The Contribution of Agricultural and Other Anthropogenic Dust Emissions to Ambient Coarse Particulate Matter in the U.S.

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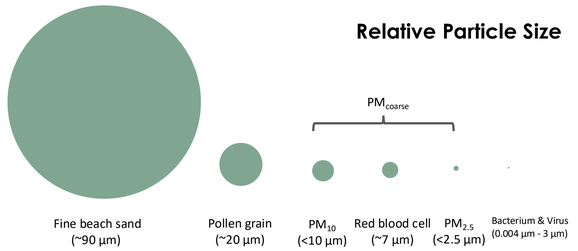
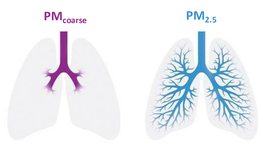
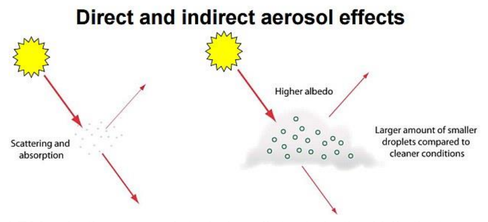
1) Anthropogenic activities emit dust that affects air quality and climate

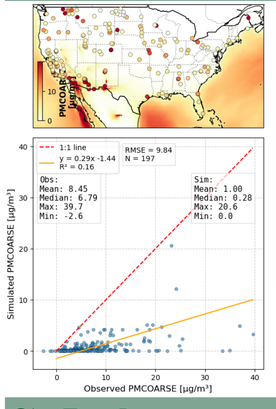






- Anthropogenic dust can contribute to $PM_{2.5}$ and PM_{10}, both are regulated air pollutants in the U.S. that can cause respirational diseases. It can change the climate through direct and indirect radiative effects.
- PM_{coarse} represents the particles larger than $PM_{2.5}$ but smaller than PM_{10}, which is mostly dust and has been understudied.

2) The GEOS-Chem model underestimates PM_{coarse} in the U.S. significantly

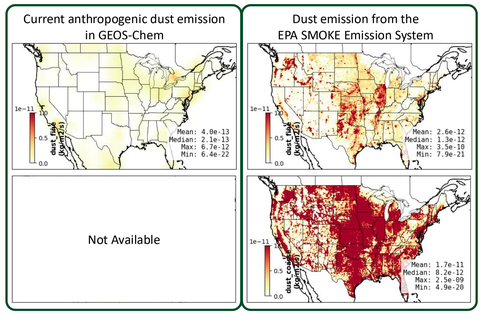


- We use the GEOS-Chem chemical transport model (v14.4.1) to simulate ambient PM_{coarse} with a spatial resolution of 0.25°. We use the default Anthropogenic, fugitive, Combustion, and Industrial Dust (AFCID) emission (Sajeev *et al.* 2017) and apply the recent update on natural dust emission scheme (Zhang *et al.* 2025, Leung *et al.* 2023).
- EPA reported $PM_{2.5}$ and PM_{10} are used as the ground truth. Note that the co-located $PM_{2.5}$ and PM_{10} measurements are limited.
- The study period is March 2019.

- We found PM_{coarse} to be greatly underestimated by GEOS-Chem across the contiguous U.S. (slope = 0.29) despite a good agreement in $PM_{2.5}$ (slope = 1.15).

Figure 1. (top) PM_{coarse} across the contiguous U.S. for March 2019, observed by EPA monitors (dots) and estimated by the GEOS-Chem simulation (background) (bottom) Scatter plot comparing the two data sources. Insets show the root mean square deviation, number of data pairs, mean, median, maximum and minimum values from both sources.

3) Anthropogenic dust emission in GEOS-Chem is low biased or missing



- We use the EPA Sparse Matrix Operator Kernel Emissions (SMOKE) Processing System that produces National Emissions Inventory (NEI) to estimate AFCID in the U.S.
- NEI reports a 5 times higher mean emission flux for fine dust compared to the AFCID emission used in GEOS-Chem.
- Coarse dust emission from anthropogenic activities is estimated to be more than 6 times higher than the anthropogenic fine dust, and it is missing in the current inventory.

Figure 2. The top panels show the fine dust emission flux used by GEOS-Chem (top left) and estimated by SMOKE (top right). The bottom right panel shows the coarse dust emission estimated by SMOKE.

4) The NEI suggests at least 30% of total coarse dust emissions come from anthropogenic sources

- With the SMOKE system, we can separate the emissions from agriculture activities apart from other sectors. We notice distinct spatial patterns of dust emission from natural sources, and agricultural activities and other anthropogenic activities.
- We also quantify that anthropogenic sources can contribute to 30% of the total coarse dust emission in the CONUS, with 10% from agriculture activities and 20% from other anthropogenic sources. For fine dust, the fractions are higher, with 20% from agriculture and almost 40% from other anthropogenic sources.
- The regional variation can be large. For states with intense agricultural activities, about 50% fine and coarse dust can come from agriculture. And the anthropogenic sources can dominant the total dust emissions.

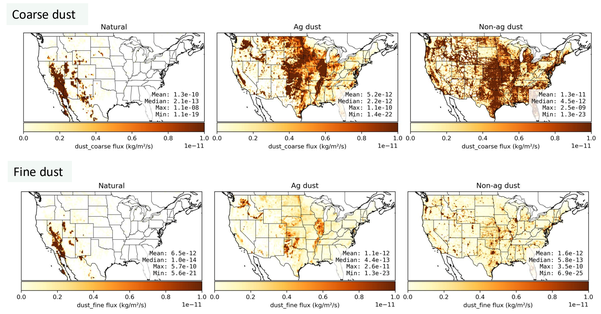


Figure 3. Maps of emission from natural (left column), agriculture (middle column), and other anthropogenic sources (right column). The top row shows emission for coarse dust, and the bottom for fine dust. Natural dust emission is based on Leung *et al.* 2023, and anthropogenic emissions are based on SMOKE. Values are the 2019 annual mean.

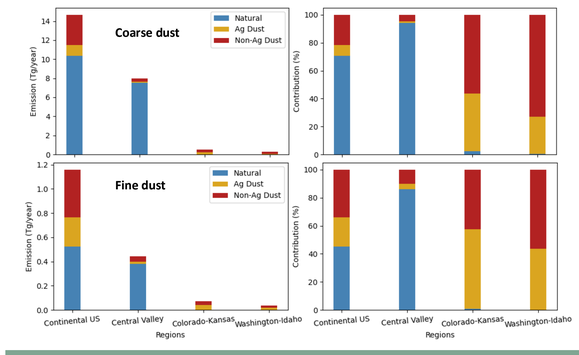


Figure 4. Absolute (left column), and relative (right column) contribution of the three sectors to dust emissions. The top row shows emission for coarse dust, and the bottom for fine dust.

5) Applying NEI improves the model-measurement agreement, but PM_{coarse} is still low biased

- By implementing the dust emissions estimated by SMOKE, we found improve agreement between GEOS-Chem and the EPA monitoring data.
- However, the national mean PM_{coarse} is still 60% lower than the observations. Regional bias can be as large as 80% (the Washinton-Idaho region).

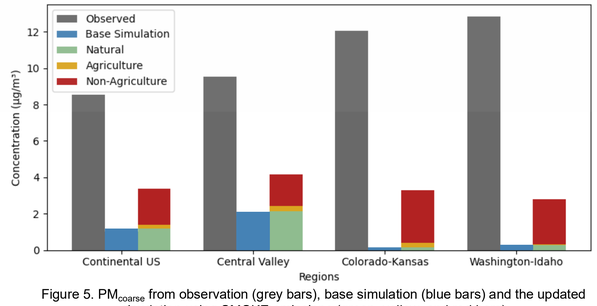


Figure 5. PM_{coarse} from observation (grey bars), base simulation (blue bars) and the updated simulation using SMOKE emissions (green, yellow, and red bars)

6) Satellite and sun photometers also indicate low bias in dust AOD

- We use ground-based AOD retrievals from AERONET, and satellite based AOD retrievals from the MODIS instrument (based on the deep blue algorithm) to evaluate simulated dust AOD. For measurements, AOD at 550 nm and the angstrom exponent between 412 and 470 nm were used to estimate the dust contribution to AOD (Ginoux *et al.* 2010).
- We found both AERONET and MODIS have higher dust contributions to total AOD (more than 30% vs. 10% in the simulation), despite the overall good agreement in total AOD.

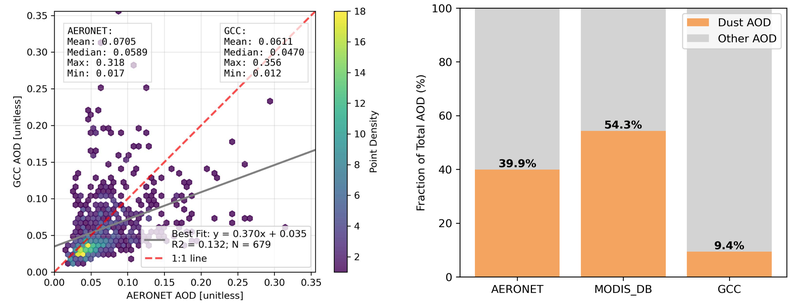


Figure 6. (left) Agreement between AERONET and simulated total AOD for CONUS; (right) dust contribution to total AOD based on measurements from AERONET, MODIS satellite instrument, and GEOS-Chem simulation.

7) Anthropogenic dust emissions might need to be 5 times higher

- Scaling anthropogenic dust emissions can reduce the mean bias between model and measurements.
- However, improvements on the spatial agreement require further investigation.

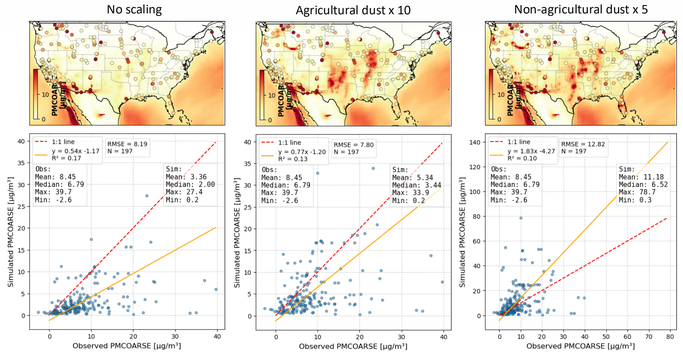


Figure 7. Maps and scatter plots comparing PM_{coarse} observation and simulation by the GEOS-Chem (background) with the SMOKE AFCID estimation (left), with agricultural emission scaled by 10 (middle), and non-agricultural emission scaled by 5 (right).

8) Future Works

- GEOS-Chem adjoint can help investigate the spatial distribution of the emission bias.
- Other sources of dust AOD, e.g. from the Infrared Atmospheric Sounder Interferometer (IASI) could help probe the uncertainty in dust AOD algorithms.
- Dust optical properties can also contribute to the model-measurement discrepancy. Examination on this will help understand the discrepancy.

Acknowledgements and References

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Philip, Sajeev, et al. "Anthropogenic fugitive, combustion and industrial dust is a significant, underrepresented fine particulate matter source in global atmospheric models." Environmental Research Letters 12.4 (2017): 044018.

Zhang, Dandan, et al. "Improving annual fine mineral dust representation from the surface to the column in GEOS-Chem 14.4. 1." Geoscientific Model Development 18.19 (2025): 6767-6803.

Leung, Danny M., et al. "A new process-based and scale-aware desert dust emission scheme for global climate models–Part I: Description and evaluation against inverse modeling emissions." Atmospheric Chemistry and Physics 23.11 (2023): 6487-6523.

Ginoux, Paul, Dmitri Garbuzov, and N. Christina Hsu. "Identification of anthropogenic and natural dust sources using Moderate Resolution Imaging Spectroradiometer (MODIS) Deep Blue level 2 data." Journal of Geophysical Research: Atmospheres 115.D5 (2010).