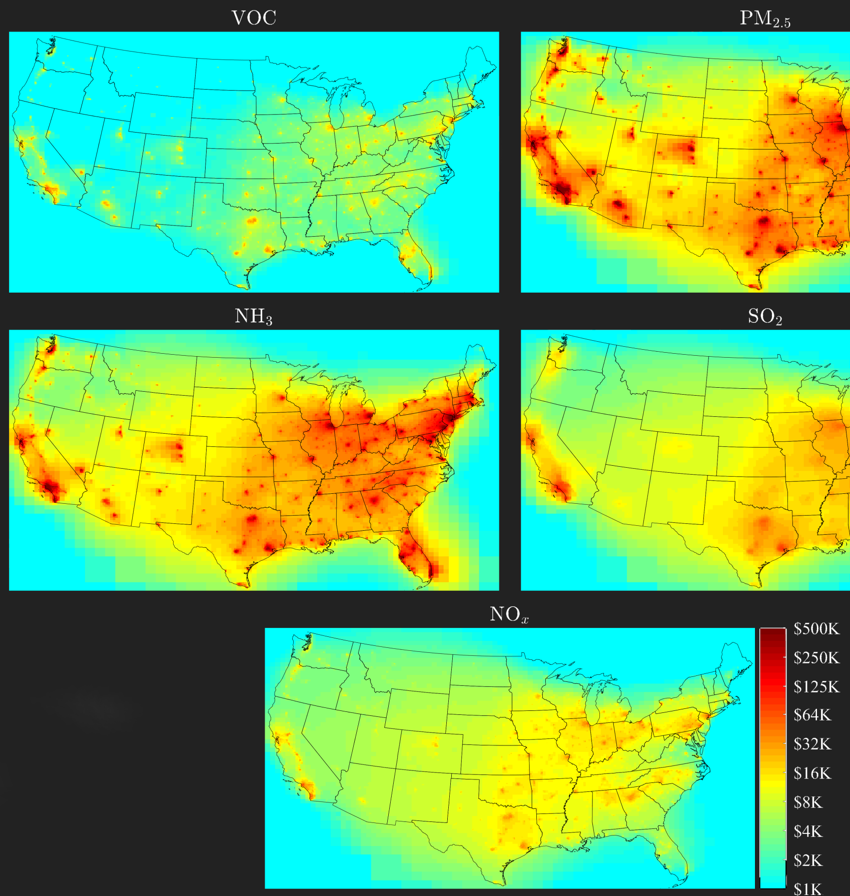
Applications: Effects of spatial resolution



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).

Paolella, D., C.W. Tessum, P. Adams, J.S. Apte, S. Chambliss, J.D. Hill, N. Muller, and J.D. Marshall (2018) Effect of Model Spatial Resolution on Estimates of Fine Particulate Matter Exposure and Exposure Disparities in the United States. *Environ. Sci. Technol. Lett*. **5**:7 436–441 .

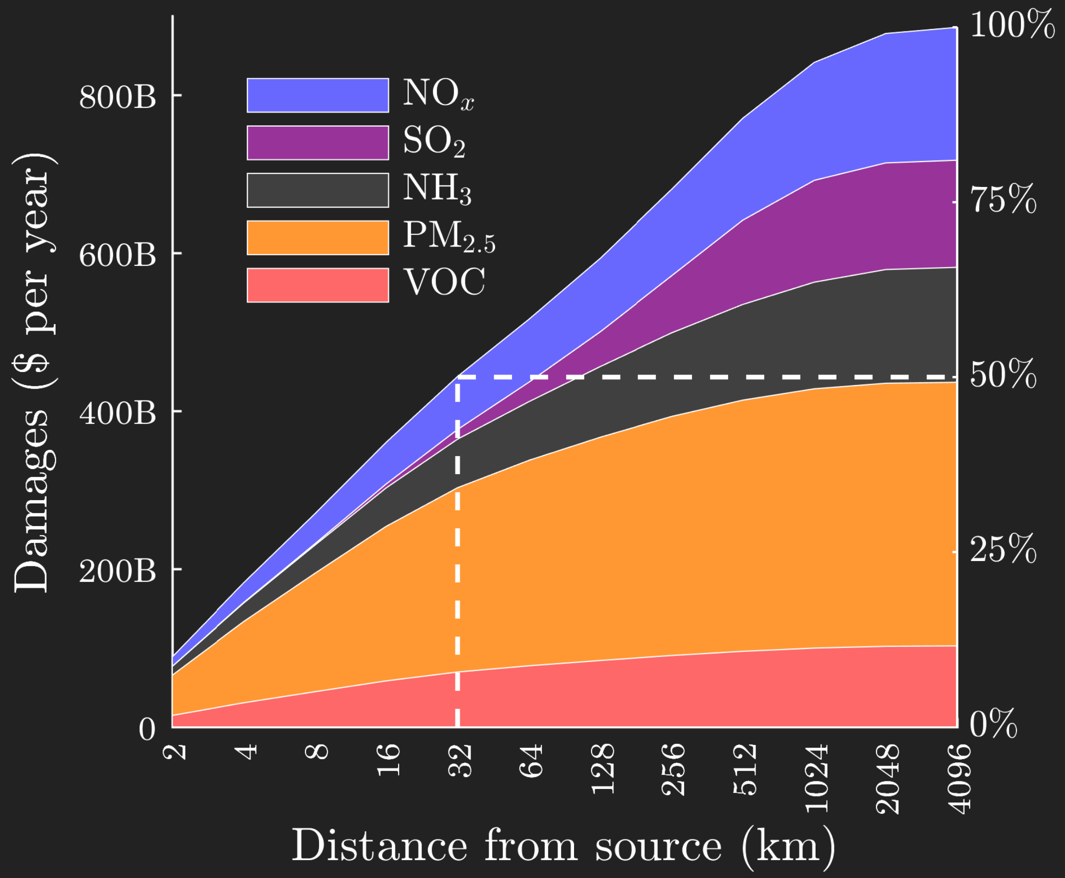
Applications: Source-receptor matrix (ISRM)



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.

Goodkind, A.L., C.W. Tessum, J.S. Coggins, J.D. Hill, and J.D. Marshall. Fine-scale, source-specific damage estimates of fine particulate matter pollution in the United States. *In review*.

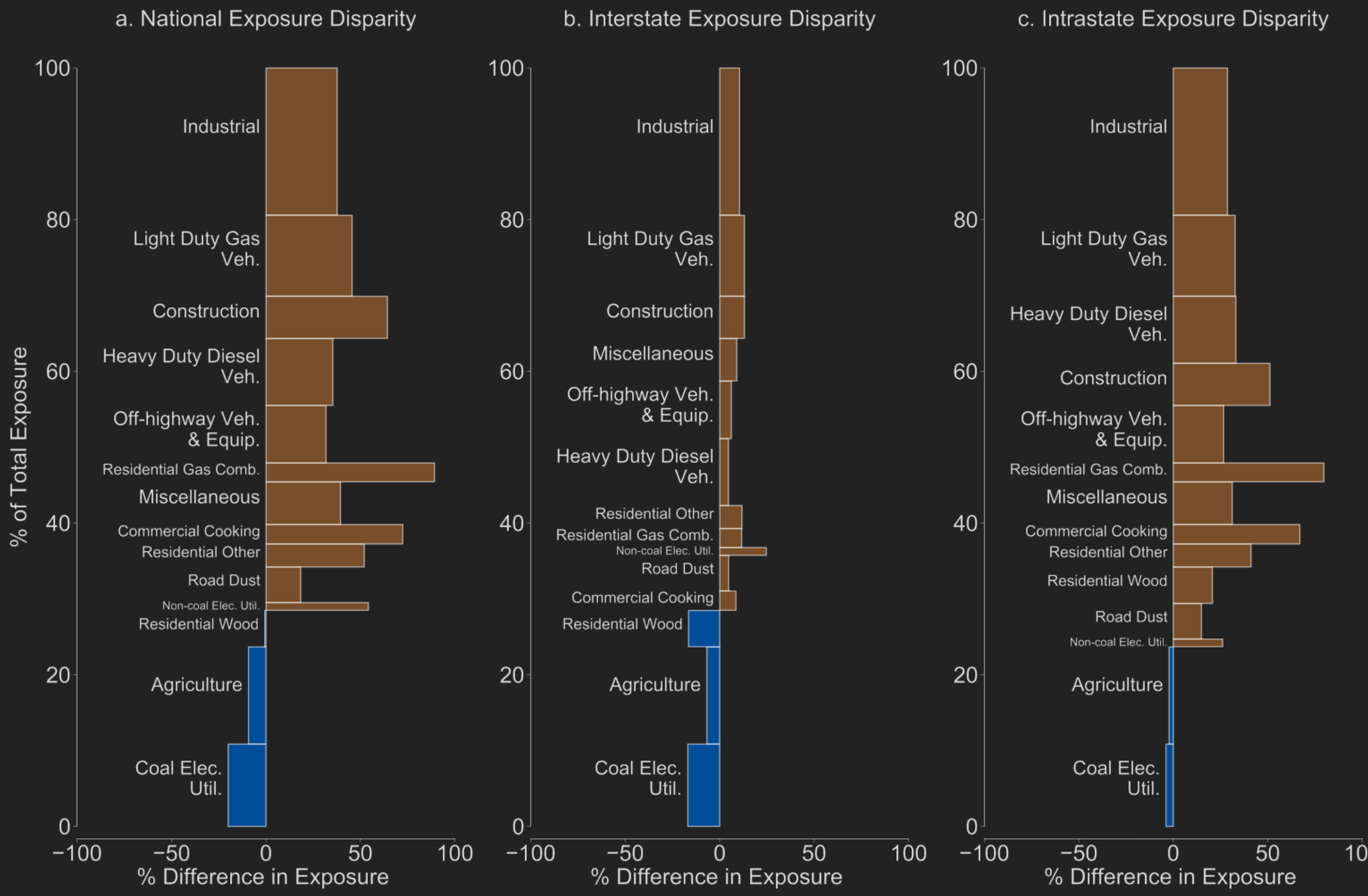
Applications: Source-receptor matrix (ISRM)



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

Goodkind, A.L., C.W. Tessum, J.S. Coggins, J.D. Hill, and J.D. Marshall. Fine-scale, source-specific damage estimates of fine particulate matter pollution in the United States. *In review*.

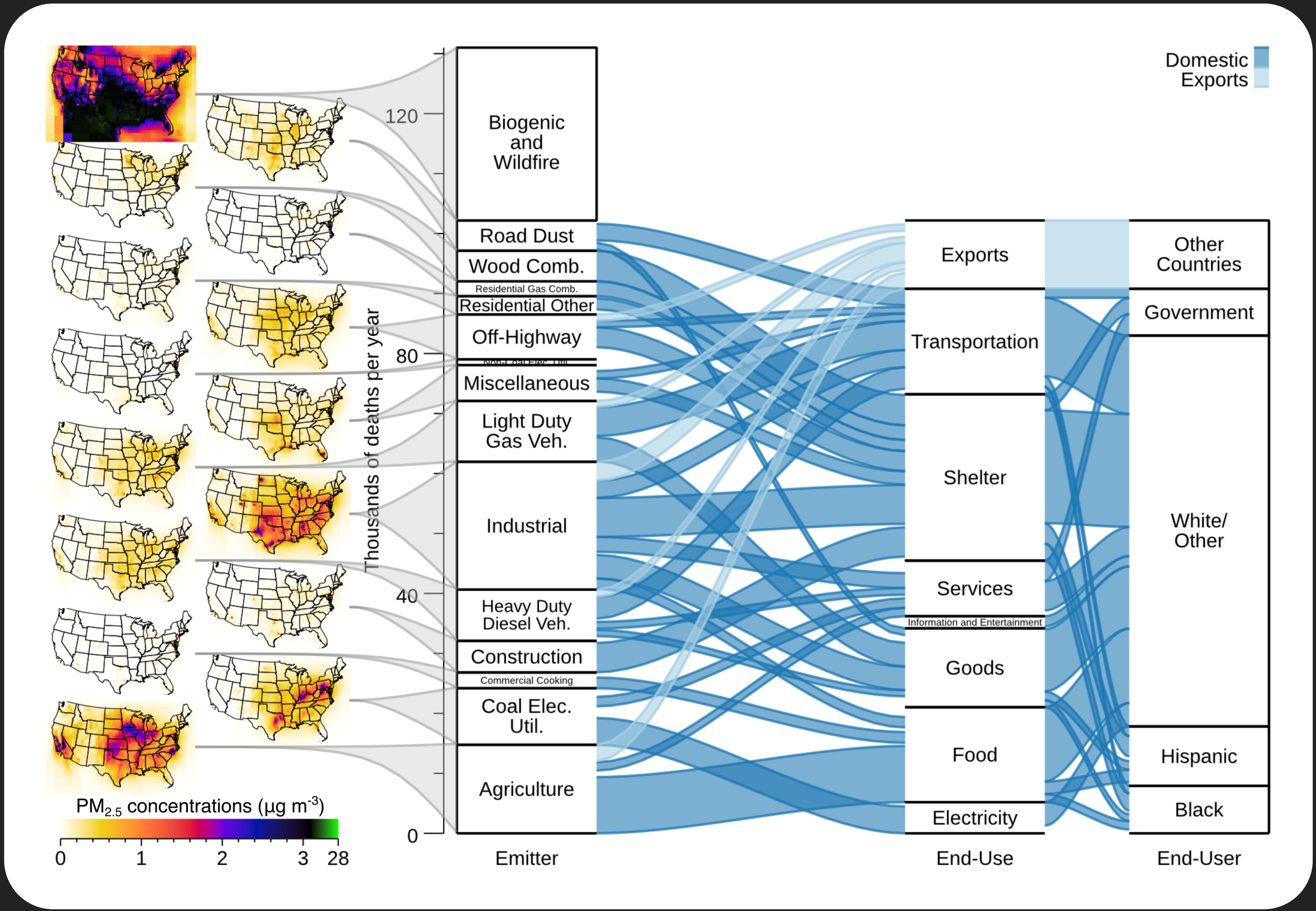
Applications: Environmental inequity



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.

Paolella, D.A., C.W. Tessum, J.D. Hill, and J.D. Marshall. Sources of racial inequity in fine particulate air pollution exposure in the United States. *In preparation*.

Applications: Model coupling



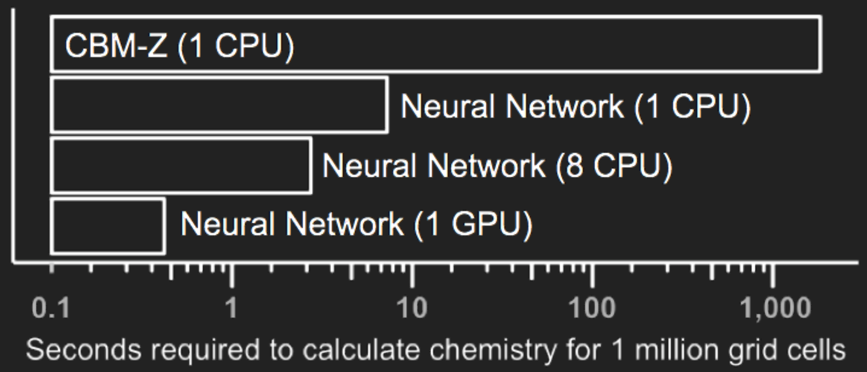
$PM_{2.5}$ concentrations resulting from emissions from each emitter group (maps on left); relationships among health impacts as attributed to emitters (left bar), end-uses (middle bar), and end-users (right bar).

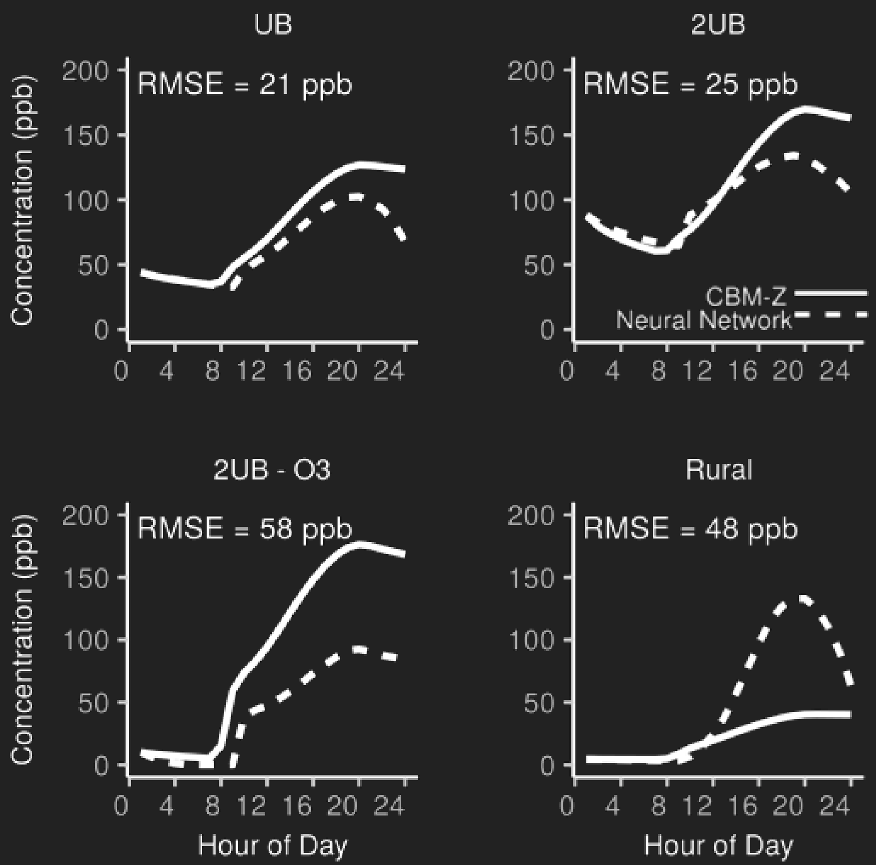
Tessum, C.W., J.S. Apte, A.L. Goodkind, N.Z. Muller, K.A. Mullins, D.A. Paolella, S. Polasky, N.P. Springer, S.K. Thakrar, J.D. Marshall, and J.D. Hill. Inequity in consumption widens racial-ethnic disparities in air pollution exposure. *Submitted*.

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_3 concentrations for representative initial conditions.

Kelp, M., C.W. Tessum, and J.D. Marshall. Orders-of-magnitude speedup in atmospheric chemistry modeling with a neural network-based surrogate model. *Submitted*. https://arxiv.org/abs/1808.03874 .

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)
- $NH_3 \leftrightarrows$ particulate NH_4
- $NO_x \leftrightarrows$ particulate NO_3
- VOC $\leftrightarrows$ 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)