The Influence of Modeling Approach and Grid Resolution on Global Exposure Estimates

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INTRODUCTION

- Recent air pollution health impact studies have attempted to account for intraurban exposure gradients, recognizing the importance of local scale spatial variability in ambient concentrations.
- Due to limits on computational power, global scale air quality models necessarily use a coarse grid resolution leading to underestimation of urban peak concentrations, particularly for $PM_{2.5}$.

OBJECTIVES

- Evaluate the influence of grid resolution on yearly average $PM_{2.5}$ concentrations over the continental US based on the outputs of satellite estimates of ground-level $PM_{2.5}$ and a chemical transport model (CTM).
- Investigate the spatial variation of each modeling approach (Satellite/CTM) by comparing the modeled concentrations with ground observations and computing the spatial autocorrelation of each dataset.
- Utilize the bias due to the grid resolution to correct for the sub-grid variation in pollution concentrations for global health assessment.

METHODS

CTM Model

- CTM data was obtained from the 2005-based Community Multiscale Air Quality (CMAQ) model version 4.7.1 from the USEPA analysis of the Light-Duty Vehicle Greenhouse Gas Final Rule (Grid resolution: 12 km).
- These data were used previously by Punger and West (2013) to investigate the influence of grid resolution on health burdens.

Satellite Estimates

- Ground-level yearly average $PM_{2.5}$ concentration in 2005 was estimated from aerosol optical depth (AOD) retrieved from two satellite instruments, MISR and SeaWiFS (Grid resolution: 0.1 degree ≈11 km).
- The GEOS-Chem CTM was used to relate each individual AOD retrieval to ground-level $PM_{2.5}$ (van Donkelaar et al, 2010) .

Influence of Grid Resolution on $PM_{2.5}$ concentration

- The concentrations were aggregated to multiple coarse resolutions, following Punger and West (2013), and population-weighted concentration (PWC) was computed at each resolution.

Spatial variation of CTM and Satellite data

- The CMAQ and satellite concentrations were compared with yearly average ground concentrations observed at 938 monitors and population density.
- Agreements with ground observations was evaluated by the following error statistics: Mean Error (ME), Root Mean Square Error (RMSE) and Spearman's correlation coefficient.
- Error statistics were also computed by stratifying the monitors by their characteristics (dominant source, measurement scale, and location setting).
- The spatial autocorrelation of CMAQ and satellite concentrations were evaluated by Moran's I index.

RESULTS

Population weighted concentration

- PWC estimated by both CMAQ and satellite data decrease at high grid resolution, indicating that coarse resolution models will underestimate population exposure.
- The magnitude of the bias due to the model resolution for CMAQ-modeled PWC is greater than that estimated by satellite data (Figure 1).
- Coarse grid resolution (400 km) reduces CMAQ-modeled PWC by 32% , whereas the reduction rate for PWC based on satellite data is 11%.

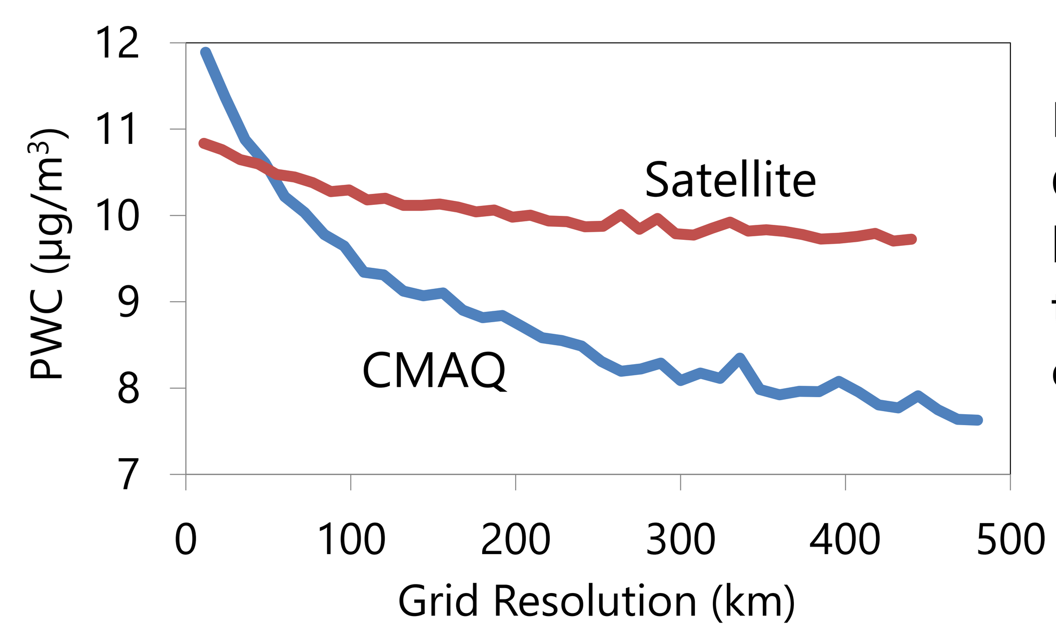

Figure 1: Population Weighted Concentration (PWC) computed by CMAQ and satellite data in the continental US as a function of grid resolution (km).

Spatial variation of $PM_{2.5}$ modeled data

- Spatial distribution of the CMAQ concentrations (Figure 2 (a)) is generally less variable than the satellite concentrations (Figure 2 (b)). This tendency is particularly obvious in the mountain region.
- Moran's I index of the CMAQ and satellite concentrations are 0.92 and 0.81, respectively. This result indicates that the CMAQ concentrations are more clustered than the satellite concentrations.

$PM_{2.5}$ concentration and population density

- The CMAQ concentrations are greater than the satellite concentrations only in the highly populated region (cell population > 100000) (Figure 3). This explains the stronger influence of grid resolution on CMAQ-modeled PWC.

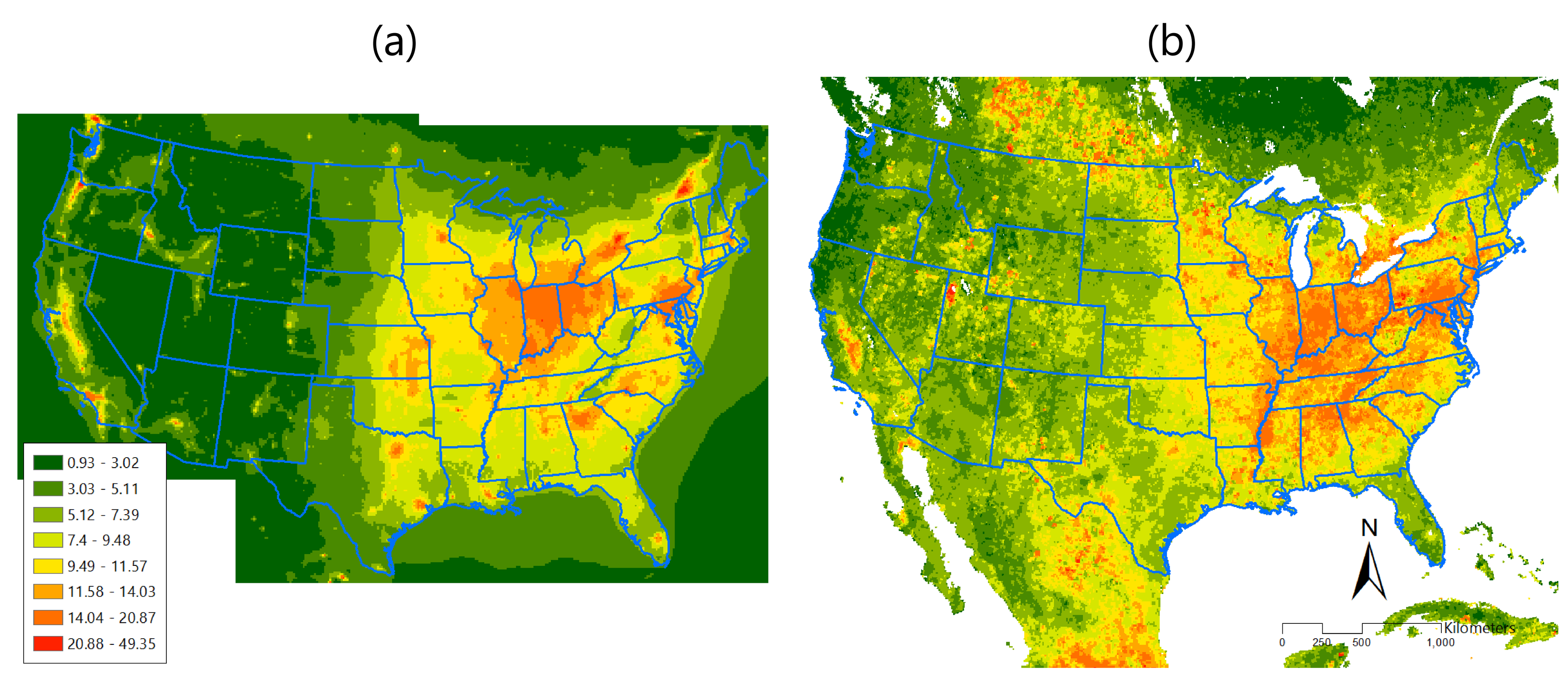

Figure 2: $PM_{2.5}$ concentration over the continental US obtained by (a) CMAQ model at 12km grid and (b) satellite data at 0.1 deg. grid.

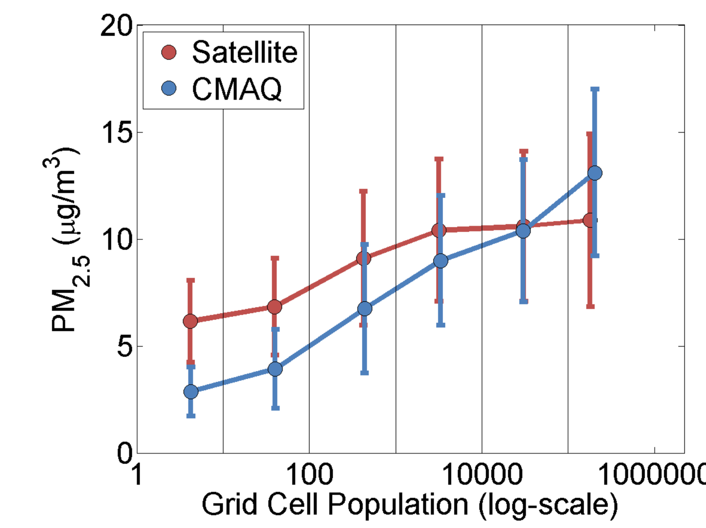

Figure 3: The mean of the CMAQ and satellite concentrations computed in six grid cell population bins (1-10, 10-100, 100-1000, 1000-10000, 10000-100000, >100000). Error bars show the standard deviation of the concentrations in each bin.

Modeled $PM_{2.5}$ concentration vs. ground observations

- Overall agreement of CMAQ and satellite modeled concentration with ground observations were similar. ME is better for CMAQ-modeled concentration, whereas RMSE and Pearson's correlation are better for satellite data (Table 1).
- CMAQ-modeled $PM_{2.5}$ shows better agreement with ground observation at monitors whose dominant source is point source (Table 2).
- In contrast, at area and mobile source monitors, agreement of satellite data is better than CMAQ-modeled concentration (Table 2).

Table 1: Error statistics showing agreement with ground observations.

Model	ME	RMSE	Correlation
CMAQ	-0.790	3.409	0.712
Satellite	-1.725	3.251	0.717

Table 2: Error statistics showing agreement with ground observations stratified by dominant source of monitors.

Source	Model	ME	RMSE	Correlation
Point	CMAQ	-0.515	2.779	0.816
	Satellite	-1.077	3.696	0.587
Area	CMAQ	-0.700	3.146	0.715
	Satellite	-1.393	2.848	0.775
Mobile	CMAQ	-0.392	3.596	0.755
	Satellite	-1.631	3.028	0.779

CONCLUSIONS

- Influence of coarse grid resolution on PWC is greater for CMAQ model than satellite data.
- Spatial distribution of the CMAQ concentration is less spatially variable than the satellite concentration.
- The CMAQ concentrations are greater in highly populated area, but lower in low populated region.
- The CMAQ concentrations agree well with observations at point source monitors, whereas at mobile and area source monitor, agreement of the satellite concentrations is better.

References:

Punger EM and West JJ (2013) The effect of grid resolution on estimates of the burden of ozone and fine particulate matter on premature mortality in the USA. Air Qual Atmos Health 6:563–573

van Donkelaar A, Martin RV, Brauer M, Kahn R, Levy R, Verduzco C, Villeneuve PJ (2010) Global Estimates of Ambient Fine Particulate Matter Concentrations from Satellite-Based Aerosol Optical Depth: Development and Application. Environ Health Perspect 118 (6):847-855

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