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On the impacts of grid resolution on the estimates of marginal societal health benefits of emissions abatement

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Outline:

- Topics will be covered:
  - Motivation
  - Background
  - Methodology
  - Results
  - Conclusion and limitations

Motivation

- This study aims to:
  - Evaluate the consistency of the estimated values of marginal health benefits of primary particulate matter ($PM_{2.5}$) and precursor emissions abatement across various horizontal grid spacings for regional scale studies conducted at a lower resolution due to computational constraints to ensure their robustness for policy making purposes.
  - Determine the grid-spacing requirements for urban scale studies to be sufficiently resolved for local decision making.
  - Examining the extent of sub-grid variability of marginal health benefits estimates that are present within coarser resolutions.

Background:

Effects of grid resolution on air pollution health impacts estimates

- Model's resolution (grid spacing) affect health benefits estimates by affecting:
  - Meteorology:

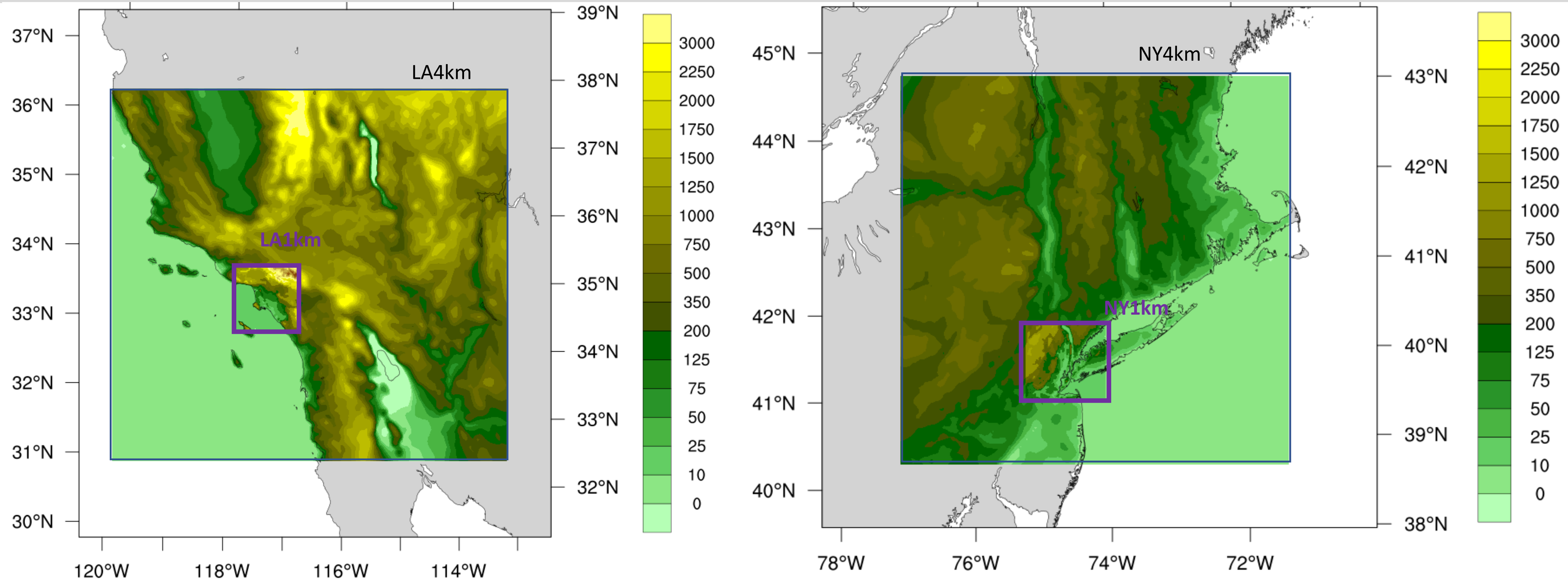
    Convective systems → Wet deposition , Winds and local circulation → Transport, Boundary layer height → Pollutant mixing
  - Emissions:
    - Emissions distribution and peak locations
    - Artificial dilution
  - Numerical accuracy:
    - Numerical noise, grid imprints
  - Exposure:
    - Population distribution

Methodology: Study parameters

	36 km	12 km	4 km	1 km
Spatial Extent	Contiguous US, parts of Canada, and Mexico		LA4: ~Southern California NY4: NYC, NJ, and New Haven	LA1: Los Angeles NY1: NYC
Meteorology	ERA5 reanalysis from ECMWF, resolution 0.25*0.25 degrees, WRF v3.9.1			
Emissions	Based on U.S. National Emission Inventory Collaborative (NEIC) 2016 emissions modelling platform			
Study Period	2016: Full Year	2016: 4 episodes each 2 weeks in Feb, May, Aug, Nov.	2016: 2 episodes each 2 weeks in Aug., Feb. (ongoing)	2016: 1 episode1, 2 weeks in Aug., Feb (ongoing)
Domain Grid Description	Rows: 148 ; Columns:172 Layers: 35	Rows: 299 ; Columns:459 Layers: 35	LA4: Rows: 156 ; Cols:165 NY4: Rows: 127; Cols:127 Layers: 35	LA1: Rows: 112 ; Cols:112 NY1: Rows: 104 Cols:104 Layers: 35
CTM	CMAQ-ADJ v5.0 (Zhao, et al. 2020)			
Cost function	Monetized mortality ($PM_{2.5}$) using Global Exposure Mortality Model (GEMM) (Burnett et al. , 2018)			
Boundary Conditions	FWD only: Hemispheric	36 km	12 km	4 km

Methodology:
High resolution Modelling Domains

Topography (height in m) for LA and NY CMAQ domains



Methodology:
health impact estimation

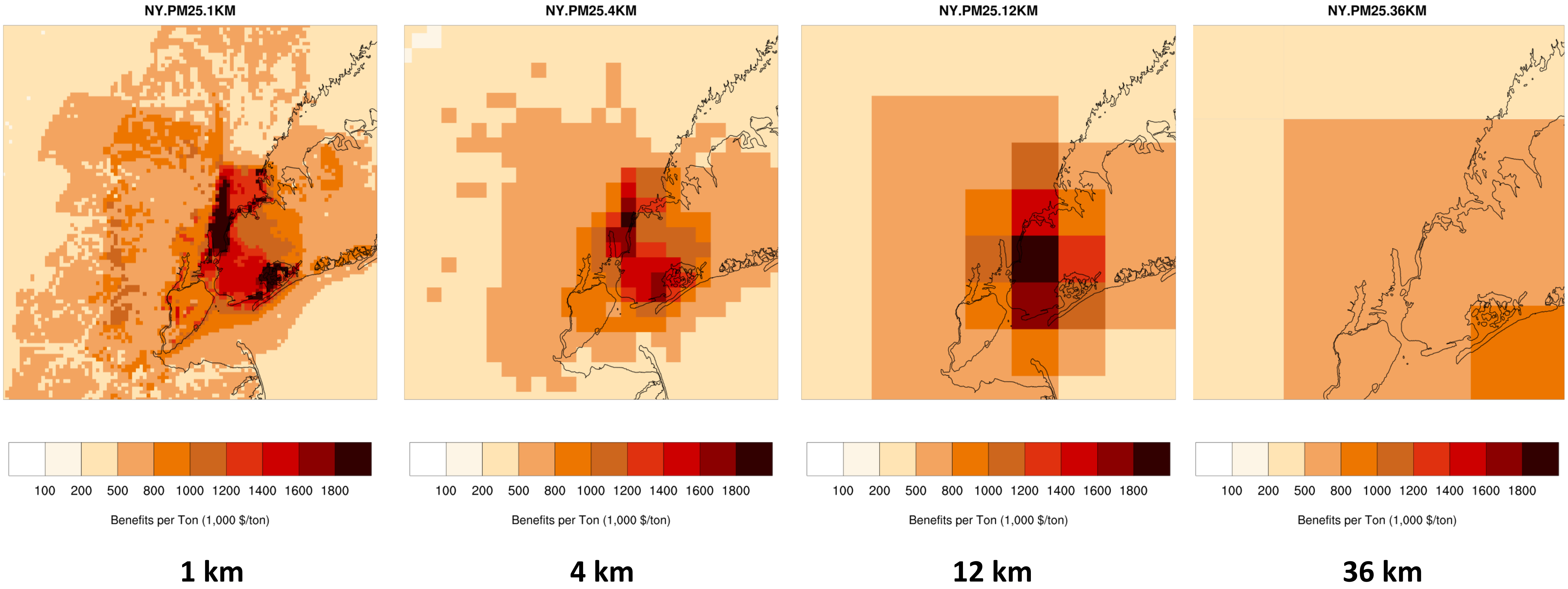
The Adjoint cost function (J) for this study is defined as the societal burden due to $PM_{2.5}$ mortality.

Location specific benefit-per-ton estimates (BPT): valuations of the health impacts from exposure to fine particulate matter resulting from emissions of one ton of a pollutant (primary $PM_{2.5}$, NOx, SO_2, and NH_3).

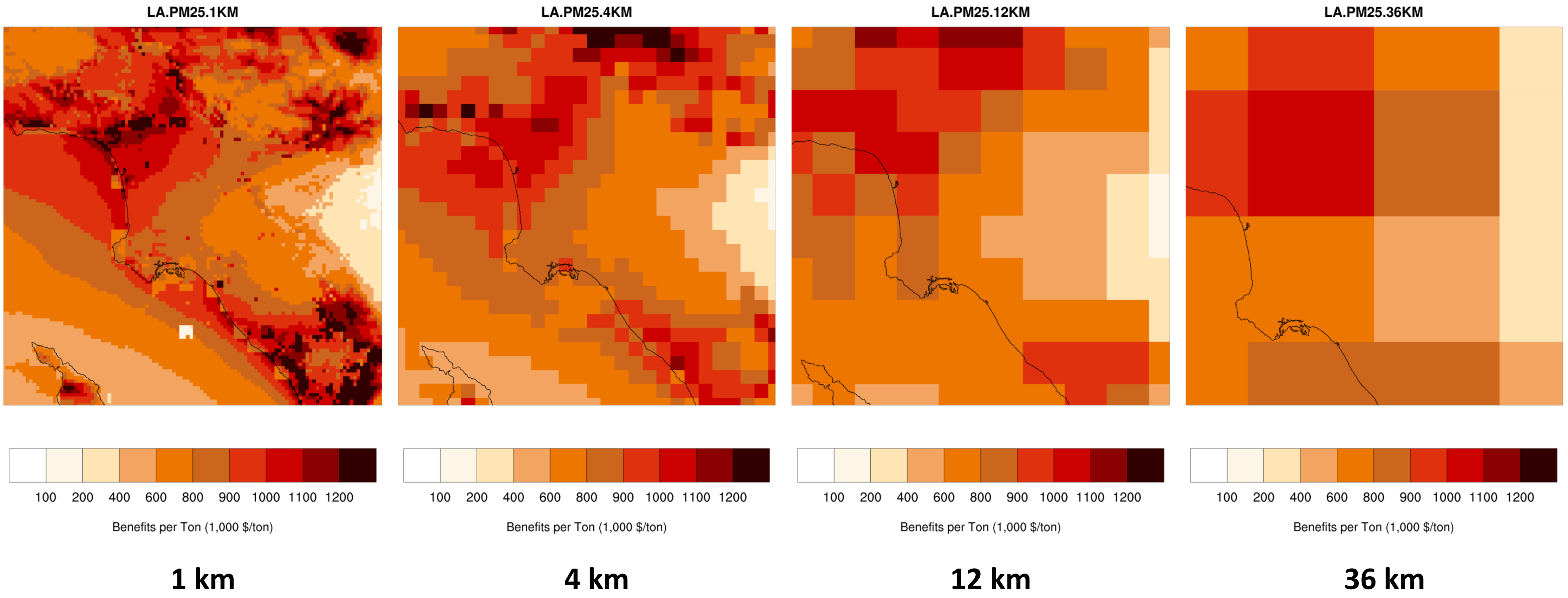
$$BPT\left(\frac{\$}{ton}\right) \approx$$

$$\frac{\$}{(Health\ Outcome)} \times \frac{(Health\ Outcome)}{\Delta(Concentrations)} \times \frac{\Delta(Concentrations)}{\Delta(ton\ of\ emissions)}$$

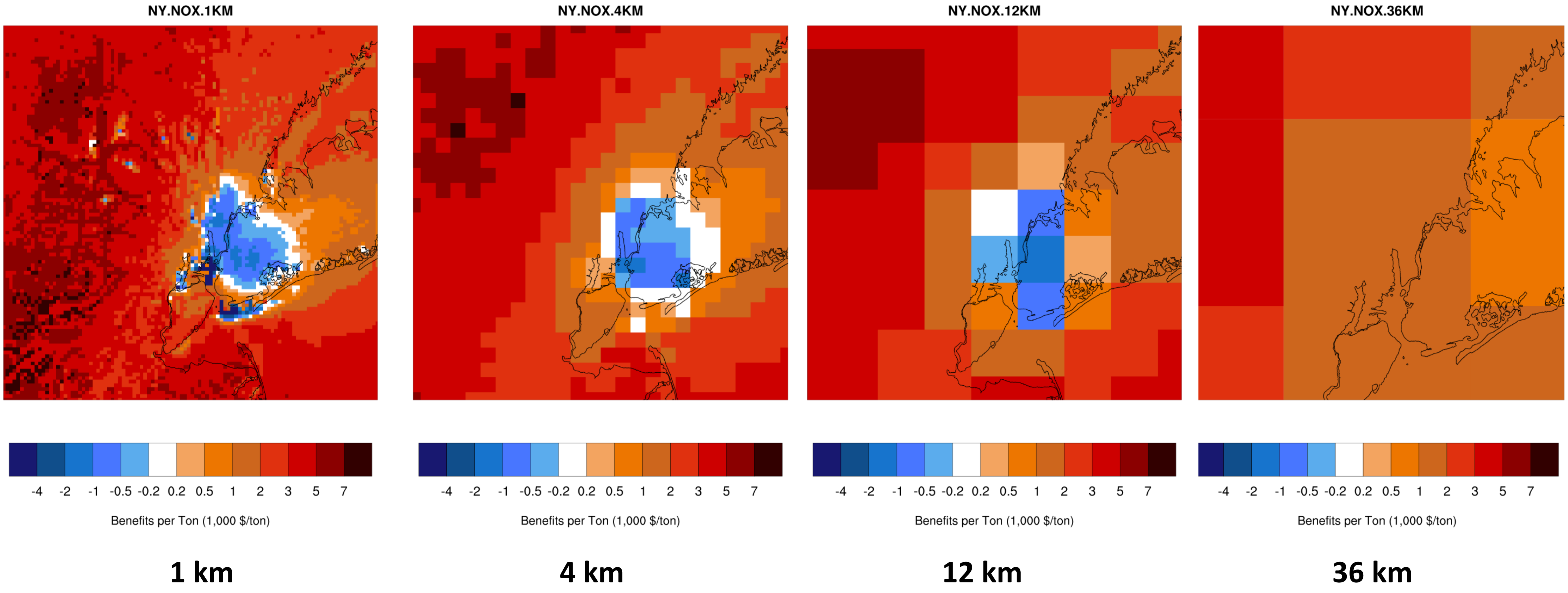
RESULTS:
Effect of resolution on BPTs (NYC: Primary $PM_{2.5}$)



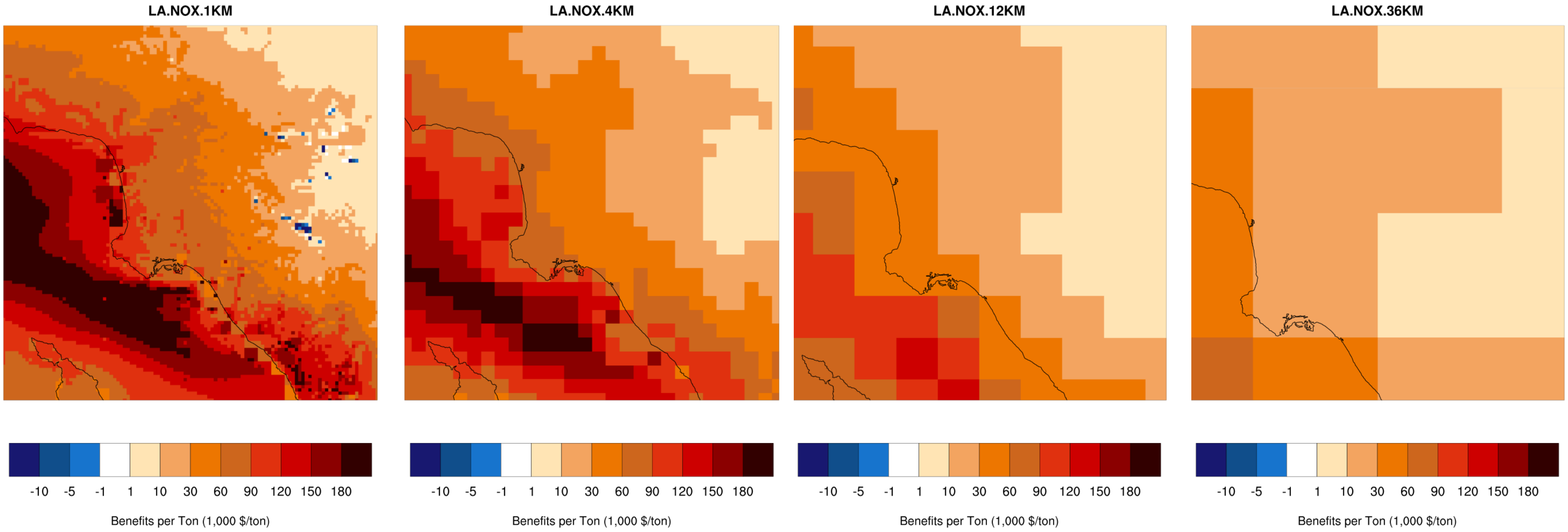
RESULTS:
Effect of resolution on BPTs (LA: Primary $PM_{2.5}$)



RESULTS:
Effect of resolution on BPTs (NYC: NO_x)

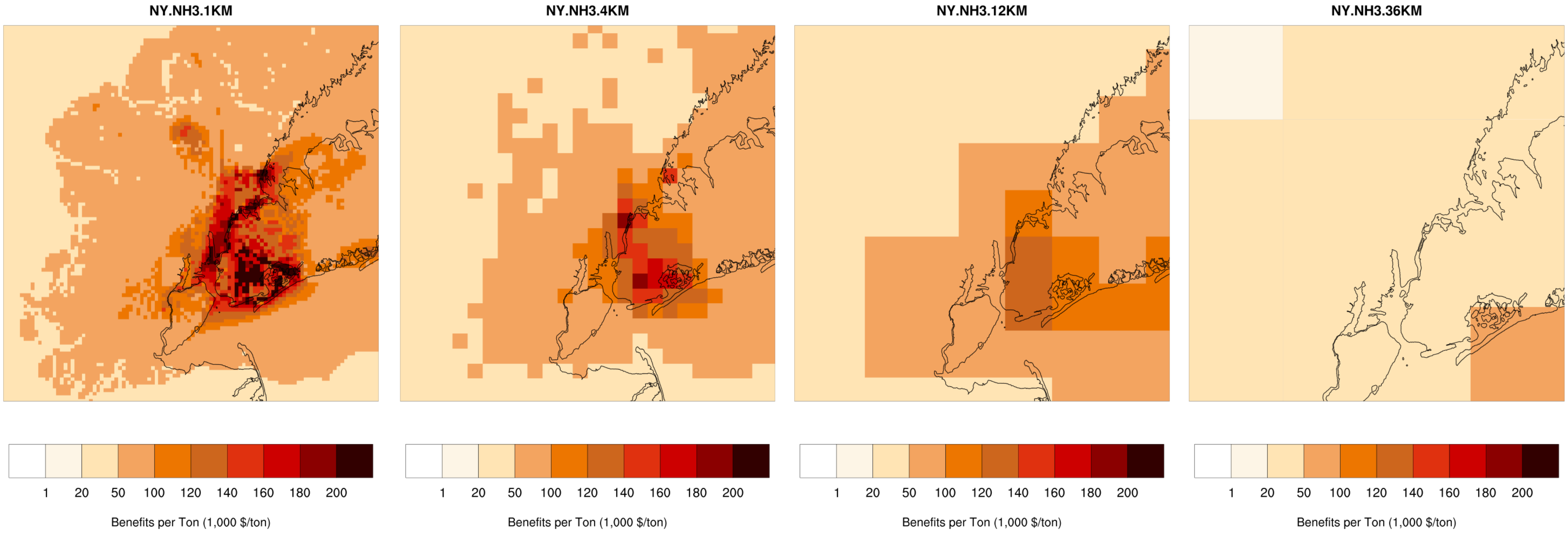


RESULTS:
Effect of resolution on BPTs (LA: NO_x)



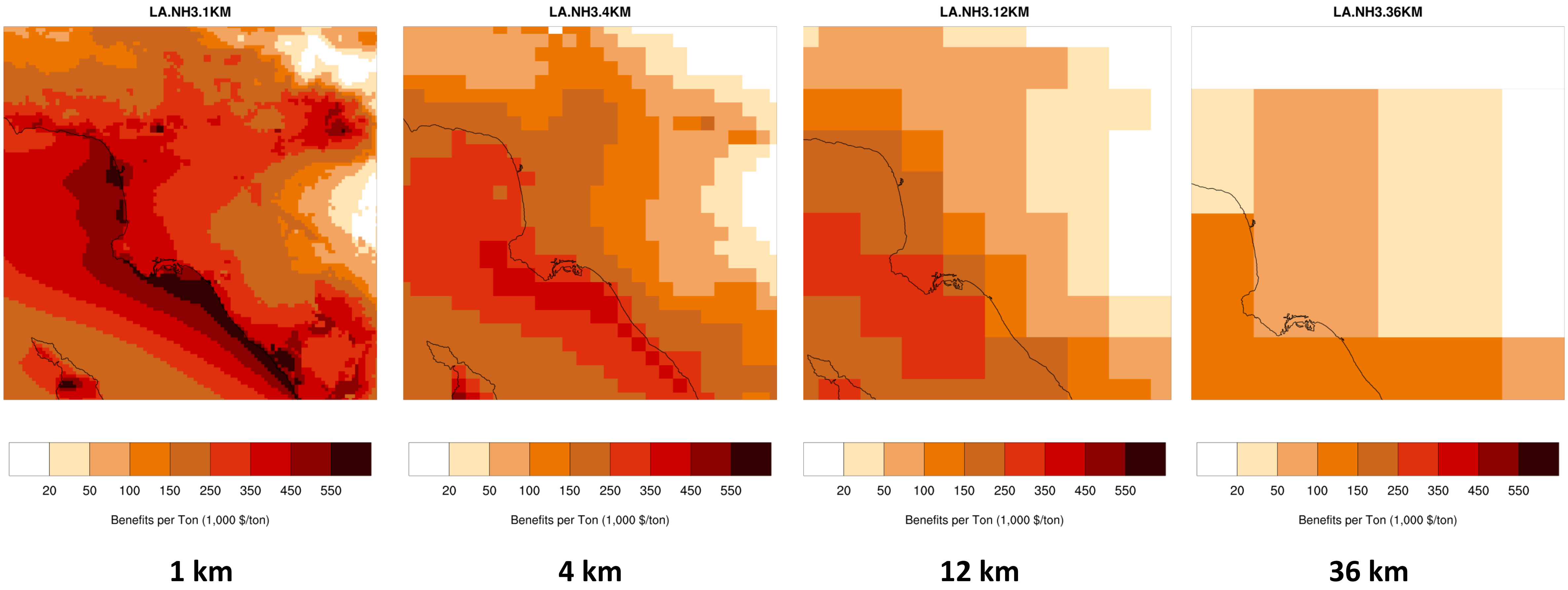
1 km **4 km** **12 km** **36 km**

RESULTS:
Effect of resolution on BPTs (NYC: NH_3)



1 km 4 km 12 km 36 km

RESULTS:
Effect of resolution on BPTs (LA: NH_3)



RESULTS:
Health Burden estimates (1/2)

Burden estimates for the New York at various resolutions ($ Billions)					
Species	Resolution	**36 km**	**12 km**	**4 km**	**1 km**
$PM_{2.5}$		**10.82**	**14.56**	**13.46**	**13.96**
NH_3		**0.28**	**0.55**	**0.60**	**0.70**
NOx		**0.16**	**0.12**	**0.11**	**0.16**
SO_2		**0.27**	**0.34**	**0.43**	**0.52**
Total		**11.52**	**15.61**	**14.60**	**15.34**

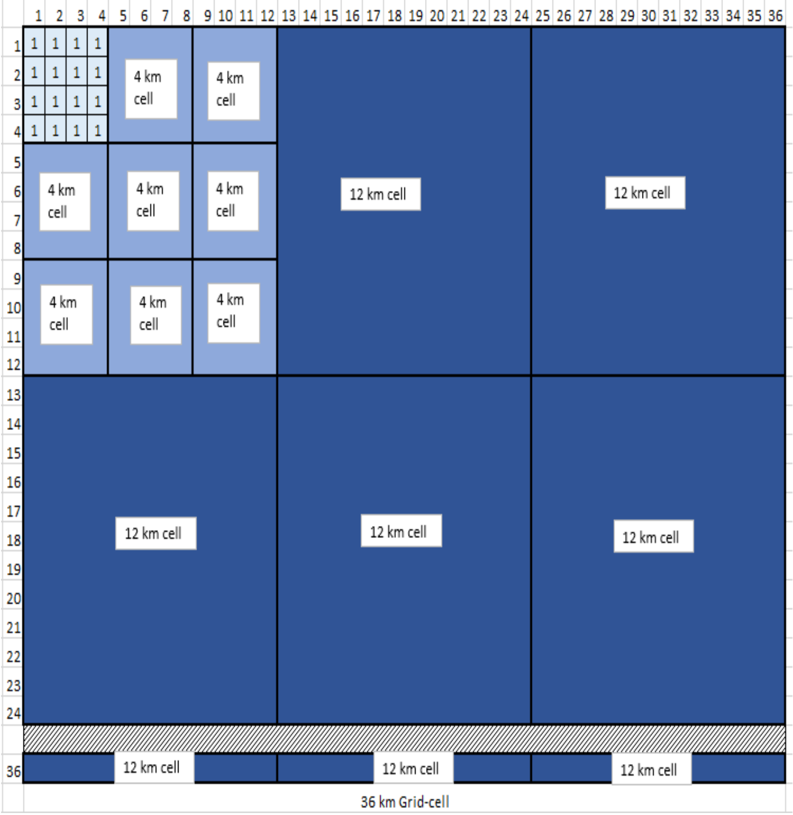
$$HEALTH\ BURDEN = \sum_{i=0}^{N} BPT_i * Emis\ (\frac{ton}{yr})_i$$

RESULTS:
Health Burden estimates (2/2)

Burden estimates for the Los Angeles at various resolutions ($ Billions)					
Species	Resolution	**36 km**	**12 km**	**4 km**	**1 km**
$PM_{2.5}$		**12.06**	**11.33**	**12.27**	**12.83**
NH_3		**1.44**	**2.00**	**2.92**	**5.50**
NOx		**1.38**	**2.13**	**3.48**	**4.84**
SO_2		**0.46**	**0.97**	**0.825**	**1.04**
Total		**15.34**	**16.42**	**19.49**	**24.21**

$$HEALTH\ BURDEN = \sum_{i=0}^{N} BPT_i * Emis\ (\frac{ton}{yr})_i$$

RESULTS: Aggregated BPTs

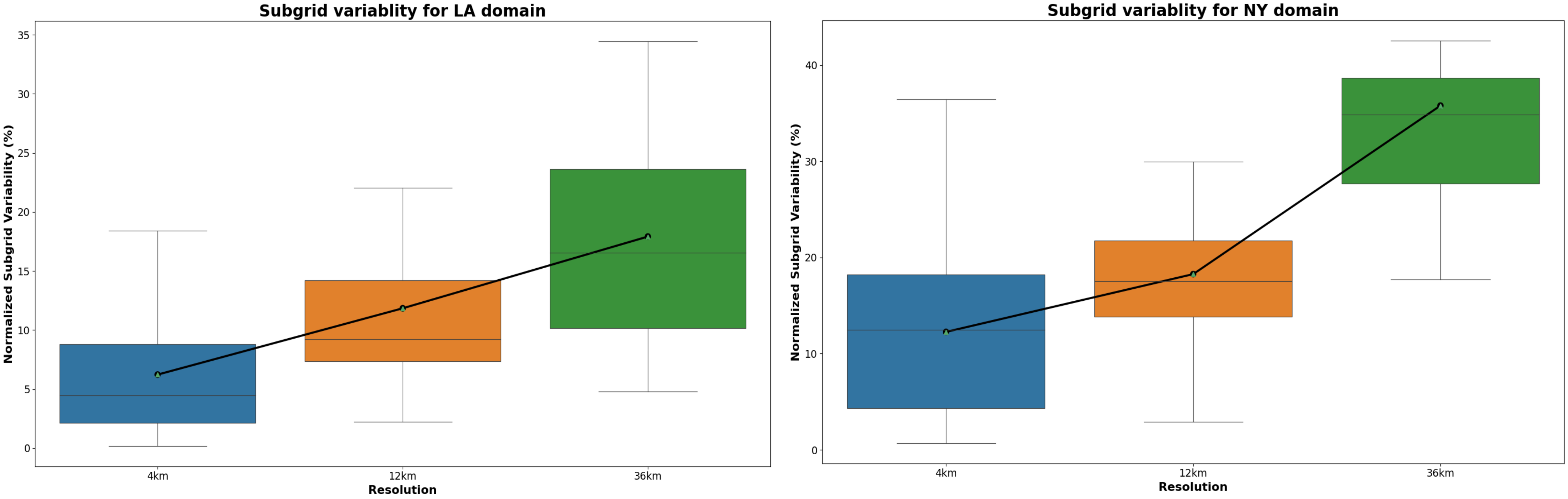


PM$_{2.5}$ domain-wide performance against aggregated 1km				
City	NYC		LA	
Resolution	R	MB	R	MB
36 km	0.589	-$20,38	0.526	-$104,189
12 km	0.942	-$21,431	0.745	-$84,945
4 km	0.943	-$68,515	0.829	-$27,050

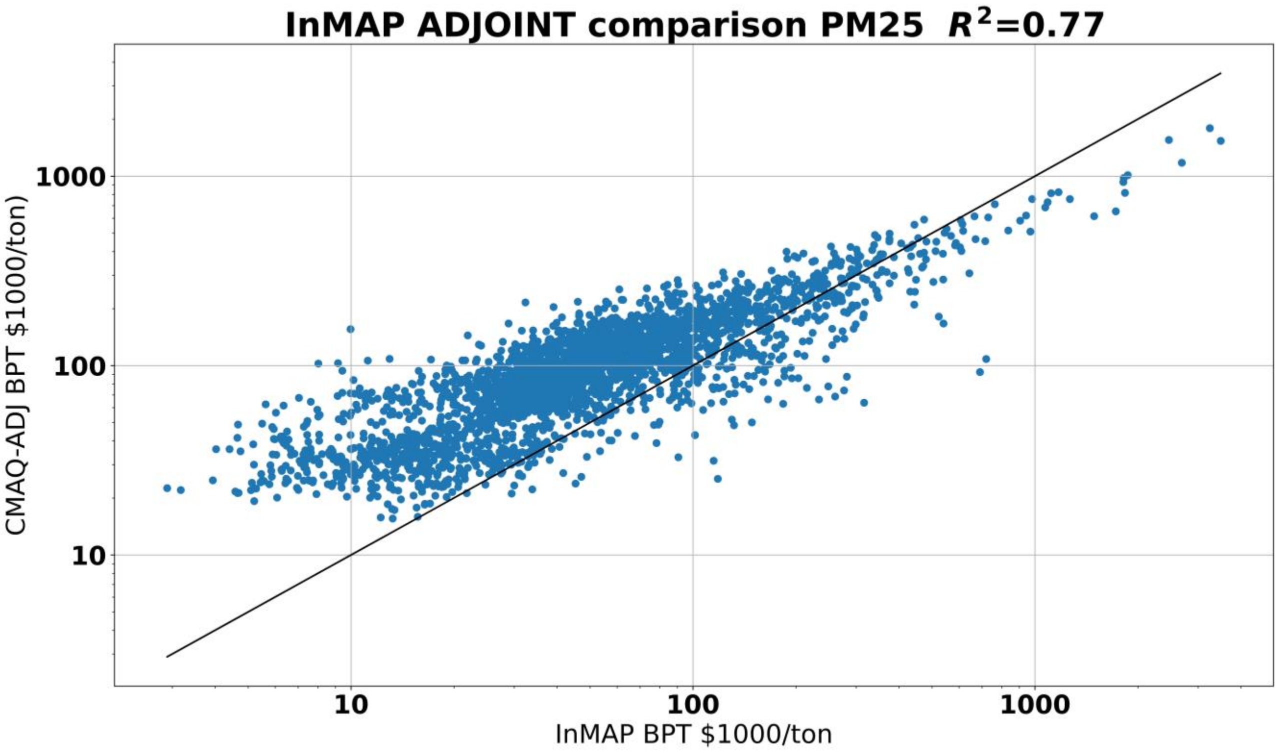
The comparison is carried out between averaged BPTs of 1-km grid cells making up the coarser resolution grid cell and the said coarser cell's BPT

RESULTS:
Sub-grid variability

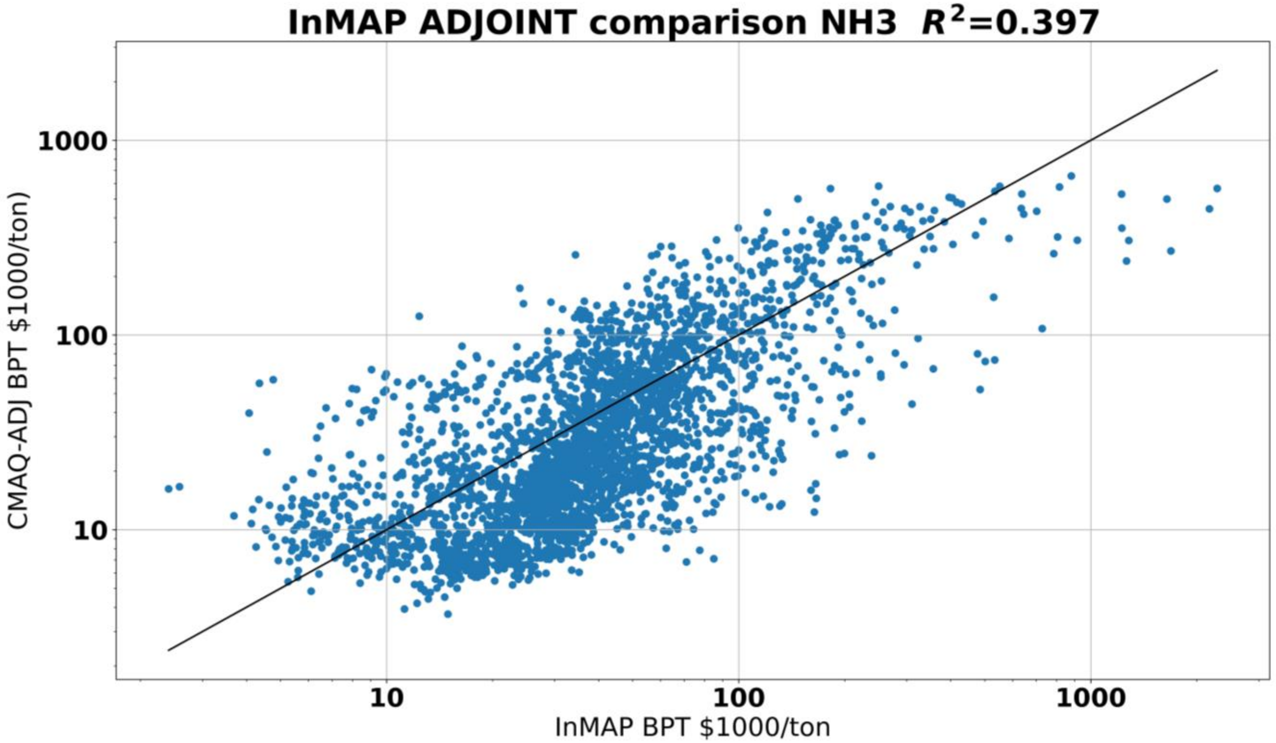
$$Normalized\ Subgrid\ variability = \frac{\sigma_{within\ a\ cell}}{Mean\ of\ a\ cell} * 100\%$$



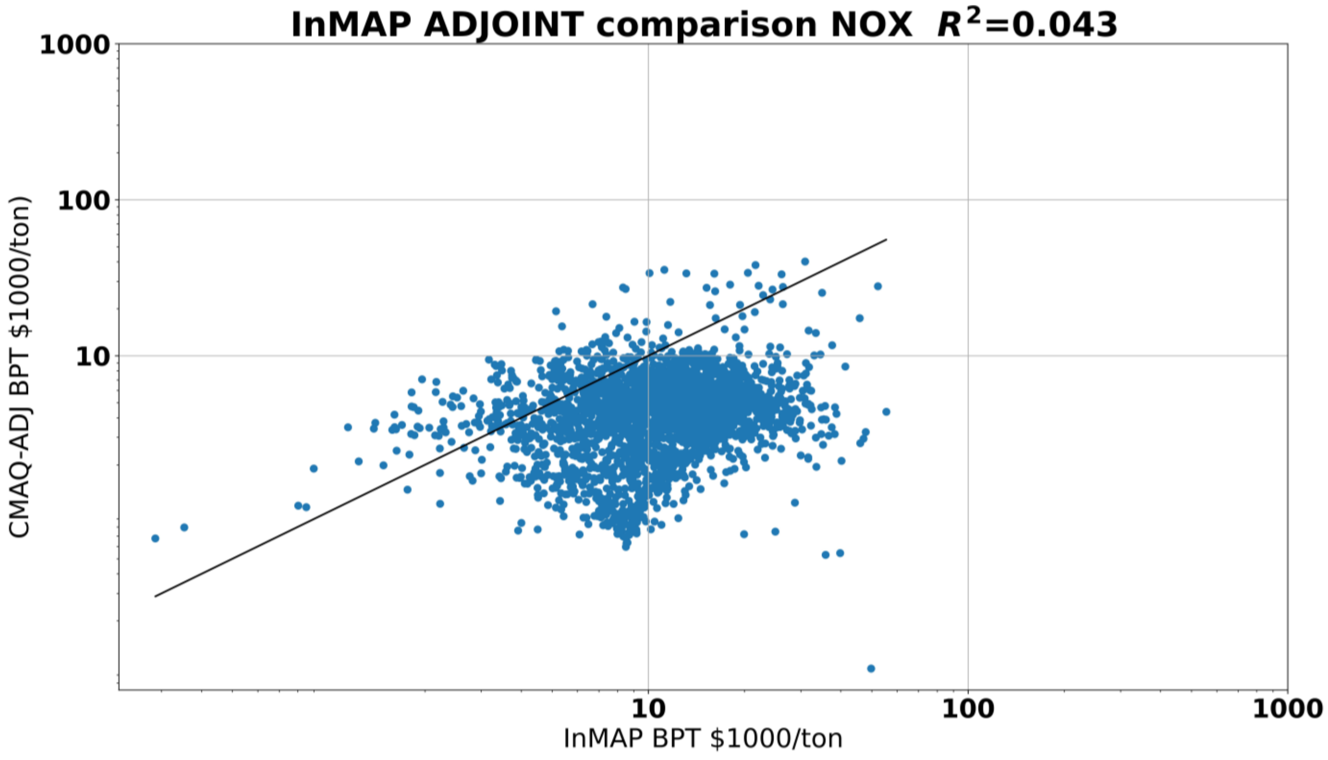
Comparison with Other BPT Estimates (ACS, county level 12km)



Comparison with Other BPT Estimates (ACS, county level 12km)



Comparison with Other BPT Estimates (ACS, county level 12km)



Conclusions:

- Sensitivity analysis to assess the impacts of horizontal grid resolution on societal health benefits of emissions abatement can help in boosting the confidence in regional scale studies.
- 12km horizontal grid spacing can be sufficient to estimate the total health burden of $PM_{2.5}$ in a metropolitan area in a regional scale study as higher grid resolution runs are not feasible.
- For decisions making on control strategies at the urban level, high resolution is required to capture local features of location specific BPTs.

Limitations:

- The study is ongoing, results presented here only represent the summer season, seasonal or even interannual variation might change the conclusions drawn here.
- BPTs are tangents to the atmospheric response surface and are based on an implied assumption of linearity.
- Uncertainties due to epidemiology, modelling of atmospheric processes, meteorological fields and emission’s inputs.

THANK YOU!

- Special thanks to:
- Health Effects Institute (HEI)
- Alliance Canada formerly known (ComputeCanada)

References:

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Methodology: Episode selection

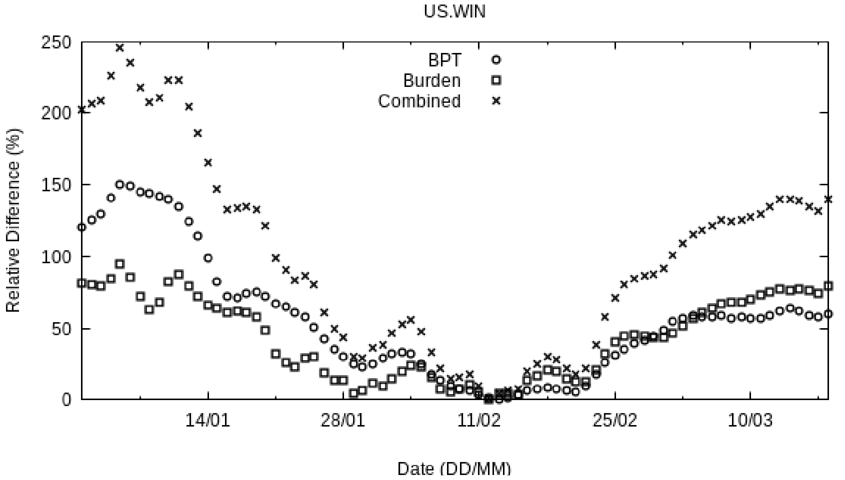
We choose seasonal episodes based on an anomaly analysis of the entire year (by season). To conduct our anomaly analysis, we generate adjoint-based BPTs for the entire year at a coarser resolution (36 km) where yearlong simulations are possible.

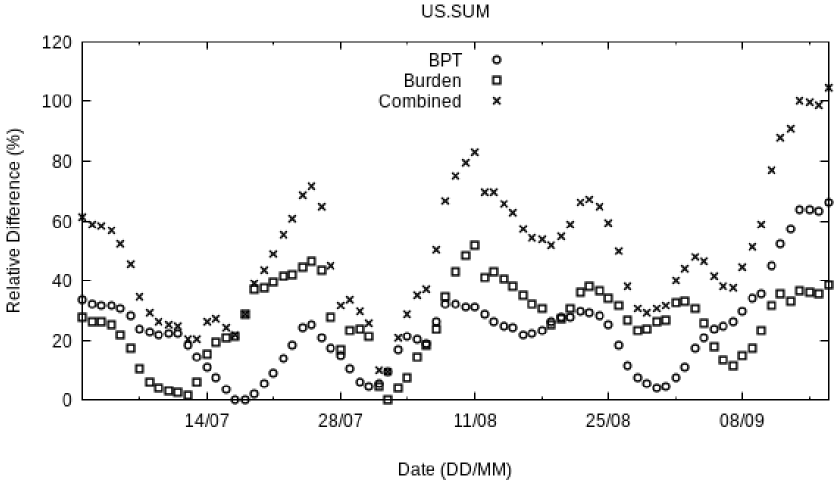
$$f_{BPT,t} = \frac{100}{N_{grids} \times N_{spc}} \sum_{spc} \sum_{grids} \frac{(BPT_{grid,spc,t} - BPT_{grid,spc,season})}{BPT_{grid,spc,season}}$$

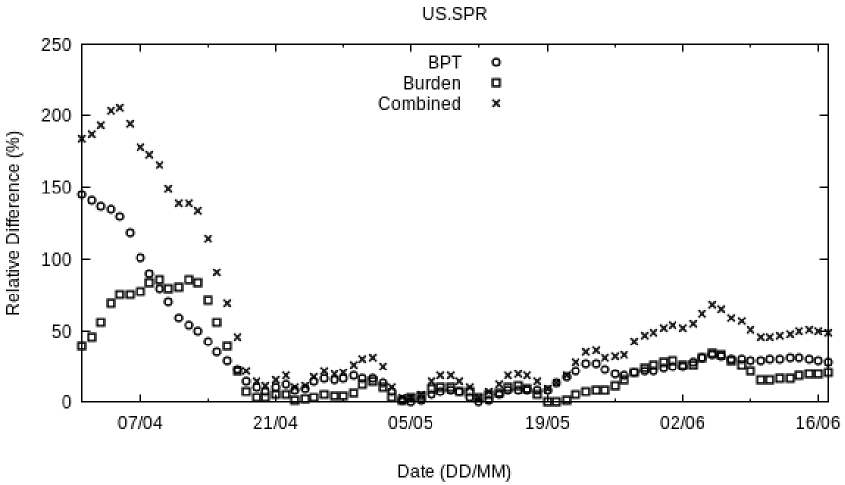
$$f_{burden,t} = \frac{100}{N_{grids} N_{spc}} \sum_{grids} \frac{(\sum_{spc} BPT_{grid,spc,t} E_{grid,spc,t} - \sum_{spc} BPT_{grid,spc,season} E_{grid,spc,season})}{\sum_{spc} BPT_{grid,season} \times E_{grid,season}}$$

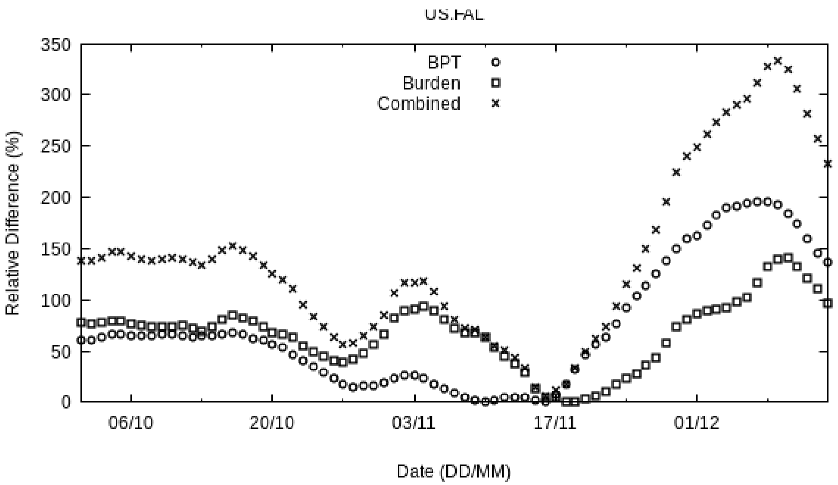
$$min.\left(\frac{f_{BPT,t} - f_{BPT,t,min}}{f_{BPT,t,min}} + \frac{f_{burden,t} - f_{burden,t,min}}{f_{burden,t,min}}\right).$$

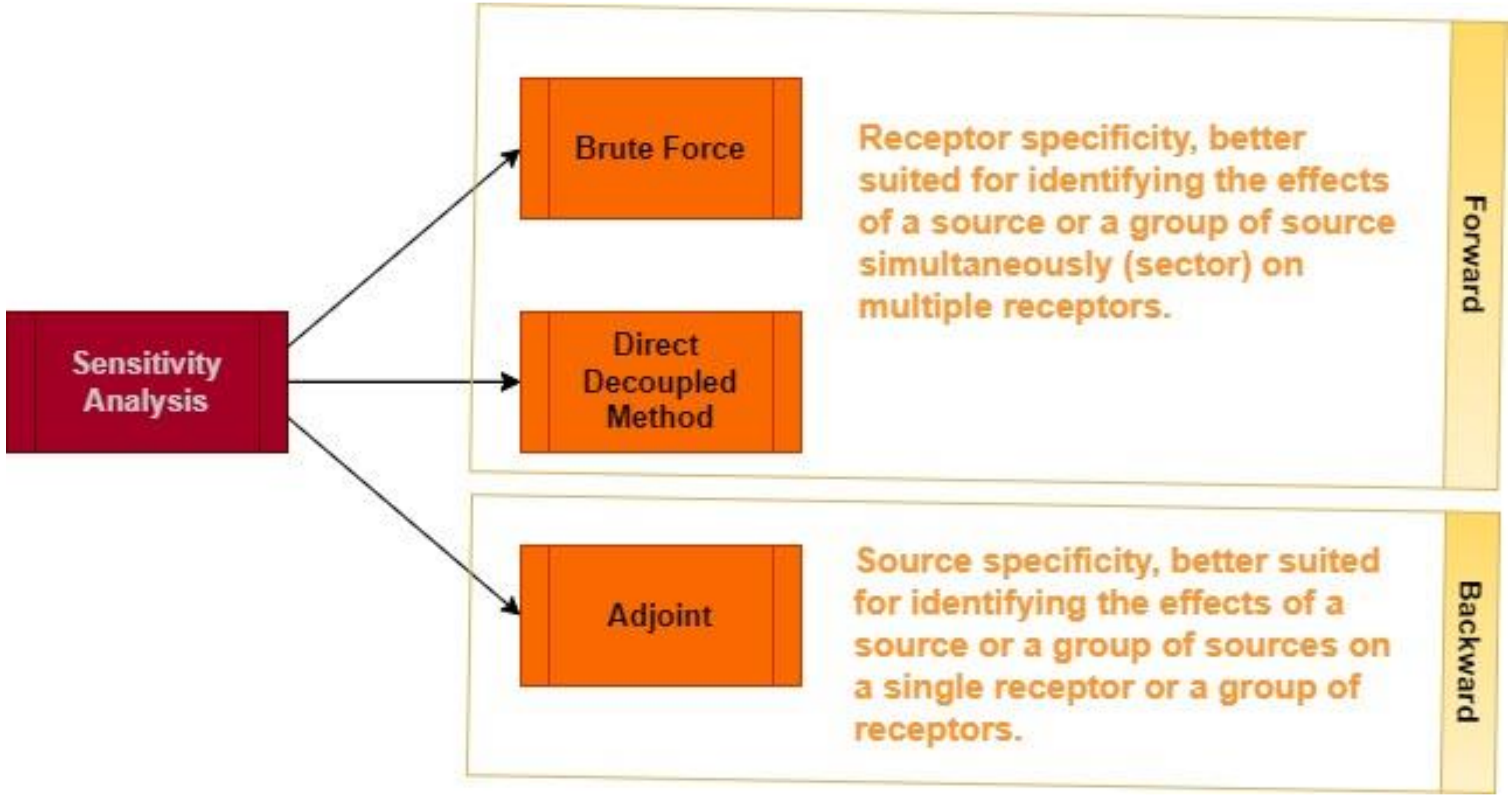
Methodology: Episode selection










Sensitivity Analysis
Brute Force
Direct Decoupled Method
Adjoint
Receptor specificity, better suited for identifying the effects of a source or a group of source simultaneously (sector) on multiple receptors.
Forward
Source specificity, better suited for identifying the effects of a source or a group of sources on a single receptor or a group of receptors.
Backward

$$J = V_{SL} \sum_i M_{0,i} \times P_i\left(1 - e^{-\theta T(z)}\right),$$

where,

$$T(z) = \log\left(1 + \frac{z}{\alpha}\right)\omega(z),$$

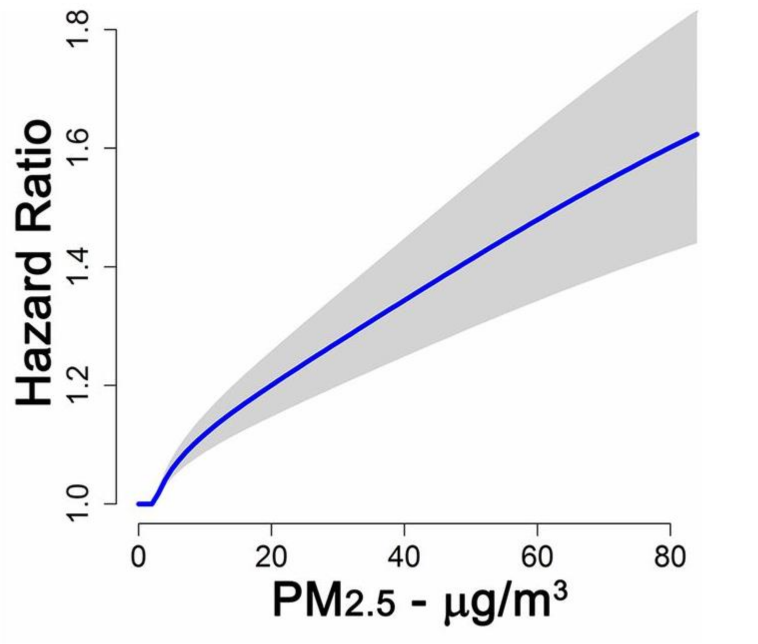
$$\omega(z) = \frac{1}{1 + e^{-(z-\mu)/\nu}} \; ,$$

$$HR = e^{\theta T(z)}$$

and

$$z = MAX(0, PM_{2.5} - cf)$$

Where:
$\theta = 0.1231$, $\alpha = 1.5$, $\mu = 10.4$, $\nu = 25.9$, and $cf = 2.4$ µg/m3



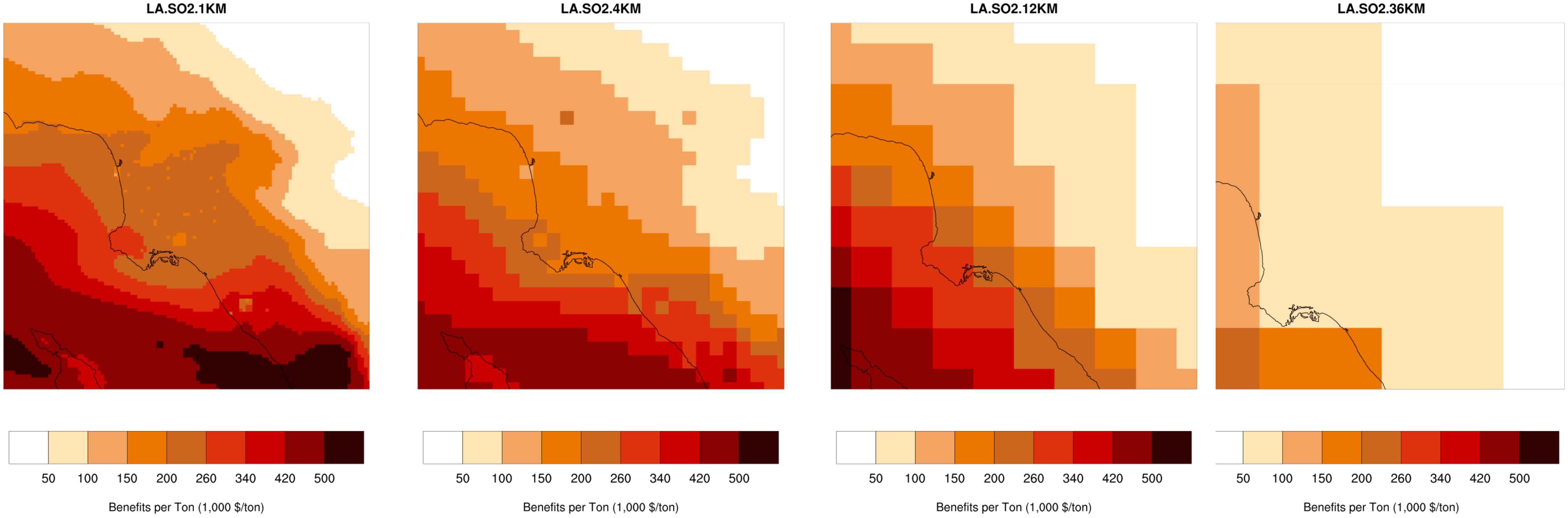
From Burnett et al., 2018

RESULTS:
Health Burden estimates (3/2)

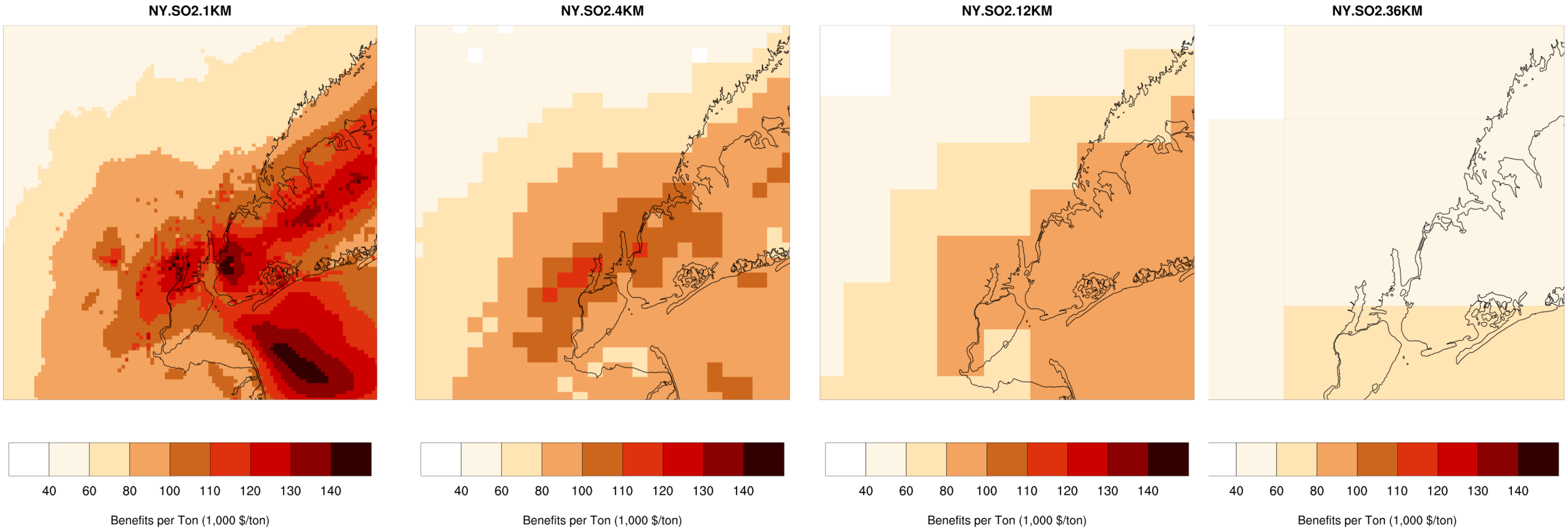
Burden estimates for the city of Los Angeles only at various resolutions					
Species	Resolution	**36 km**	**12 km**	**4 km**	**1 km**
$PM_{2.5}$		**3.98**	**4.00**	**4.17**	**4.29**
NH_3		**0.40**	**0.70**	**1.01**	**1.88**
NOx		**0.54**	**0.79**	**1.18**	**1.67**
SO_2		**0.23**	**0.50**	**0.38**	**0.47**
Total		**5.15**	**5.99**	**6.74**	**8.31**

$$HEALTH\ BURDEN = \sum_{i=0}^{N} BPT_i * Emis\ (\frac{ton}{yr})_i$$

RESULTS:
Effect of resolution on BPTs (LA: SO_2)



RESULTS:
Effect of resolution on BPTs (NYC: SO_2)



RESULTS:
Comparison with Other BPT Estimates

RCM models vs CMAQ-ADJ (12km) statistics at the county level				
Model	**$PM_{2.5}$**	**NH_3**	**NO_x**	**SO_2**
AP2	0.772	0.365	0.002	0.223
EASIUR	0.819	0.696	0.086	0.062
InMAP	0.755	0.409	0.027	0.088
AVG3	0.903	0.513	0.061	0.195