Supplemental Materials

S.1 4 km Domain Performance Evaluation

A performance evaluation for the 4 km domain is not available within the cited EPA document so we conducted a brief evaluation of the metrics of interest, specifically the daily maximum 8 hr ozone and the 24 hr average PM2.5 using measurements made at a single monitor within each domain. The monitor was selected based on proximity to the major city within each of the regions characterized as urban areas and available measurements of both ozone and PM2.5. Within the two rural areas, there was only one monitor each, and that monitor only measured one of the two pollutants (PM2.5 is measured in the rural Virginia region and ozone is measured in the rural New York region).

We calculated the Mean Normalized Gross Error (MNGE) and Mean Normalized Bias (MNB) for each of the pollutants of interest, in each region modeled at each resolution using Eq. 1 and Eq. 2 respectively.

$$MNGE = \frac{1}{N}\sum_{1}^{N}\left(\frac{|Model - Obs|}{Obs}\right) * 100\ \% \qquad (1)$$

$$MNB = \frac{1}{N}\sum_{1}^{N}\left(\frac{(Model - Obs)}{Obs}\right) * 100\ \% \qquad (2)$$

Results are presented in Table S.1. Ozone bias and error decrease as resolution increases for all regions except for New York City (and a small change in error in New York State. In the case of PM2.5, model performance with respect to these two metrics does not follow a clear pattern with respect to model resolution. PM2.5 performance is worse at 4 km in Boston and Houston but better in New York City, Western Pennsylvania and Virginia.

S.2 Concentrations Changes over Atlanta

Maps showing the difference between 2014 and 2005 daily maximum 8 h ozone concentrations averaged for the ozone season (top row) and the difference between 2014 and 2005 annual average PM2.5 (bottom row) over Atlanta, New York City and Rural New York are presented in Supplemental Information Figures S-1,2&3 respectively.

S.3 Average Population-Weighted Concentrations – Modeling Results Analysis by Resolution

With the exception of Boston, the differences in ozone production in large cities (areas associated with large and heterogeneous population density: Atlanta, Boston, Washington DC, Detroit, Houston, and New York City) are more sensitive to model resolution than ozone production in areas with smaller and more homogeneous population densities (New York, Western Pennsylvania and Virginia), as shown in Figure S.4. Population weighted ozone results modeled at 12 km resolution are similar to 4 km resolution for each of the nine regions. Coarse resolution modeling (36 km) allows for maximum chemistry over the largely population areas by including more emissions sources, which are assumed (by nature of the Eulerian modeling process) to be perfectly mixed. Maximum chemistry causes the model to estimate the largest decrease due to the control policy. In the fine resolution modeling (12 and 4 km), emissions of ozone precursors that are released in areas of high population density (NOx from vehicles for example) are transported to areas of less population density before they are well mixed with VOCs in order to form ozone.

Interpretation of the change in population-weighted total $PM_{2.5}$ concentration is complicated because, unlike ozone, which is only one species, PM is made up of many different species. Some PM species are secondary species (similar to ozone) and therefore their production may be enhanced by large, perfectly mixed grid cells containing many emissions sources. Particulate sulfate and nitrate are some examples of these secondary PM species. Emissions of nitrogen oxides and sulfur dioxide react with ammonium in the atmosphere to form particulates. These reactions are likely to be maximized (and therefore the impacts of emissions reductions maximized) in coarse resolution models. While this pattern of secondary $PM_{2.5}$ occurs in Atlanta, as shown in Figure S.5 below, it does not occur as clearly in New York City or Rural New York.

This is in contrast to primary PM species where in fine resolution modeling, direct emissions are diluted less than in coarse resolution modeling. Therefore decreases in emissions of primary PM will lead to larger decreases in the concentration of those primary PM species when the model resolution is finer. This hypothesis is supported by Figure S.5 below showing the population weighted concentration changes of primary and secondary $PM_{2.5}$ individually. However, changes to population weighted concentrations of secondary $PM_{2.5}$ show no clear pattern with respect to resolution. Since secondary $PM_{2.5}$ dominates the impact, it also dominates the response of total $PM_{2.5}$ to resolution.

The combined impact of primary and secondary species in PM modeling is the reason why there is no clear pattern emerging in the population weighted concentrations of $PM_{2.5}$ when estimated using three different model resolutions, as shown in Figure S.6.

S.4 Mortality Impacts by Region: Modeling Results by Resolution

S.4.1 Boston

Boston mortality impacts show little variability by resolution for each species. Changes in mortality due to changing concentrations of ozone and $PM_{2.5}$ estimated using coarse scale modeling results are 2% larger and 8% smaller respectively than corresponding finer scale estimations as shown in Figures S.7 a and b.

S.4.2 Washington DC

The change in mortality due to changes in ozone calculated using a 36 km model resolution are 40% larger than the change in ozone mortality estimated using 12 km resolution modeling. For $PM_{2.5}$, the difference in the mortality changes due to PM concentration changes is 3% larger using 36 km results versus 12 km results, and 0.1% smaller versus 4 km results. These results are shown in Figure S.8 a and b.

S.4.3 Detroit

Detroit, similar to Houston and New York City, showed large sensitivity to resolution when estimating ozone mortality. The point estimate for avoided ozone mortality obtained using 36 km modeling resolution results fell outside the uncertainty range of the finer resolution mortality results. This finding indicates that modeling ozone human health impacts in Detroit at coarse scale resolution has the potential to over-estimate benefits associated with reductions by 100%. In Detroit the changes in mortality due to $PM_{2.5}$ emissions changes calculated using coarse scale modeling are 10% smaller than results calculated using finer scale modeling. Detroit mortality results are shown in Figs. S.9 a and b.

S.4.4 Houston

Houston, similar to Detroit and New York City, shows large sensitivity to resolution when estimating ozone mortality. The point estimate for avoided ozone mortality obtained using 36 km modeling resolution results fell outside the uncertainty range of the finer resolution mortality results. This finding indicates that modeling ozone human health impacts in Houston at coarse scale resolution could severely over-estimate benefits associated with reductions (in this study, 36 km mortality benefits were nine times larger than benefits estimated using finer scale results). $PM_{2.5}$ health benefits calculated using 36 km modeling results were at most 8% larger than results calculated using finer scale modeling. Houston mortality results, consistent with previous findings (Thompson and Selin, 2012) are shown in Figs. S.10 a and b.

S.4.5 New York State

Mortality changes calculated in a rural area of New York State show low sensitivity to model resolution for both ozone and $PM_{2.5}$ as shown in Figs. S.11 a and b. Changes in mortality due to changes in concentrations estimated using 36 km modeling results were 9% larger than benefits estimate using finer scale modeling results for ozone. Mortality changes due to changes in $PM_{2.5}$ concentrations estimated using 36 km modeling results were and 7% larger than 12 km results and 9% smaller than 4 km results.

S.4.6 New York City

New York City, like Detroit and Houston, shows large sensitivity to resolution when estimating ozone mortality. The point estimate for avoided ozone mortality obtained using 36 km modeling resolution results fell outside the uncertainty range of the finer resolution mortality results. This finding indicates that modeling ozone human health impacts in New York City at coarse scale resolution could potentially over-estimate benefits associated with reductions by 250%. Mortality point estimates from $PM_{2.5}$ in New York City are at most 7% smaller when calculated using coarse scale modeling versus fine scale modeling. Mortality results for New York City as shown in Figs. S.12 a and b.

S.4.7 Western Pennsylvania

Mortality changes calculated for Western Pennsylvania show low sensitivity to model resolution for both ozone and $PM_{2.5}$ as shown in Figs. S.13 a and b. Human health benefits estimated using

36 km modeling results were 14% and 3% larger than benefits estimate using finer scale modeling results for ozone and $PM_{2.5}$ respectively.

S.4.8 Virginia

Mortality changes calculated for rural Virginia show low sensitivity to model resolution for both ozone and $PM_{2.5}$ as shown in Figs. S.14. a and b. Human health benefits estimated using 36 km modeling results were 1% and 6% larger than benefits estimated using finer scale modeling results for ozone and $PM_{2.5}$ respectively.

S.4.9. Eastern US

Mortality changes calculated for ozone and PM2.5 for the entire Eastern US are shown in Figs. S.15. a and b. Human health benefits estimated using 36 km modeling results (12 km versus 36 km resolution only) due to reductions in ozone are 30% larger when estimated using 36 km model resolution versus 12 km resolution. For PM2.5 the benefits estimated using 36 km model resolution are 4% larger than those estimated at 12 km resolution. Similar to results presented by Punger and West (2013), we show larger impacts when health results are calculated using 36 km modeling results versus 12 km modeling results. Although the results were similar, results presented here indicated a stronger impact of resolution on ozone health estimations and a weaker impact of resolution on PM2.5 health estimations. The differences between the two studies could be attributed to differences between the metrics evaluated (health impacts of pollutant control strategies versus health burden of total modeled concentrations) and warrants further study.

Table S.1. Model Mean Normalized Bias and Mean Normalized Gross Error for Ozone and PM2.5 at a single monitor location in each of the nine regions evaluated.

	MNB			MNGE		
Ozone	36 km	12 km	4 km	36 km	12 km	4 km
Atlanta	32%	22%	15%	39%	27%	24%
Boston	-36%	-18%	-17%	42%	29%	26%
Washington DC	-25%	-3%	0%	29%	19%	18%
Detroit	-36%	-22%	-18%	39%	29%	27%
Houston	-20%	-8%	-6%	40%	31%	29%
New York State	-9%	-8%	-7%	16%	17%	17%

New York City	-27%	-19%	-25%	35%	29%	33%
Western Pennsylvania	-21%	-17%	-13%	24%	22%	21%
Virginia		Not Available			Not Available	

	MNB			MNGE		
PM2.5	36 km	12 km	4 km	36 km	12 km	4 km
Atlanta	-55%	-32%	-41%	66%	52%	58%
Boston	-65%	-82%	-104%	102%	111%	130%
Washington DC	8%	-2%	-7%	51%	51%	52%
Detroit	-5%	5%	-3%	48%	43%	47%
Houston	21%	6%	-26%	42%	42%	53%
New York State		Not Available			Not Available	
New York City	-68%	-58%	-51%	76%	68%	62%
Western Pennsylvania	18%	22%	17%	41%	40%	40%
Virginia	-25%	-33%	-27%	49%	49%	45%

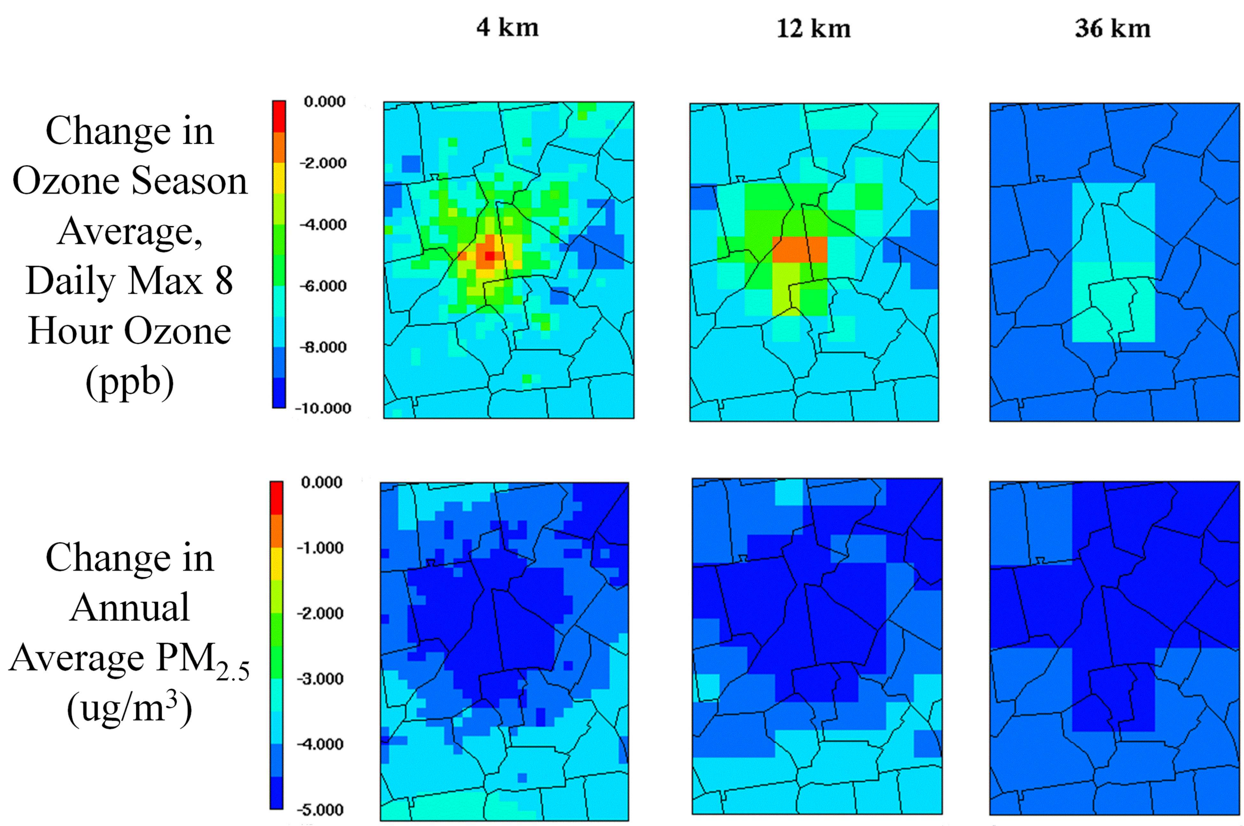


Figure S.1. Maps showing changes to concentration at three different resolutions, of the average over the ozone season of the daily maximum 8-hour averaged ozone concentration over Atlanta (ppb - top row), and the annual average $PM_{2.5}$ concentration over Atlanta (ug/m3 – bottom row).

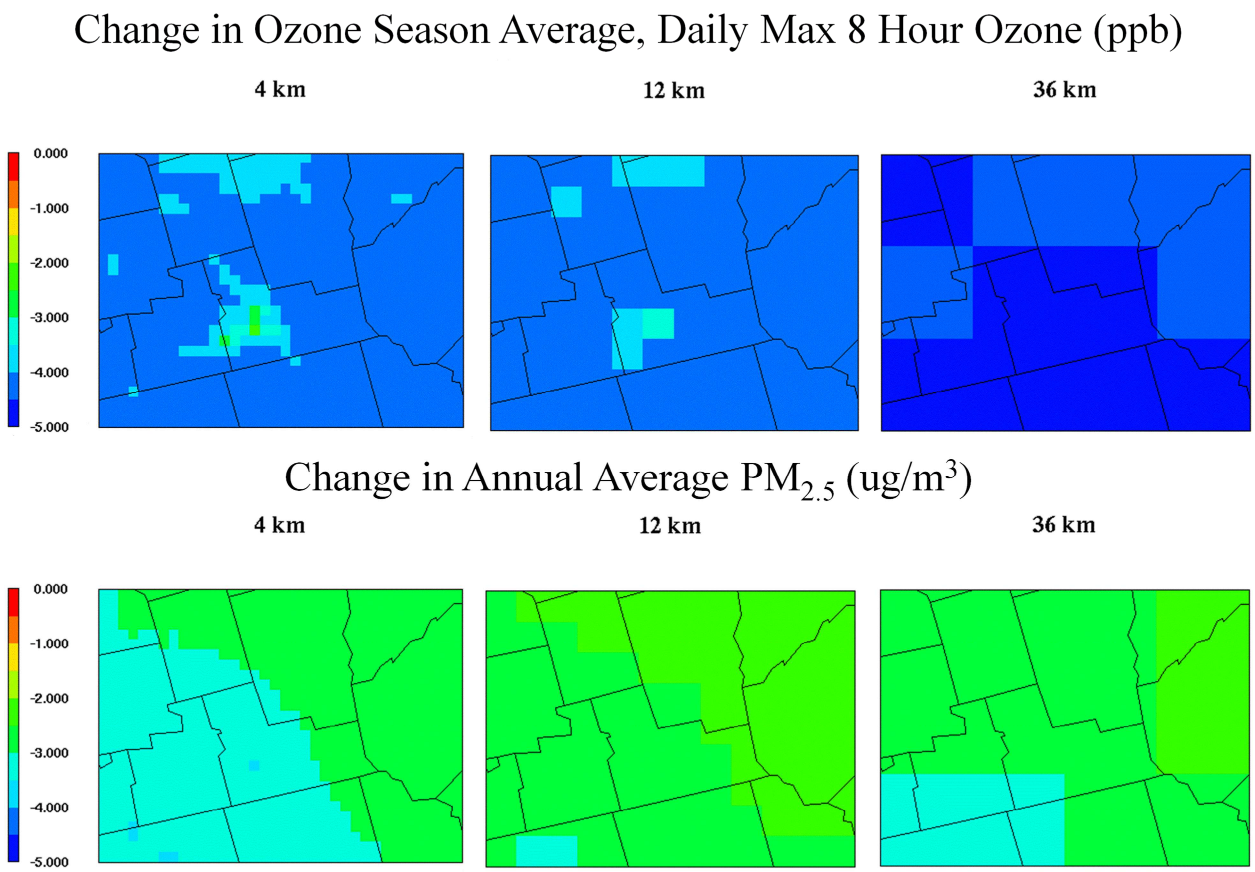


Figure S.2. Maps showing changes to concentration at three different resolutions, of the average over the ozone season of the daily maximum 8-hour averaged ozone concentration over Rural New York (ppb - top row), and the annual average $PM_{2.5}$ concentration over Rural New York (ug/m3 – bottom row).

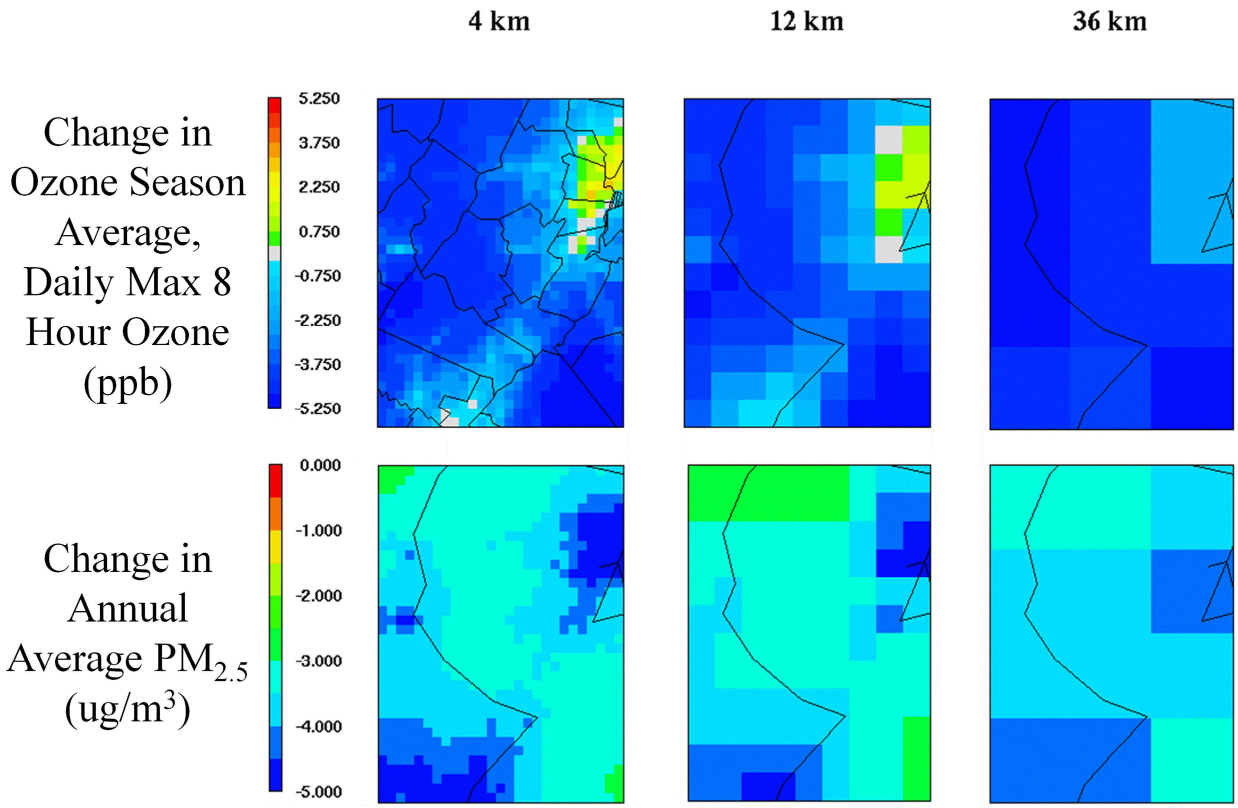


Figure S.3. Maps showing changes to concentration at three different resolutions, of the average over the ozone season of the daily maximum 8-hour averaged ozone concentration over New Jersey/New York City (ppb - top row), and the annual average $PM_{2.5}$ concentration over New Jersey/New York City (ug/m3 – bottom row).

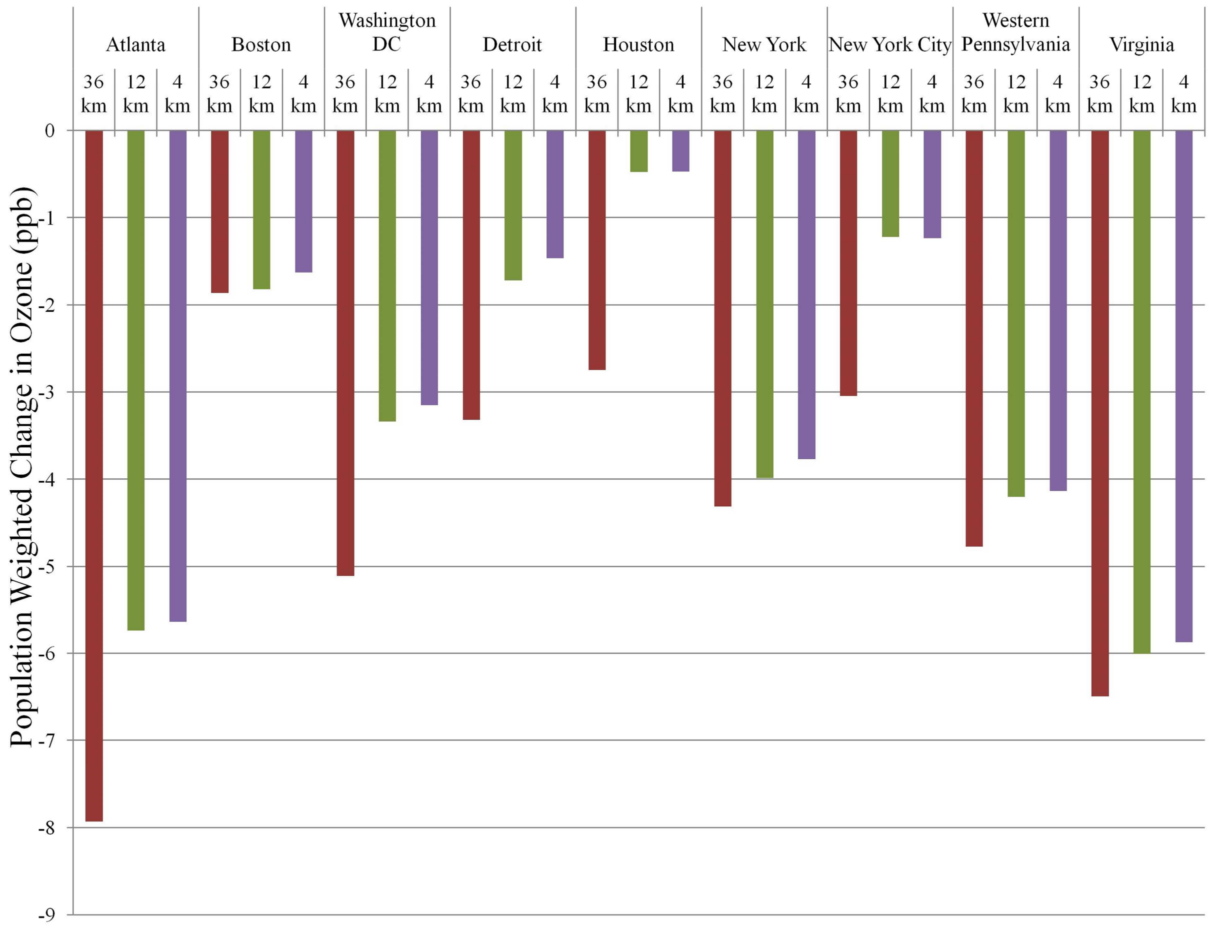


Figure S.4. Change in population weighted daily maximum 8 hr averaged ozone concentration averaged over the ozone season calculated using results modeled at three resolutions in each of nine regions.

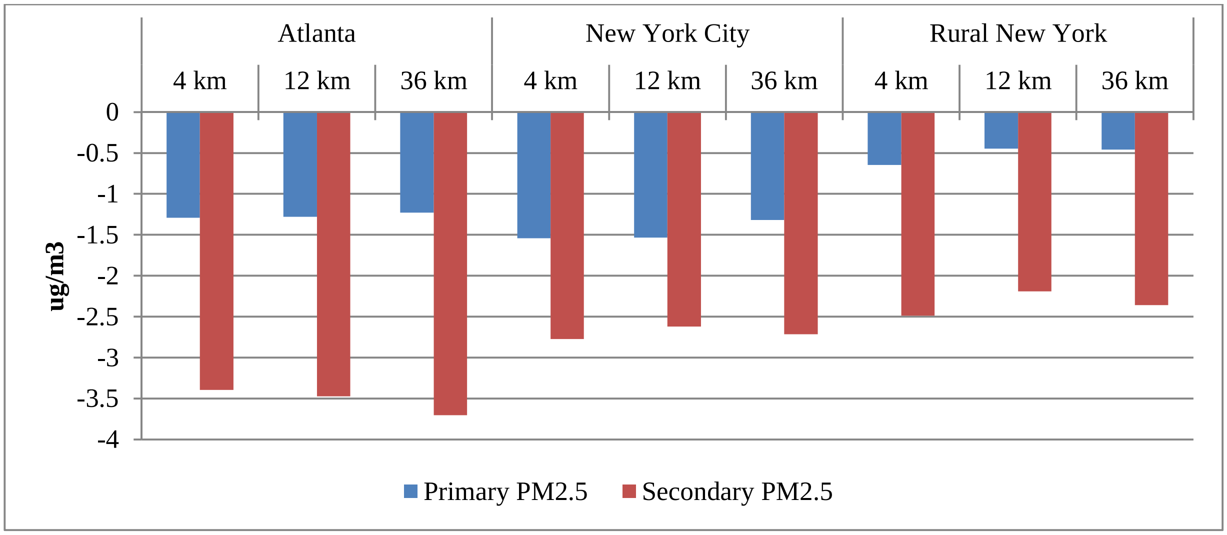


Figure S.5. Change in population weighted annual averaged Primary and Secondary $PM_{2.5}$ concentrations calculated using results modeled at three resolutions in Atlanta, New York City and Rural New York.

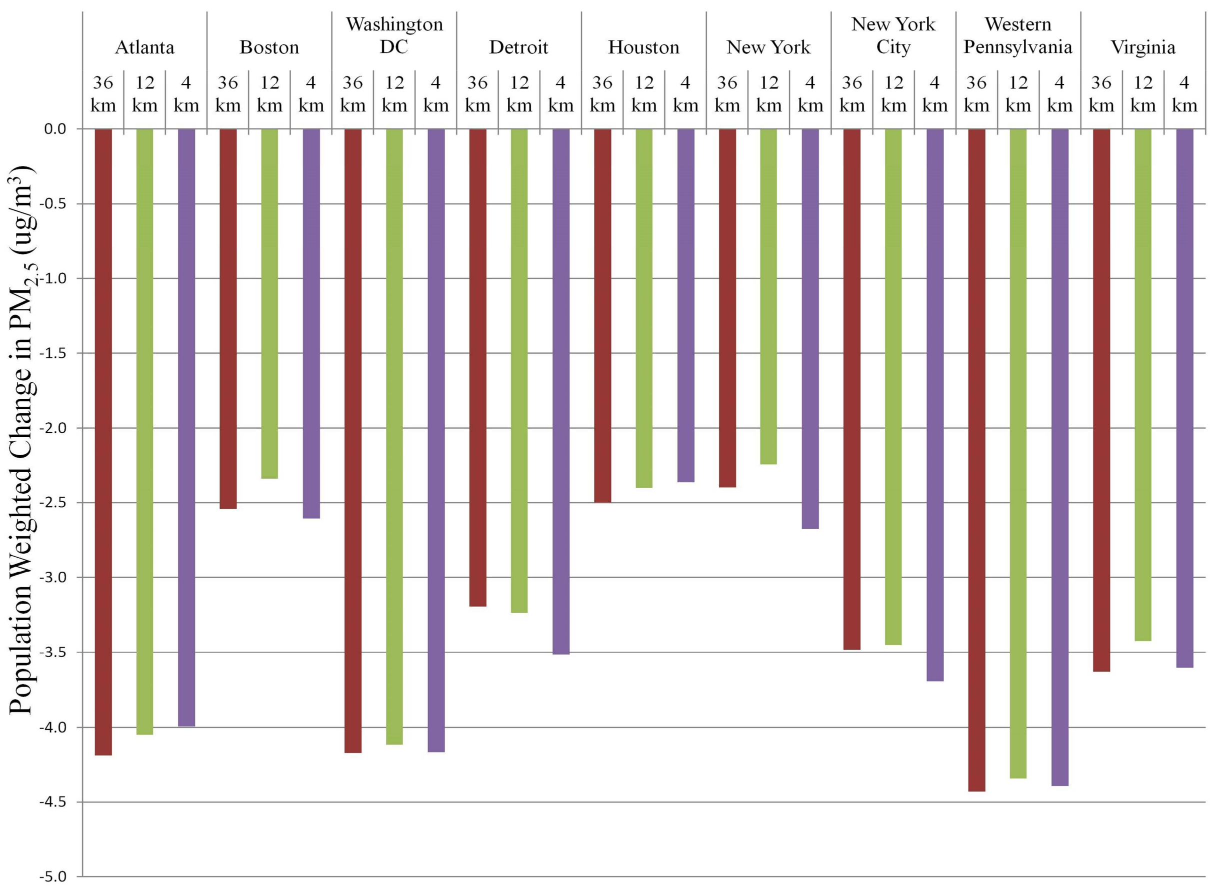


Figure S.6. Change in population weighted annual average $PM_{2.5}$ concentration calculated using results modeled at three resolutions in each of nine regions.

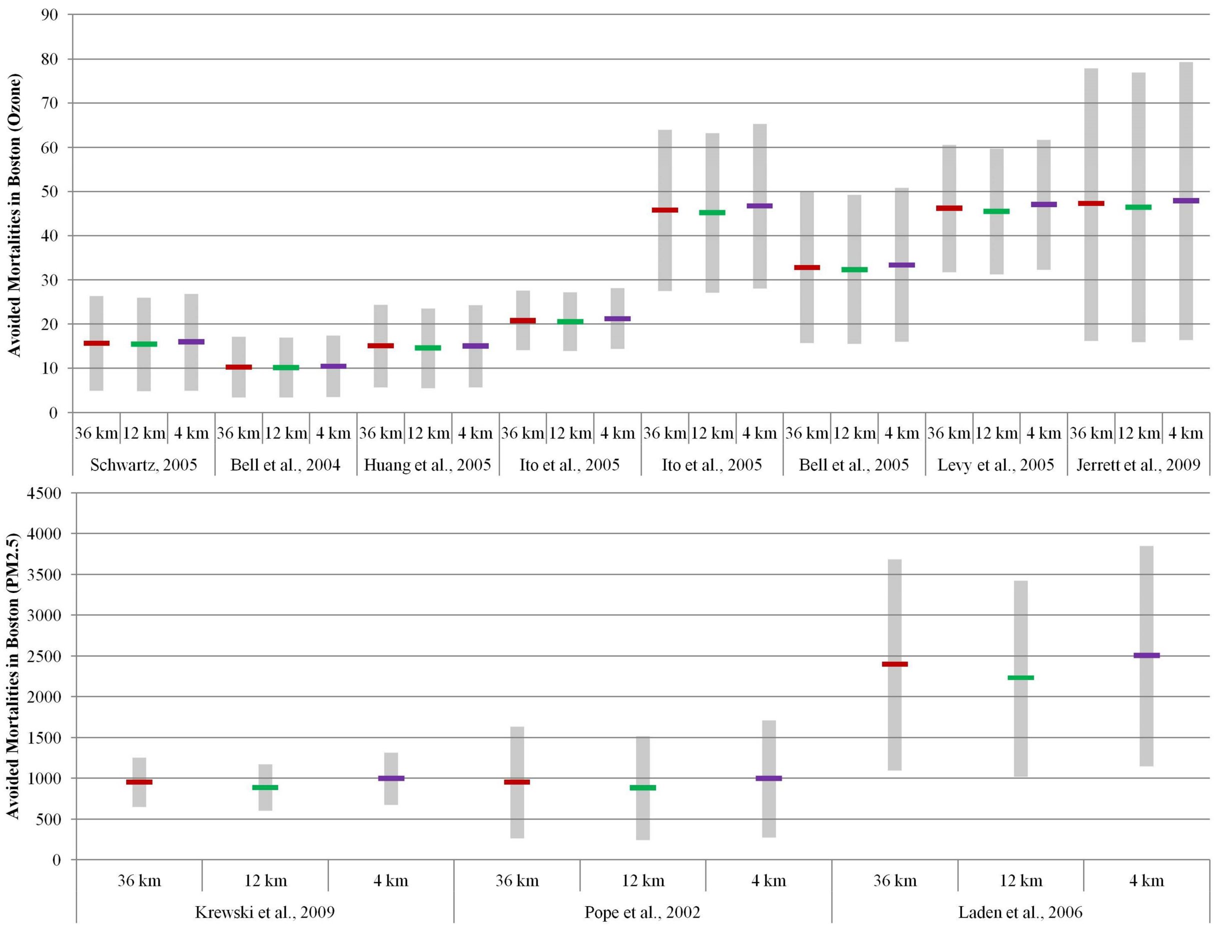


Figure S.7. a. Mortalities avoided in Boston due to changes in ozone concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using eight different concentration response functions. The right most result by Jerrett et al. (2009) estimates for long-term effects of ozone exposure. All other ozone results represent short-term effects. **b.** Mortalities avoided due to changes in $PM_{2.5}$ concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using three different concentration response functions. All $PM_{2.5}$ crf functions represent estimates for long-term effects of $PM_{2.5}$ exposure.

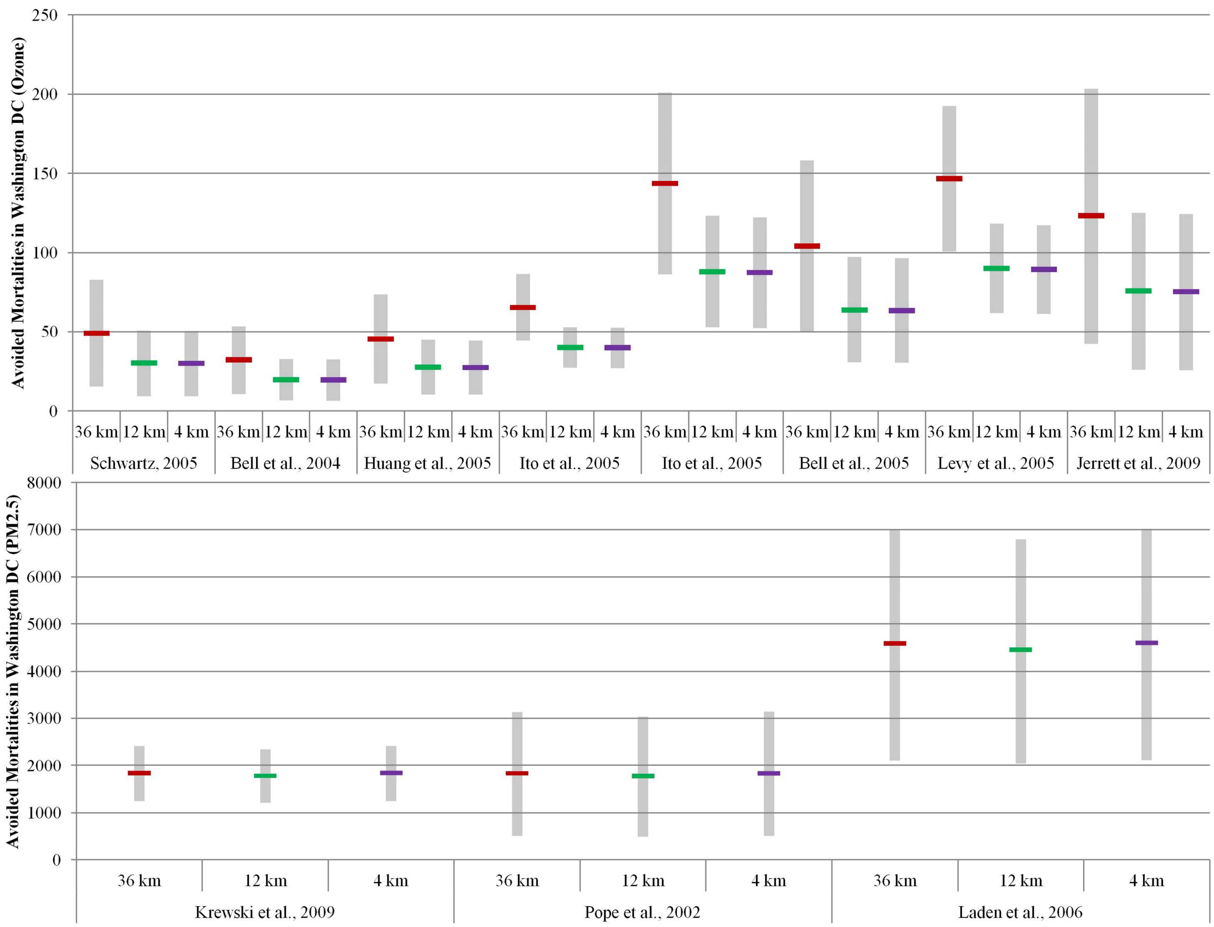


Figure S.8. a. Mortalities avoided in Washington DC due to changes in ozone concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using eight different concentration response functions. The right most result by Jerrett et al. (2009) estimates for long-term effects of ozone exposure. All other ozone results represent short-term effects. **b.** Mortalities avoided due to changes in $PM_{2.5}$ concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using three different concentration response functions. All $PM_{2.5}$ crf functions represent estimates for long-term effects of $PM_{2.5}$ exposure.

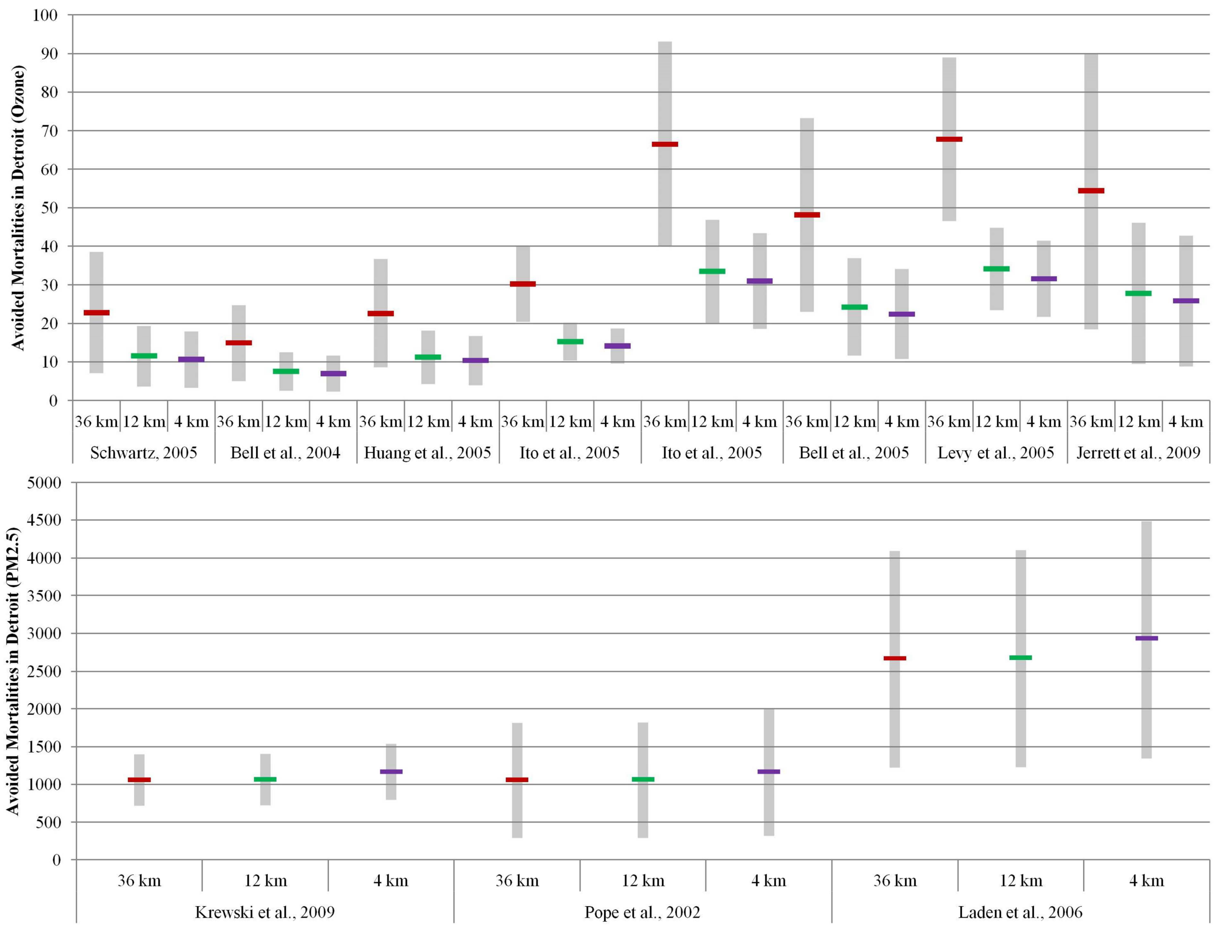


Figure S.9. a. Mortalities avoided in Detroit due to changes in ozone concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using eight different concentration response functions. The right most result by Jerrett et al. (2009) estimates for long-term effects of ozone exposure. All other ozone results represent short-term effects. **b.** Mortalities avoided due to changes in $PM_{2.5}$ concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using three different concentration response functions. All $PM_{2.5}$ crf functions represent estimates for long-term effects of $PM_{2.5}$ exposure.

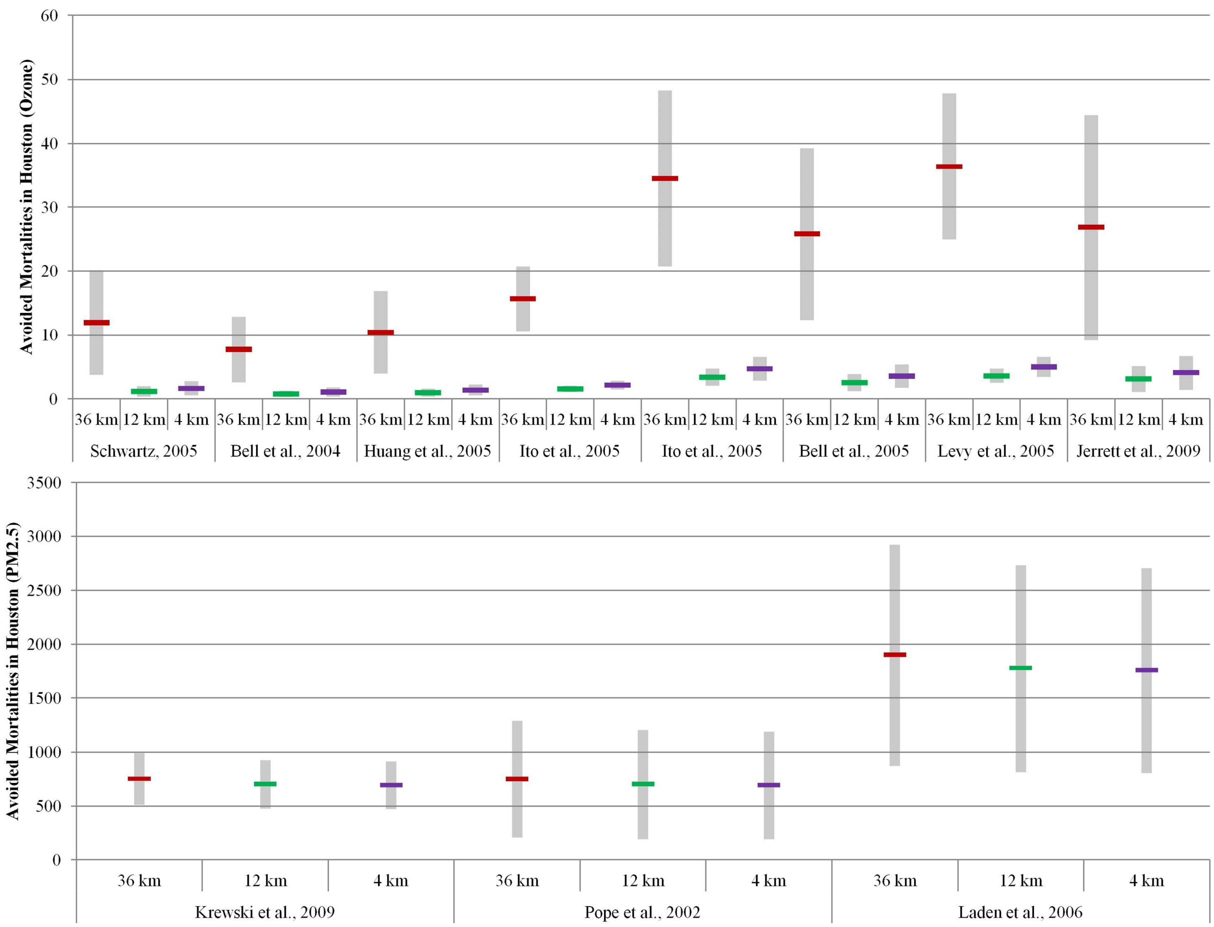


Figure S.10. a. Mortalities avoided in Houston due to changes in ozone concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using eight different concentration response functions. The right most result by Jerrett et al. (2009) estimates for long-term effects of ozone exposure. All other ozone results represent short-term effects. **b**. Mortalities avoided due to changes in $PM_{2.5}$ concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using three different concentration response functions. All $PM_{2.5}$ crf functions represent estimates for long-term effects of $PM_{2.5}$ exposure.

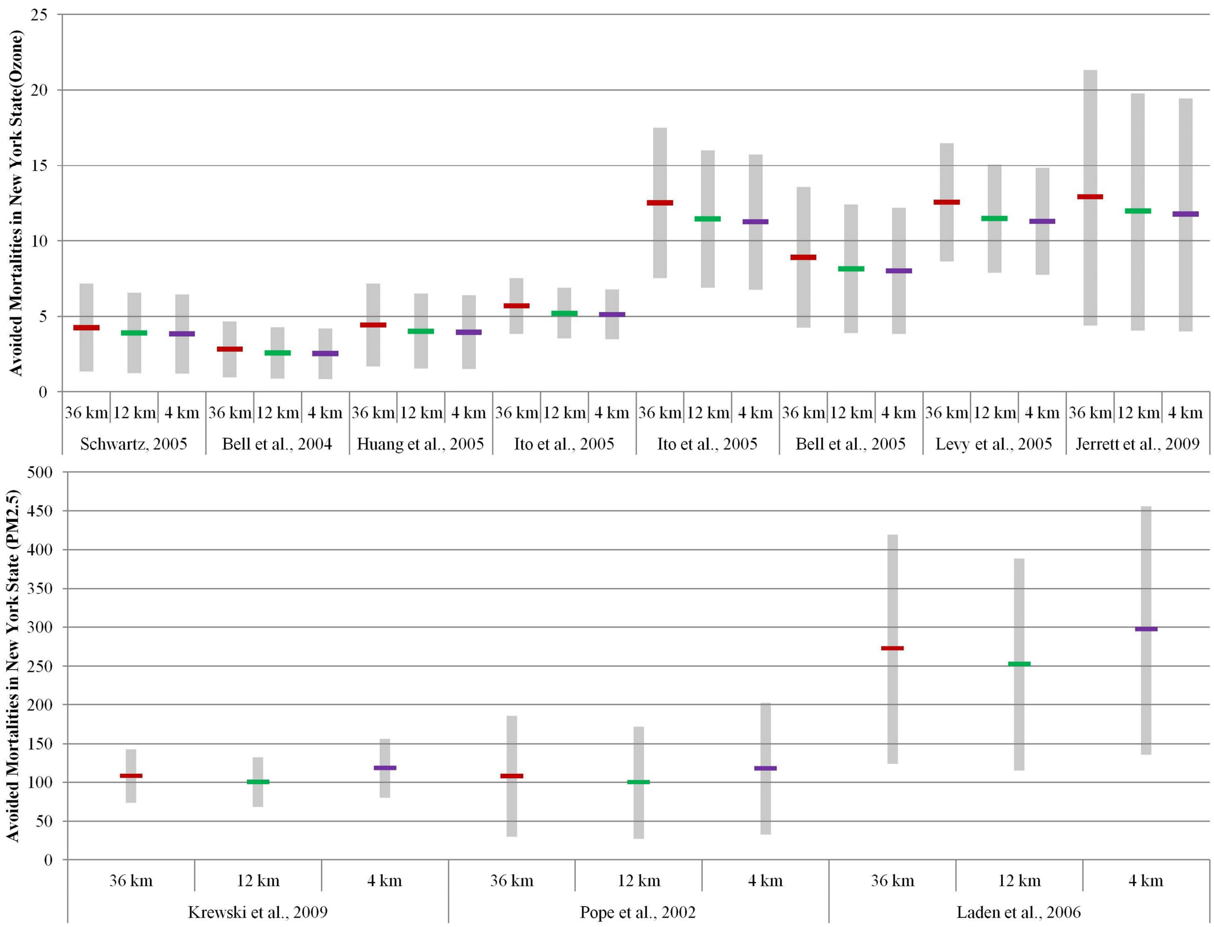


Figure S.11. a. Mortalities avoided in New York State due to changes in ozone concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using eight different concentration response functions. The right most result by Jerrett et al. (2009) estimates for long-term effects of ozone exposure. All other ozone results represent short-term effects. **b**. Mortalities avoided due to changes in $PM_{2.5}$ concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using three different concentration response functions. All $PM_{2.5}$ crf functions represent estimates for long-term effects of $PM_{2.5}$ exposure.

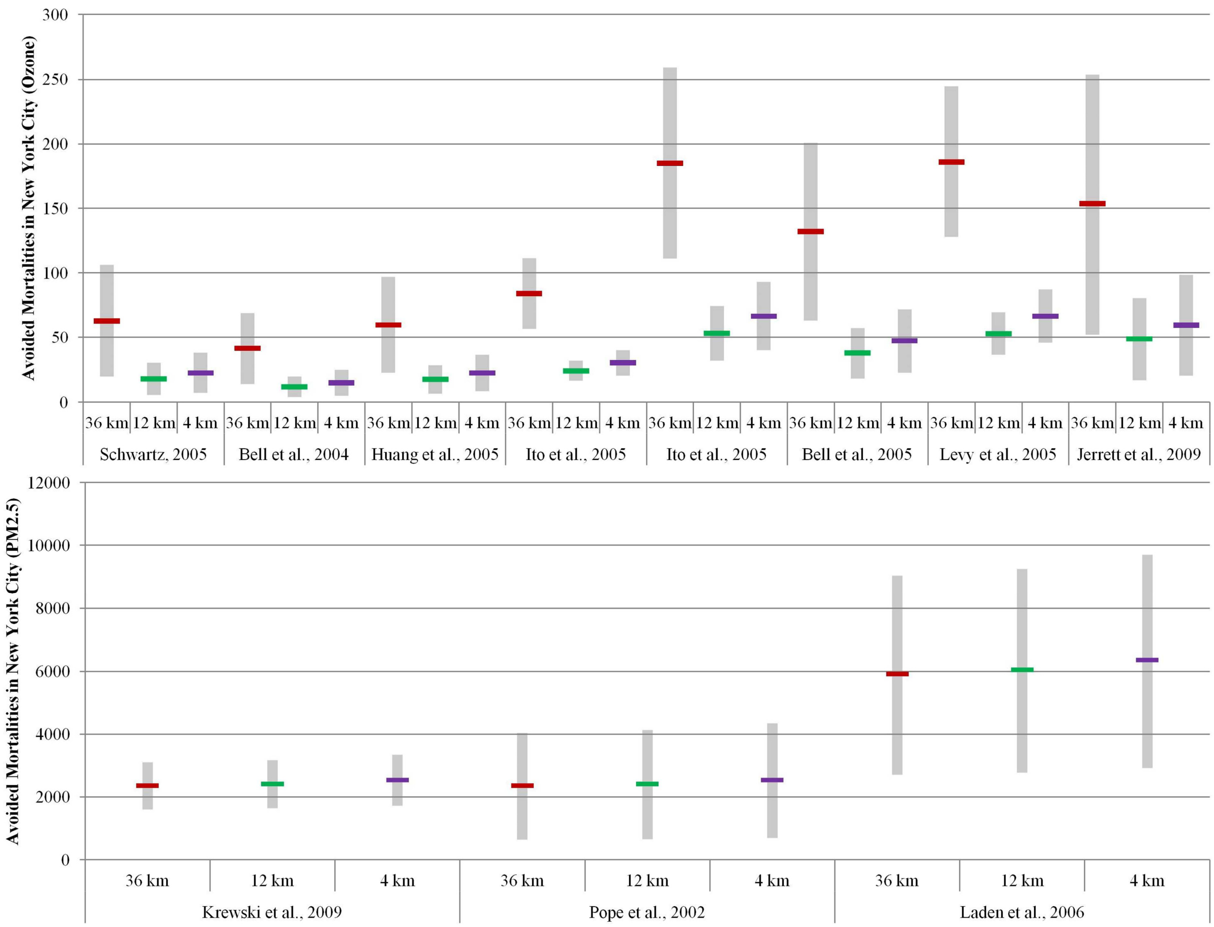


Figure S.12. a. Mortalities avoided in New York City due to changes in ozone concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using eight different concentration response functions. The right most result by Jerrett et al. (2009) estimates for long-term effects of ozone exposure. All other ozone results represent short-term effects. **b.** Mortalities avoided due to changes in $PM_{2.5}$ concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using three different concentration response functions. All $PM_{2.5}$ crf functions represent estimates for long-term effects of $PM_{2.5}$ exposure.

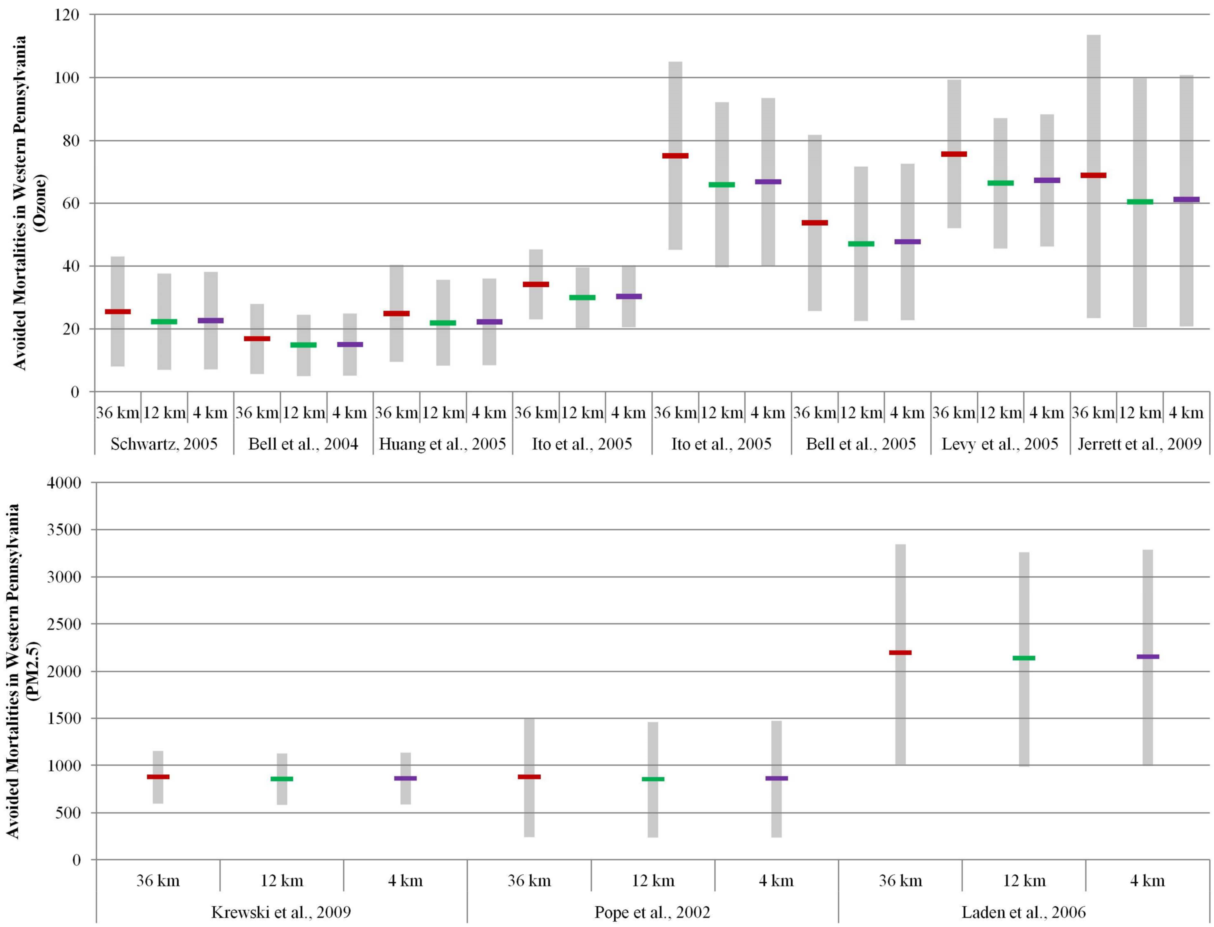


Figure S.13. a. Mortalities avoided in Western Pennsylvania due to changes in ozone concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using eight different concentration response functions. The right most result by Jerrett et al. (2009) estimates for long-term effects of ozone exposure. All other ozone results represent short-term effects. **b.** Mortalities avoided due to changes in $PM_{2.5}$ concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using three different concentration response functions. All $PM_{2.5}$ crf functions represent estimates for long-term effects of $PM_{2.5}$ exposure.

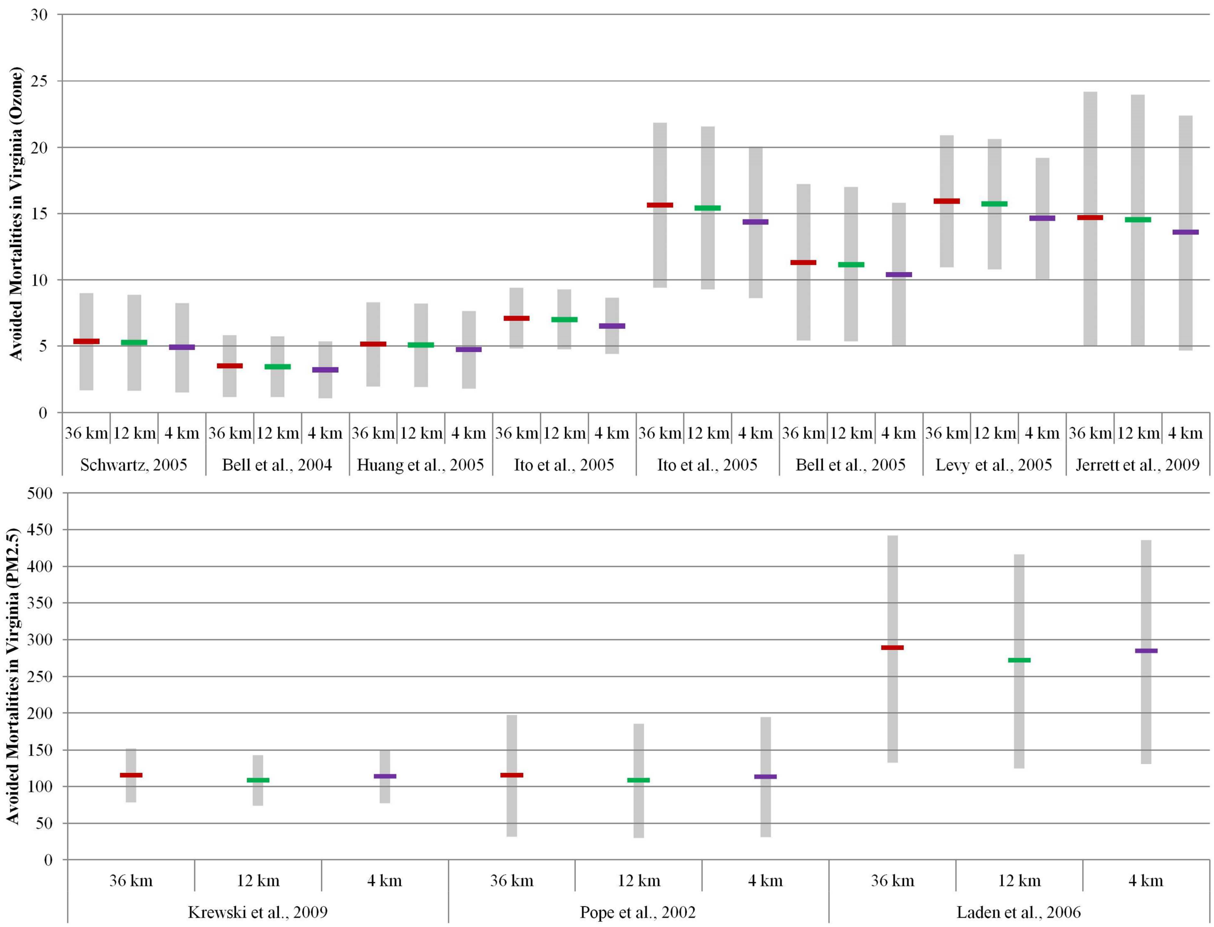
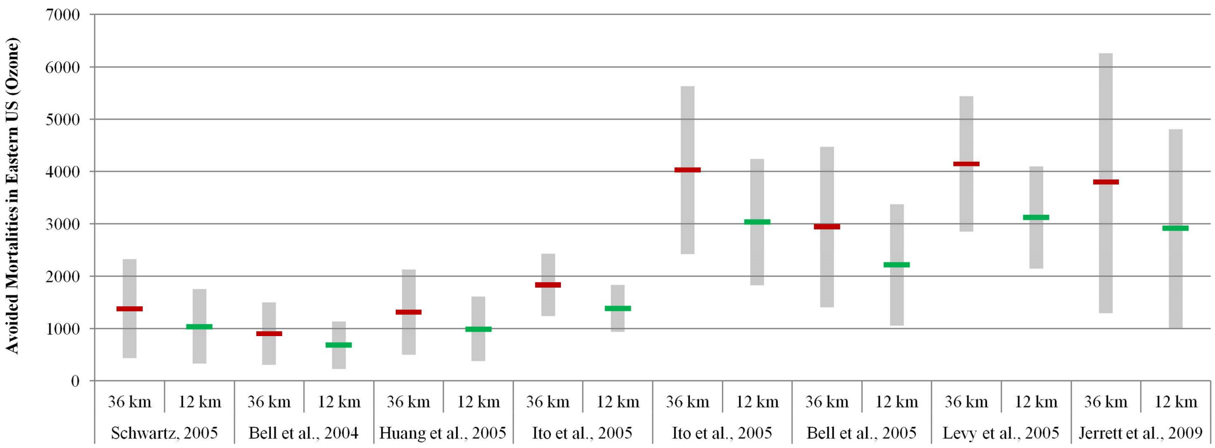


Figure S.14. a. Mortalities avoided due to changes in ozone concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using eight different concentration response functions. The right most result by Jerrett et al. (2009) estimates for long-term effects of ozone exposure. All other ozone results represent short-term effects. **b.** Mortalities avoided due to changes in $PM_{2.5}$ concentrations between the 2005 base case and the 2014 control case for each model resolution (red = 36 km, green = 12 km, blue = 4 km), calculated using three different concentration response functions. All $PM_{2.5}$ crf functions represent estimates for long-term effects of $PM_{2.5}$ exposure.



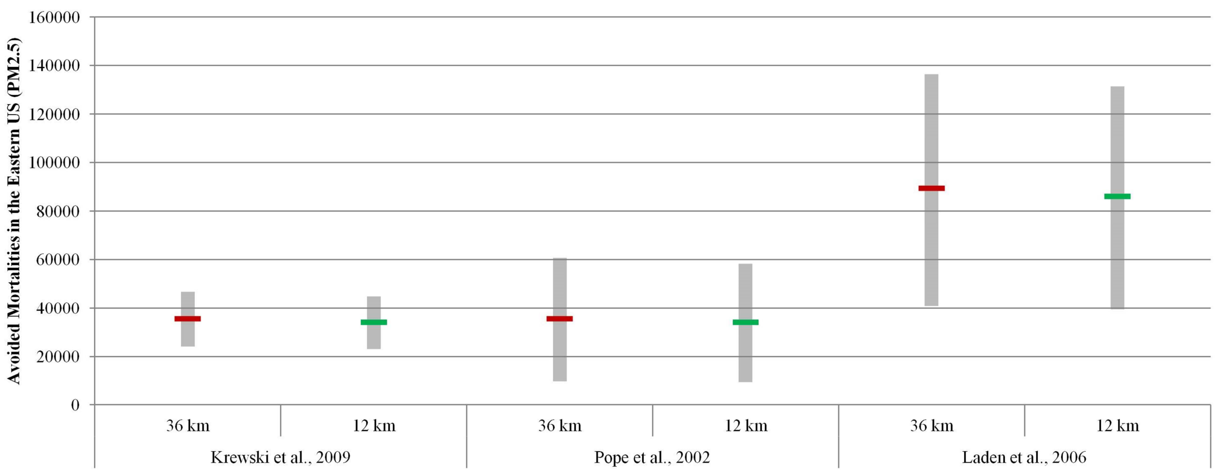


Figure S.15. a. Mortalities avoided due to changes in ozone concentrations between the 2005 base case and the 2014 control case for two model resolutions (red = 36 km, green = 12 km), calculated using eight different concentration response functions. The right most result by Jerrett et al. (2009) estimates for long-term effects of ozone exposure. All other ozone results represent short-term effects. **b.** Mortalities avoided due to changes in $PM_{2.5}$ concentrations between the 2005 base case and the 2014 control case for two model resolutions (red = 36 km, green = 12 km), calculated using three different concentration response functions. All $PM_{2.5}$ crf functions represent estimates for long-term effects of $PM_{2.5}$ exposure.