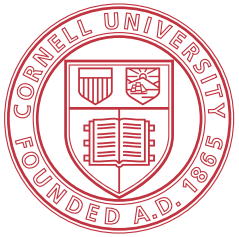

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Air Pollution Social Cost Accounting

with High Spatial, Sectoral, and Temporal Resolutions

Jinhyok Heo[1], Peter J. Adams[2,3], and H. Oliver Gao[1]

[1] School of Civil and Environmental Engineering, Cornell University
[2] Department of Civil and Environmental Engineering, Carnegie Mellon University
[3] Department of Engineering and Public Policy, Carnegie Mellon University

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Current Methods of Identifying $PM_{2.5}$ Sources

- Receptor Models: Chemical Mass Balance (CMB), Positive Matrix Factorization (PMF)
  $\Rightarrow$ limited spatial/sectoral/temporal resolutions
- Chemical Transport Models (CTMs): Brute-force method, Tagging method
  $\Rightarrow$ computationally expensive

New: The Air Pollution Social Cost Accounting Model

- quantifies sources of $PM_{2.5}$ social costs and their contributions
  $\Rightarrow$ spatially resolved for the entire U.S. domain,
  $\Rightarrow$ temporally resolved for four seasons,
  $\Rightarrow$ sectorally resolved for emission inventory's resolution.

Social Cost of Emissions

$$\text{Social Cost}\ [\$] = (\Delta \text{PM}_{2.5}) \times (\text{Concentration-Response Relation}) \times (\text{Value of Statistical Life})$$

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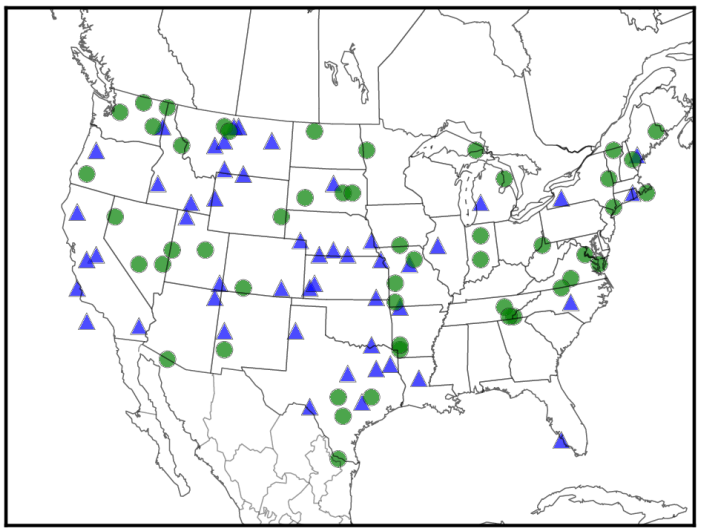
The Estimating Air pollution Social Impact Using Regression (EASIUR) model



▲ : Training sample ● : Test sample

- 100 random locations
  - 50 for building model
  - 50 for out-of-sample test
- CTM generated a large dataset (∼30 TB)
  - CAMx with tagging (PSAT)
  - 2005 emissions and meteorology
- Regression derived parameterizations

Per-tonne Social Cost [\$/t] = f (Exposed Population, Atmospheric Variables)

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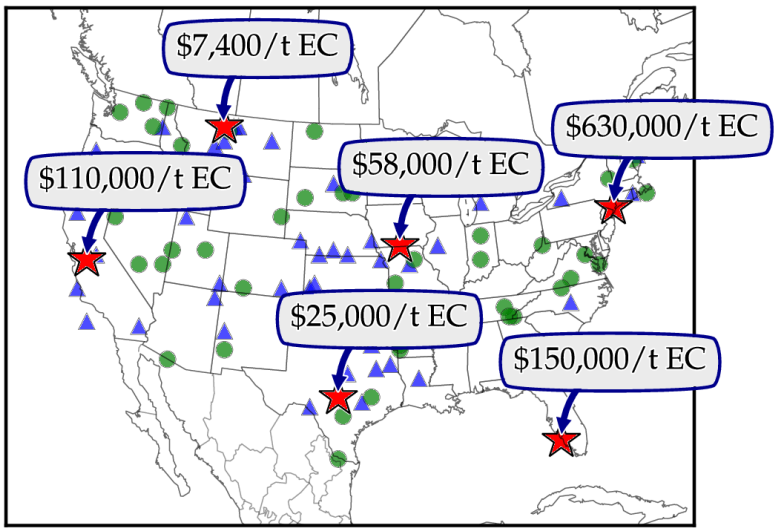

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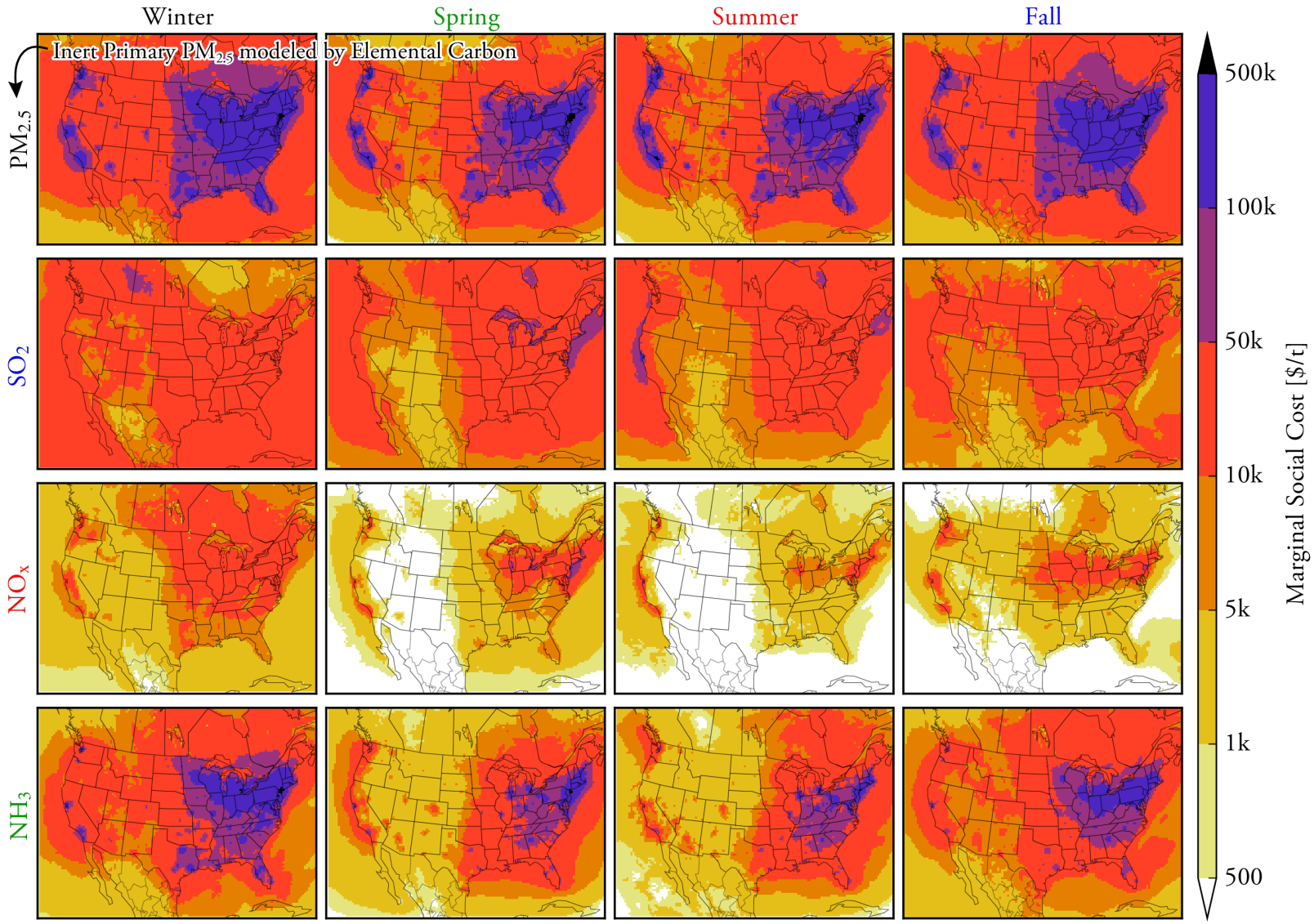
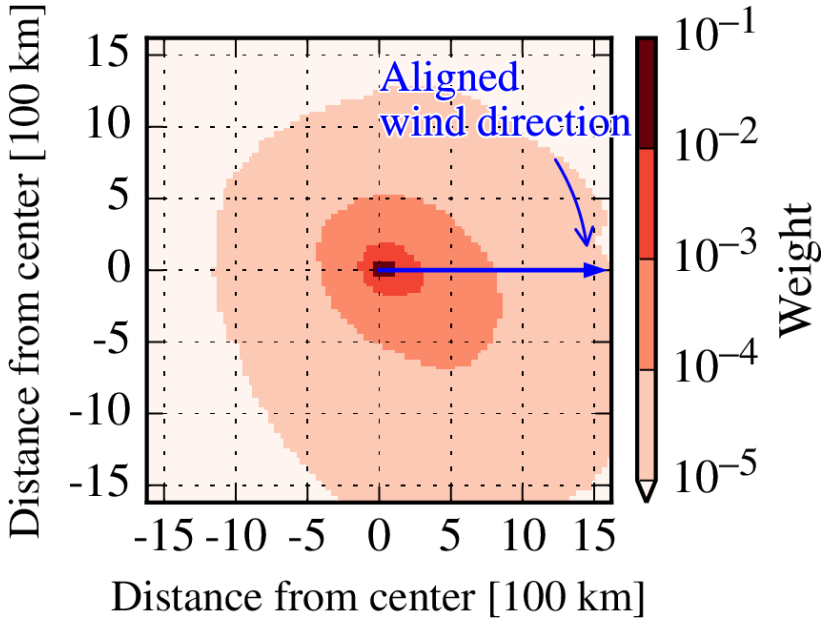
EASIUR's Marginal Social Costs [$/t] at the Point of Emissions



This is for ground-level emissions. We have two more for 150 m and 300 m emission elevations.

Average Plumes for Quantifying Exposed Population



(a) EC Average Plume (Summer)

- averaged CTM results of 50 sample locations.
- normalized an average plume created from CTM results.
  $\sum_{x,y} \text{Weight}_{x,y} = 1.0$
- used to express exposed population in regression
  $\text{Exposed Population} = \sum_{x,y} \left(\text{Wind-Direction-Adjusted Weight}_{x,y} \times \text{Population}_{x,y} \right)$

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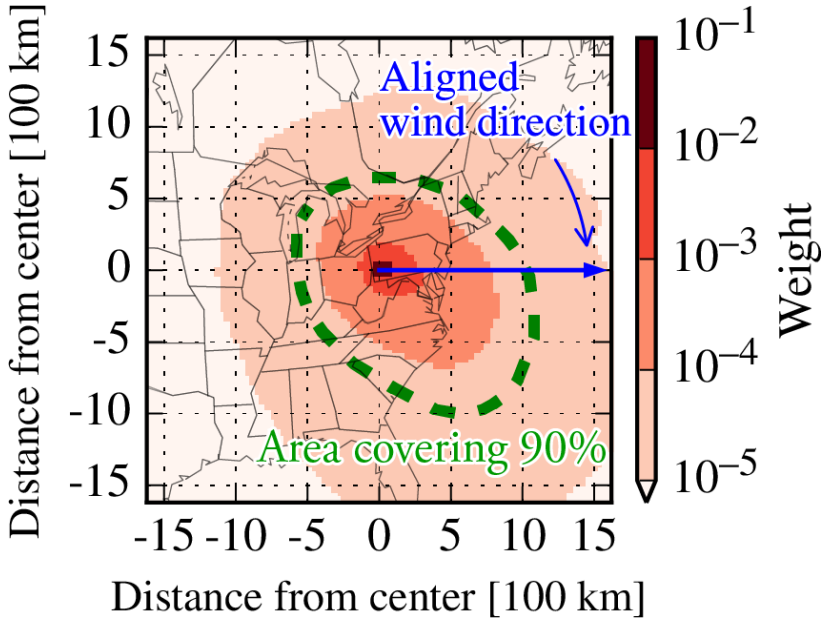

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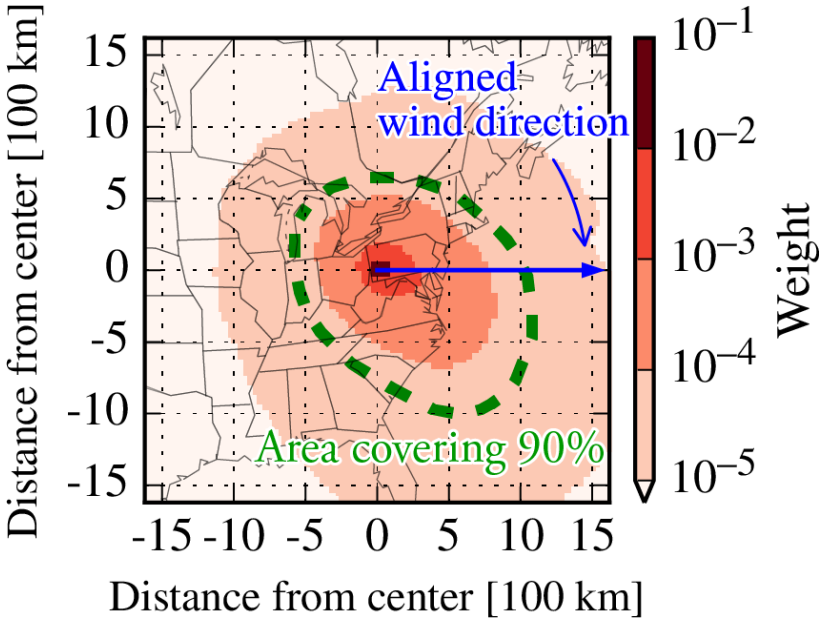

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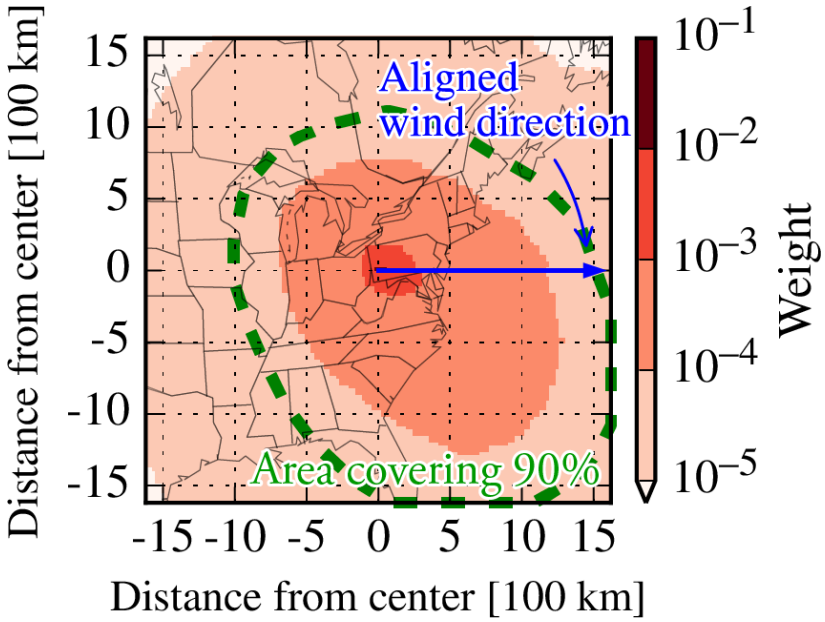

(b) SO_2 Average Plume (Summer)

- averaged CTM results of 50 sample locations.
- normalized an average plume created from CTM results.
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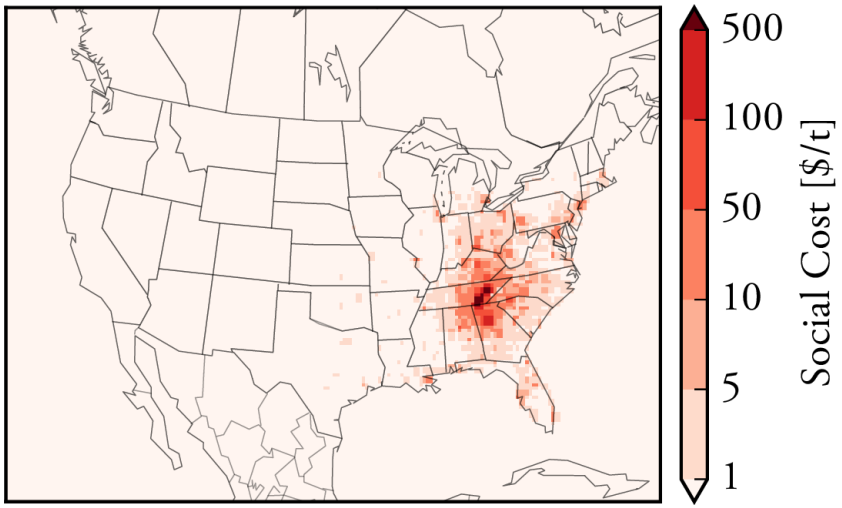
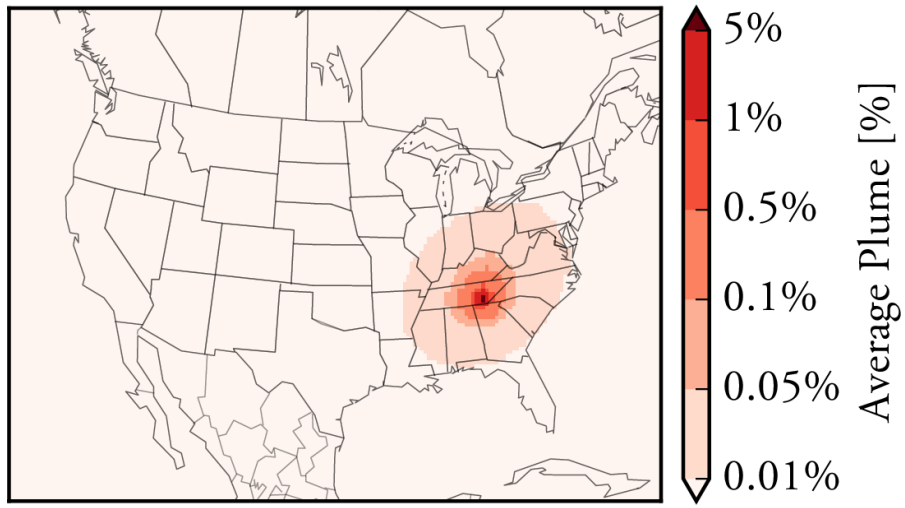
New: The Air Pollution Social Cost Accounting Model

- Key idea: spatially distribute EASIUR's social costs with population-weighted average plumes.

Social costs originated from EC at one out-of-sample location (Chattanooga, TN):



v.s.



by a sophisticated CTM (CAMx)

Average plume

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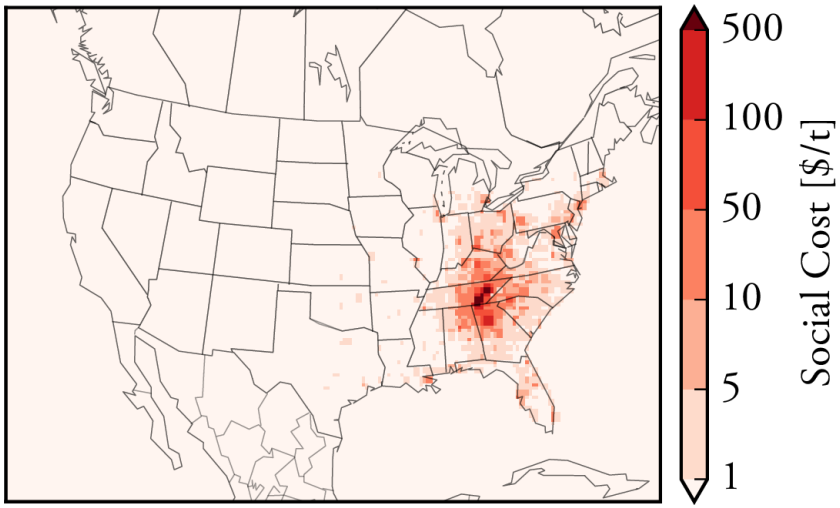

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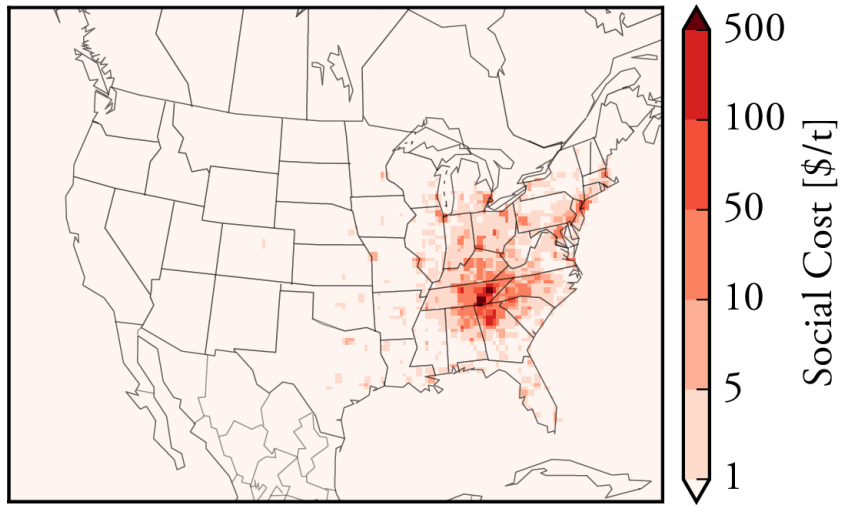

by population-weighted average plume

Evaluation: CTM v.s. New Method

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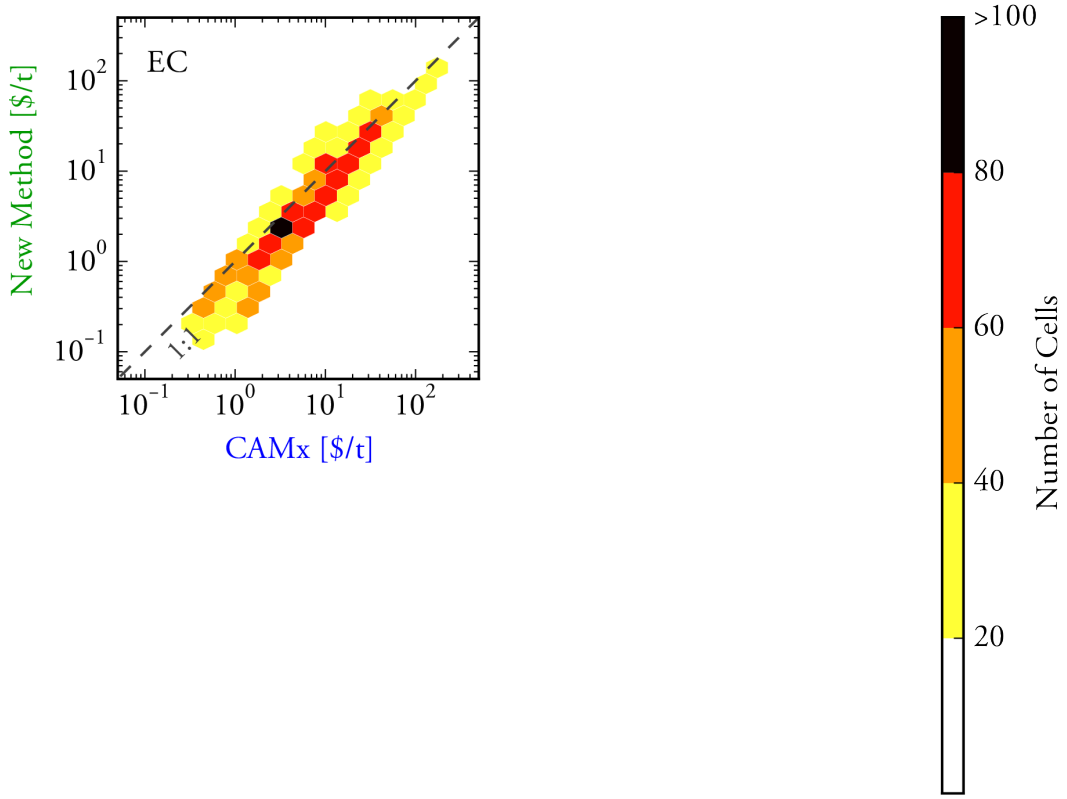
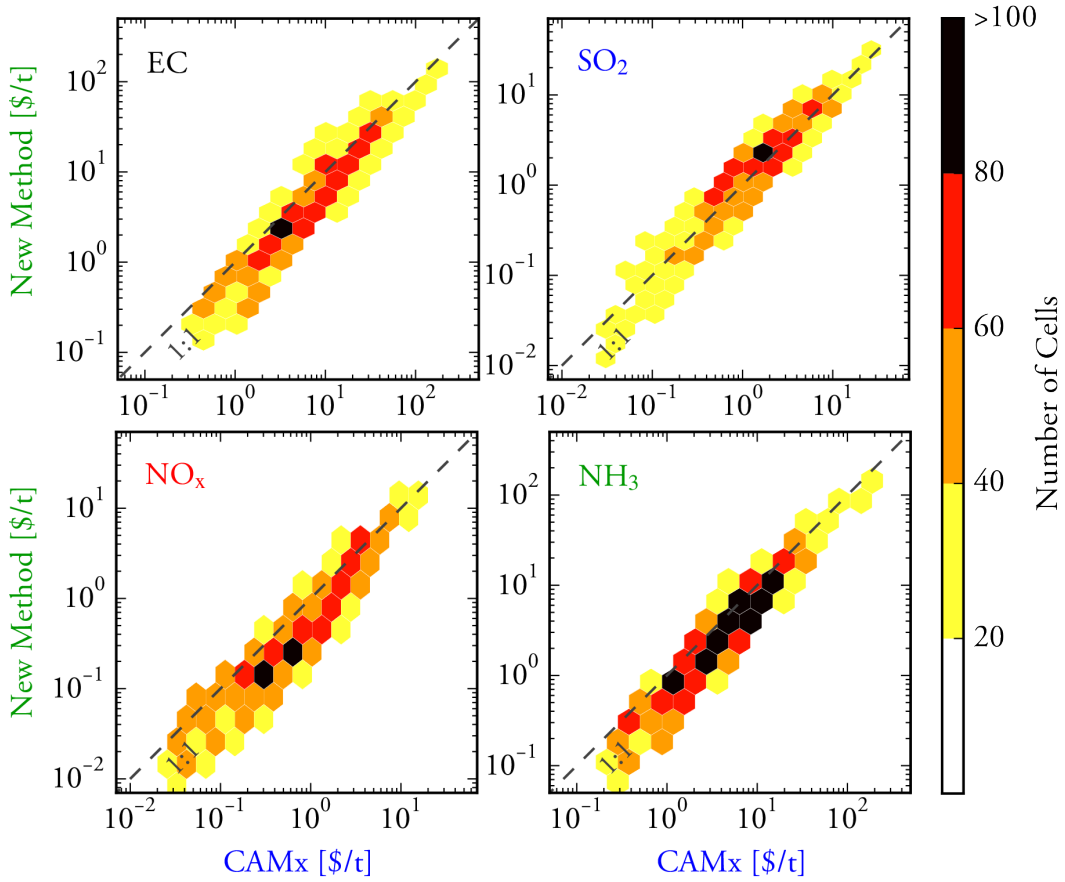


Evaluation: CTM v.s. New Method

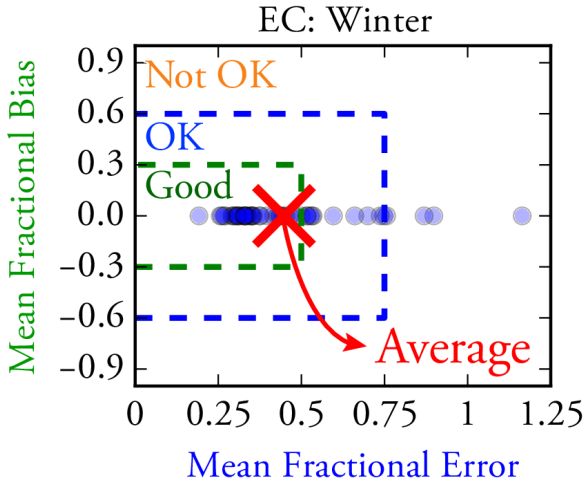
- Key idea: spatially distribute EASIUR's social costs with population-weighted average plumes.

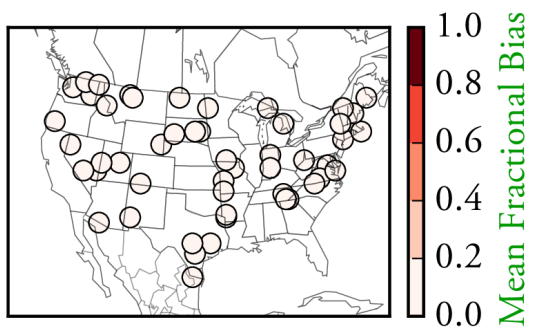
Social costs originated from EC, SO_2, NO_x, NH_3 at Chattanooga, TN:

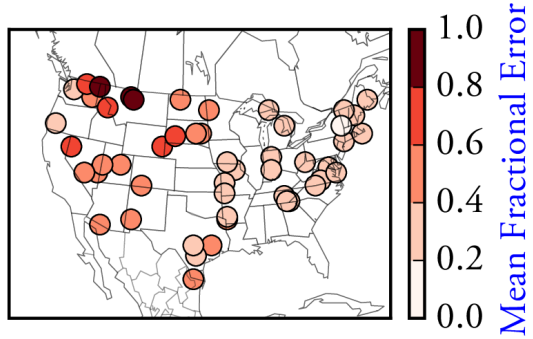


Evaluation: Winter EC at 50 out-of-sample locations

- Common evaluation metric for air quality models (Boylan and Russel, 2006)
  - Mean Fractional Bias
  - Mean Fractional Error







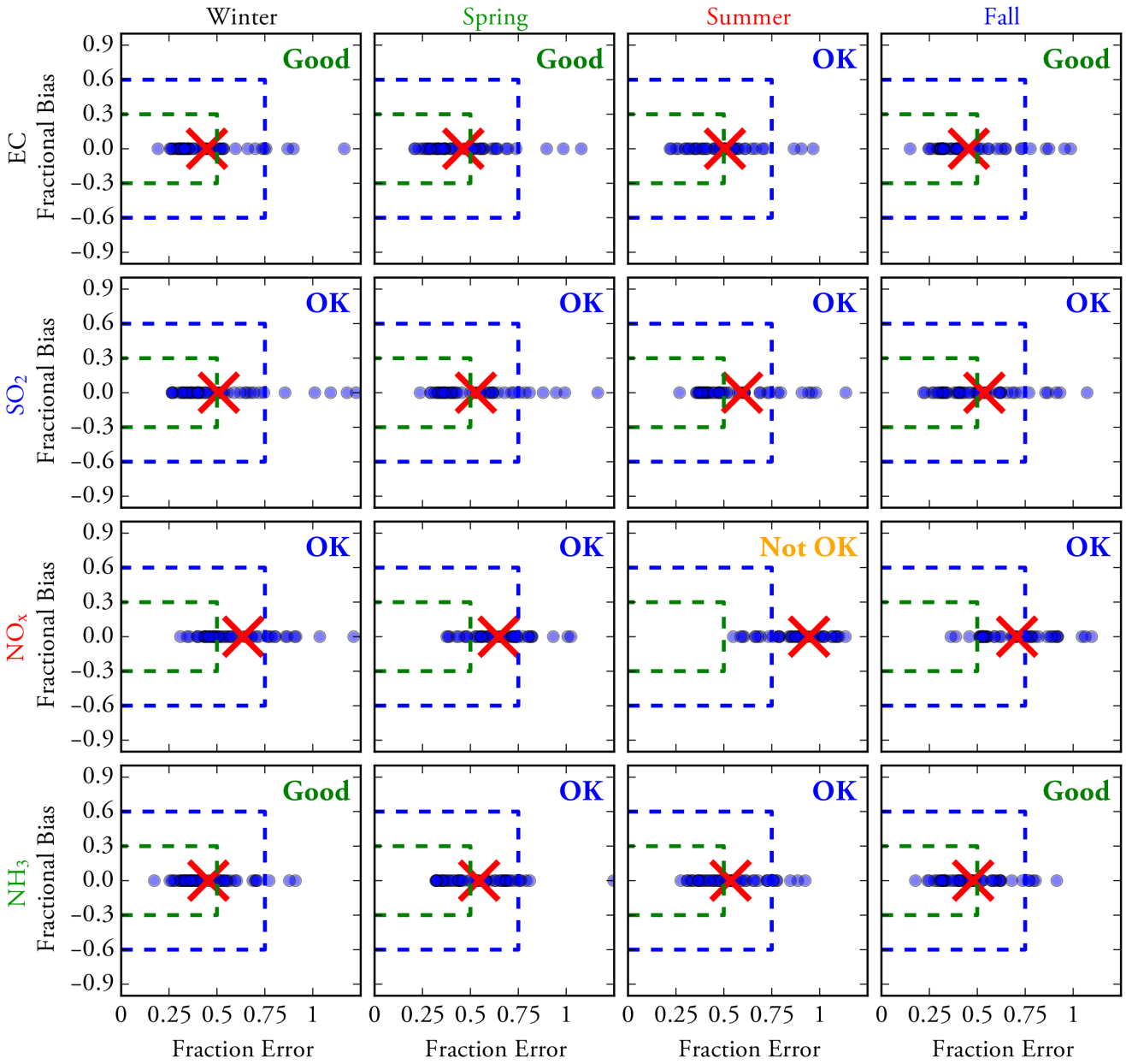
- Zero Mean Fractional Bias:

  $\Rightarrow$ Because all social costs are distributed.

- Small Mean Fractional Errors in densely-populated areas:

  $\Rightarrow$ Performance will be better for important areas.

Works well for All Species and All Seasons!



⇒ Mostly Good or OK

⇒ Better in real applications

(for areas with

large emissions and

large population)

The Air Pollution Social Cost Accounting Model

Input

- Emission Location
- Amount of Emissions

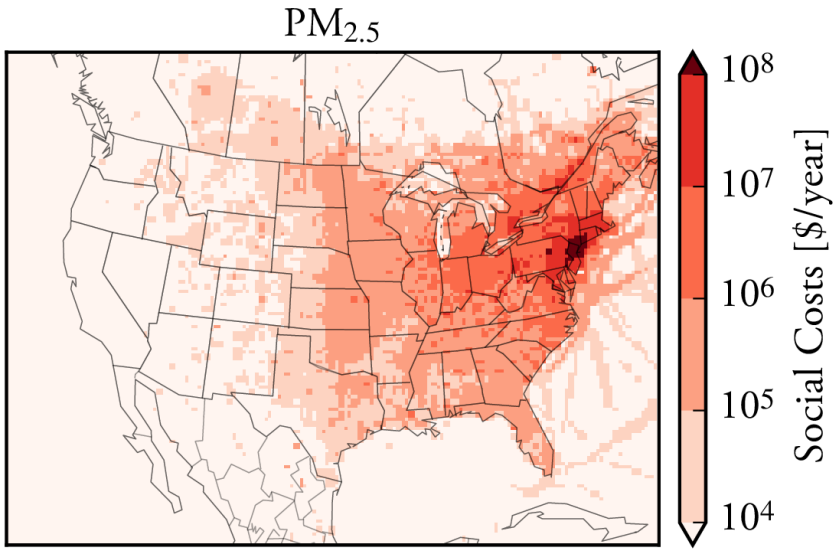
← Within ~50% Mean Fractional Error
← Negligible Computational Costs

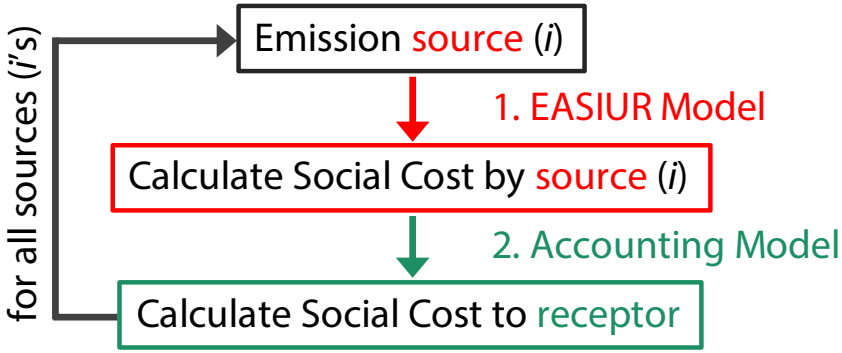
Output

- Social Costs in All Downwind Grid Cells

Emission Sources responsible for

Air Quality Social Cost in the New York Metropolitan Area





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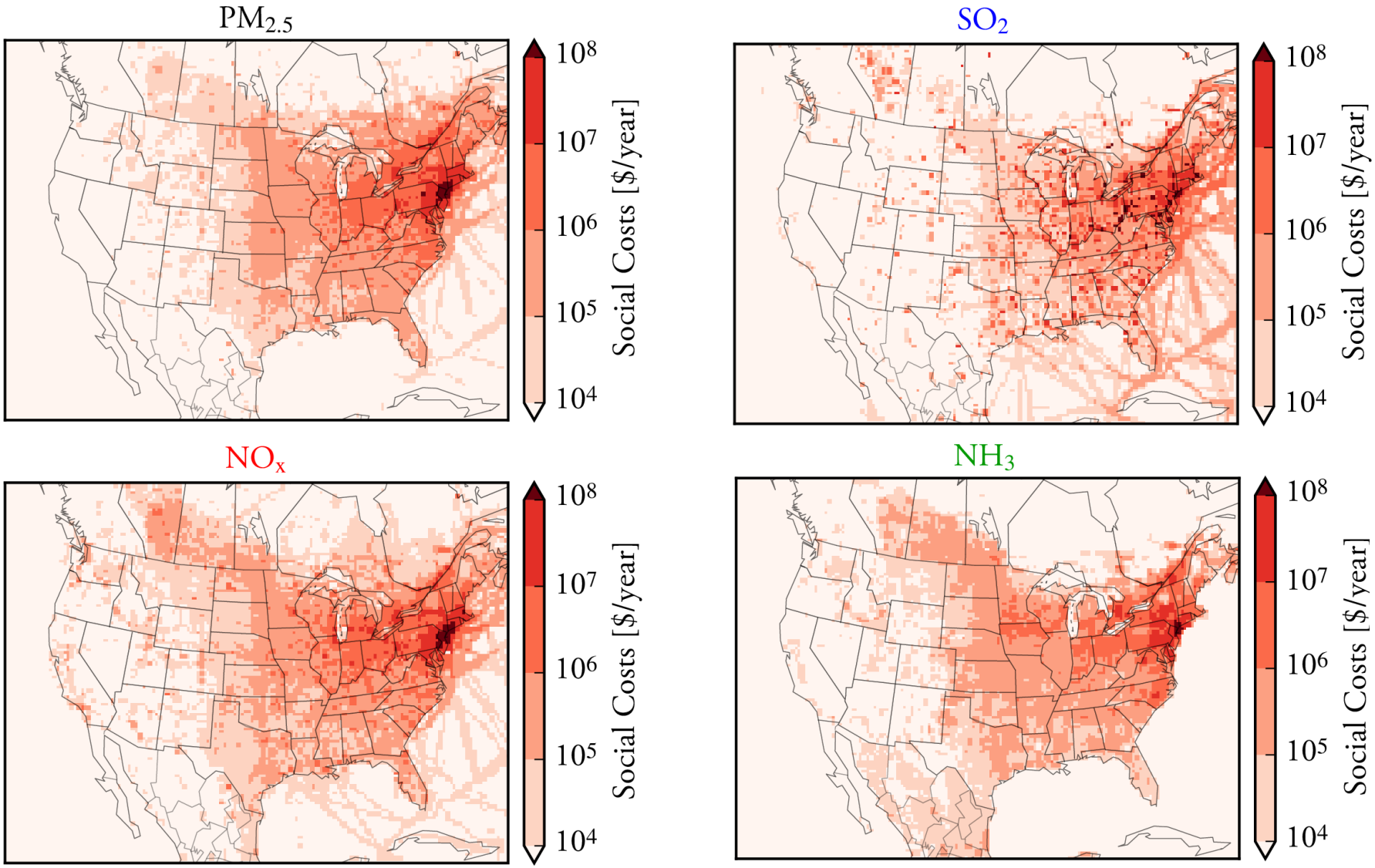
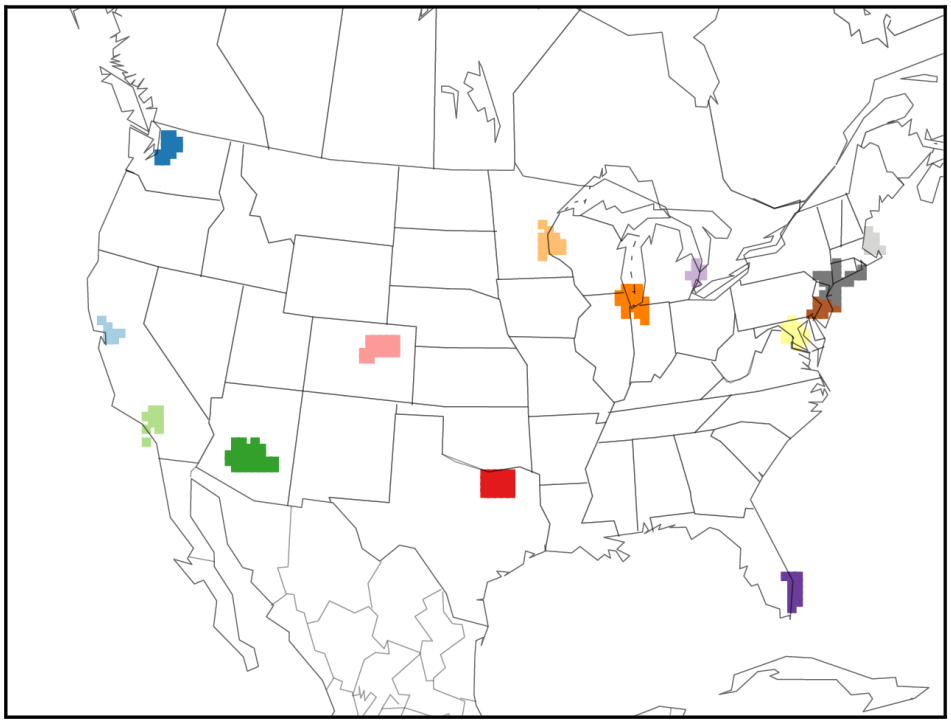
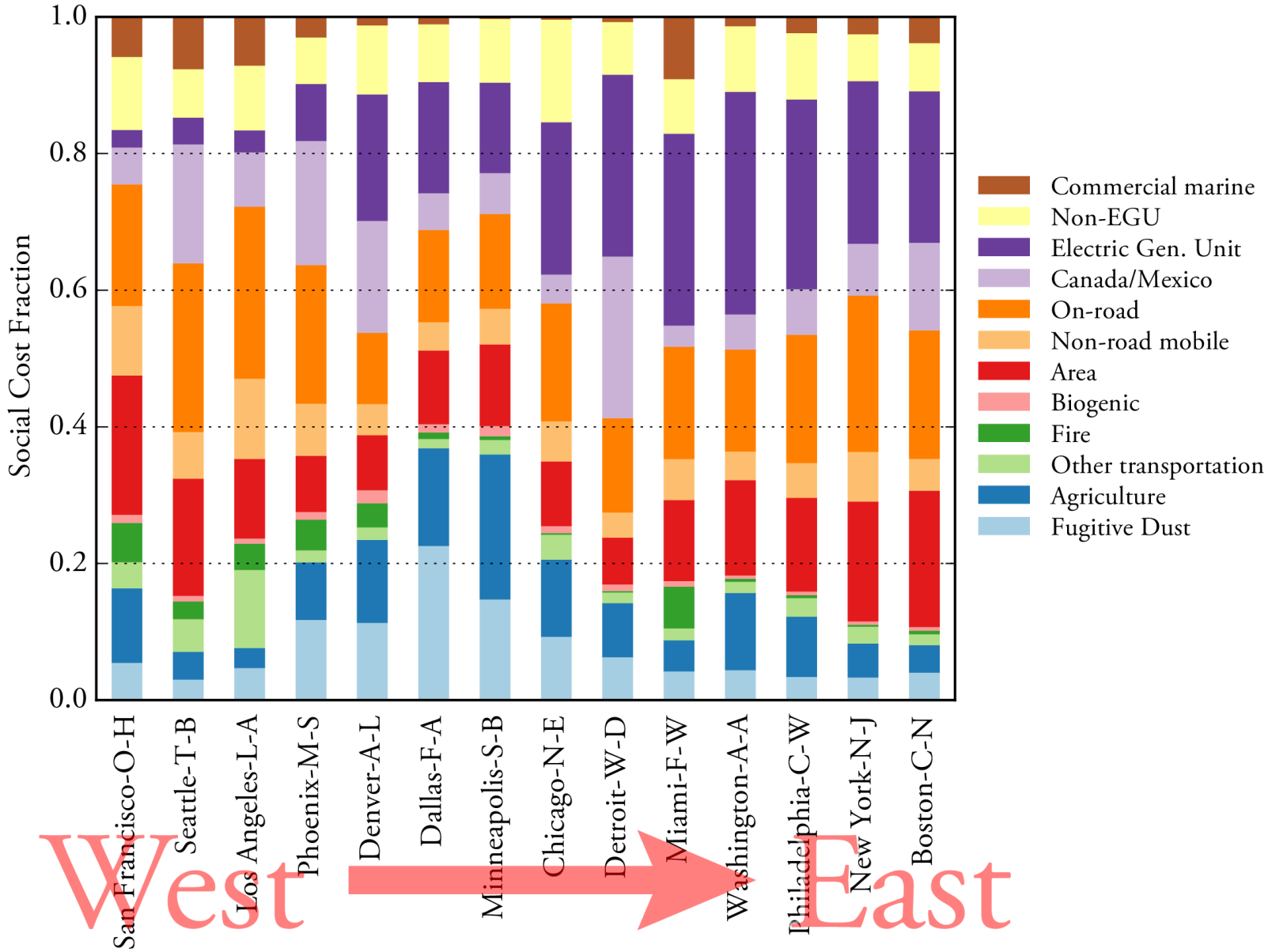


Application: 14 Metropolitan Areas



- **San Francisco**-Oakland-Hayward CA
- **Seattle**-Tacoma-Bellevue WA
- **Los Angeles**-Long Beach-Anaheim CA
- **Phoenix**-Mesa-Scottsdale AZ
- **Denver**-Aurora-Lakewood CO
- **Dallas**-Fort Worth-Arlington TX
- **Minneapolis**-St.Paul-Bloomington MN/WI
- **Chicago**-Naperville-Elgin IL/IN/WI
- **Detroit**-Warren-Dearborn MI
- **Miami**-Fort Lauderdale-West Palm Beach FL
- **Washington**-Arlington-Alexandria DC/VA/MD/WV
- **Philadelphia**-Camden-Wilmington PA/NJ/DE/MD
- **New York**-Newark-Jersey City NY/NJ/PA
- **Boston**-Cambridge-Nashua MA/NH

14 Metropolitan Areas: Social Cost Fractions by 12 Source Sectors



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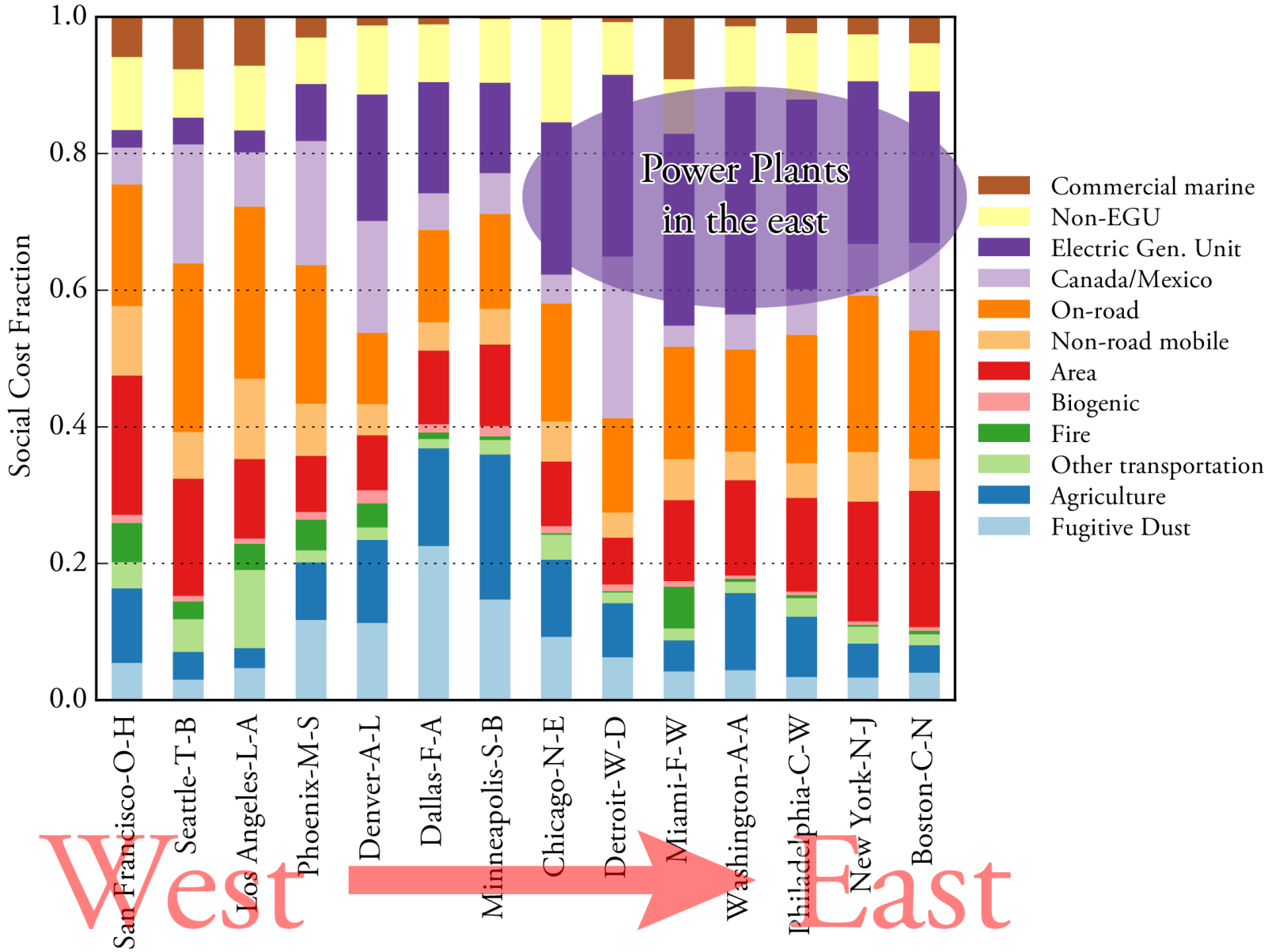

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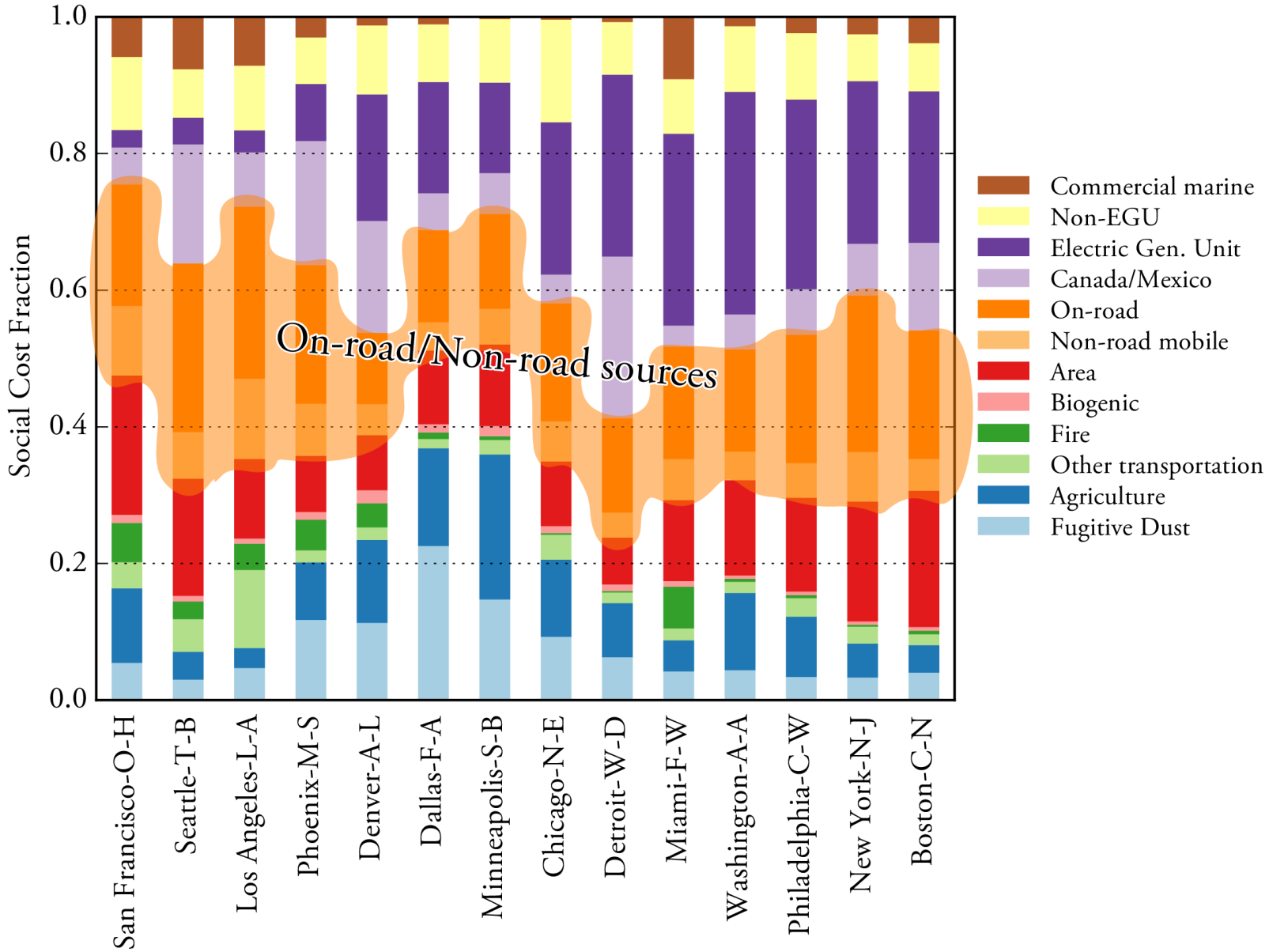

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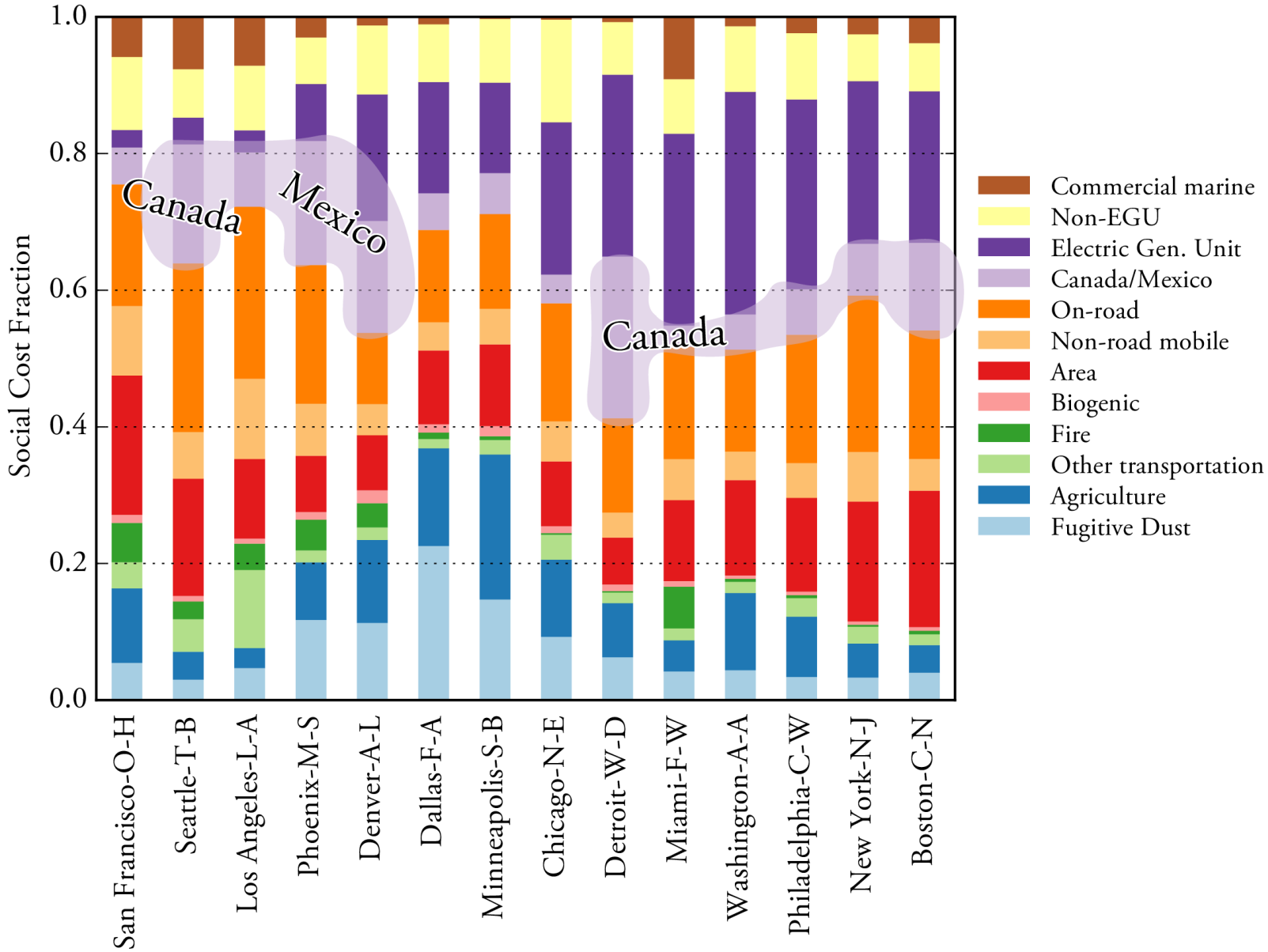
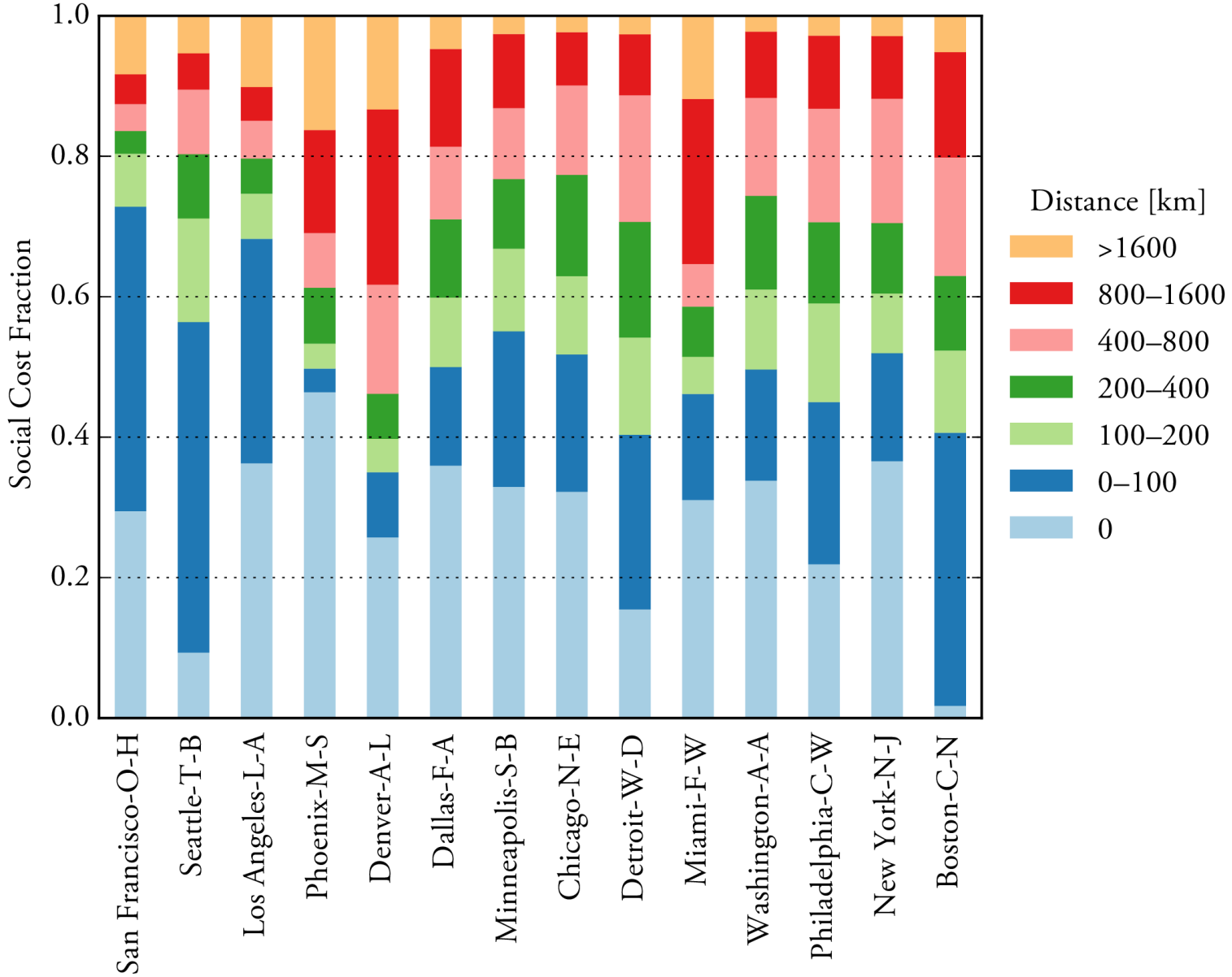


14 Metropolitan Areas: Social Cost Fractions by Source Distance



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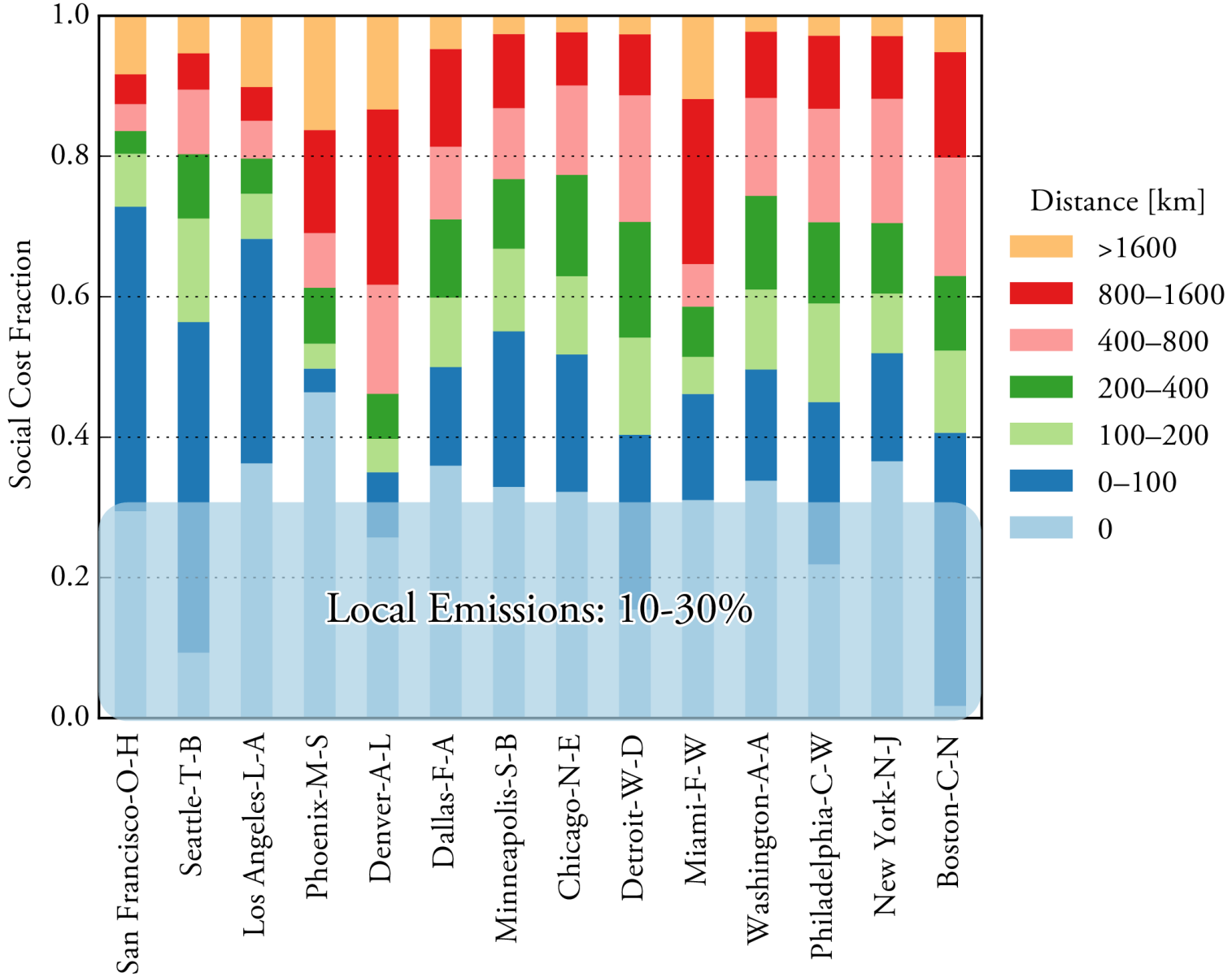

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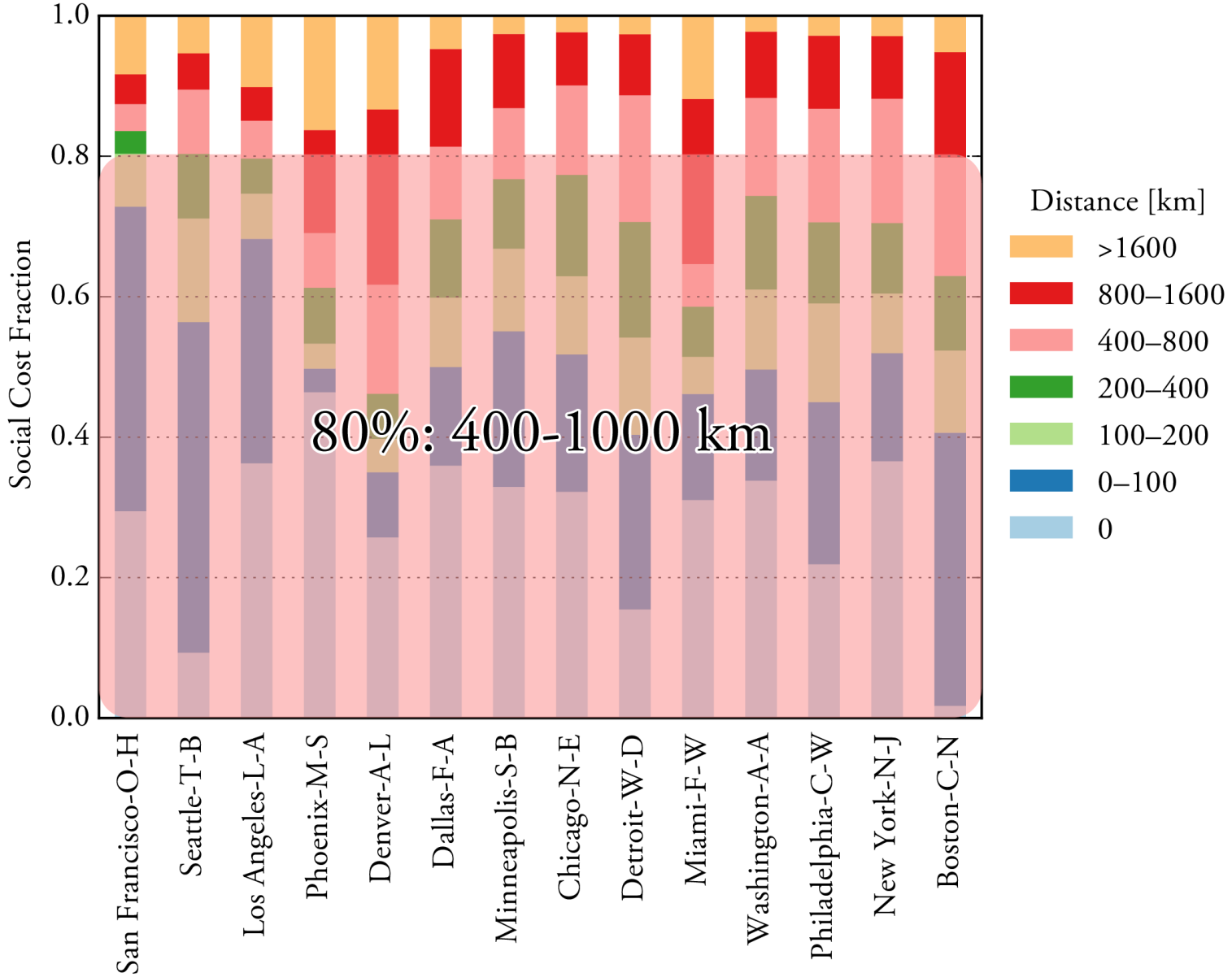


Conclusions

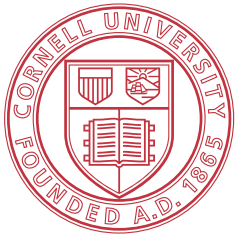
- The Air Pollution Social Cost Accounting Model identifies the sources of air quality burden at a receptor location with high spatial, sectoral, and temporal resolutions.
- The most comprehensive accounting of air pollution social costs is produced.
- The new model provides useful information for policy strategies from a receptor's point of view.

Future Plans

- Evaluate the current practices of State Implementation Plans.
- Develop a method for designing optimal air quality and energy policies.

Acknowledgments

- This work was supported by the Lloyd's Register Foundation and the New York Metropolitan Transportation Council (NYMTC).
- Center for Atmospheric Particle Studies (CAPS), Carnegie Mellon Univ.
- Center for Climate and Energy Decision Making (CEDM), Carnegie Mellon Univ.
- Bonyoung Koo (ENVIRON), Cheol-Heon Jeong (Univ. of Toronto)



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Thanks! Any Questions?

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