Evaluating Satellite-Identified Dust Storms over the US

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1) Mineral dust is a major component of PM_{coarse} in the US but is understudied [1].

- Sources of coarse particulate matter (PM_{coarse}; particulate matter > 2.5 μm and < 10 μm) include deserts, dry lake beds, agriculture, and construction[1,2].
- PM_{coarse} impacts human health, ecosystems, climate, and visibility[3,4,5,6].

- In the US, data sources for dust storms and PM_{coarse} are limited and lack complete spatiotemporal coverage.
- Despite limited data, it has been found that the presence of dust is likely increasing over the contiguous US (CONUS)[2,3,7].

2) To investigate dust in the US, we used satellite and surface data.

- Satellite: GOES-16 Advanced Baseline Imager (ABI)
  - GOES-16 is a geostationary satellite with sub-hourly retrievals over the CONUS.
  - Pink Dust Index (PDI) value[8] is a longwave-based algorithm that detects dust by leveraging its unique spectral signature in the longwave.
- Surface data: US EPA co-located hourly PM_{10} and $PM_{2.5}$ monitors
- We evaluated the agreement between satellite and surface observations of PM_{coarse}
- In comparing monitor and satellite observations, the thresholds were determined by an F-score, a metric used to evaluate performance of a classification model to give the satellite product the best chance of performance.

3) The highest F-score occurred at PDI values >0.75 and PM_{coarse} observations >330 μg m^{-3}.

$$\text{Precision} = \frac{\text{True Positive}}{\text{True Positive + False Positive}}$$

$$\text{True Positive Rate} = \frac{\text{True Positive}}{\text{True Positive + False Negative}}$$

$$F_\beta = \frac{(1+\beta^2) \times (\text{precision} \times \text{true positive rate})}{(\beta^2 \times \text{precision}) + \text{true positive rate}}$$

β > 1 minimizes false negatives

β < 1 minimizes false positives

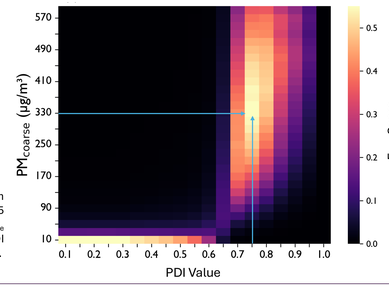


Figure 1: F-scores with a beta of 0.25 comparing PM_{coarse} observations to PDI value from 2018-2023.

4) PDI value identifies ~9% of high surface PM_{coarse} observations in 2018-2023.

True positives (PM_{coarse} >330 μg m^{-3} and PDI value >0.75) occurred in the southern and western US.

False positives (PM_{coarse} <330 μg m^{-3} and PDI value >0.75) occurred in the southern and western US.

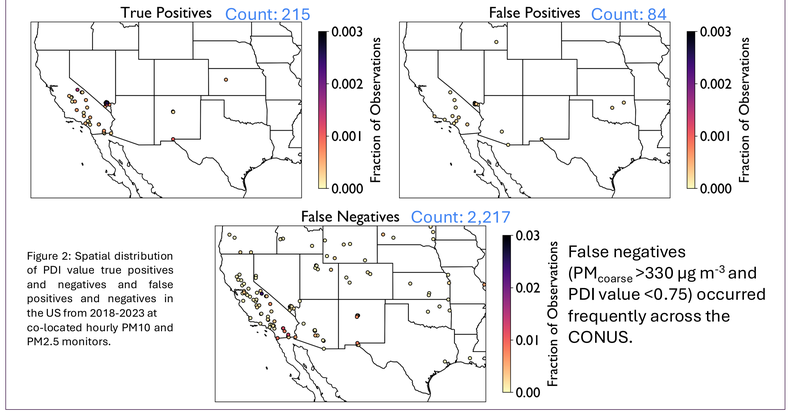


Figure 2: Spatial distribution of PDI value true positives and negatives and false positives and negatives in the US from 2018-2023 at co-located hourly PM10 and PM2.5 monitors.

False negatives (PM_{coarse} >330 μg m^{-3} and PDI value <0.75) occurred frequently across the CONUS.

5) When PDI values >0.75, PM_{coarse}, observations are generally elevated.

- When the satellite dust detection was positive (PDI value >=0.75), 80% (215/267) of PM_{coarse} observations >330 μg m^{-3}.
- When the satellite dust detection was negative (PDI value <0.75), 0.009% (2,217/2.4e6) of PM_{coarse} observations >330 μg m^{-3}.

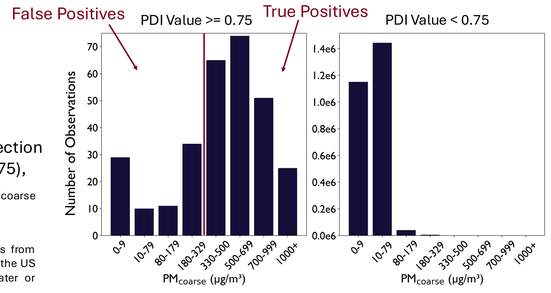


Figure 3: Distribution of PM_{coarse} observations from co-located hourly PM_{10} and $PM_{2.5}$ monitors in the US from 2018-2023 when the PDI value is greater or equal to 0.75 (left) and less than 0.75 (right).

6) Most satellite-identified dust plumes occurred over the Southwest and South Central regions (2018-2024).

- Using positive PDI value retrievals (PDI value >0.75) and the temporal resolution of GOES (5-minutes), we calculated dust plume hours over the US.
- We found that the southern and western US had the most hours with satellite-identified dust plumes.
- In states like Arizona, the algorithm under-identified dust, likely because convectively driven storms were masked by clouds and water vapor.[9]

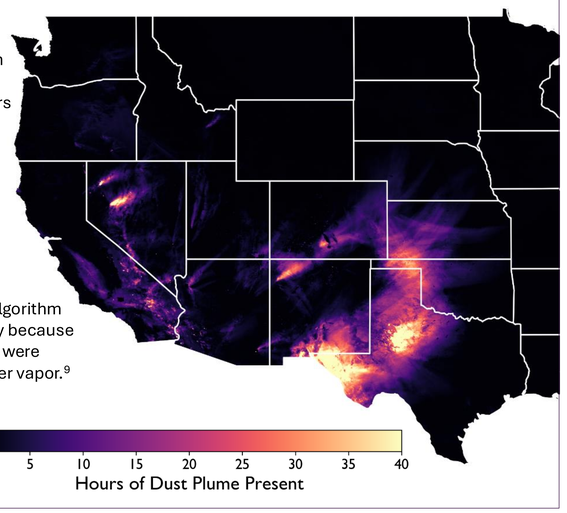


Figure 4: Hours of dust plumes present between 2018-2024 over CONUS according to the PDI value.

7) Using a clustering algorithm (DBSCAN), we grouped positive PDI value pixels into individual dust plumes.

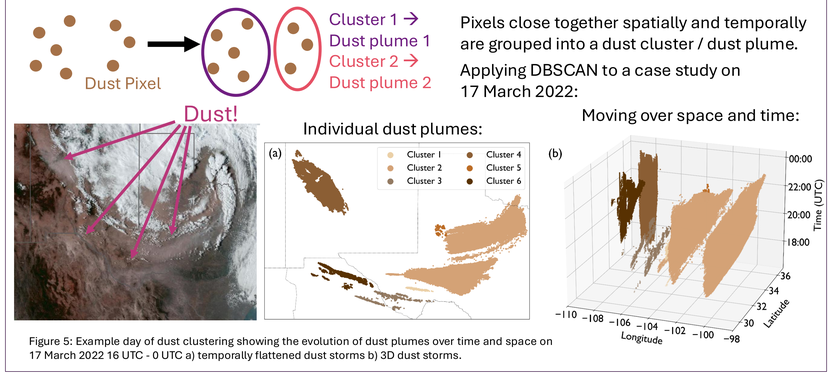
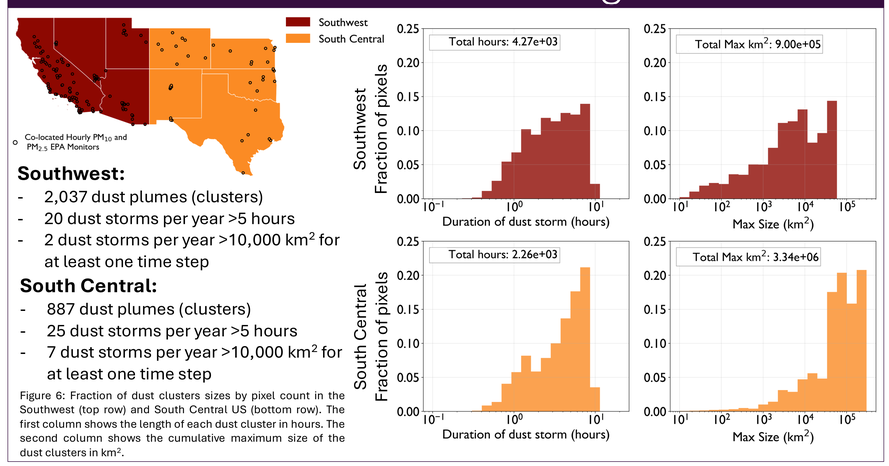


Figure 5: Example day of dust clustering showing the evolution of dust plumes over time and space on 17 March 2022 16 UTC - 0 UTC a) temporally flattened dust storms b) 3D dust storms.

8) Dust plumes were more frequent in the Southwest region but larger and of longer duration in the South Central region.



Southwest:
- 2,037 dust plumes (clusters)
- 20 dust storms per year >5 hours
- 2 dust storms per year >10,000 km^2 for at least one time step

South Central:
- 887 dust plumes (clusters)
- 25 dust storms per year >5 hours
- 7 dust storms per year >10,000 km^2 for at least one time step

Figure 6: Fraction of dust clusters sizes by pixel count in the Southwest (top row) and South Central US (bottom row). The first column shows the length of each dust cluster in hours. The second column shows the cumulative maximum size of the dust clusters in km^2.

9) Over 90% of dust storms were >10 km from ground monitors, and PM_{coarse} estimates were elevated when storms were nearby.

Southwest:
- 92.4% of dust storms are >10 km away from co-located hourly PM_{10} and $PM_{2.5}$ monitors.
- 88.8 % of dust storms are >10 km away from hourly PM_{10} monitors.

South Central:
- 95.0% of dust storms are >10 km away from co-located hourly PM_{10} and $PM_{2.5}$ monitors.
- 90.6% of dust storms are >10 km away from hourly PM_{10} monitors.

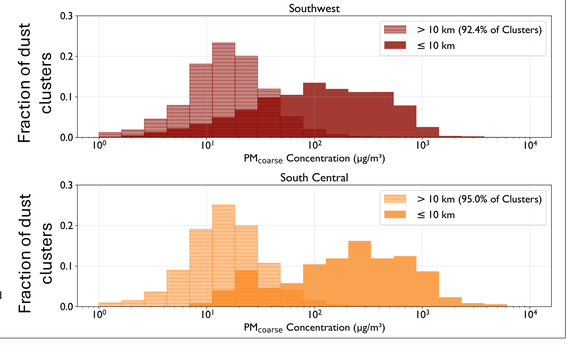


Figure 7: Hourly PM_{coarse} estimates at co-located PM_{10} and $PM_{2.5}$ monitors within 10 km of a clustered dust storm (solid bars) compared to hourly PM_{coarse} estimates at the same monitors when a cluster is not within 10 km (hatched bars).

8) Key Takeaways

- **Ground Monitor Perspective:** The satellite data product evaluated in this work underestimates the frequency of elevated PM_{coarse} estimates.
  - The PDI value identified 9% of enhanced PM_{coarse} observations in CONUS
- **Satellite Perspective:** More than 90% of satellite-observed dust storms occur away from monitors.
- **PDI value satellite algorithm + clustering algorithm:**
  - The Southwest US region had more frequent dust storms while the South Central US region had larger scale (>10,000 km^2) dust storms.

Acknowledgements and References

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