Satellite-Derived vs. Ground Truth: How Environmental Conditions Modify Their Agreement Across the Western United States

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INTRODUCTION

Fine particulate matter ($PM_{2.5}$; < 2.5 μm in diameter) has been ranked by the Global Burden of Disease as the 2nd leading global risk factor for premature death, making $PM_{2.5}$ a major concern for public health.

$PM_{2.5}$ ground monitor networks are sparse, with monitors mainly located in highly populated cities. Satellite-derived $PM_{2.5}$ surface data can extend observations globally, but agreement with monitors varies with environment.

Mountain, desert, and high wildfire risk regions are known to decrease satellite agreement with monitors on the county-level (Acker et al., accepted), but it is unknown how that agreement will change distributionally, and with changing emissions, vertical mixing, and removal processes which are all likely to be affected by climate change.

AIM

We explore how distributional agreement changes throughout the Western United States (US) and these complex environments by comparing ground monitor and satellite-derived total and speciated $PM_{2.5}$ distributions. Ongoing modeling work will diagnose how agreement may change when varying key atmospheric processes.

SATELLITE-DERIVED DATA

Satellite-derived surface total and speciated $PM_{2.5}$ data is from Washington University in St. Louis, specifically the biweekly 2021-2023 North American Regional Estimates with Composition V5.NA.05 product (Van Donkelaar et al., 2024).

The product contains the following species:

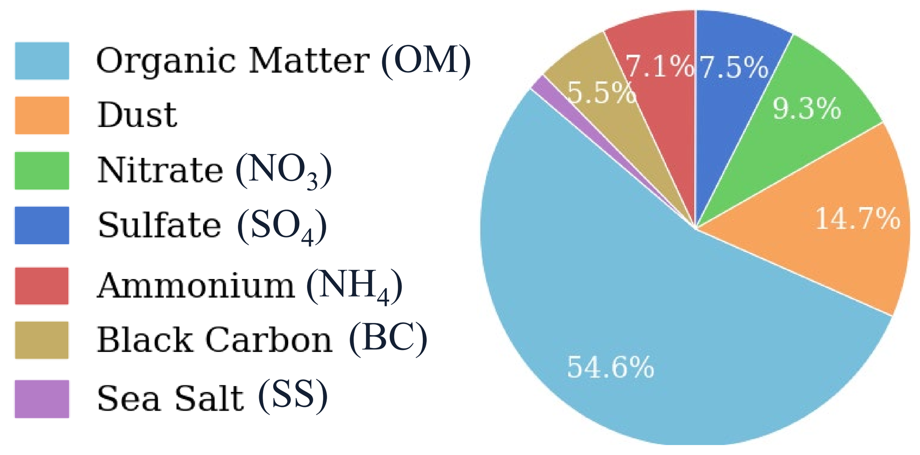


Figure 1. Satellite-derived species percentages for Western US total $PM_{2.5}$.

GROUND-MONITOR DATA

EPA ground $PM_{2.5}$ monitors are used, with the Chemical Speciation Network (CSN) and Interagency Monitoring of Protected Visual Environments (IMPROVE) being used for the speciated $PM_{2.5}$. Concentrations of dust, BC, SS, and OM are calculated using the IMPROVE data documentation.

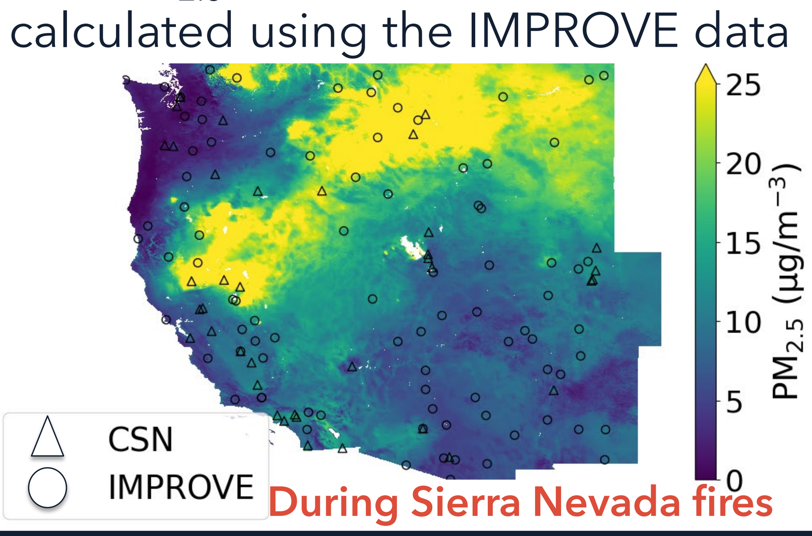


Figure 2. Satellite-derived total PM2. for biweekly avera starting at 7/16/2021 with CS and IMPROVE monitor locations.

METHODS

1) Average daily monitor values to biweekly
2) Compute monitor-satellite pairs, identifying satellite grids containing monitors
3) Clip data to the three West complex environments:

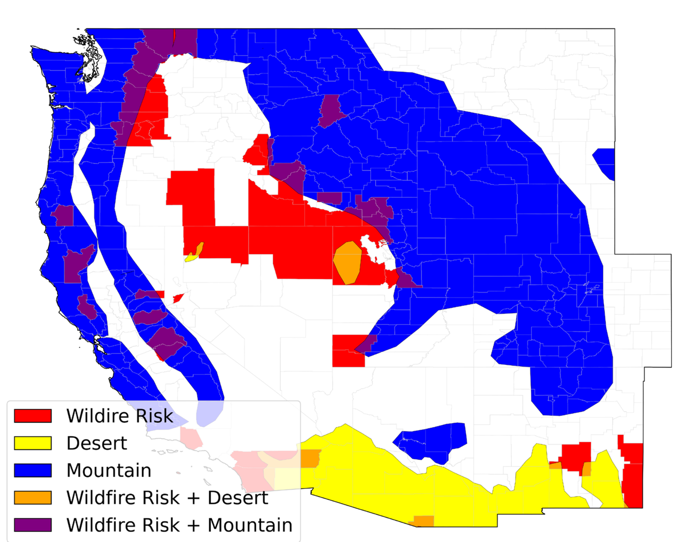


Figure 3. Locations of complex environments.

Wildfire risk regions are counties within the 90th percentile of annual wildfire frequencies from FEMA

METHODS

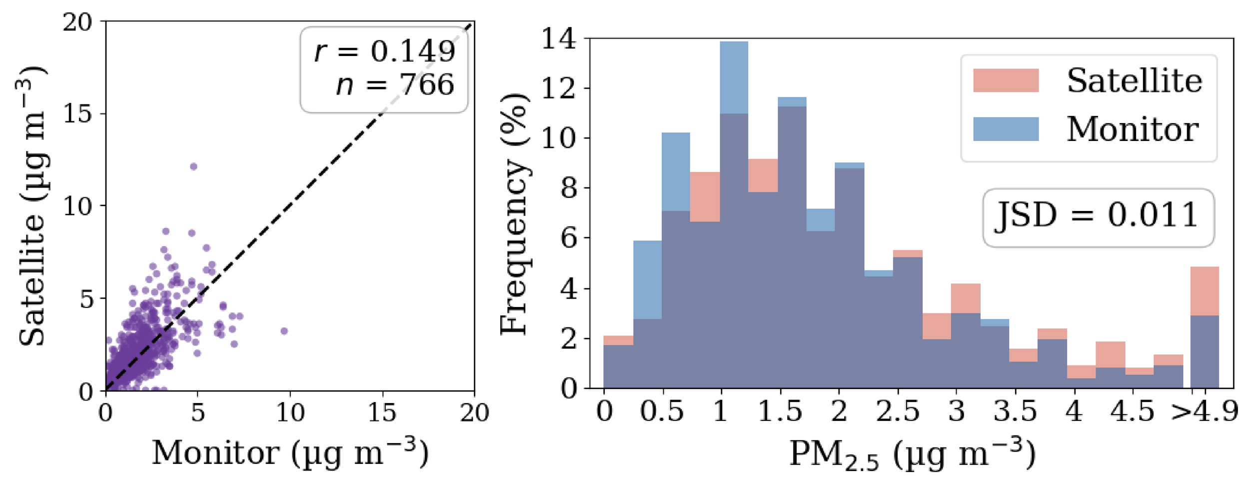
The **Jensen-Shannon Divergence (JSD)** is a metric used to quantify the similarity of two probability distributions where:

- JSD ≥ 0.3 Poor
- 0.1 < JSD < 0.3 Moderate
- JSD ≤ 0.1 Good

4) Compute JSD and Pearson correlation coefficient between satellite and monitor distributions (JSD) or pairs (r) for each species and environment

Pearson r vs. JSD
Pearson r = linear agreement
JSD = distributional agreement

Pearson r and JSD for Desert Dust



CURRENT PROJECT STAGE

Running 3-D atmospheric chemical transport model GEOS-Chem (nested grid) to establish a baseline comparison to monitors and satellite, then running the following simulations:

- Scale transportation, agriculture, and energy sector CEDs emissions by ±25%
- Scale boundary layer height by ±25
- 1) Turn on Luo et al. (2023) wet deposition scheme, and 2) Decrease warm cloud rainout fractions by 25%

PRELIMINARY RESULTS

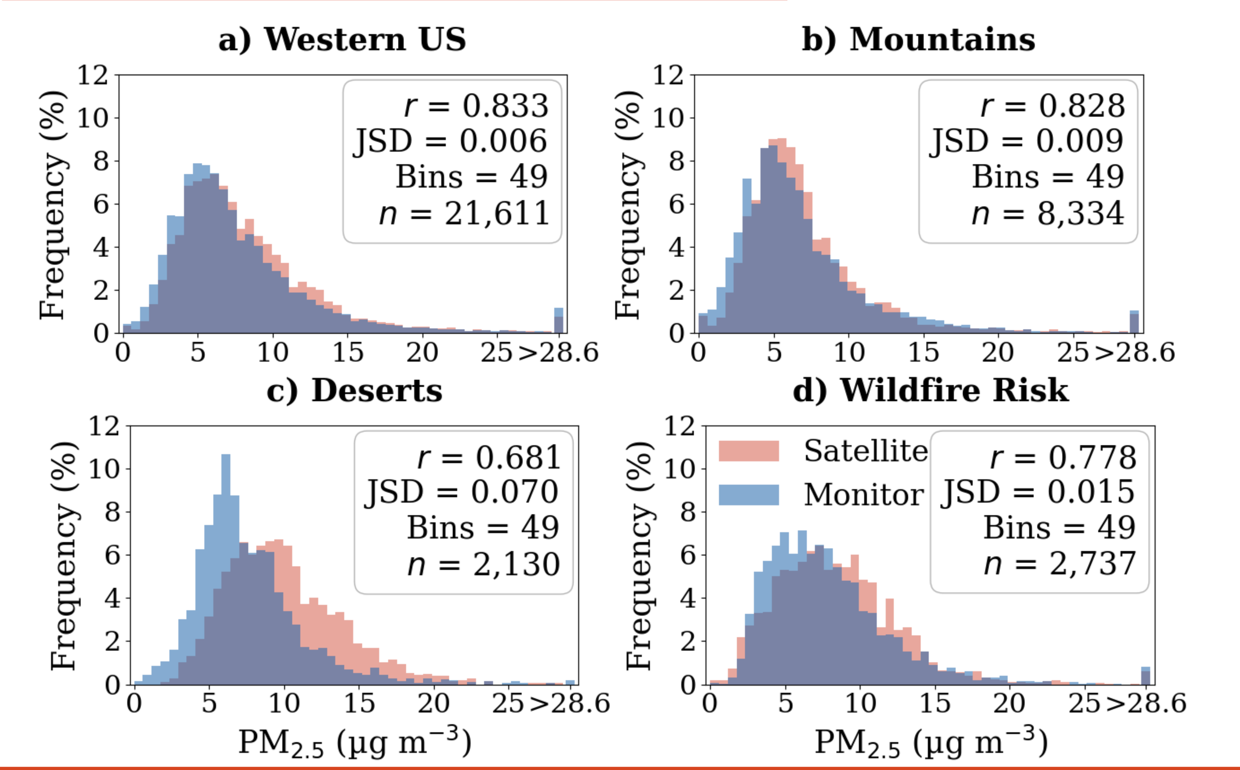
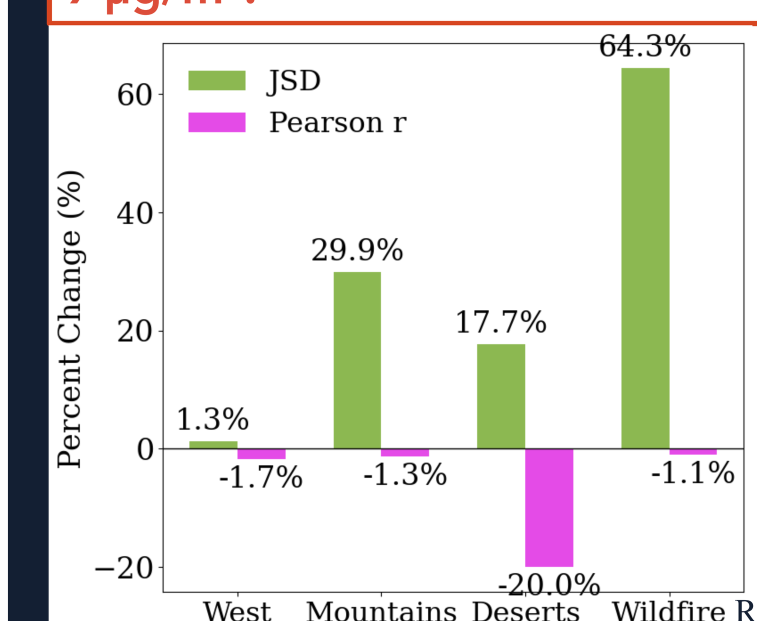


Figure 4. Monitor vs. satellite-derived 2021-2023 biweekly, total $PM_{2.5}$ frequency distributions.

- Monitor distributions are skewed further left (lower $PM_{2.5}$ levels) than satellite distributions, but monitors have a longer tail suggesting more detected extremes
- Distributional agreement worsens in complex environments, especially in deserts; Pearson r are less affected by environmental differences

Figure 5. Percent change in JSD and r between all values and biweekly satellite-monitor pairs greater than 9 μg/m³.



- Agreement worsens for health relevant concentrations
- JSD is most affected in wildfire risk regions; r most affected in deserts

PRELIMINARY RESULTS

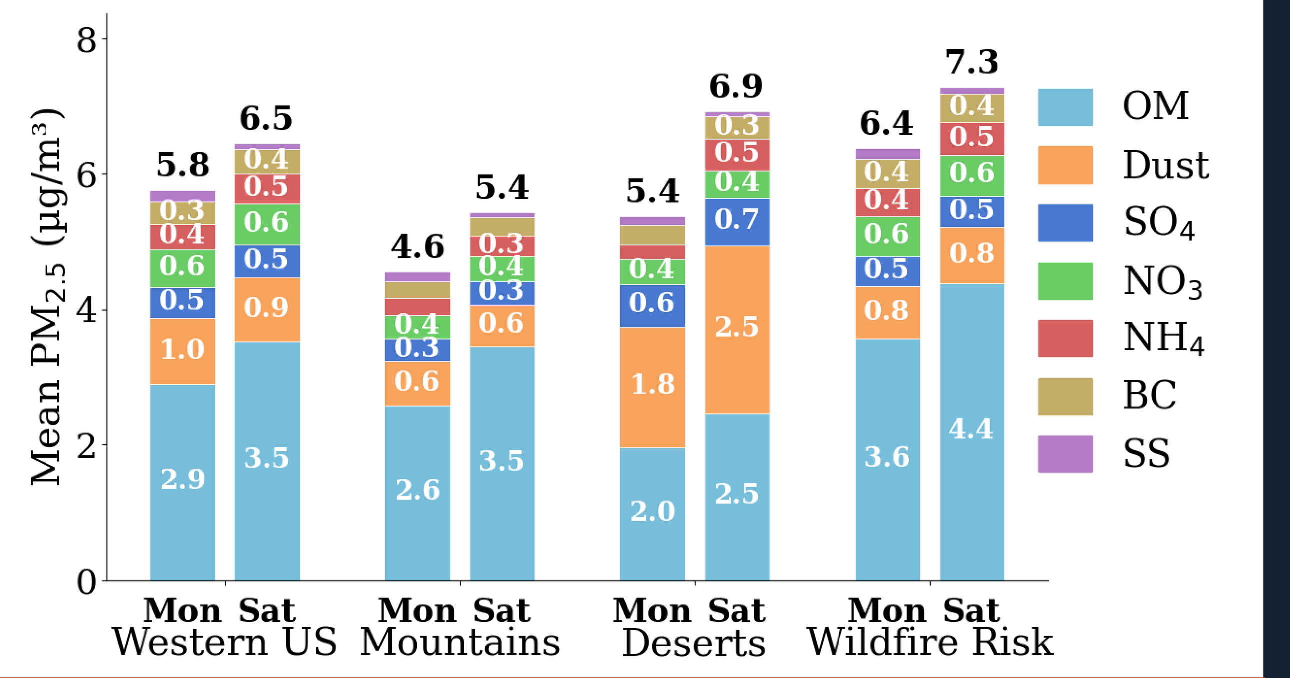
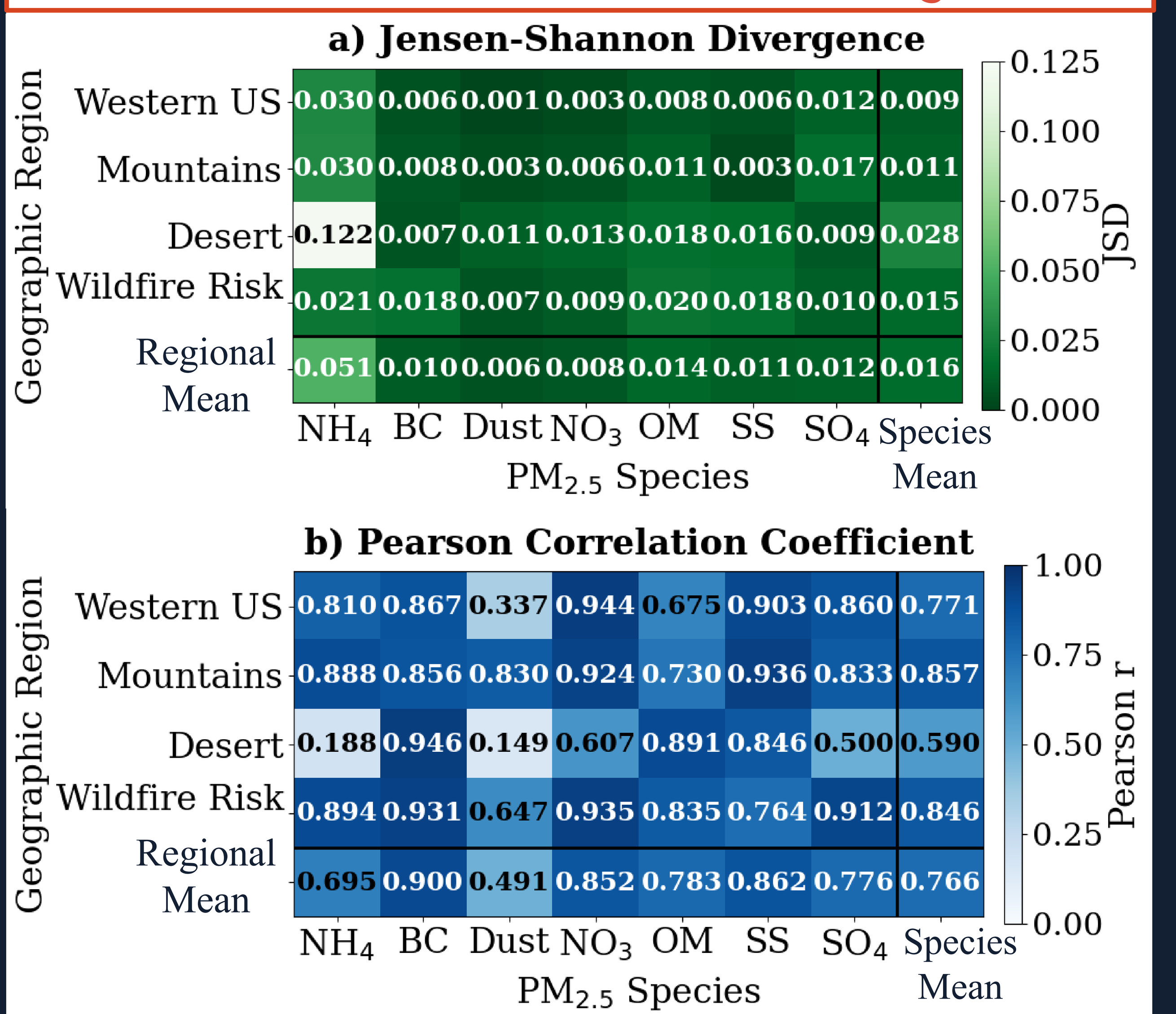


Figure 6. Mean $PM_{2.5}$ species concentrations per environment for monitor and satellite-derived data.

- OM is the dominant species in all environments
- Dust in deserts drives the greatest disagreement between satellite and monitors (+32.9% sat), except SS
- OM (25.9%) and SS (-42.7%) have the highest % change across regions between satellite and monitors
- Wildfire conditions increase total $PM_{2.5}$ above the Western mean, with most increase attributable to OM

Figure 7. JSD and r values for speciated $PM_{2.5}$ in all environments. Darker colors indicate better agreement.



- Deserts have worst distributional & linear agreement
- Western US has best JSDs; Mountains have best r
- NH_4 has the worst JSDs; dust has the worst r values
- Dust has best JSDs; BC has the best r values
- Inorganics have better agreement than organics

SUMMARY & NEXT STEPS

- Satellite-derived data are recording higher total $PM_{2.5}$ more frequently than monitors in complex environments, worsening distributional agreement in those regions, particularly at higher, health-relevant concentrations
- When evaluating speciated $PM_{2.5}$, agreement varies much more within species and environments
- This high variation in agreement motivates our ongoing GEOS-Chem modeling work to diagnose how atmospheric processes will affect total and speciated $PM_{2.5}$ agreement across environments

ACKNOWLEDGEMENTS & REFERENCES

Summer Acker thanks the University of Illinois at Urbana Champaign Civil and Environmental Engineering Department for the funding to complete this work.

- Acker, S., Holloway, T., Stewart, K., Van Donkelaar, A., & Martin, R.V. (accepted). Comparison of policy-relevant air quality metrics calculated with sparse in situ monitoring and contiguous satellite-derived data. *GeoHealth*.
- Van Donkelaar, A., Martin, R. V., Ford, B., Li, C., Pappin, A. J., Shen, S., & Zhang, D. (2024). North American Fine Particulate Matter Chemical Composition for 2000-2022 from Satellites, Models, and Monitors: The Changing Contribution of Wildfires. *ACS ES&T Air*, 1(12), 1589–1600. https://doi.org/10.1021/acsestair.4c00151

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