An Empirical Assessment of Exposure Measurement Error and Effect Attenuation in Bi-Pollutant Epidemiologic Models

Lisa Baxter[1], Kathie Dionisio[1], and Howard Chang[2]

[1] U.S. EPA
[2] Emory University

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Office of Research and Development
National Exposure Research Laboratory.

Date

Background

- Exposed to a complex mixture of pollutants
- Multipollutant models can be used to understand the health effects of exposure to mixtures
- Exposures typically estimated using ambient monitoring data but these may not adequately capture
  - spatial and temporal coverage
  - exposures in different microenvironments
  - infiltration

Background

- Differing degrees of exposure error across pollutants
- Previous focus on quantifying and accounting for exposure error in single-pollutant models
- Examine exposure errors for multiple pollutants and provide insights on the potential for bias and attenuation of effect estimates in single and bi-pollutant epidemiological models

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Objectives

Quantify the relationships among multiple pollutants and their associated exposure errors across exposure metrics

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Use empirical values to determine the potential attenuation of coefficients in bi-pollutant epidemiologic models

Methods

1. Compare exposure metrics within- and across-pollutants
2. Compare exposure errors within- and across-pollutants
3. Using results from 1) and 2) calculate attenuation factors for single and bi-pollutant model coefficients

Methods: Exposure Metrics

- Estimated daily exposures to ambient air pollution for 193 ZIP codes in the Atlanta, GA (1999-2002)

1. CS: Central-site measurements
   - From SEARCH, ASACA, and U.S. EPA's AQS monitoring networks
   - 24-hr average concentrations ($PM_{2.5}$, EC, and SO_4)
   - Hourly concentrations aggregated to 24-hr averages (CO, NO_x) or 8-hr maximum (O_3)
2. AQ: Air quality model estimates
   - Combines local-and regional-scale model results
3. PE: Stochastic population exposure model estimates
   - Stochastic Human Exposure and Dose Simulation Air Toxics (SHEDS-AT) model

Dionisio et al. (2013). "Development and evaluation of alternative approaches for exposure assessment of multiple air pollutants in Atlanta, Georgia." J Expos Sci Environ Epidemiol 23(6): 581-592.

Methods: Exposure Error

- Exposure error, δ, is calculated as the difference between two exposure metrics:
  - $\delta_{spatial}$ = AQ – CS; exposure error due to a lack of spatial refinement
  - $\delta_{population}$ = PE – AQ; exposure error due to lack of human exposure factors
  - δ_{total} = PE – CS; exposure error due to lack of both spatial variability and human exposure factors

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Methods: Attenuation Factors for Single Pollutant Models

$$\lambda = \frac{1}{1 + \frac{var(\delta)}{var(x_{fine})}}$$

$$\beta_{observed} = \lambda * \beta_{true}$$

λ = attenuation factor

δ = exposure error

var (δ) = the variance across days of δ

x_{fine} = the exposure metric with the greater degree of refinement (i.e., increased spatial resolution, or inclusion of weighting by population factors)

var(x_{fine}) = the variance across days of x_{fine}

β = model coefficients

λ = 1 indicates no attenuation

λ = 0 indicates null results

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Methods: Attenuation Factors for Bi-pollutant Models

$$\lambda_{x_1} = \mathbf{S}(\mathbf{S}+\mathbf{V})^{-1}$$

$$\beta_{observed,x_1} = \lambda_{x_1} \times \beta_{true,x_1}$$

λ_{x_1} = attenuation factor for pollutant x_1 in a classical error, bi-pollutant model, assuming pollutant x_2 has no effect (β_{x_2}= 0)

S = covariance of the more refined exposure metric for x_1 and x_2

V = covariance of the exposure errors for x_1 and x_2

Modified from Zeger et al. (2000). "Exposure measurement error in time-series studies of air pollution: concepts and consequences." Environmental Health Perspectives 108(5): 419-426.

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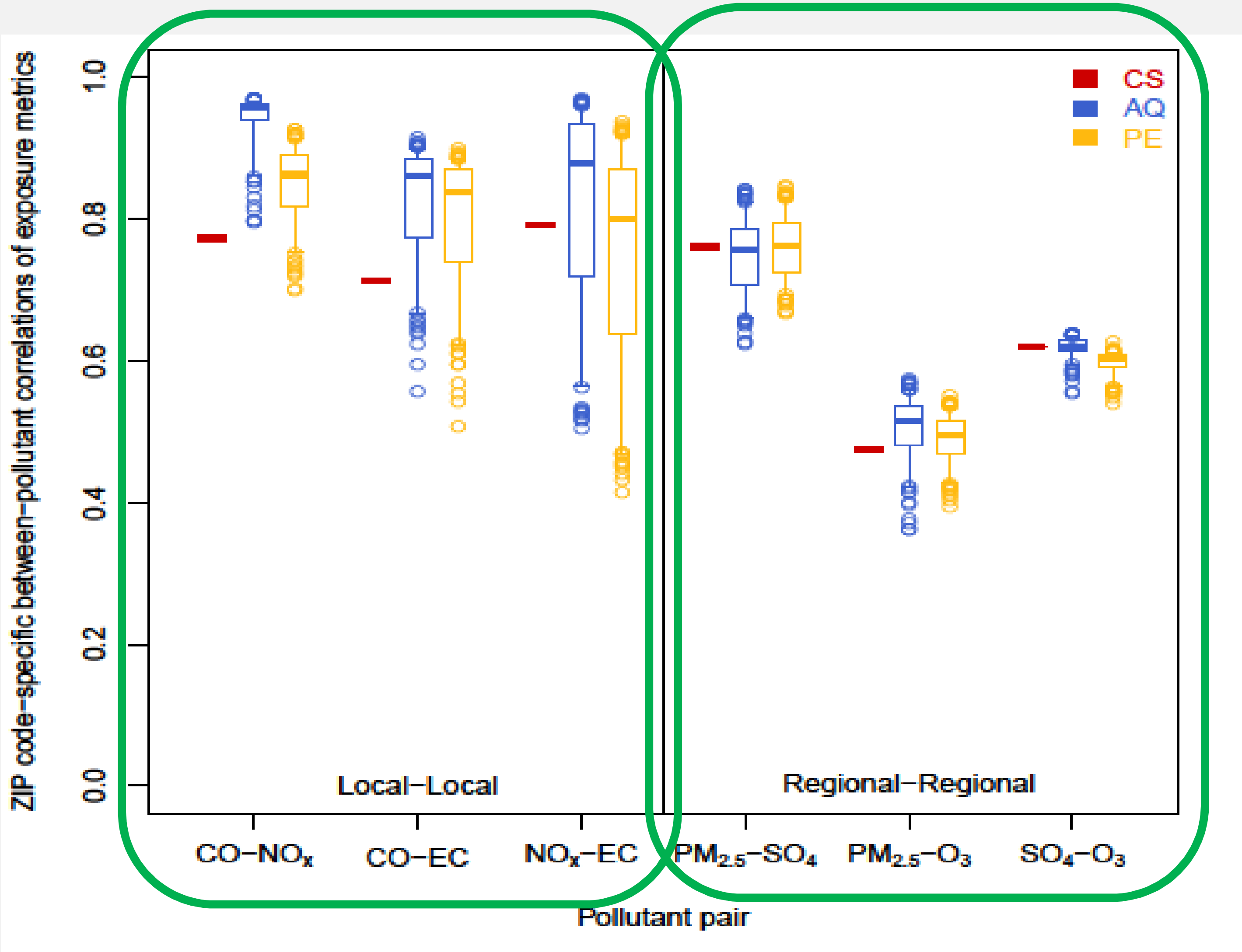
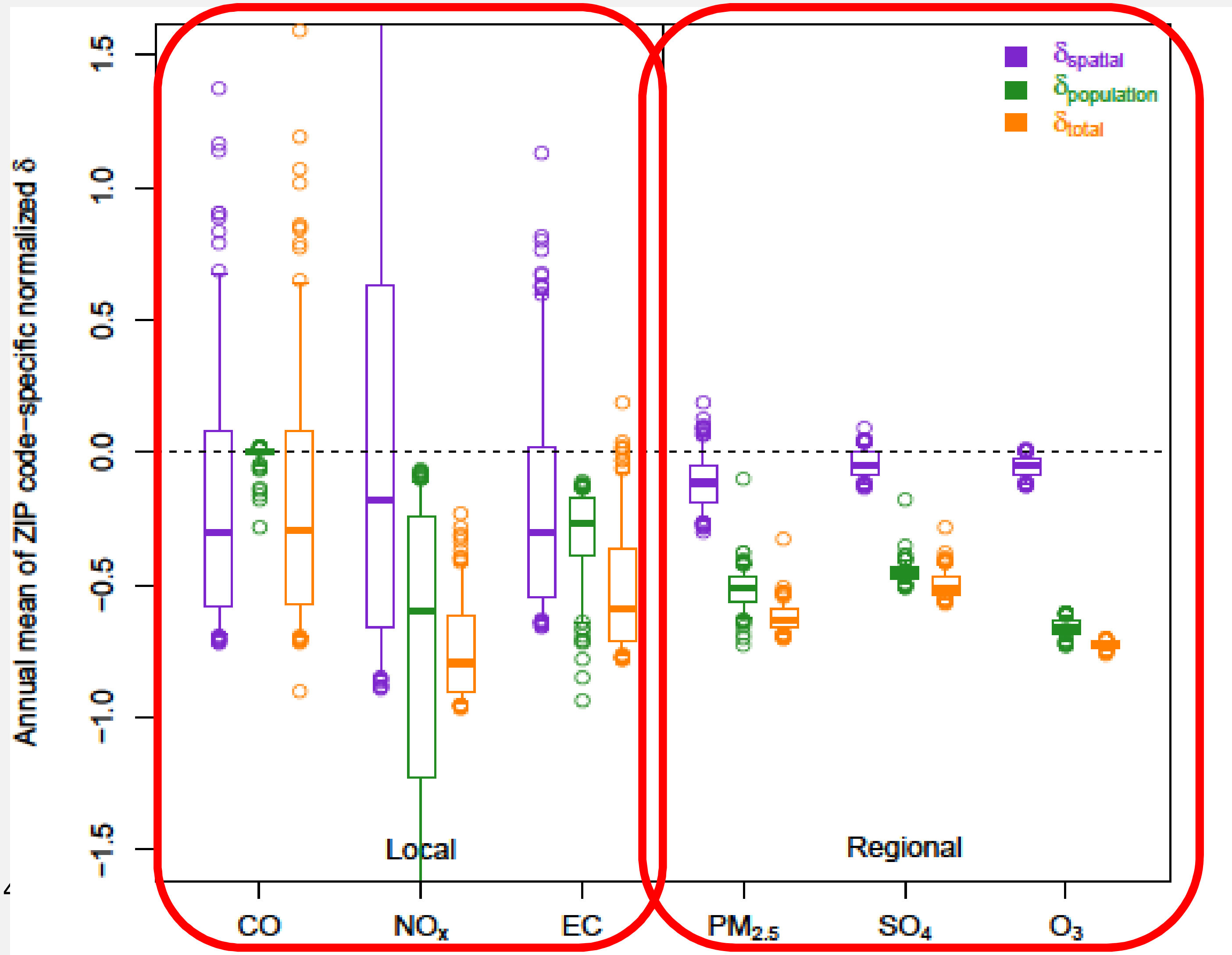
Results: Relationships between multiple pollutants and their associated exposure errors

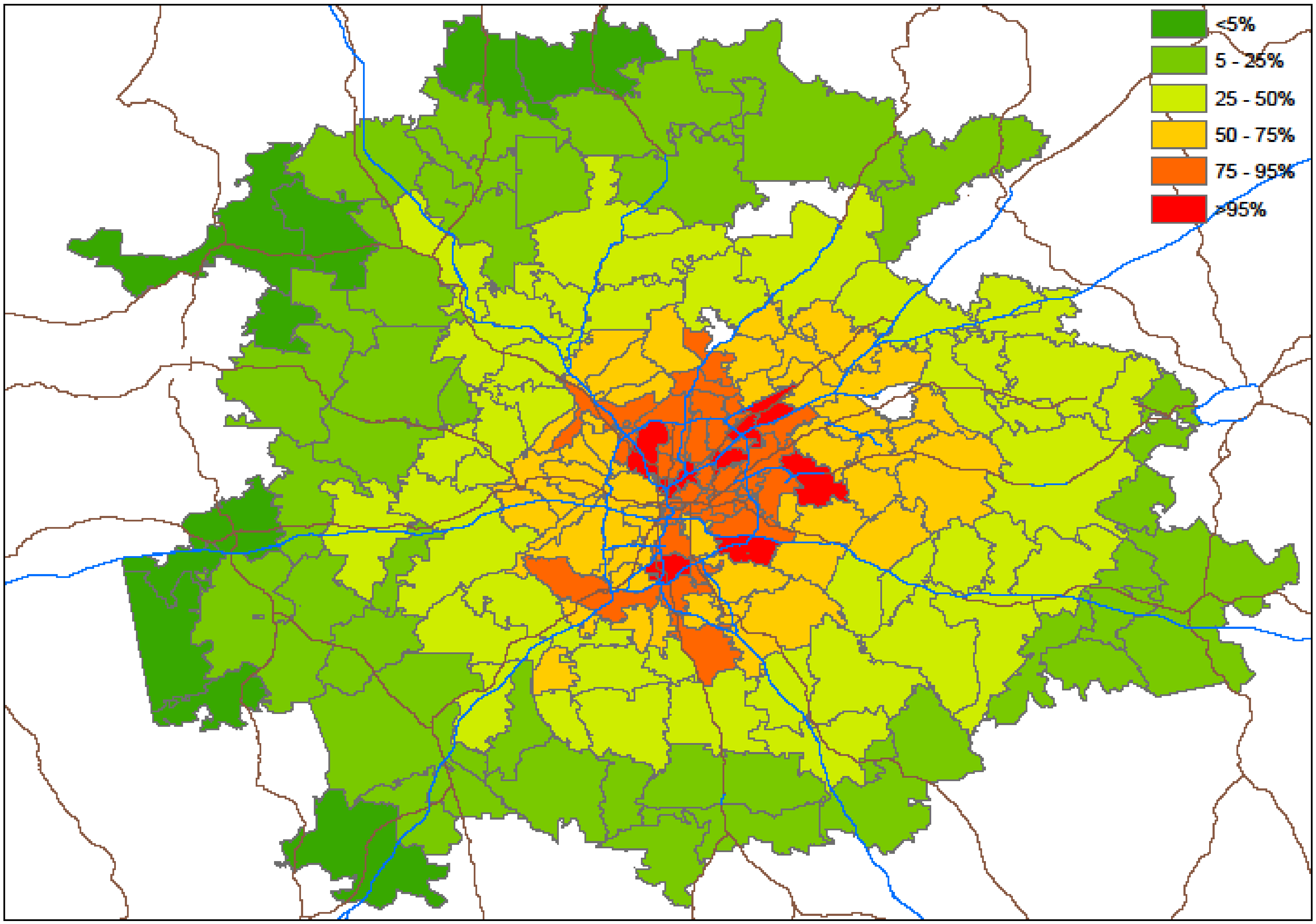
Distributions of pearson correlations between daily exposure metrics (n= 193 zip codes)



Normalized (divided by annual average CS measurement) ZIP code-specific exposure error estimates



Map of $\delta_{spatial}$ for NO_x in Atlanta, GA



Colored regions represent ZIP codes in the study area, blue and brown lines indicate major roads.

Legend is grouped by percentile, where 5% = -0.85; 25% = -0.66; 50% = -0.18; 75% = 0.63; and 95% = 1.73.

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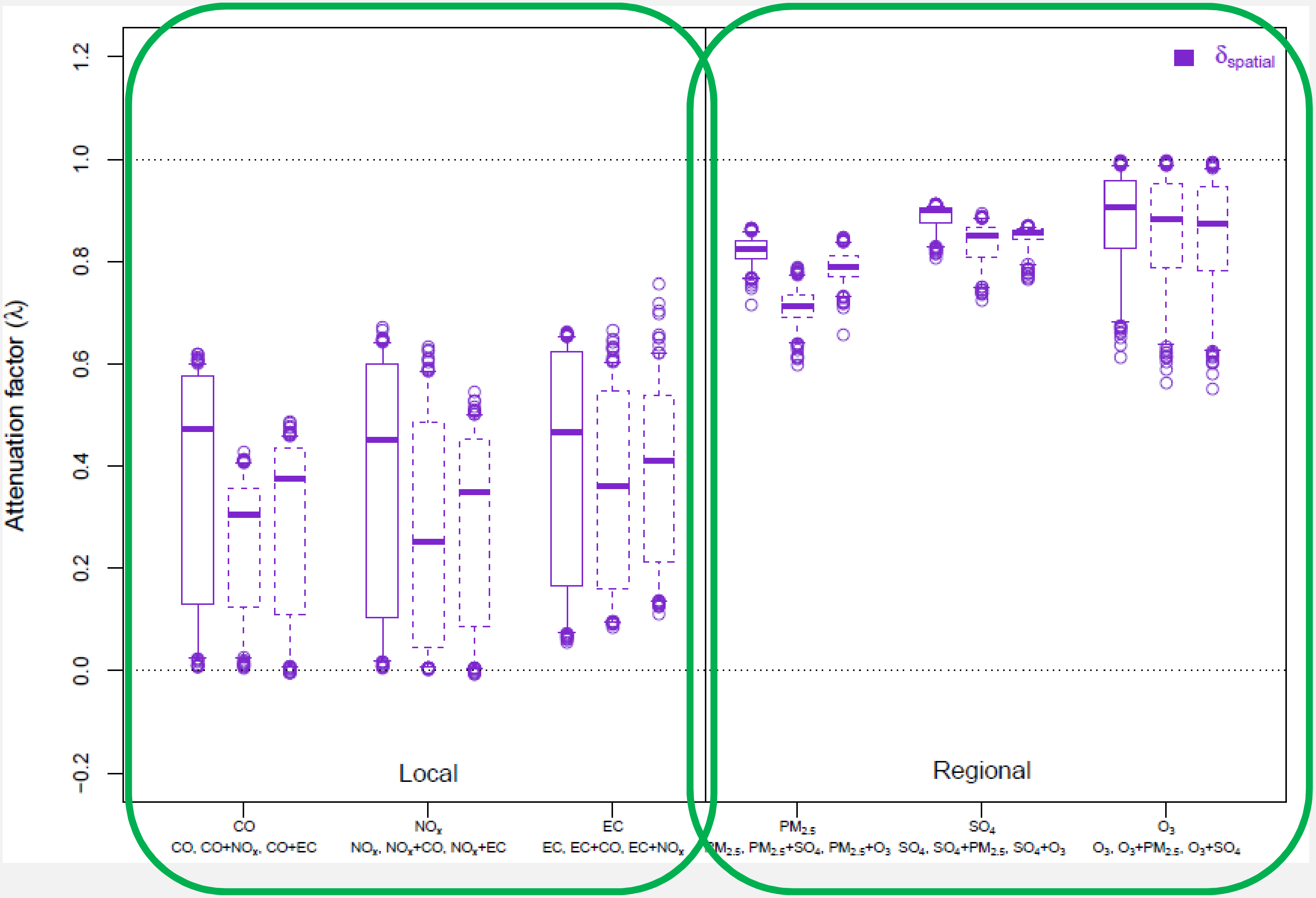
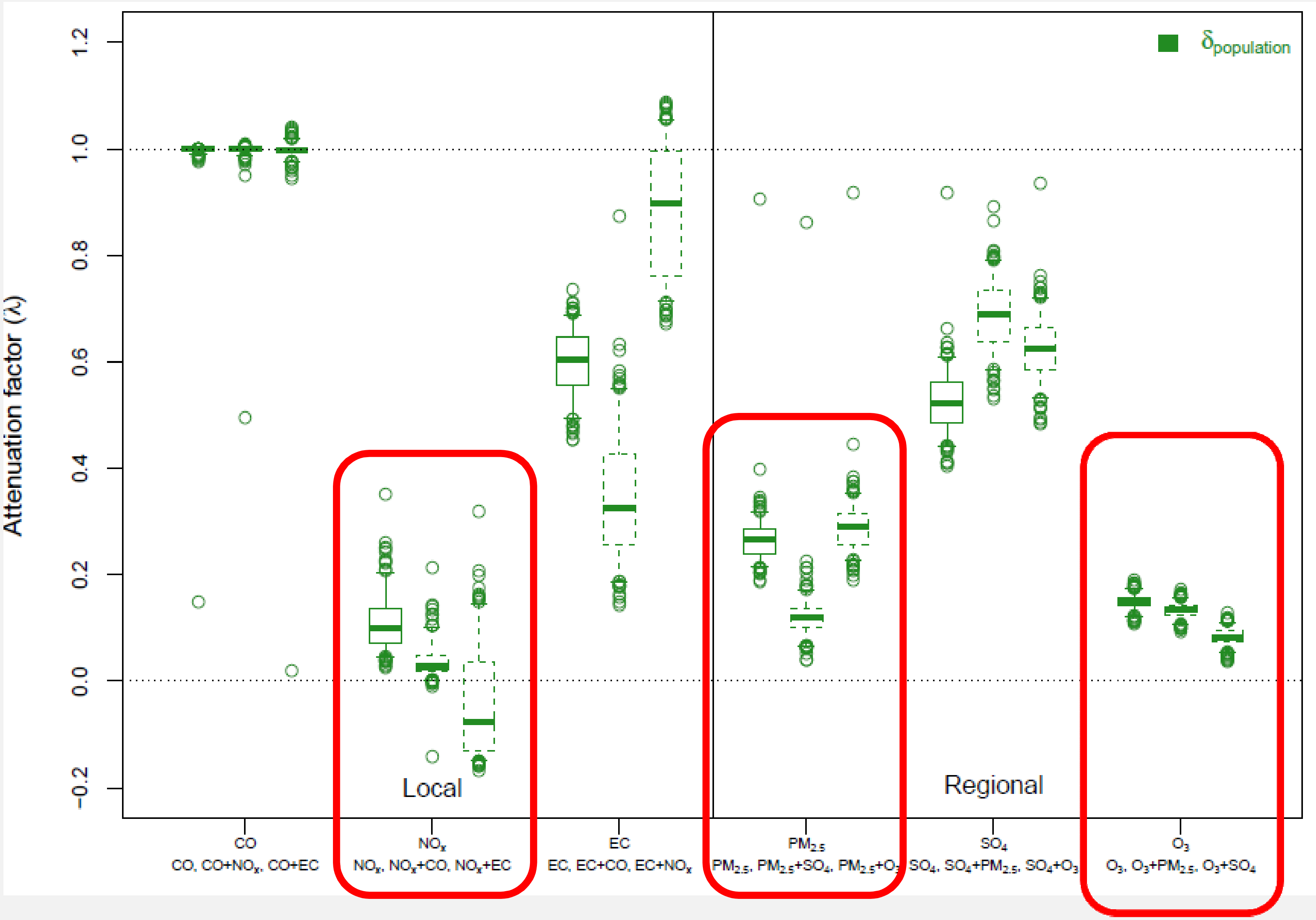
Results: Attenuation Factors

Attenuation factors due to $\delta_{spatial}$



Solid boxplots = single pollutant models; Dashed boxplots = bi-pollutant models

Attenuation factors due to $\delta_{population}$



Solid boxplots = single pollutant models; Dashed boxplots = bi-pollutant models

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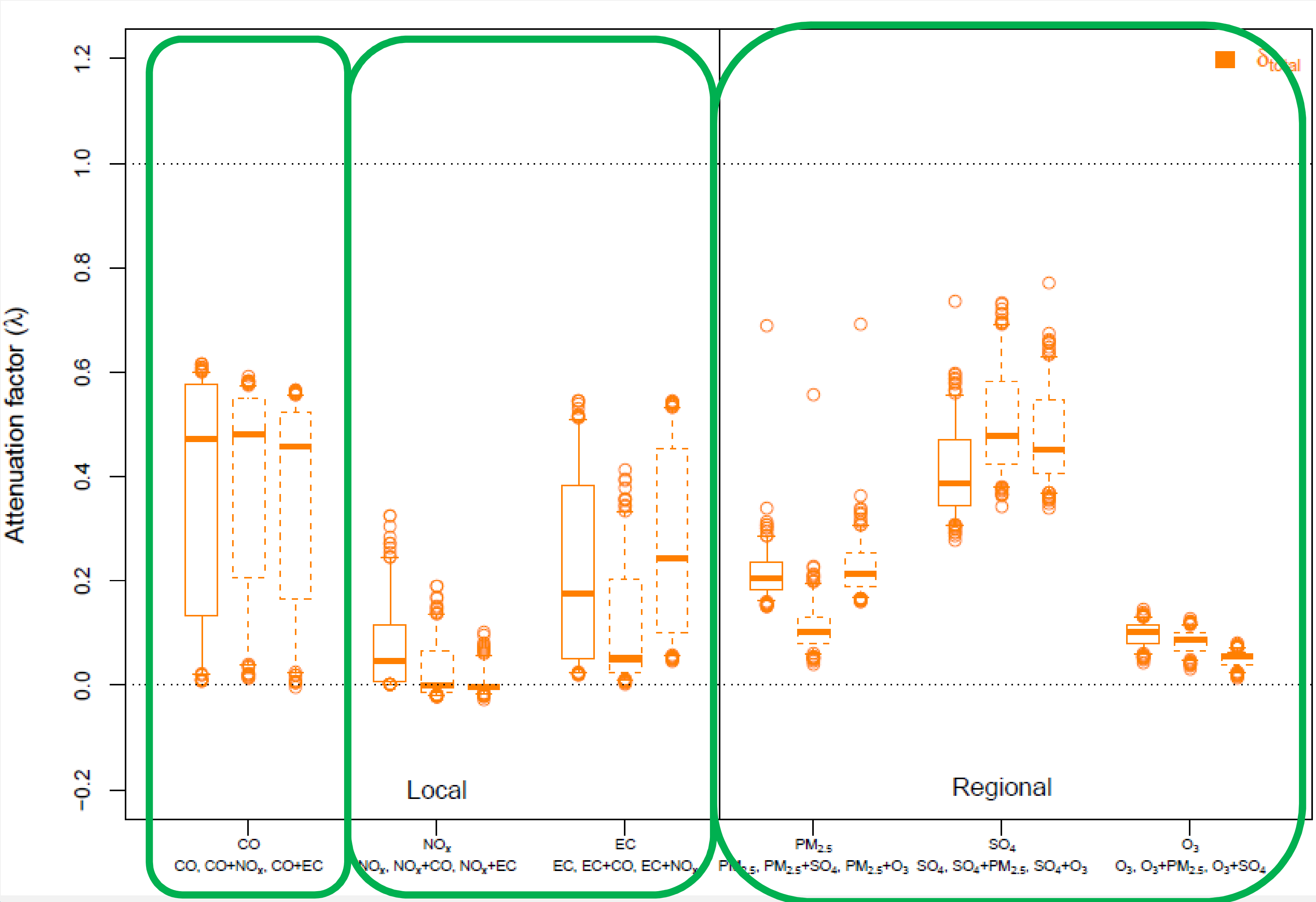
Attenuation factors due to δ_{total}



Solid boxplots = single pollutant models; Dashed boxplots = bi-pollutant models

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Summary and Conclusions

- Attenuation of coefficients for bi-pollutant models, particularly for local pollutants (CO, NO_x, EC)
- Spatially varying attenuation due to spatial variability (i.e. differences between zip codes)
- More research are exploring multipollutant approaches
  - Effects on model coefficients will depend on relationships between pollutants and their errors
- Next step: simulation study including the empirically determined covariance structures to quantify the effect on bi-pollutant model coefficients

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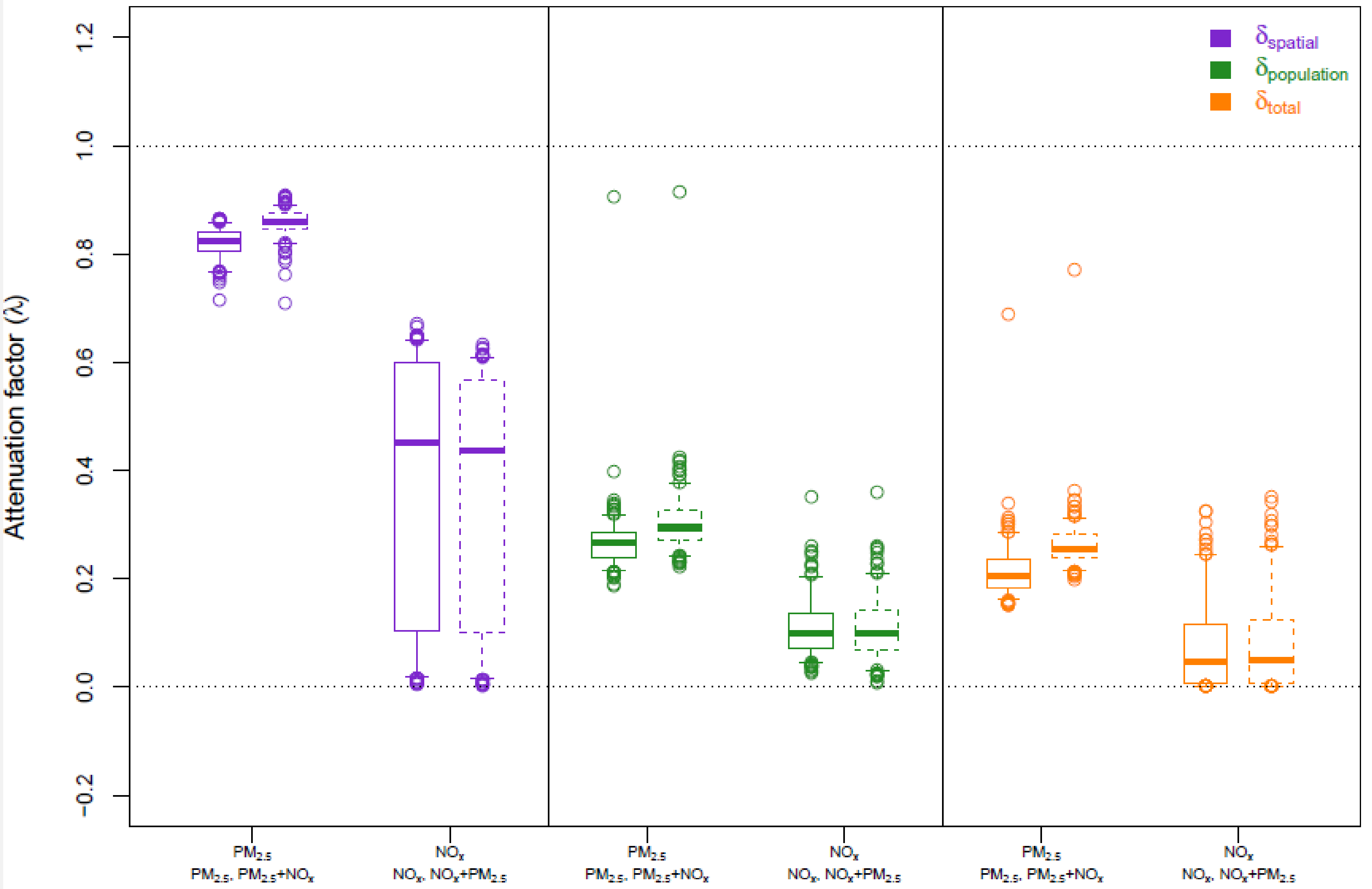
- Georgia Tech: Jim Mulholland

Attenuation Factors for a local-regional pollutant pair example



Results: Parameters impacting attenuation and bias in a bivariate pollutant model[a]

		AQ	PE	$\delta_{spatial}$			$\delta_{population}$			δ_{total}		
x_1	x_2	Corr(x_1,x_2)	Corr(x_1,x_2)	Var(δ_1)[b]	Var(δ_2)[b]	Corr(δ_1, δ_2)	Var(δ_1)[b]	Var(δ_2)[b]	Corr(δ_1, δ_2)	Var(δ_1)[b]	Var(δ_2)[b]	Corr(δ_1, δ_2)
Local-Local pollutant pairs												
CO	NO_x	0.96	0.86	0.25	0.83	0.73	0.00	0.32	-0.13	0.25	0.80	0.35
CO	EC	0.86	0.84	0.25	0.30	0.65	0.00	0.05	-0.19	0.25	0.33	0.52
NO_x	EC	0.88	0.80	0.83	0.30	0.76	0.32	0.05	0.85	0.80	0.33	0.72
Regional-Regional pollutant pairs												
$PM_{2.5}$	SO_4	0.76	0.76	0.04	0.05	0.21	0.09	0.10	0.77	0.12	0.16	0.70
$PM_{2.5}$	O_3	0.52	0.49	0.04	0.02	0.03	0.09	0.11	0.52	0.12	0.16	0.41
SO_4	O_3	0.62	0.60	0.05	0.02	0.11	0.10	0.11	0.62	0.16	0.16	0.57

[a] All values presented are median across all ZIP codes; [b] Var(δ) represents variance of normalized exposure error

* builds upon the hypothetical simulation presented in Zeger et al. (2000)