Improving of atmospheric model simulation of aerosol diurnal variation through ground-based and satellite observation

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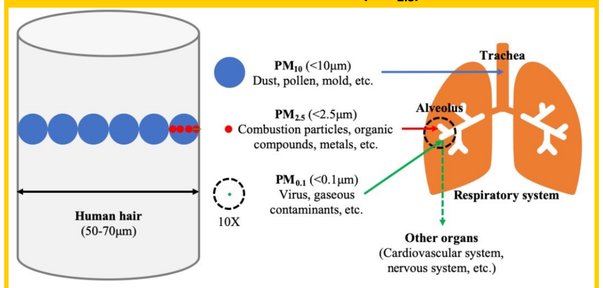
Motivation and Research Goal

Atmospheric aerosols affect the global climate by changing the Earth's radiative budget and influence public. MAIA (Multi-Angle Imager for Aerosol) Mission will focus on aerosol concentration and its impact on public health.

To support MAIA Mission, a specialized CTM, UI-WRF-Chem (Unified Input Weather Forecast Model coupled with Chemistry) could be applied to simulate aerosol concentration and species. Quantifying anthropogenic emissions is the largest source of uncertainty in atmospheric models.

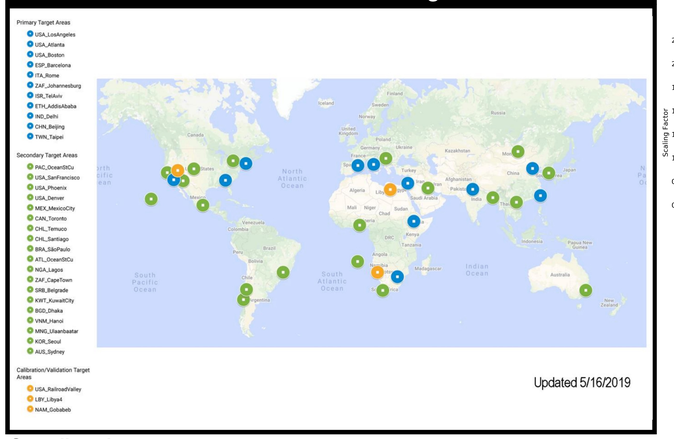
In this research, we to improve the presentation of diurnal variation of aerosol mass concentration and aerosol optical properties (including size distribution) through rapid adjusting of emission inventories (EI) in chemical transport model (CTM) utilizing ground-based and satellite observations.

Particle Matter 2.5 ($PM_{2.5}$)



https://www.frontiersin.org/articles/10.3389/fcell.2020.00091/full

MAIA Mission candidate target area



Overall goal:

- **Adjust the aerosol emission inventories of the WRF-Chem model utilizing EPA $PM_{2.5}$ observation for each region.**
- **Apply long-term AERONET aerosol particle size distribution data to improve aerosol optical properties of CTM.**
- **Use the GOES-R and TEMPO data to evaluate and constrain the model parameters**

Methodology

Adjust emission inventory through ΔC_{dv}

$$dE = \Delta C_{dv}\left(\frac{\partial C_{dv}}{\partial E_{dv}}\right)^{-1}$$

DV: Diurnal variation of PM2.5 conc.
$\Delta C_{dv} = C_{dv,observation} - C_{dv,simulation}$

Jacobian of PM2.5 conc. wrt emission
Calculated by only adjusting the emission of the corresponding hour and running a WRF-Chem simulation.

- **Scale emission rate into each hour.**
- **Diurnal factor could be adjusted specifically for each domain.**

Observation Data source

- The ground-based AERONET observation of aerosol:
  ---- AOD at 440, 500 nm
  ----aerosol size distribution
- U.S. EPA Hourly measurement of surface PM2.5 data
- GOES-R ABI AOD, TEMPO AOD and trace gases (Planned)

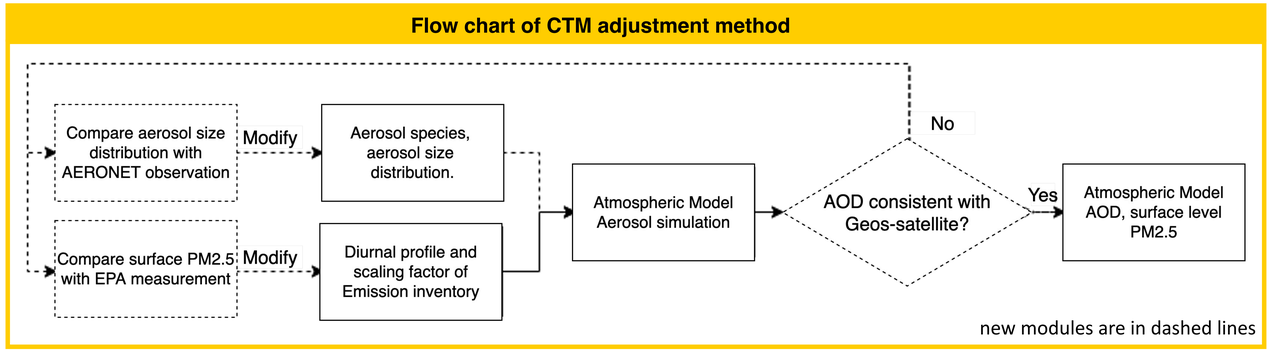
UI-WRF-Chem setting

Domain	Ethiopia
# Of Domain	2
Time period	2021 Feb-Mar
Domain size	10°*10°
# of grid box	95*89
Emission inventory	EDGAR
Vertical layer	48
Aerosol chemical scheme	RADM2/MADE/SORGAM

Domain	Boston-NY
# Of Domain	2
Time Period	2018 Jan-Dec
Domain size	10°*14°
# of grid box	96*94
Emission inventory	NEI 2011
Vertical layer	48
Aerosol chemical scheme	RADM2/MADE/SORGAM

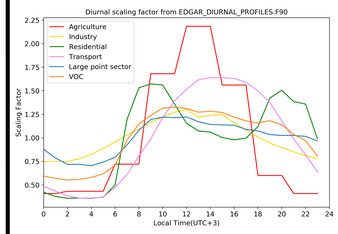
- UI-WRF-Chem provides 3 emission inventories setting: NEI 2011 for North America, MIX 2010 for east Asia and EDGAR-HTAP for Europe-Africa.
- For EDGAR-HTAP daily emission inventory, diurnal scaling factor from previous research was applied (see case study 1).

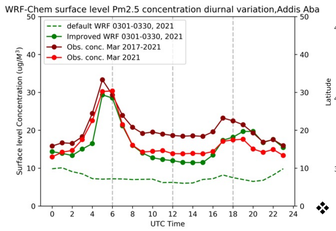
Flow chart of CTM adjustment method



Case Study

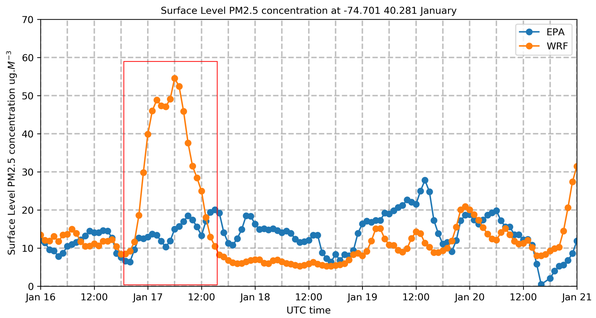
Case 1: MAIA PTA Addis Ababa, EI: EDGAR



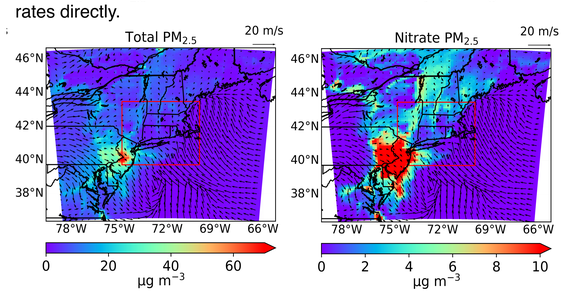


- Previous diurnal factor for EDGAR (left figure) gives large deficiency on ground level $PM_{2.5}$ (green dashed line on right figure).
- Compared with the results of the default simulation, the improved model (green dotted line on right figure) is in better agreement with diurnal variation curves of observation (red dotted line and brown dotted line).
- Compared with Ethiopia, the continental United States has more abundant surface observation data (EPA, IMPROVE, PurpleAir etc.) and more accurate emission inventories (NEI), which are conducive to improving the simulation of atmospheric aerosols by WRF-Chem.

Case 2: MAIA PTA Boston, EI: NEI 2011



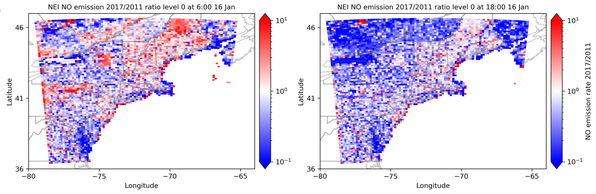
- Comparing EPA $PM_{2.5}$ measurements from multiple sites, we found that WRF-Chem's surface $PM_{2.5}$ simulations show abnormally high bursts in winter.
- Analysis of the January 2018 simulation results showed that this short-term high $PM_{2.5}$ value could not be eliminated by scaling emission rates directly.



- The PM2.5 composition simulations indicated that the abnormally high PM2.5 concentration was mainly contributed by Nitrate $PM_{2.5}$.
- Under the MADE/SORGAM chemical scheme, Nitrate $PM_{2.5}$ is mainly related to NO and NO2 emissions. Therefore, to eliminate this effect, it is necessary to update the emission inventory of NO and NO2.
- Since 2010, NOx emissions in the United States have been declining year by year due to stricter vehicle emission limits, the closure of coal-fired power plants, and industrial transformation.

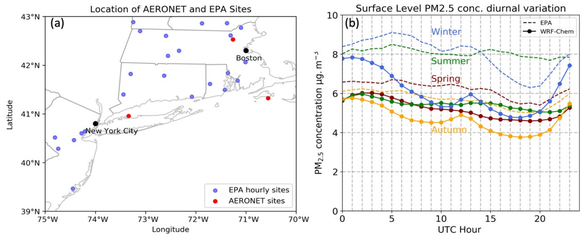
Manuscript in preparation

Apply NEI 2017 to northeast US



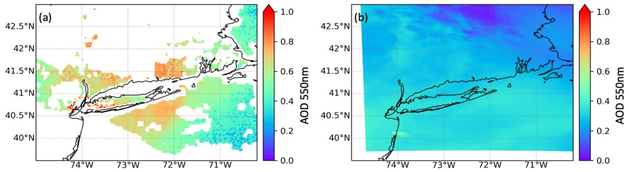
- In most area at northeast US, 2017 NO emission rate has decreased since 2011. However, the percentage of reduction varies in different regions and at different times.
- Simulations of NO emissions and NOx $PM_{2.5}$ over the last five years will be based on the updated NEI2017 emissions inventory.

$PM_{2.5}$ diurnal variation for different season in US



- When the results of the improved WRF-Chem model using NEI 2017 are fully validated, the simulation time period and area will be gradually enlarged. The goal of the project is to accurately simulate the aerosols in the entire United States over whole year.
- In Northeastern US, Default WRF-Chem simulation underestimated 5%-25% surface level PM2.5. During the winter season, when the Diurnal variability is most pronounced, WRF-Chem simulated PM2.5 exhibited a diurnal variation pattern similar to observed, but the largest deviation occurred in the simulations at night (5-10 UTC time).

Constrain AOD with geo-satellite observation



(a): GOES-16 ABI AOD. (b) Default WRF-Chem simulated AOD of selected domain at UTC 16:00, 16th Aug 2018.

- Similar to PM2.5, WRF-Chem underestimated columnar AOD by 5-20%, especially urban region near the coast. Compared with the observed PM2.5 and AOD valence results, the current WRF-Chem aerosol simulation in this area is not accurate. From our preliminary results here, we can see that WRF-Chem model needs to be adjusted for simulation of aerosol in United States.
- After the launch of Tropospheric emissions: Monitoring of pollution (TEMPO) satellite, trace gases (SO2, NO2, etc.) from TEMPO will also be utilized into this project.

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