Particulate Matter Emission Inventory Based on Remote Sensing

Development of PEIRS 2.0

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Introduction

Health Risks of $PM_{2.5}$

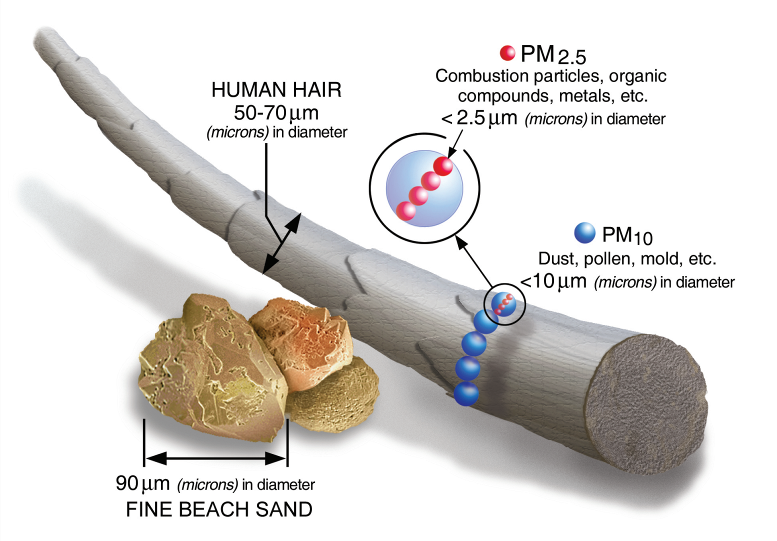


Figure Courtesy of U.S EPA

Conventional & Standard $PM_{2.5}$ Emission Inventory

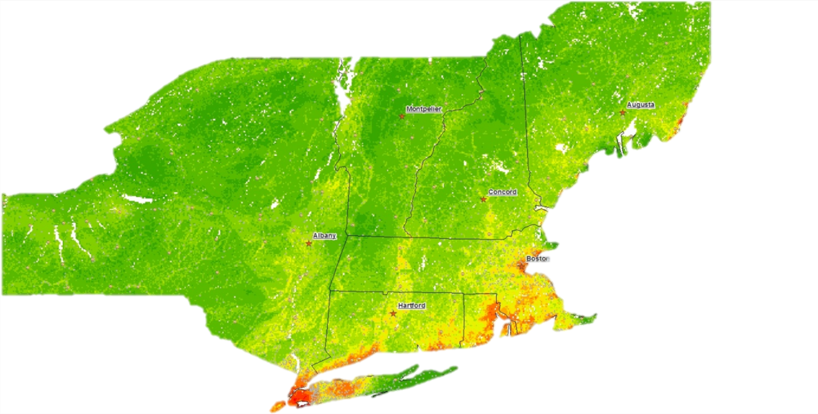
Major $PM_{2.5}$ *emission activities covered by NEI*

1. Fuel combustion and industrial processes other than combustion
   emissions are from the state, local, and tribal air quality management agencies and are estimated using emission factors
2. On-road vehicles and Non-road vehicles and engines
   mobile source models for on-road and state-supplied model inputs for non-road vehicles
3. Fugitive dust and miscellaneous sources
   fire activity and location based on satellite detection

Limitations

1. Many emissions are based on estimation instead of actual measurements
2. Coarse spatial resolution also limits the utility of the NEI data to assess human health risks

Development of PEIRS 1.0



1. Limits in estimating primary emission
2. Works in areas with dens monitor network
3. Not efficient enough

Shows the great potential of remote sensing in creating emission inventory

Aerosol Optical Depth

Aerosol Optical Depth (AOD) is the measure of aerosols distributed within a column of air from the earth's surface to the top of the atmosphere.

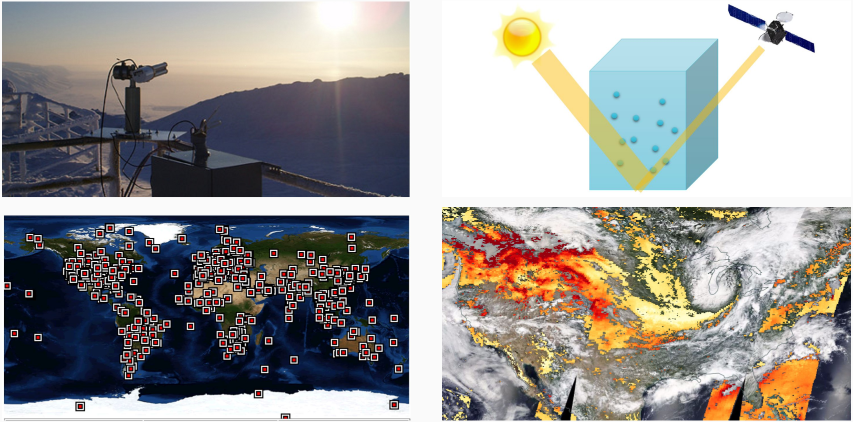
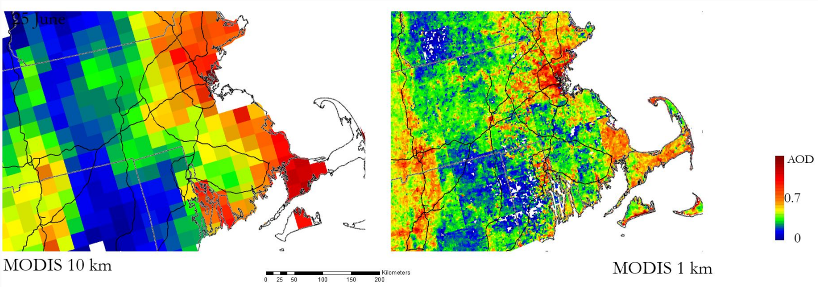


Table 1: Ground based & on satellite based AOD

MAIAC AOD



Multiangle Implementation of Atmospheric Correction (MAIAC) algorithm performs aerosol retrievals and atmospheric correction over both dark vegetated surfaces and bright deserts based on a time series analysis and image-based processing.

Data and Tools

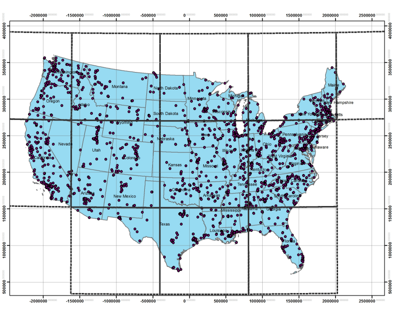
Data Sources

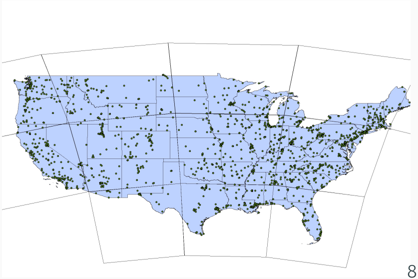
Study period: from 2006 to 2016
Study region: Continental United States
Data used in the model:

- AOD Data: North America MAIAC product (updated in June)
- Aeronet Data: level 2.0 Aeronet daily AOD data
- $PM_{2.5}$ Monitor Data: daily $PM_{2.5}$ mass concentration from AQS Data Mart
- Model Meteorological Data: daily downscaled wind field, temperature, relative humidity, planetary boundary layer height, snow cover from North America Reanalysis.
- Monitor Meteorological Data: daily wind field, temperature, relative humidity from weather stations and AQS sits are also collected for evaluation.

Multi-source data means multi-coordinates: Two Datum systems (WGS84 and NAD83) are used in $PM_{2.5}$ monitor network locations. We convert all data to Albers Equal Area Conic Coordinates to be certain that every grid covers exactly 1 square kilometers.

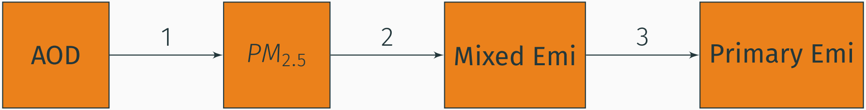
Based on this projection, we create 1km grids covering continental U.S.





Emission Estimation Model

Big Picture



- 1. AOD/$PM_{2.5}$ calibration.
- 2. Local emission estimation based on box model
- 3. A wavelet decomposition to decompose the local emission rate map into low frequency part and high frequency part.

AOD/$PM_{2.5}$ Calibration

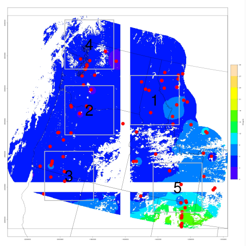
A two-step calibration is used here:

- Aeronet/MAIAC AOD calibration: linear regression was applied on every single day to remove bias due to remote sensing retrieval.
- MAIAC AOD/$PM_{2.5}$ calibration: linear regression was applied on a daily basis from each climate zones. Select the better model between Terra Model and Aqua Model.

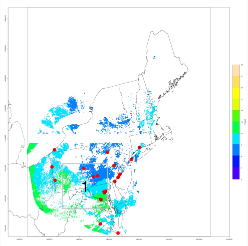
$$PM_{2.5} = AOD + HPBL^{-1} + Ws + Temp + Hum + Ngb$$

If there're more than 20 pairs of AOD&$PM_{2.5}$ available, cross-validation is applied subsequently to detect over-fitting. If the adjusted R^2 of linear model is above 0.8 and Mean Square Error (MSE) is smaller than 10, a model will be considered reliable and used to predict the $PM_{2.5}$ for that climate zone on that day.

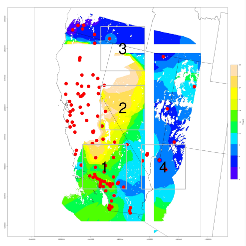
AOD/$PM_{2.5}$ Calibration



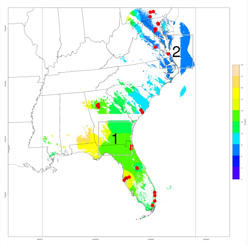
North West



North East

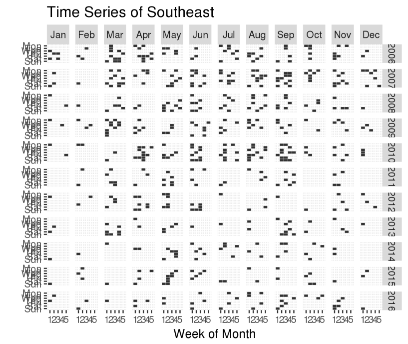


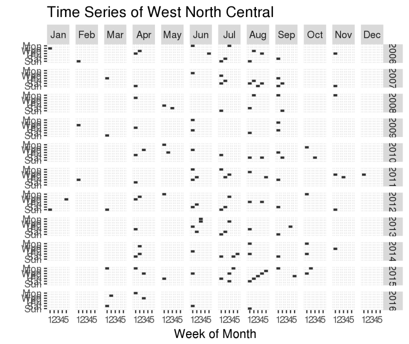
West



South East

AOD/$PM_{2.5}$ Calibration

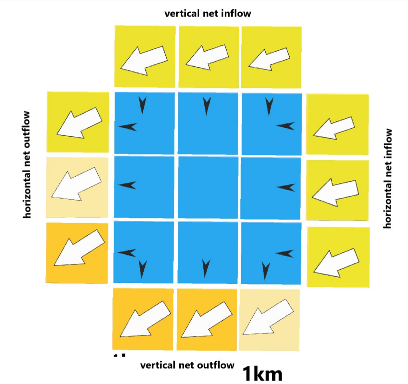


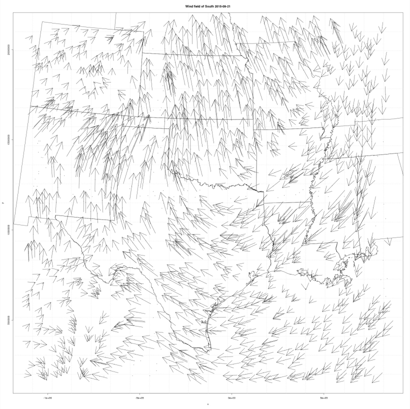


Model Days in Southeast

Model Days in North West

Mix Emission Estimation



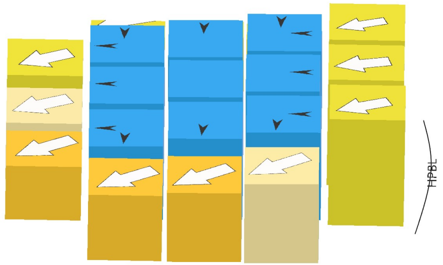


5×5 km neighbor

downscaled wind field

5km neighbors are used to calculate the emission in the core 3×3 km area

Mixed Emission Estimation



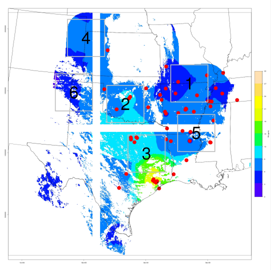
Assuming $PM_{2.5}$ is uniformly distributed under PBL.

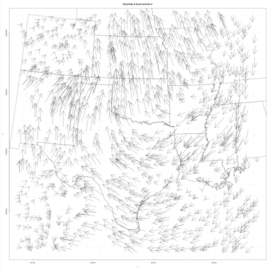
Mass balance equation is used to calculate mix emission (secondary formation + primary emission + deposition)

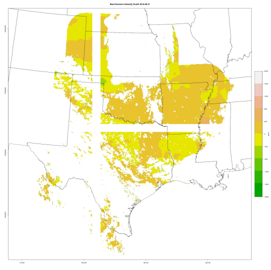
$$\frac{dM}{dt} = \sum_{upwind} inflow + \sum_{downwind} outflow + \sum_{in} pemi + \sum_{in} sfmt + \sum_{in} rmv = 0 \quad (1)$$

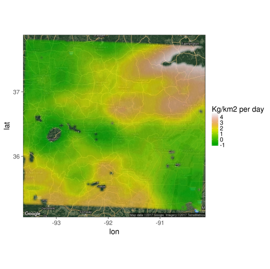
$$flow(\mu g/s) = ws(m/s) \times C(\mu g/m^3) \times HPBL(m) \times Edge(m) \quad (2)$$

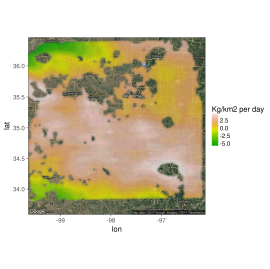
Mixed Emission Estimation

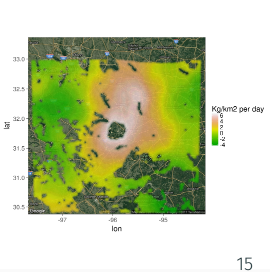












Primary Emission Estimation

- One dimension case:

$$f(x_i, \theta) = \theta_0 + \sum_{k=1}^{K} \theta_k z_k(x_i) \tag{3}$$

where k is the number of levels. $z_k(\cdot)$ is the basis function from Debauchies 5 wavelet family. θ_k is the coefficient for basis function.

- Two dimension case:

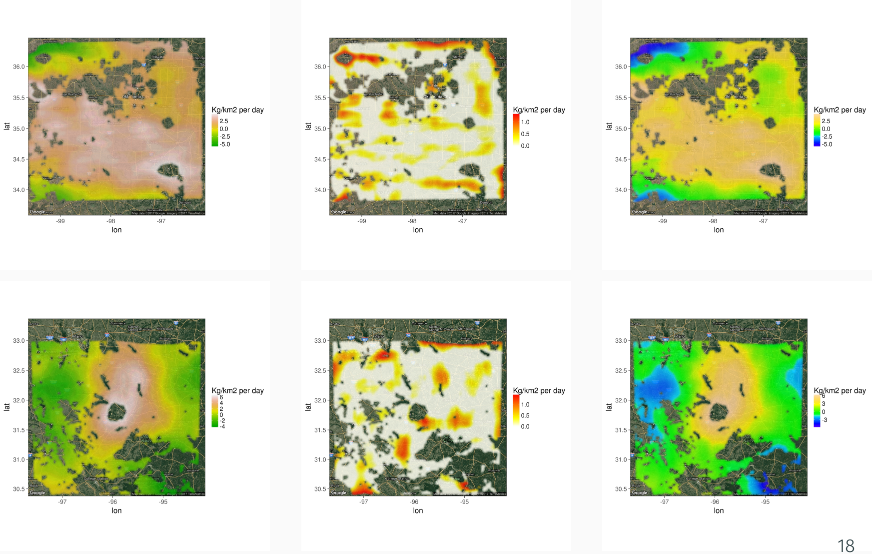
$$f(x_i, y_i, \theta) = \theta_0 + \sum_{l=1}^{K} \sum_{m=1}^{K} \theta_k z_{l,m}(x_i, y_i) \tag{4}$$

here $z_{l,m}(x_i, y_i) = z_l(x_i) \times z_m(y_i)$ convert the one dimensional basis to two dimensional. Then use LASSO to estimate θ_k

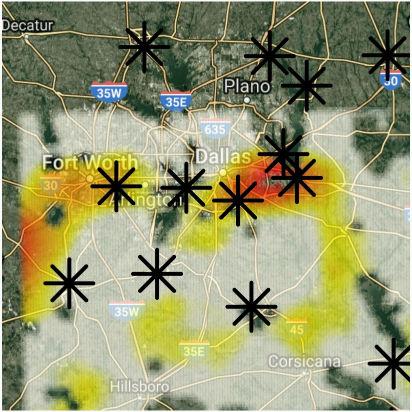
Primary Emission Estimation

- *Sub-regions size of 300km $\times$ 300km are selected where AOD coverage percentage is above 0.5 in every region on daily basis.*
- *The wavelet was applied for each sub-region not centered off-shore, we use 5 wavelet levels in each direction, yielding* $2^{10} = 1024$ *basis functions and a coefficient matrix of dimension 1,024$\times$10,000*
- *Irregular2dWavelets R package developed by another researcher in ACE center was used: available at https://github.com/jantonelli111/Irregular2dWavelets*

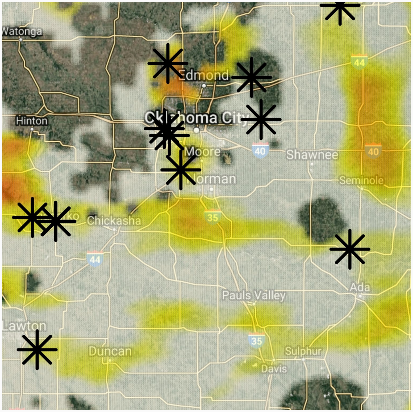
Primary Emission Estimation



Primary Emission Estimation



Power Plant in Dallas



Power Plant in Oklahoma City

Future Work

Future Work

1. Comprehensive comparison between this primary $PM_{2.5}$ emission inventory and NEI data.
2. Check the randomness of days with emission intensity and calculate the seasonal or annual emission rate based on daily data.
3. Include more related variables such as topographic friction index, vegetation index, road density and apply more robust statistical model to improve the calibration parts.
4. Apply this data in multiple air quality model to check the quality.

Thank you!

Questions?