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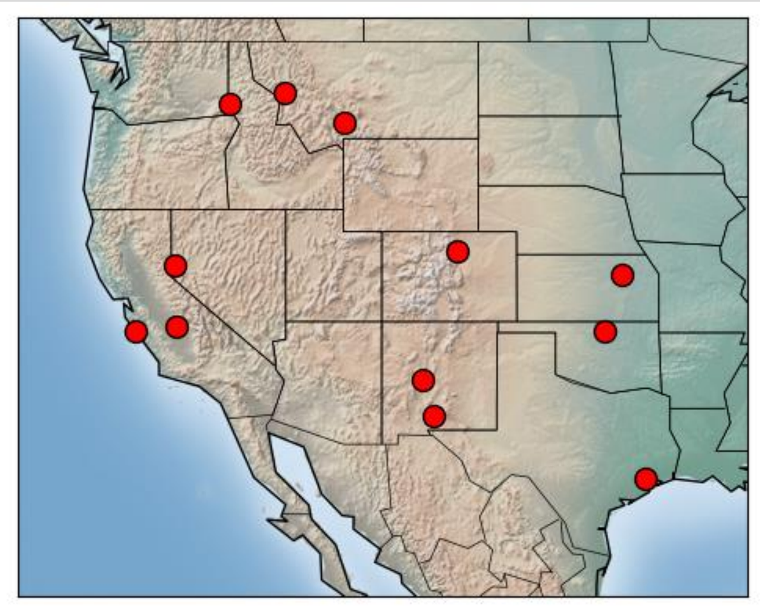
Toward Understanding Smoke Aerosol Optical Properties due to Local-Generated and Transported Smoke from 2011-2023 Measurements from the Western to the Great Plains United States

Motivation



AERONET Station Locations

Wildfires and controlled burns are significant agents of ecological disturbance and landscape management across the globe. With an increasing number and intensity of wildfires each year, exposure to smoke is a growing health concern. These fires produce significant loadings of aerosols, which travel thousands of miles downwind. While many field campaigns have been developed to study smoke physical and chemical properties in near proximity to the smoke plumes, investigating the effect on aerosol physical properties due to long-range transport aging is a subject of vigorous study.

This research aims to investigate the differences in aerosol optical properties (intensive and extensive), such as **Aerosol Optical Depth (AOD), Absorption Aerosol Optical Depth (AAOD), Extinction Ångström Exponent (EAE), Single Scattering Albedo (SSA), and Absorption Ångström Exponent (AAE) between locally-generated and long-range transport smoke in the Southern Great Plains (SGP), USA.**

Approach

Datasets: This research uses NASA AERONET Level 2 and satellite retrieval of deep blue AOD datasets for aerosol optical properties. HYSPLIT North American Model data to study the time for the smoke to travel from the source to the SGP and the impact on the evolution of aerosol physical properties.

Domain: The study covers the period from 2011 to 2023, during which significant fire events in California (e.g., Rim, King, Carr, Monterrey, Camp, and Loyalton fires) and Montana (Elmo and Ash Creek fires) occurred. Fire sources from Kansas and Oklahoma are considered local smoke, while smoke from Canada, Mexico, and the western U.S. to the SGP is considered long-range transport. Approximate travel times of smoke were used as the lag component in correlations between smoke physical properties between each station.

Objectives

1. **Differentiate between local sources and long-range transport of smoke aerosols** in the Southern Great Plains using satellite remote sensing and HYSPLIT back trajectory analysis.
2. **Investigate the changes in intensive (AOD) and extensive (EAE, AAE, and SSA) aerosol physical properties from the Western United States to the Southern Great Plains** using remote sensing sun photometry measurements from well-established observational networks.
3. **Examine Lidar profiles for specific smoke aerosol sources** (locally generated or long transported) and vertical distribution (ground level and high altitude) in the Southern Great Plains.

Summary

1. We found **evidence of an increase in AOD at SGP, OK,** from late spring to fall due to locally-generated prescribed fires and long-range transport of smoke from the western U.S. and Canada during late summer and early fall.
2. Smoke trajectories from California can take 1 to 4 days, but the average arrival time is only one day.
3. Trajectory analysis and Lidar backscattering signal showed heterogenous (horizontal and vertical) aerosol transport to the SGP, OK.
4. Preliminary results show an increase of 0.007 AOD and a decrease of 0.01 EAE between a smoke source and the SGP.

Acknowledgments

The MODIS, VIIRS (https://earthdata.nasa.gov), and AERONET (https://aeronet.gsfc.nasa.gov) data used in this study are freely available from NASA. Lidar data is available from the DoE SGP ARM site (https://adc.arm.gov/discovery/#/results/site_code::sgp). The ERA5 (https://cds.climate.copernicus.eu/#!/home) data used in this study are available from Copernicus. The authors are grateful to the AERONET and DOE SGP ARM site managers.

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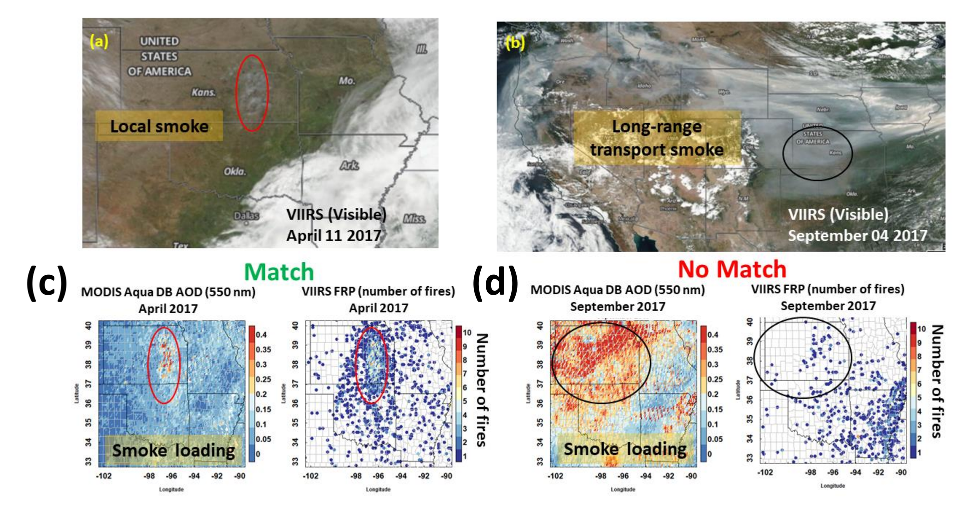
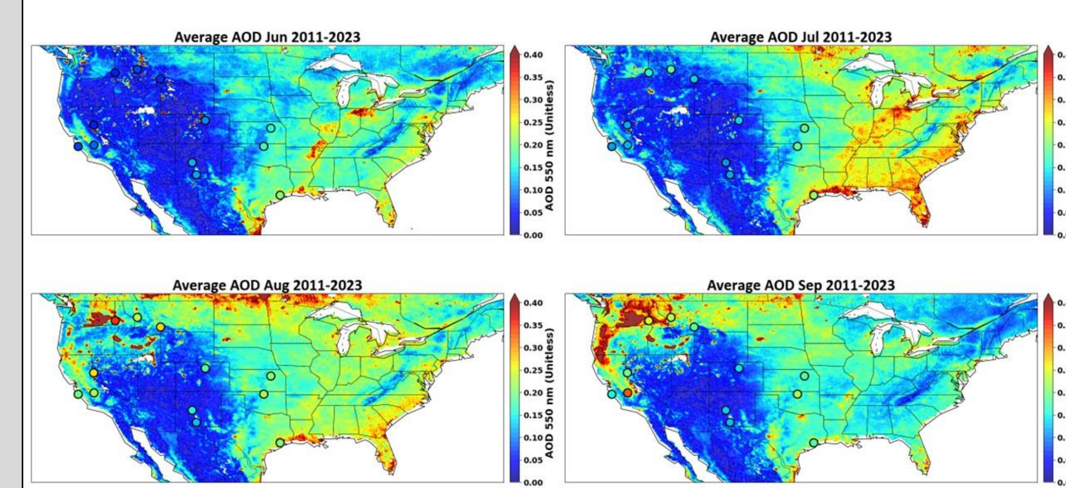
Local and Long-Range Smoke



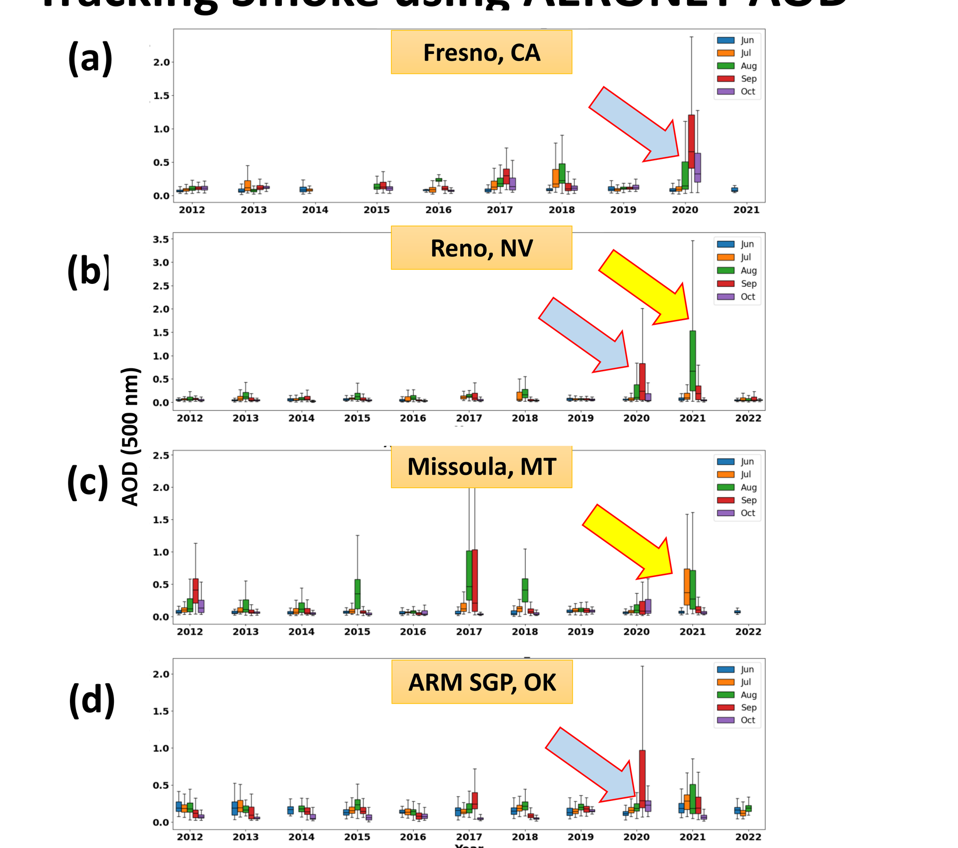
Visible imagery (a and b), AOD, and fire radiative power (FRP) retrievals show a local maximum fire activity because of agricultural burns in spring (c). We found that the burn scar in Kansas is present during March and April every year (local smoke). Therefore, AOD and the FRP count retrievals spatially match fire areas during locally generated fires. In contrast, AOD and FRP retrievals do not spatially match fire areas when there is long-range transport of smoke, often observed in late summer and fall (d).

AOD June to September (2011-2023)



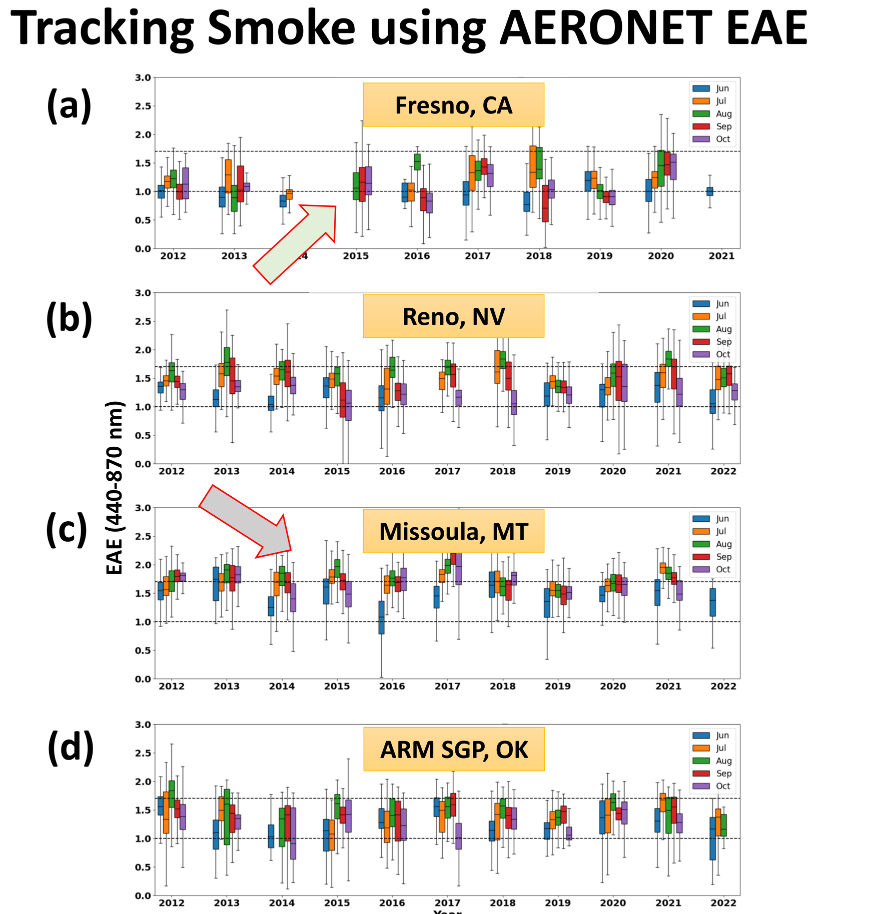
The summer months have lower averages of AOD in the Pacific Northwestern U.S. (due to the lack of sources of smoke) and higher values of AOD in the SGP due to prescribed fires to preserve the ecological equilibrium. AOD average values maximized in fall across all stations as wildfires along the western U.S. are at their seasonal peak.

Tracking Smoke using AERONET AOD



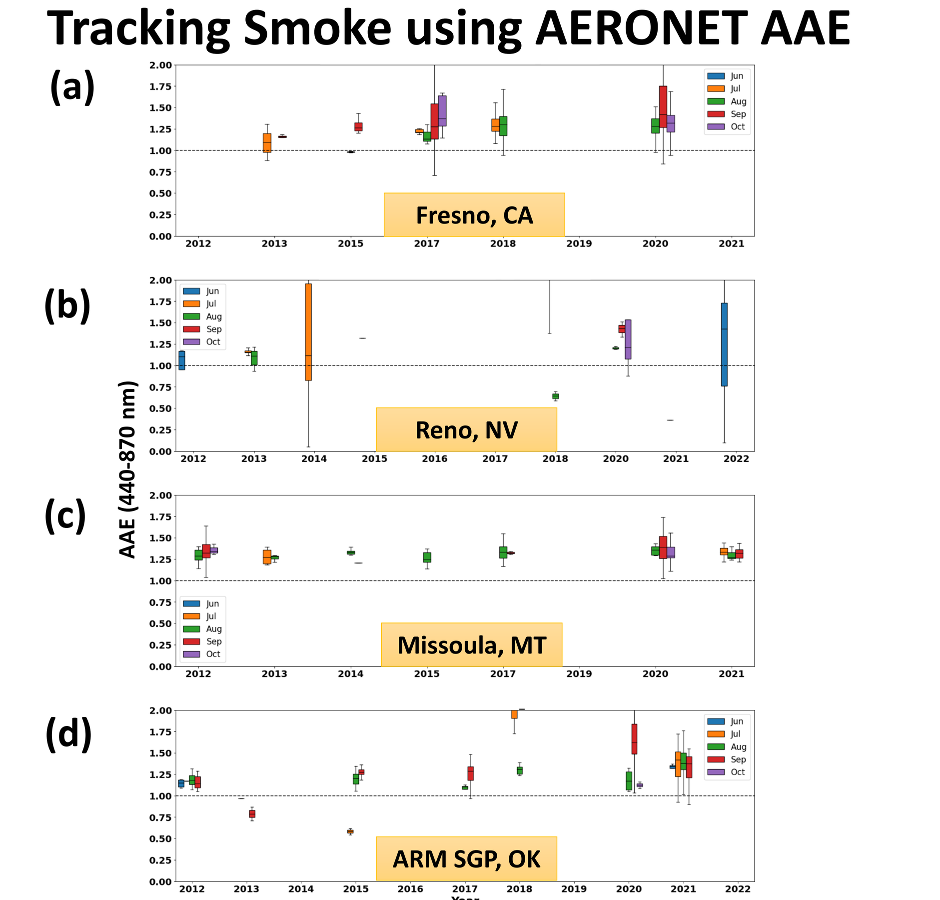
The highest AOD values recorded were in Fresno, CA (a, Sep 2020) and Reno, NV (b, Aug 2021). Secondary highest Missoula, MT (c, Aug-Sep 2017). These AOD values are indicators of the transport process taken by smoke. For example, in Sep 2020, there was an increased AOD in Fresno, CA, apparent in Reno, NV, and SGP, OK (d), but not in Missoula, MT.

Tracking Smoke using AERONET EAE



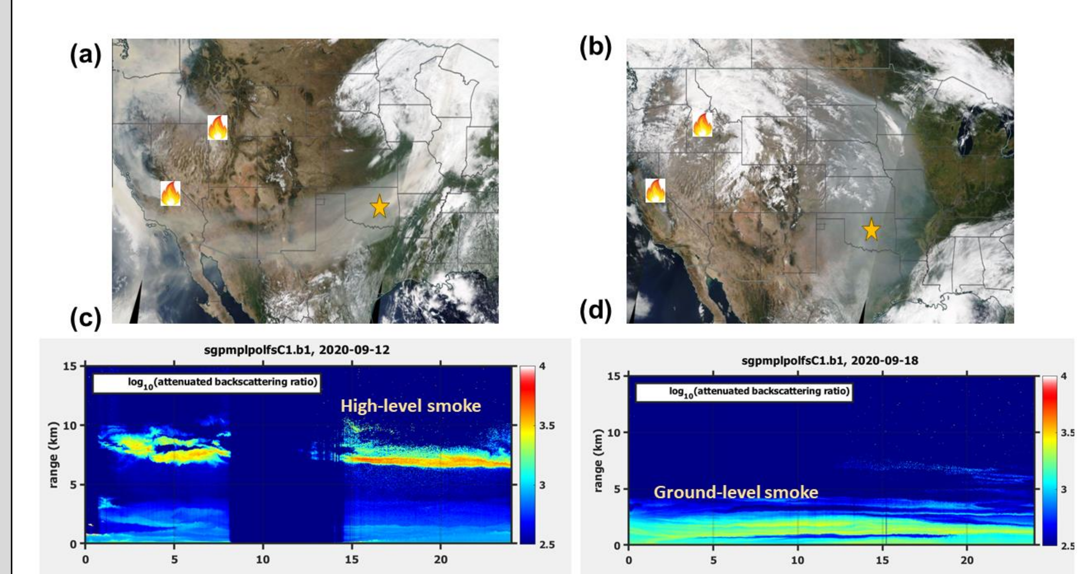
Fresno, CA, (a) is dominated by course mode (EAE ≤ 1) and Missoula, MT (c), by fine mode (EAE ≥ 1.7) particles. Reno, NV, (b) and the ARM SGP, OK (d) sites show evidence of coarse and fine modes at different months and years.

Tracking Smoke using AERONET AAE



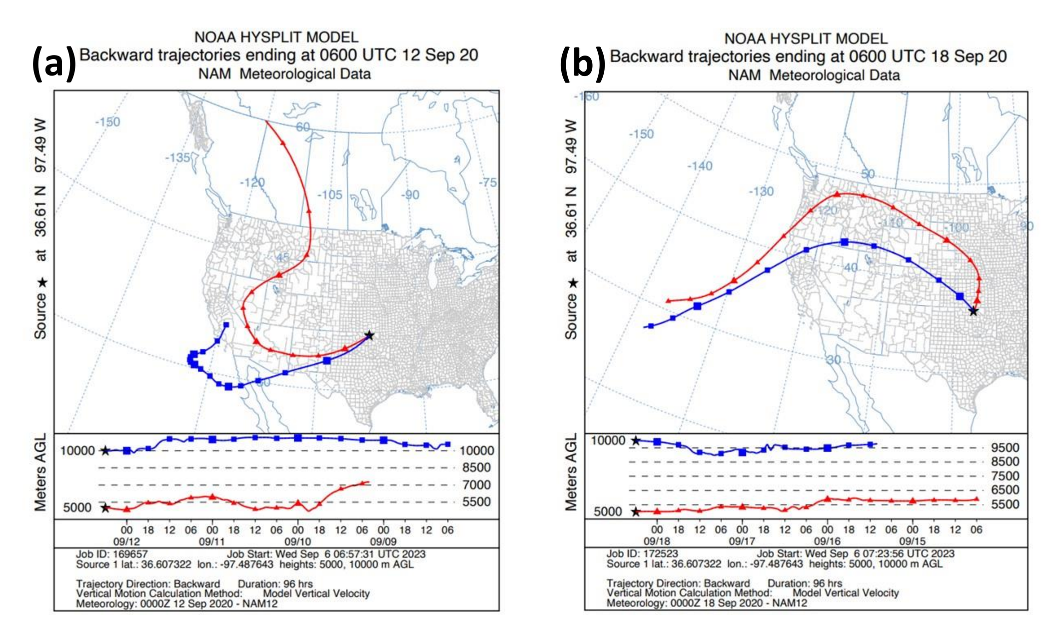
AAE approaching one indicates black carbon. While AAE is relatively stable across other stations (AAE~1.3). The ARM SGP, OK (d) site exhibits a more erratic AAE pattern, most likely caused by smoke transported to the site and aging processes (AAE>>1.3).

Lidar of Different Smoke Transports



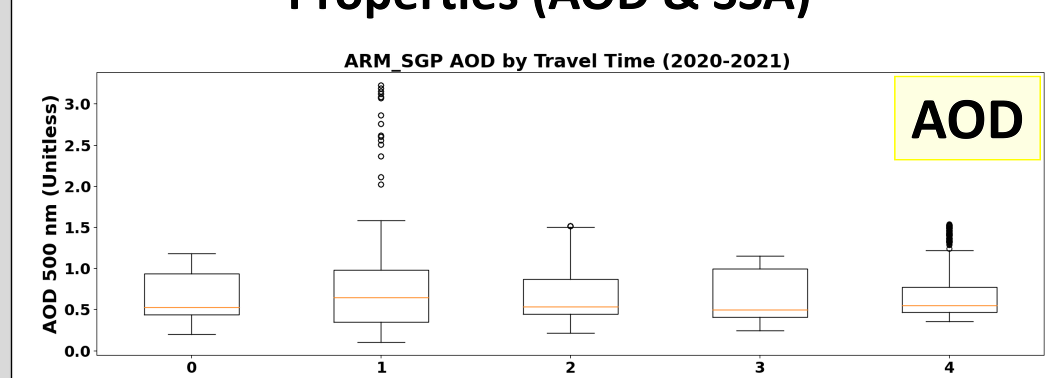
Different smoke transport paths can result in smoke arriving at the SGP, OK at different altitudes, influencing the aging of the aerosols and physical properties. For example, we found a southern trajectory (a) from California fires that recirculated in the Pacific Ocean. The transport took ~ 5 days and smoke was found above the planetary boundary layer (PBL) (c). The north-to-east trajectory (b) is a more common trajectory found (~3 days) and the smoke is found to arrive within the PBL (d). Trajectories a and c show the impact of aerosol aging on the color of the smoke. This will impact how the smoke interacts with public health and the atmospheric boundary layer.

HYSPLIT Back Trajectories

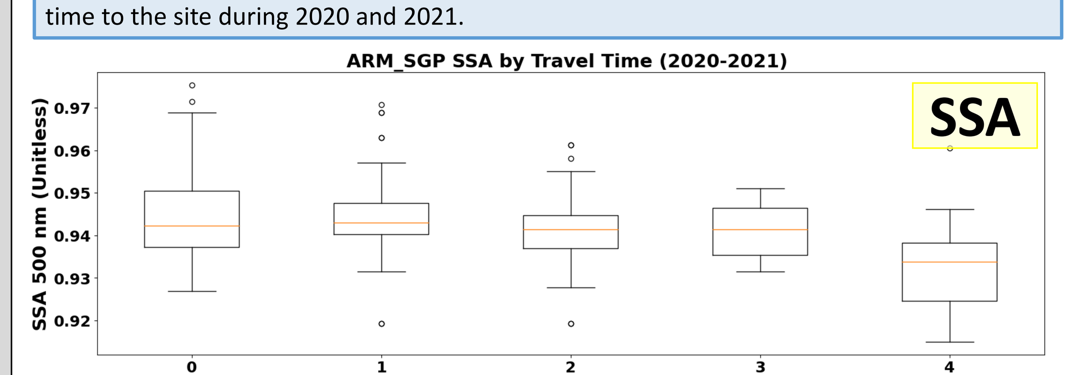


The most common trajectories smoke plumes took to the SGP were directly East to West or an arcing path from Northwest to South (b). However, some cases showed smoke traveling from the South to North (a). In this case, the smoke was carried over the Pacific before being blown back toward the SGP. This resulted in the longest transport time recorded.

Travel Time's Aging Effects on Smoke Aerosol Properties (AOD & SSA)

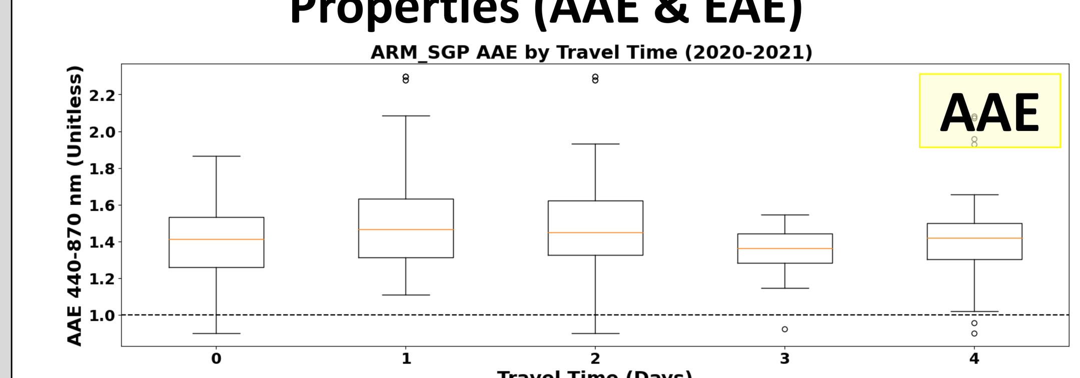


The average AOD over the ARM SGP site did not vary significantly (AOD~0.6) between travel time to the site during 2020 and 2021.

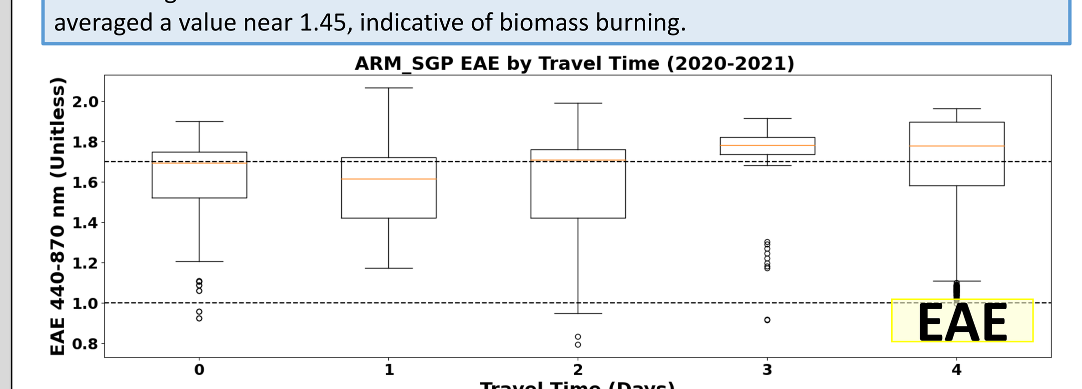


Average SSA was marginally lower for smoke with a travel time of 4 days (SSA~0.935) compared to the travel times of 0-3 days (SSA~0.945).

Travel Time's Aging Effects on Smoke Aerosol Properties (AAE & EAE)



The average AAE was above the theoretical value of 1 for black carbon. All travel times averaged a value near 1.45, indicative of biomass burning.



Average EAE of smoke arriving at the SGP site was dominated by fine mode particles. Particles size also appears to decrease with time travel time.