Temporal Evolution of Long-Range Transported Biomass Burning Aerosols using Remote sensing

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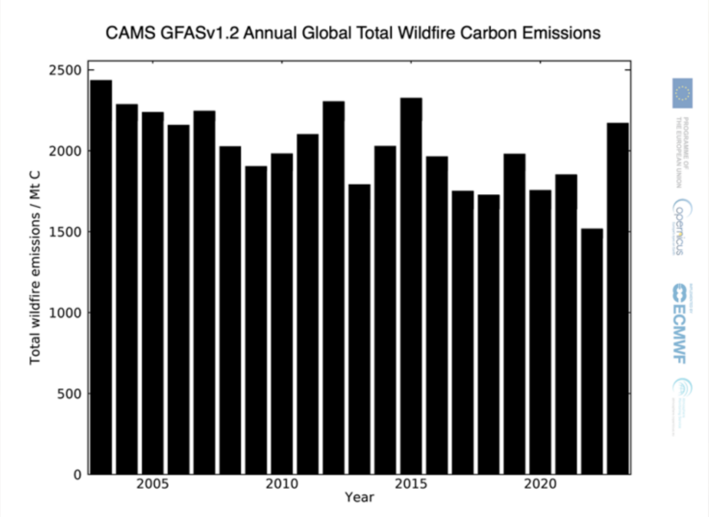
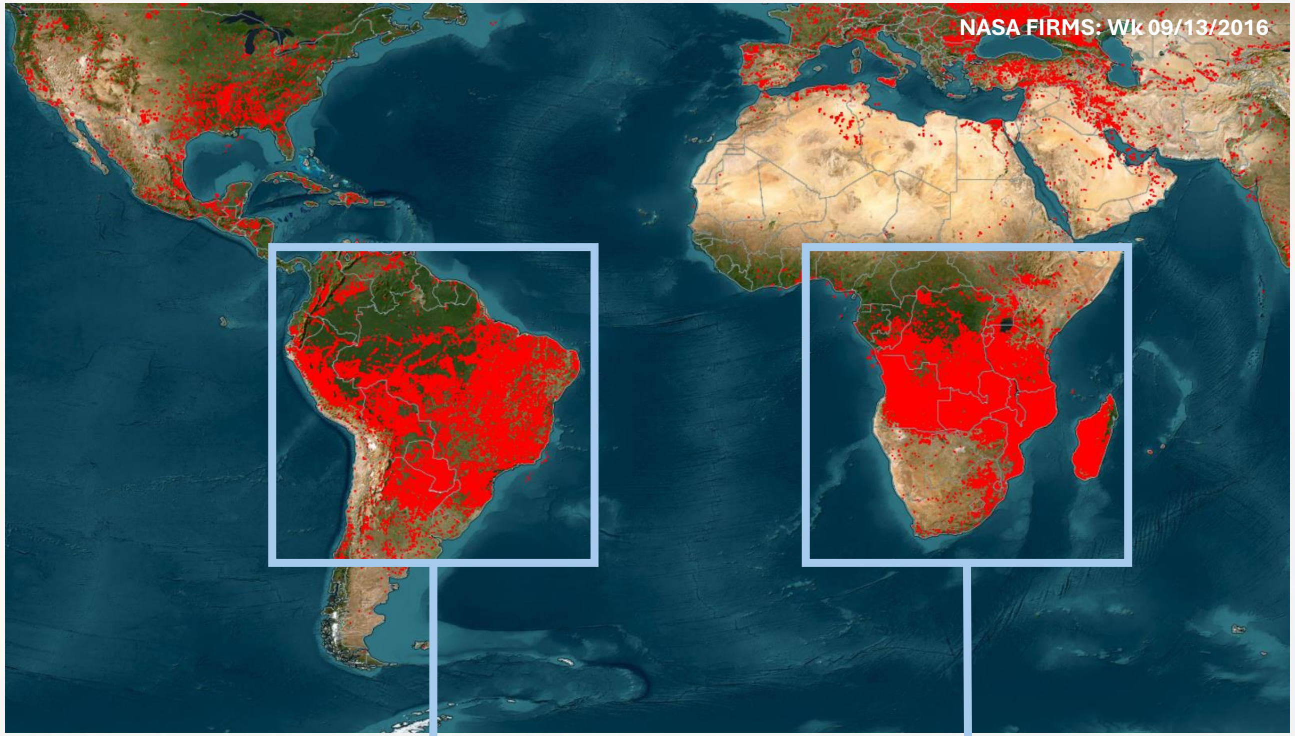
CLouds · CLimatE · Aerosols · Radiation

AERONET *Science and Application Exchange*
September 18, 2024

Background to Study



~ 2000 megatons of carbon (annual avg)

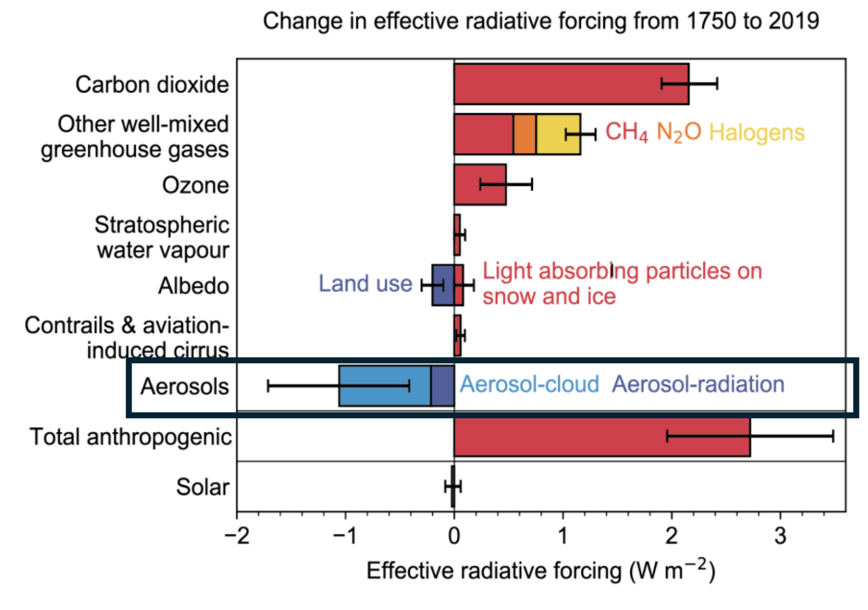


- Complex mix of aerosols & gases
- Brown (BrC) & black (BC) carbon (Bond et al. 2004, 2013)

Fires in these regions account for nearly half of global carbon emissions with ~30% from south Africa (van der Werf et al. 2010)

Background to Study

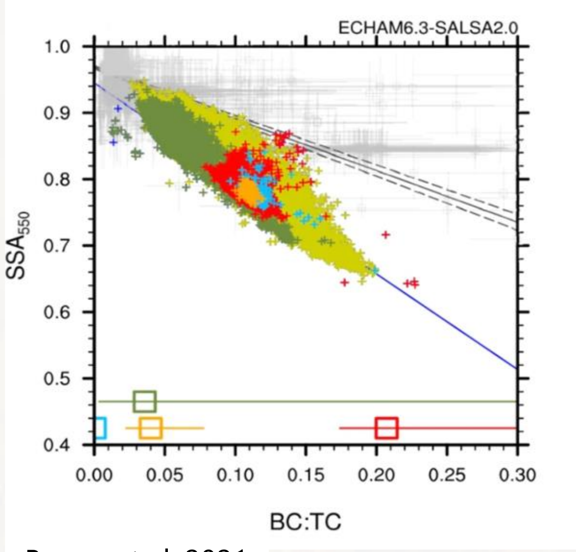
Significance



IPCC AR6, 2021

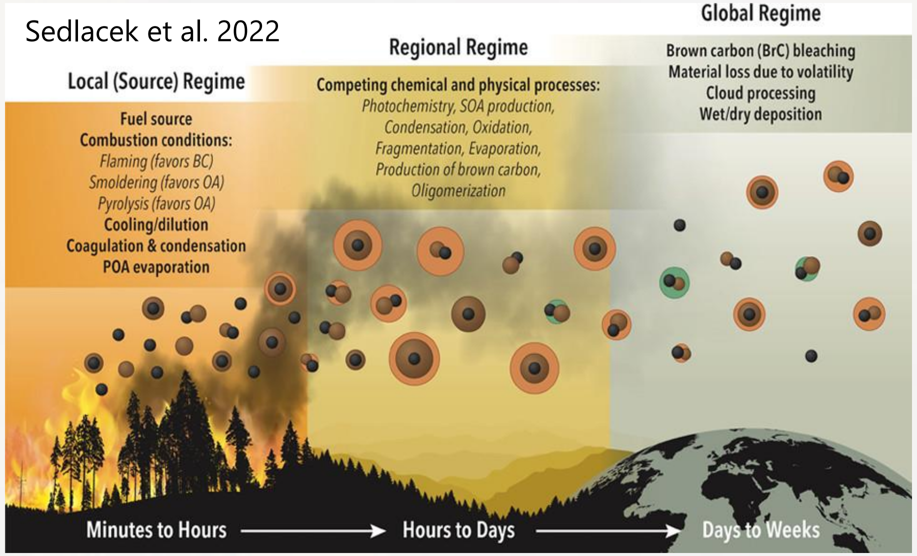
Largest uncertainty in radiative forcing

Knowledge Gaps



Brown et al. 2021

Sedlacek et al. 2022



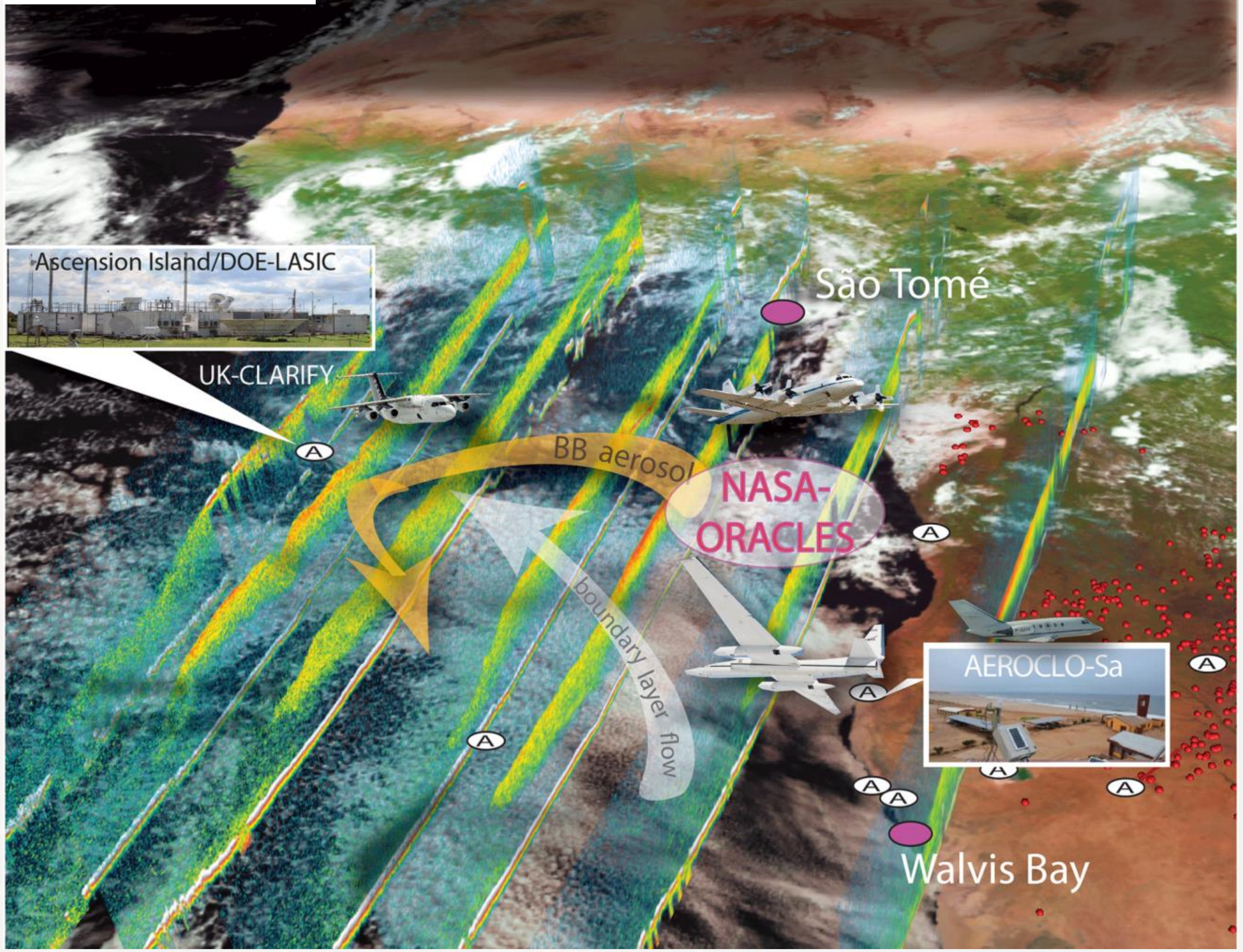
- Inaccurate model representation of wildfires; model overestimates absorption by aerosols
- Lack of process-level understanding of emissions; atmospheric processes occurs at scales models can't capture
- Aging-induced evolution of wildfire aerosols remains undocumented

The Southeast Atlantic; A Natural Laboratory

- The fire season in southern Africa coincides with the period of maximum cloud cover over the SEA (July – October)
- Biomass Burning Aerosols (BBA) from continental fires are transported over the ocean for days to weeks (Adebiyi et al., 2016)
- Unique interaction of BBA with the stratocumulus cloud deck over the SEA can help study the ARI and ACI

Combination of remote-sensing observations to study the evolution of Southern Africa BBA

Redemann et al. 2021



Objective and Methods

Research Goal

To document the evolution of BBA absorption, during long-range transport across the southeast Atlantic region from a combination of remote sensing observations and modeling.

Analysis

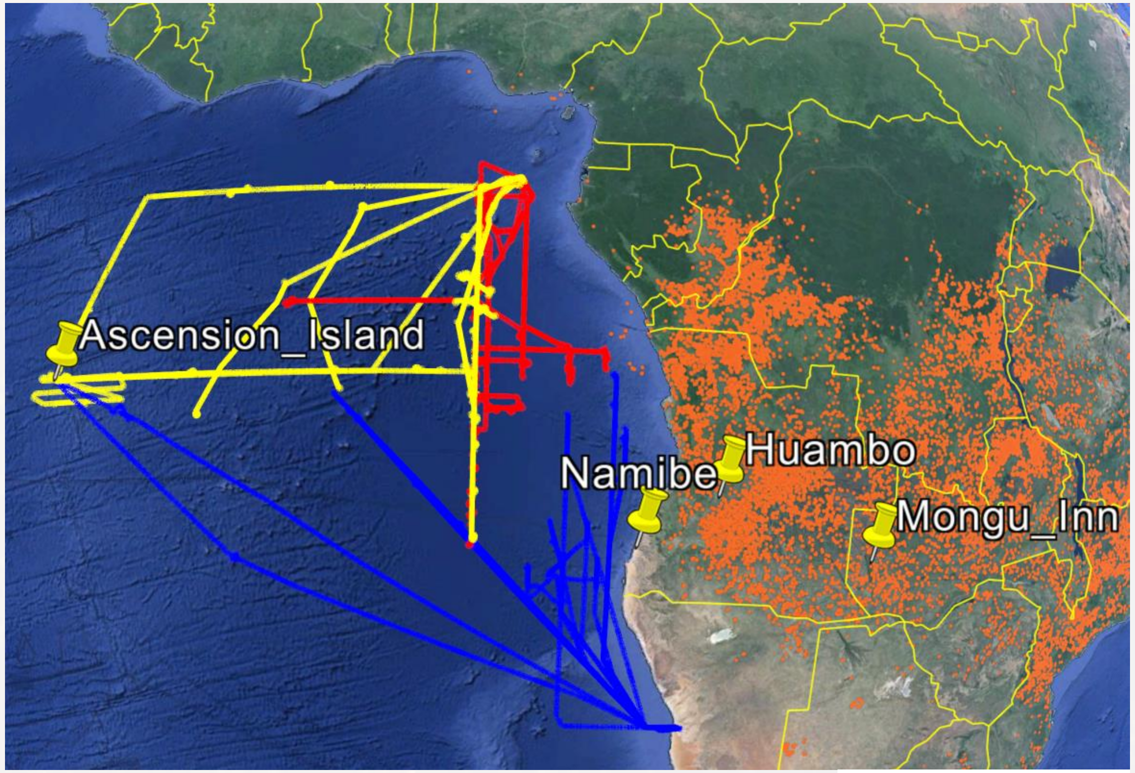
- Collocate SSA and AE retrievals from AERONET and 4STAR with aerosol age estimates from WRF-AAM
- Aerosol age is estimated as the extinction-weighted average of CO tracers in WRF-AAM (Saide et al. 2016)

Focused analysis on free-tropospheric BBA aerosols, isolating non-BBA contributions from the total column measurements.

Dataset

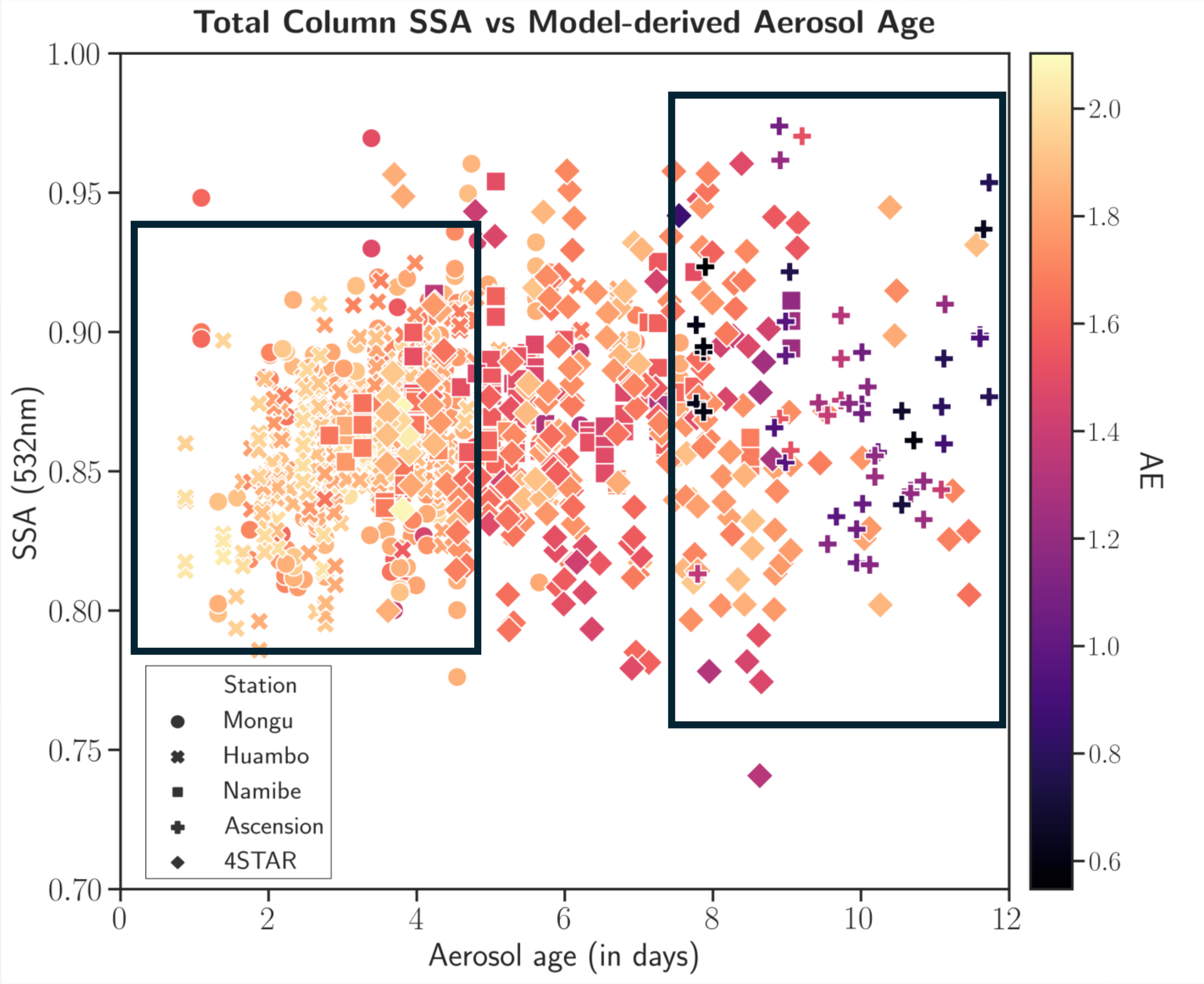
NASA ORACLES: Sept. 2016, Aug. 2017, Oct. 2018

- Ground-based AERONET and Airborne 4STAR
- WRF-AAM and WRF-CAM5 Outputs



Fakoya et al. *in prep*

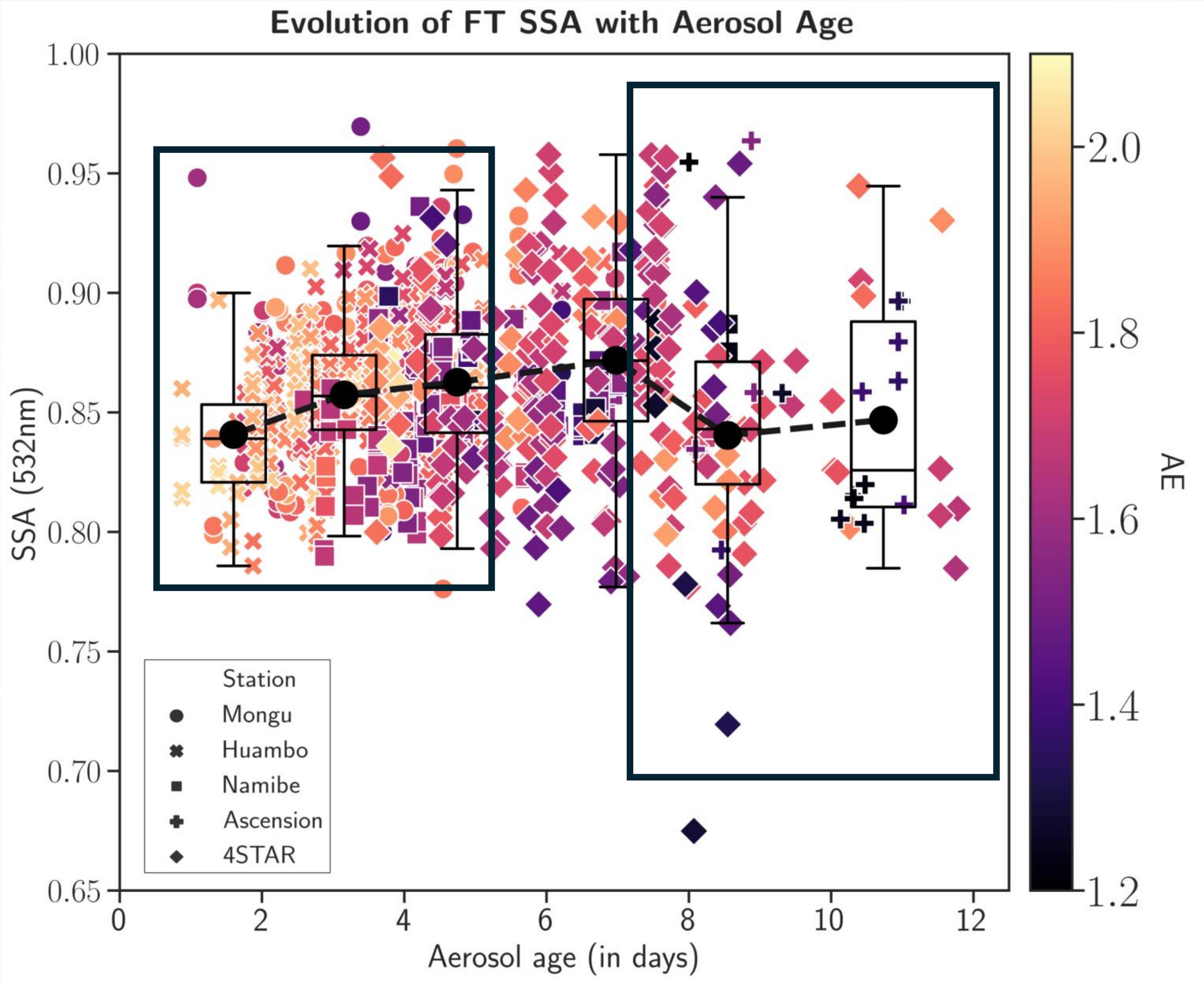
Results – BBA in the Total Column



Prevalence of small-sized aerosols in the continent indicate mainly BB within the total column

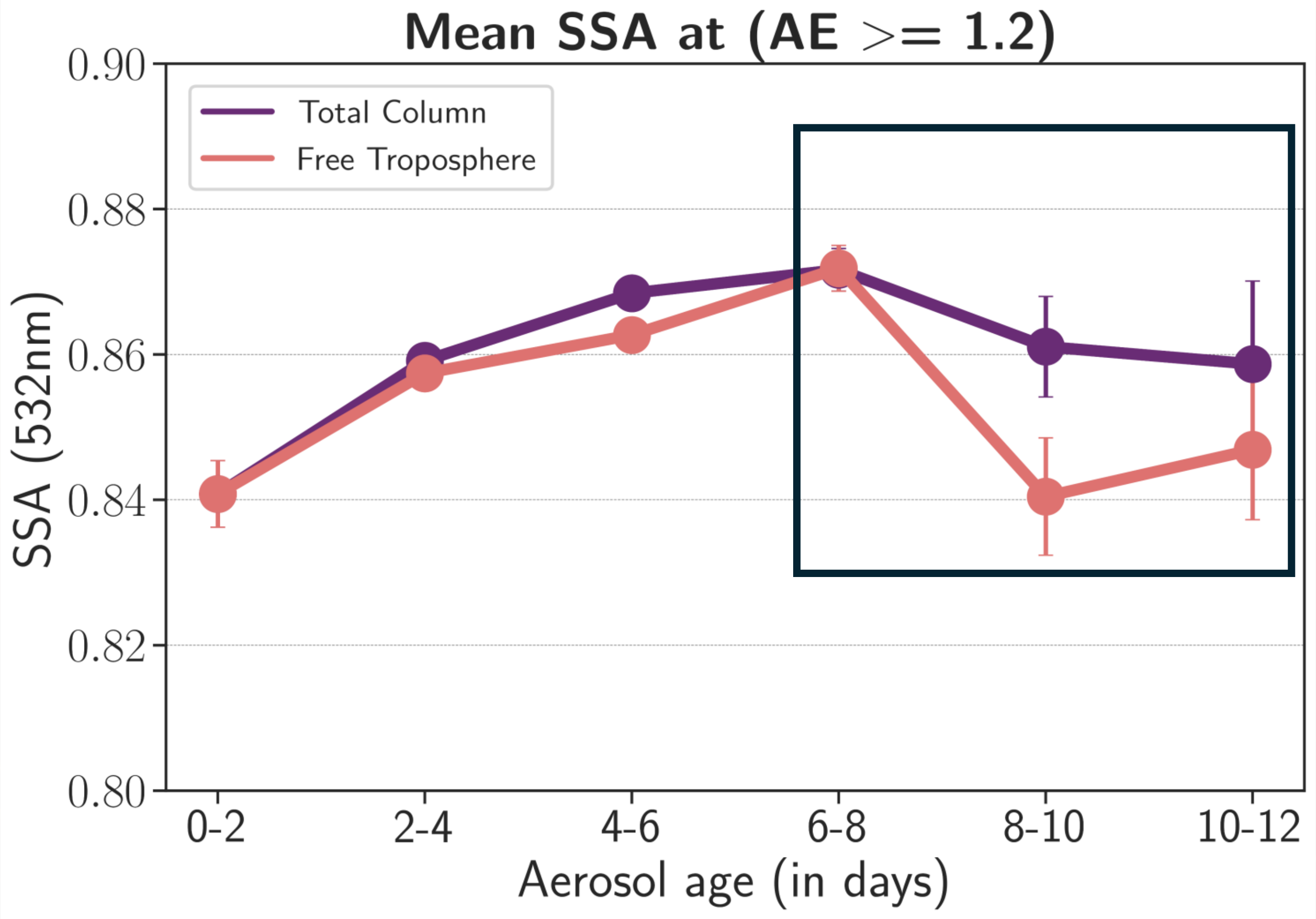
Increased size over the ocean suggest mixing with other particles or different aerosol types

BBA in the Free Troposphere



Reduced absorptivity from emission up to 8 days. Increase in absorptivity over the ocean

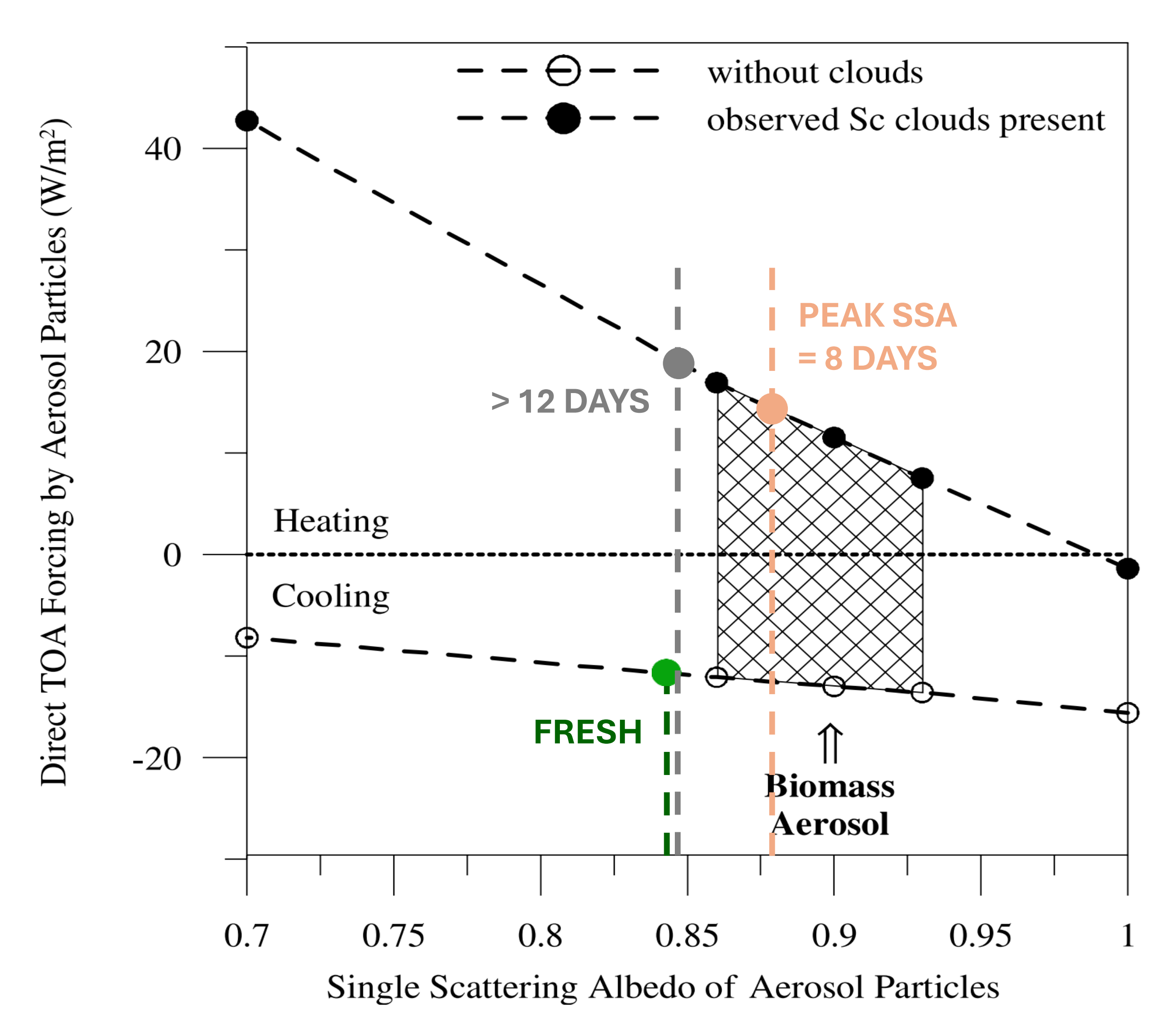
Temporal Evolution of BBA absorption



- Up to 2% decrease in mean SSA in the FT relative to the TC
- Changes in SSA for aged aerosols due to chemical processing. (Sedlacek et al., 2022; Dobracki et al., 2023)

This vertical dependence of atmospheric processes and their influence on SSA is poorly captured in most models

Big Picture Perspective



Keil & Haywood et al. 2003

- BBA evolution can potentially change the magnitude and sign of direct TOA forcing in the SEA (Keil and Haywood, 2003; Wilcox, 2012)

Capturing the constant change in BBA properties through their lifecycle in models is the next step for improving model fidelity and predictive capability

Future Work

New Science Questions

- To what extent does burning material and condition affect changes in radiative properties?
    - Combine model simulations with observations over other wildfire emission regions (WE-CAN, ASIA-AQ, FIREX-AQ) to compare the evolution.
- How can the results of this study help to improve future predictions of climatic impact of smoke aerosols?
    - What factors contributing to the evolution trend is missing in models and how can these be incorporated into models

Amazon Wildfires, 2019

Acknowledgment

- Co-authors
- Doctoral Committee
- OU Supercomputing (OSCER)
- NSF NCAR ACOM

Questions?

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https://scholar.google.com/citations?user=LYj7bDgAAAAJ&hl=en

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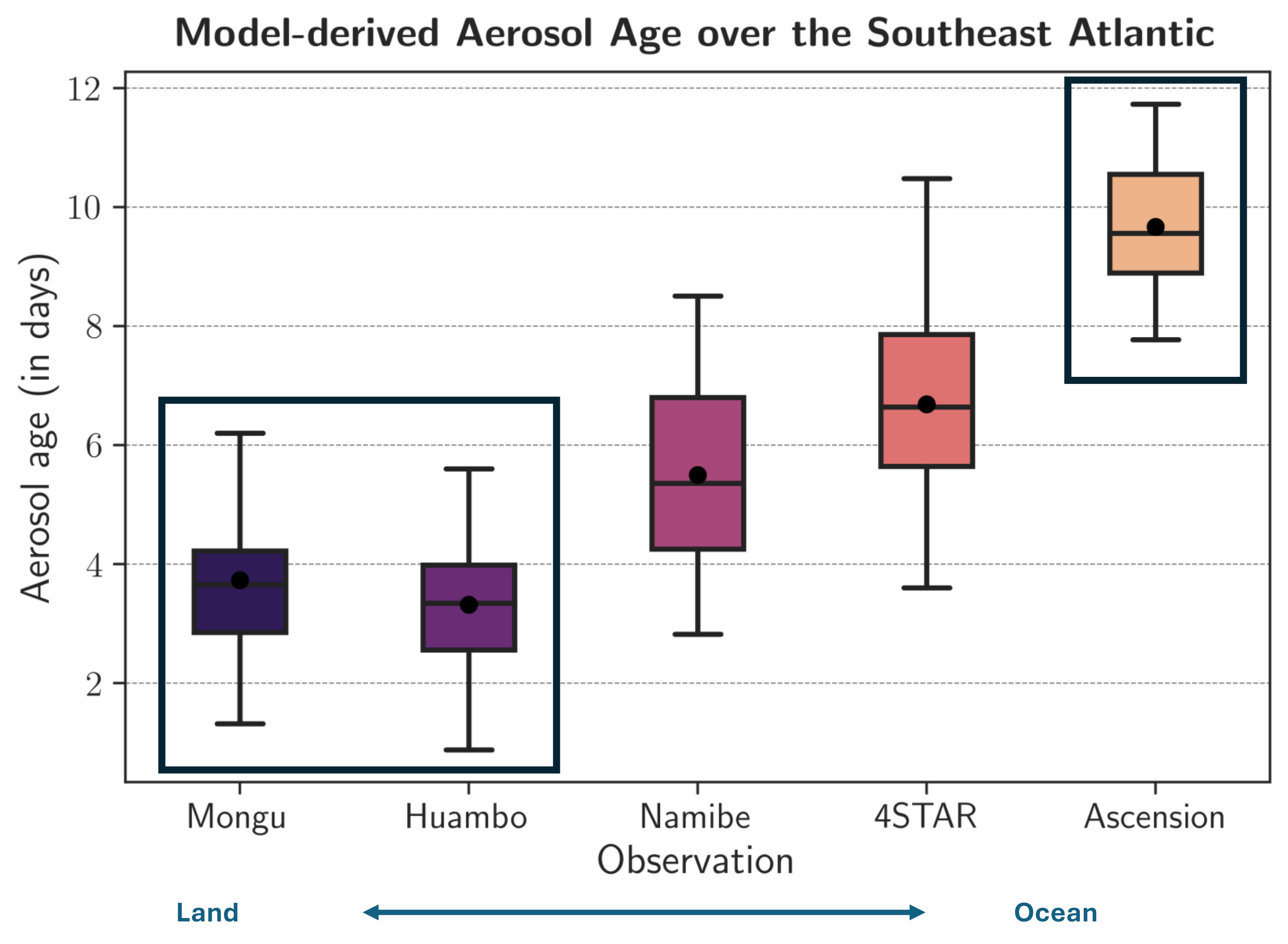
Supplementary - Aerosol Age

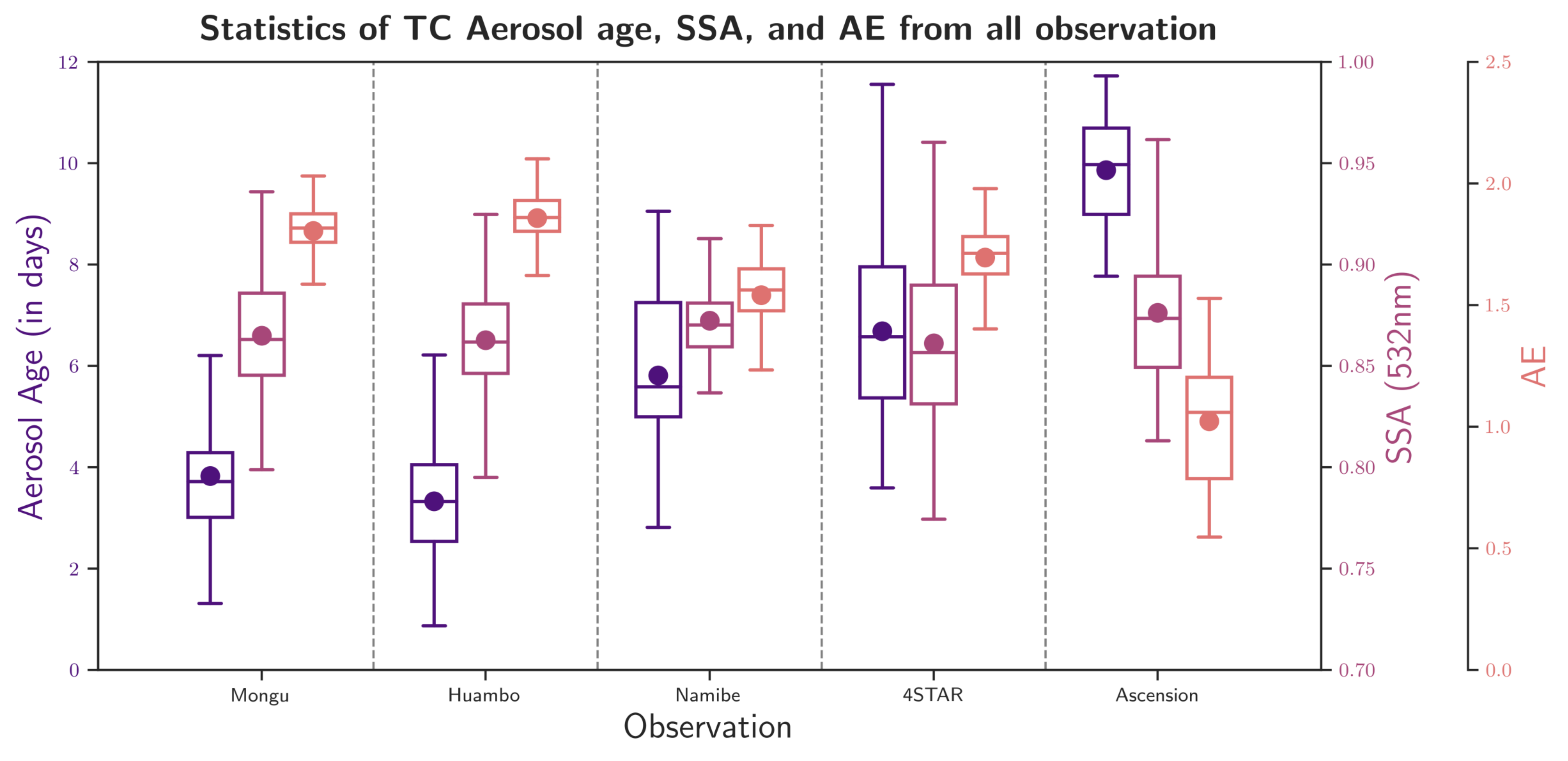


- Youngest aerosols, **< 1 – 6 days** in the source region (Mongu and Huambo)

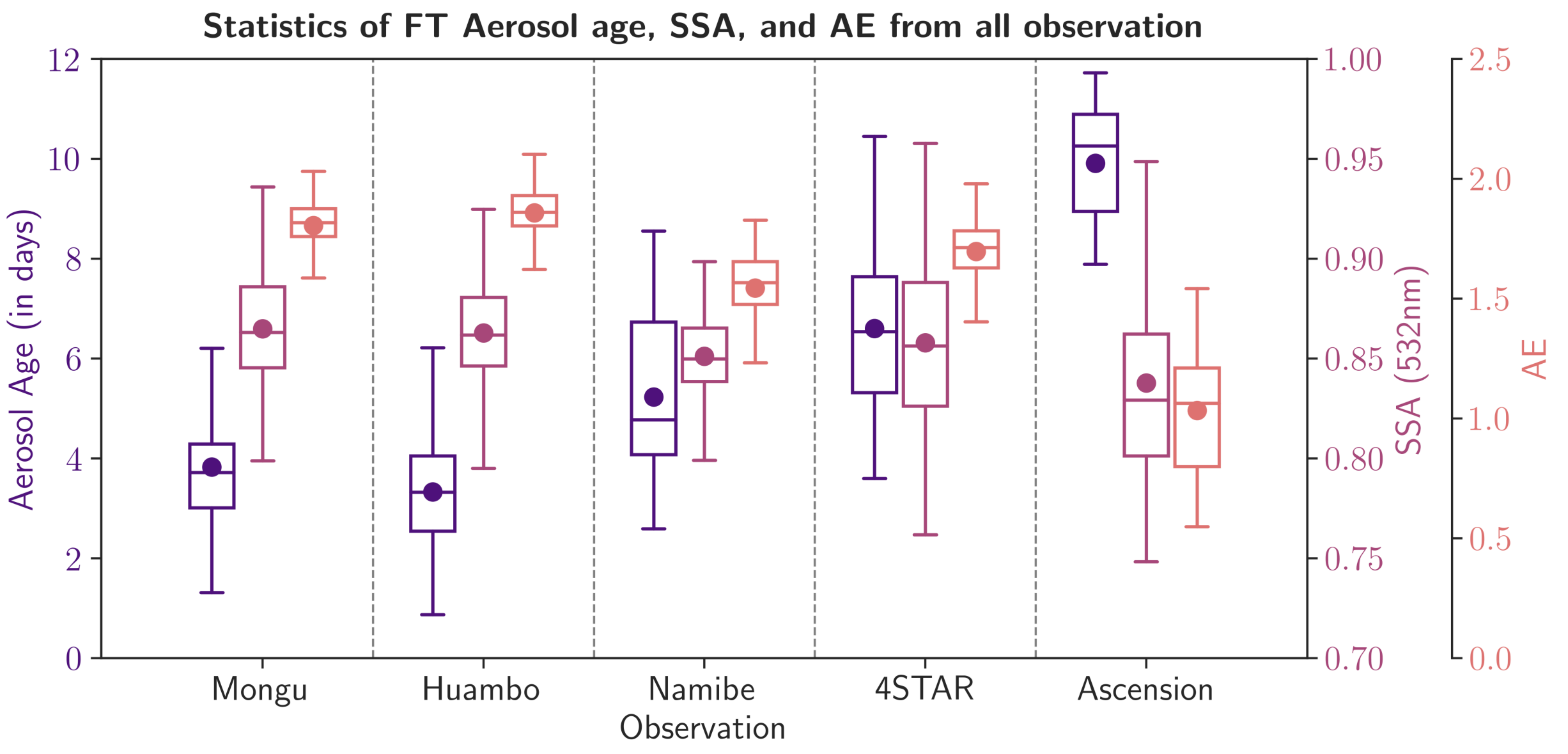
- Oldest, **8 – 12 days** at Ascension

Smoke from the continental fires follows a relatively steady trajectory up to Ascension

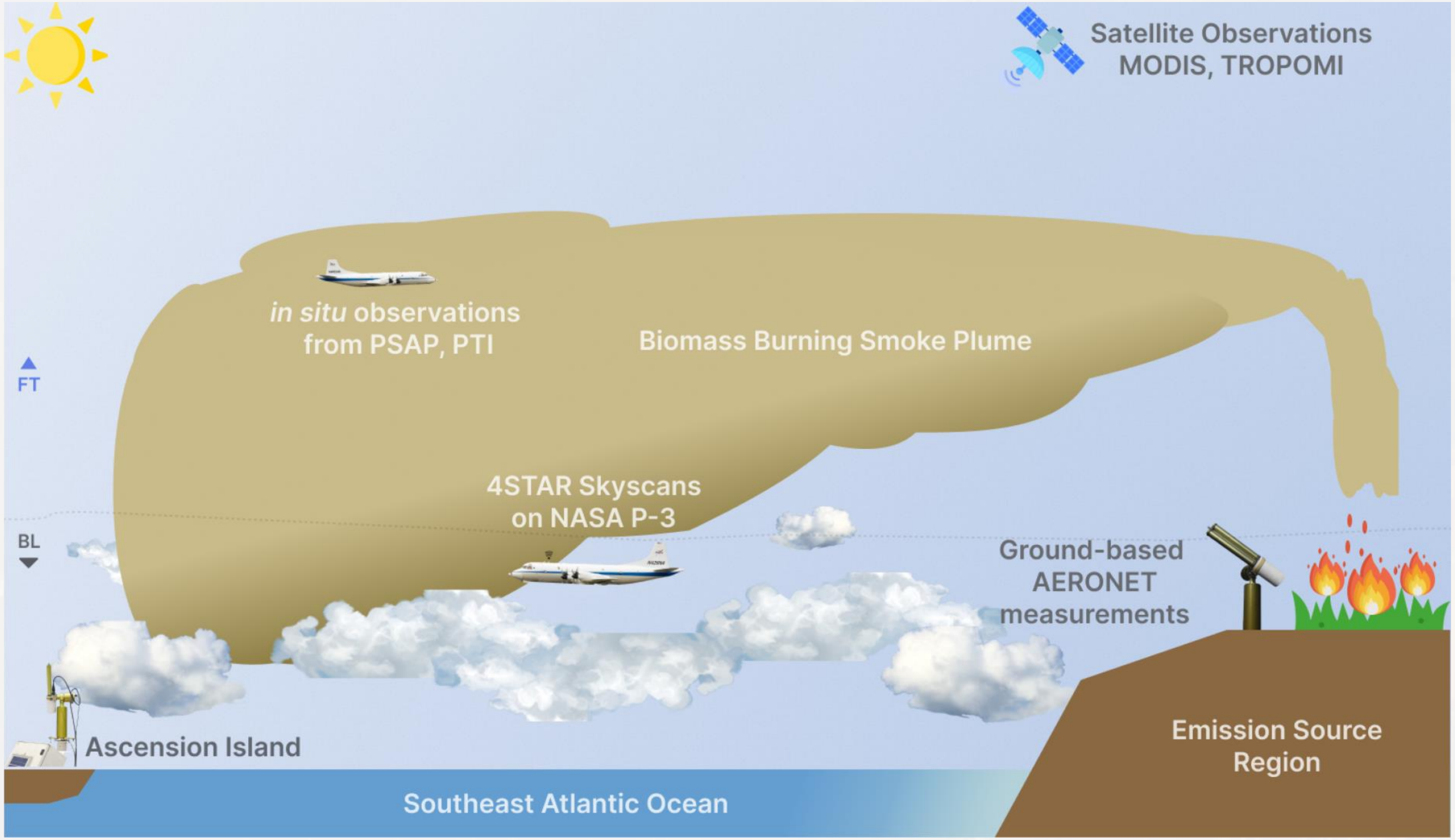
Supplementary – Age, SSA, AE in the Total Column



Supplementary – Age, SSA, AE in the Free Troposphere



Supplementary - Partitioning



$$\text{Aerosol age} = \frac{\int_{s\_elv}^{toa} \beta_{ext} \times \text{tracer age}\, dz}{\int_{s\_elv}^{toa} \beta_{ext}\, dz}$$

$$R_{m\_BL} = \frac{\int_{s\_elv}^{BLH} \beta_{ext} dz}{\int_{s\_elv}^{toa} \beta_{ext} dz}$$

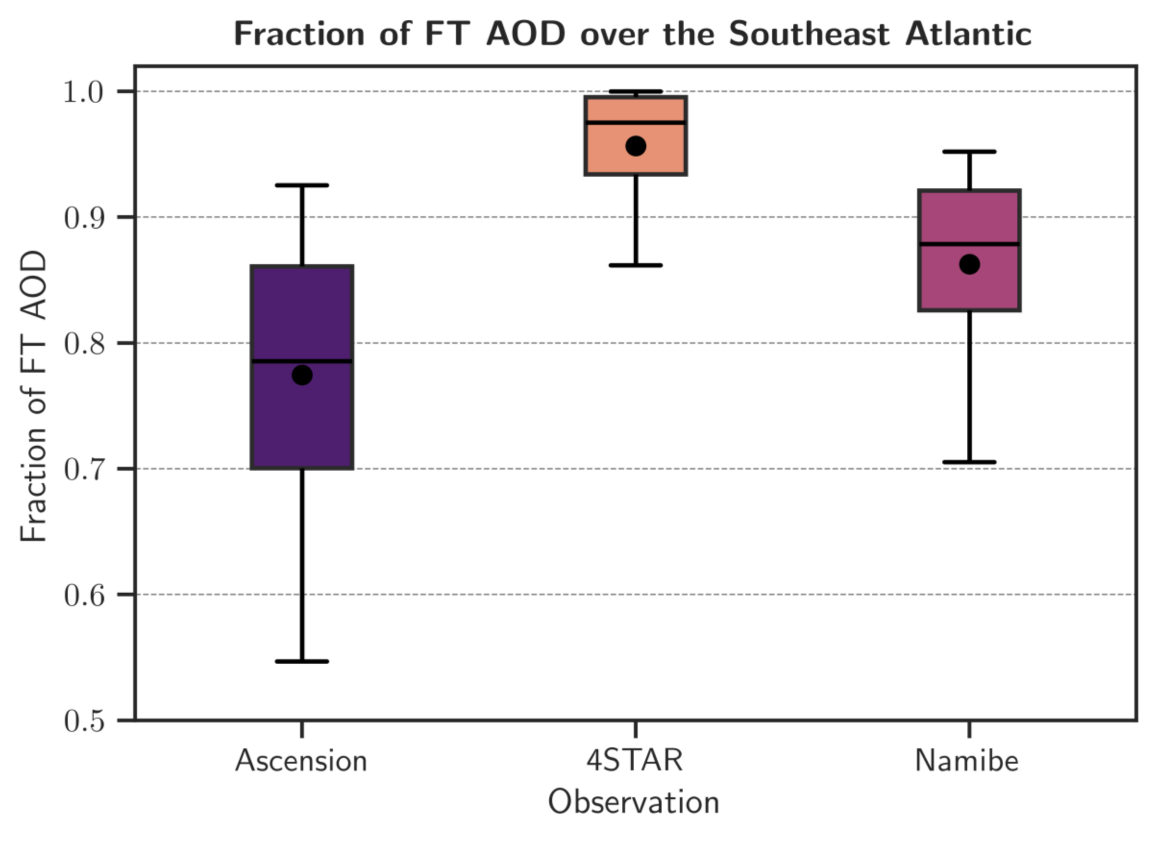
$$R_{m\_FT} = 1 - R_{m\_BL}$$

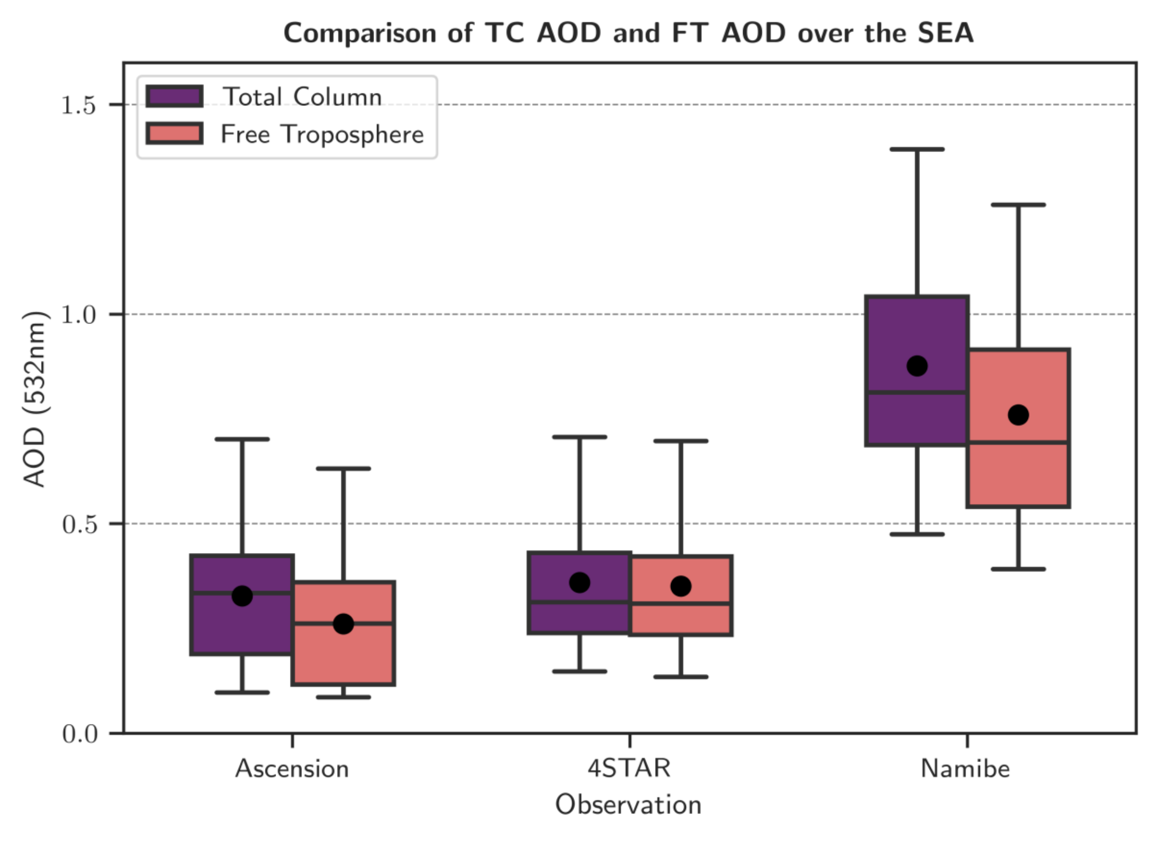
$$AOD_{BL} = \mathrm{R_{m_{BL}}} * \mathrm{AOD_{TC}}$$

$$AOD_{FT} = \mathrm{R_{m_{FT}}} * \mathrm{AOD_{TC}}$$

$$\mathrm{SSA_{FT}} = \frac{(\mathrm{SSA_{TC}} * \mathrm{AOD_{TC}}) - (\mathrm{SSA_{BL}} * \mathrm{AOD_{BL}})}{\mathrm{AOD_{FT}}}$$

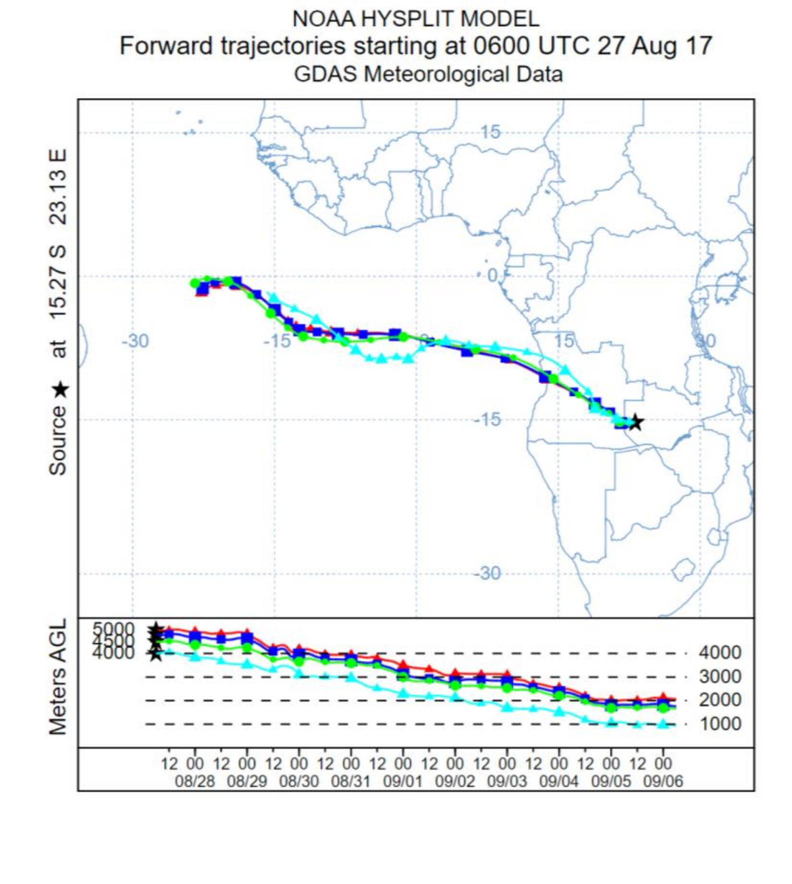
Supplementary – FT Partitioning

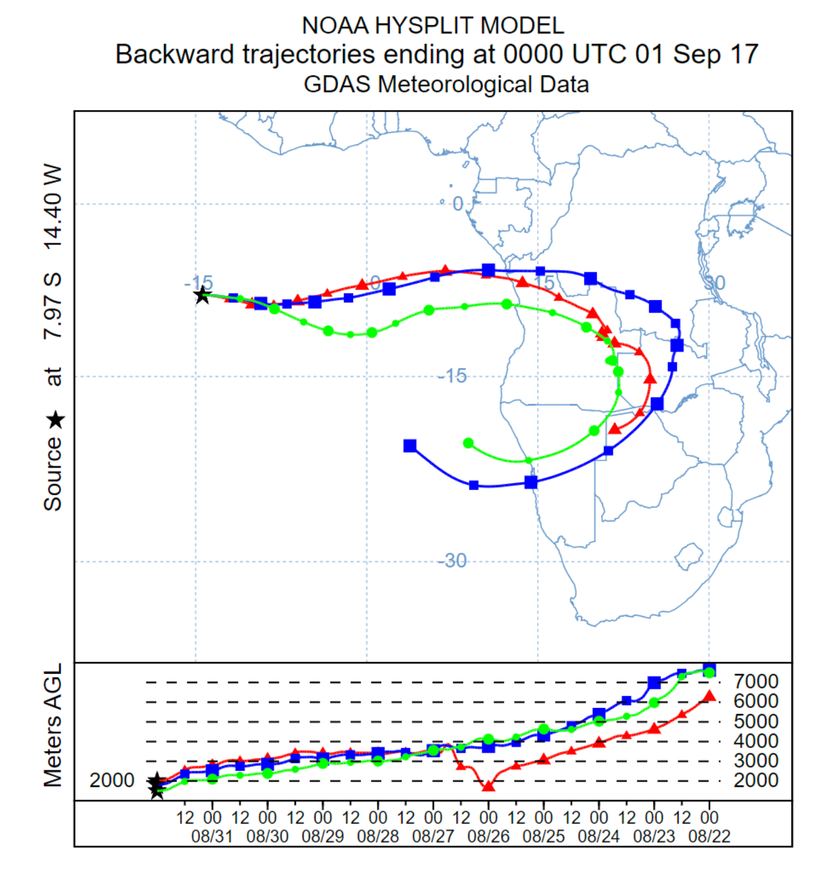


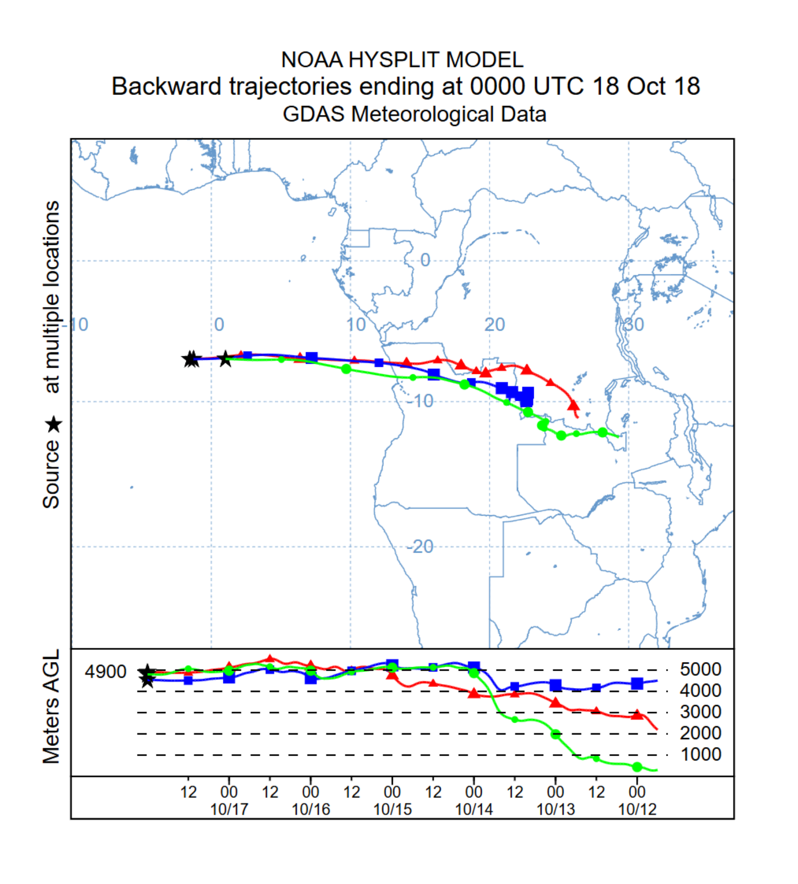


Isolating BL contribution using WRF-CAM BLH over the ocean showed that over 50% of aerosol loading is in the FT with significant variability

Supplementary – Trajectory Analyses



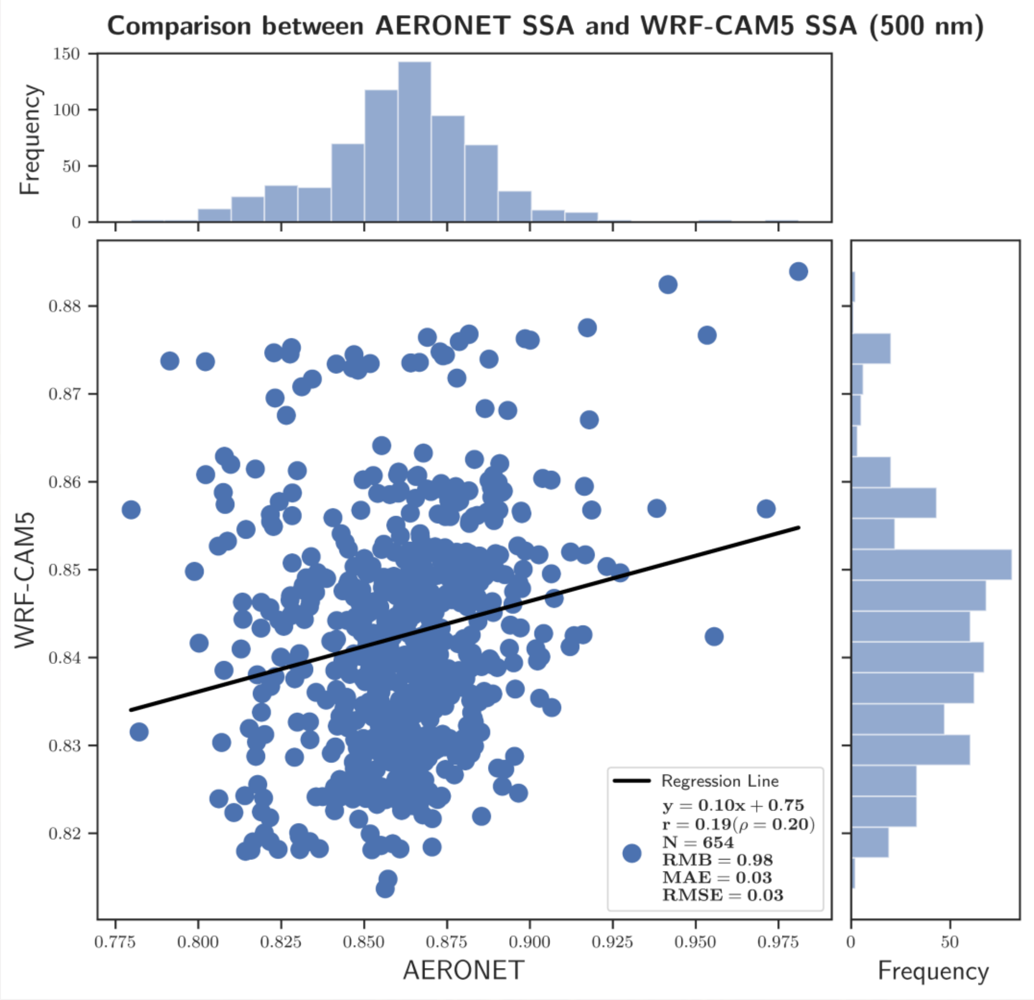


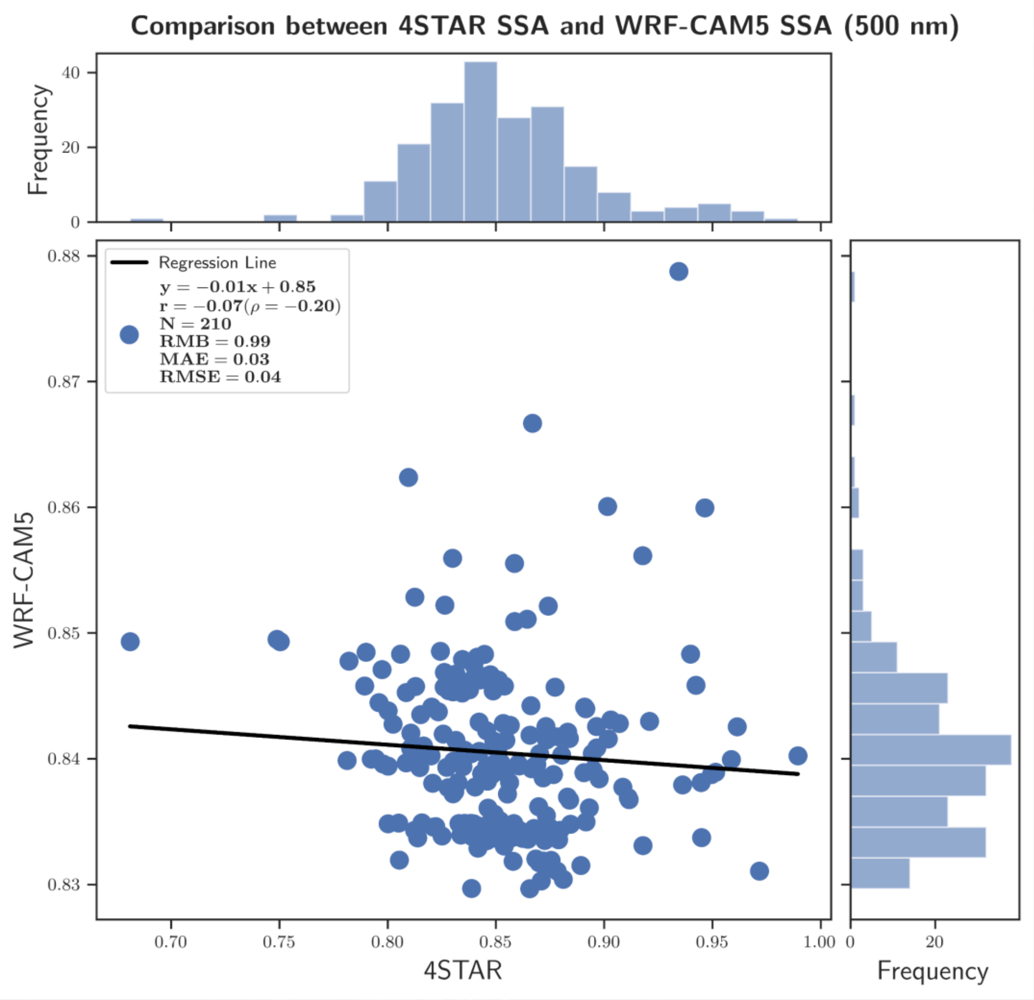


10-day forward and backward trajectories shows airmass over the SEA originates from burning sources in southern Africa

7-day back trajectory to intercept with NASA P3 aircraft during ORACLES 2018

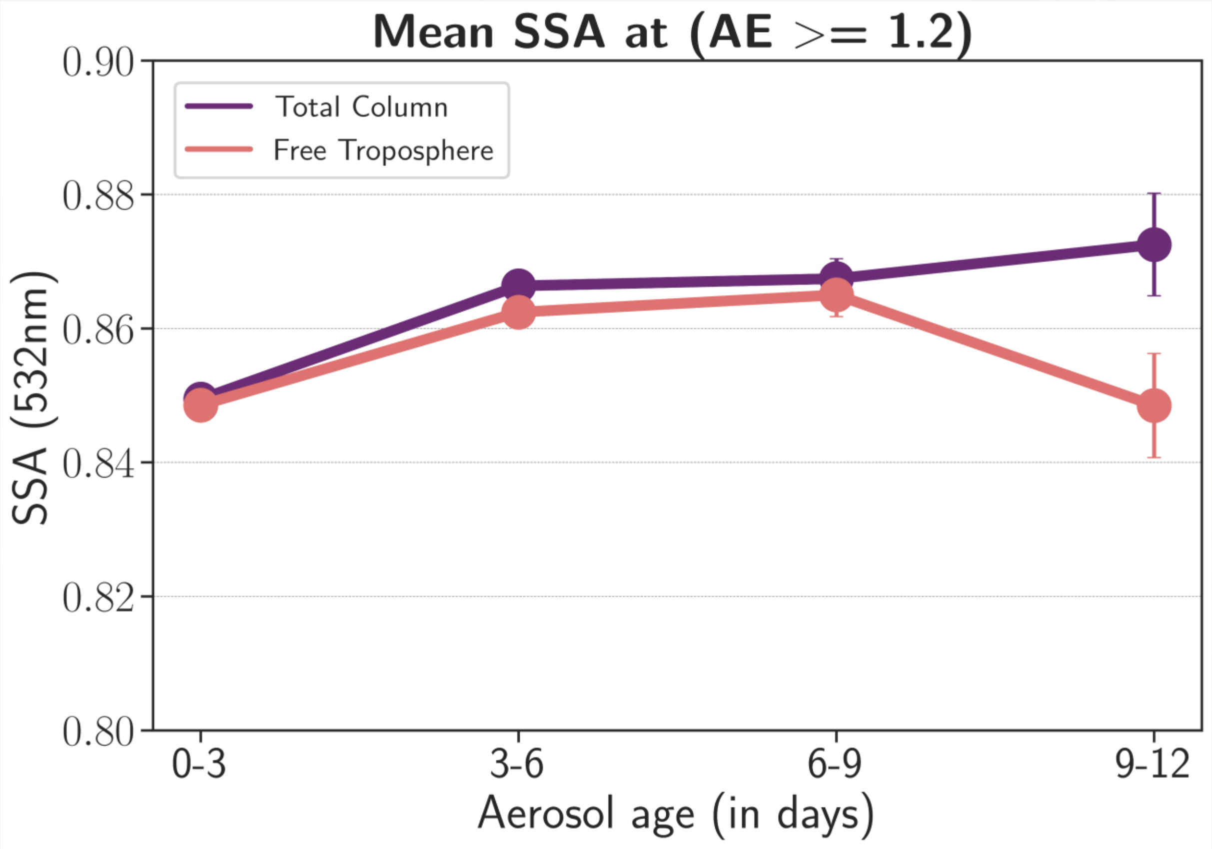
Supplementary – Model-Observation Comparison

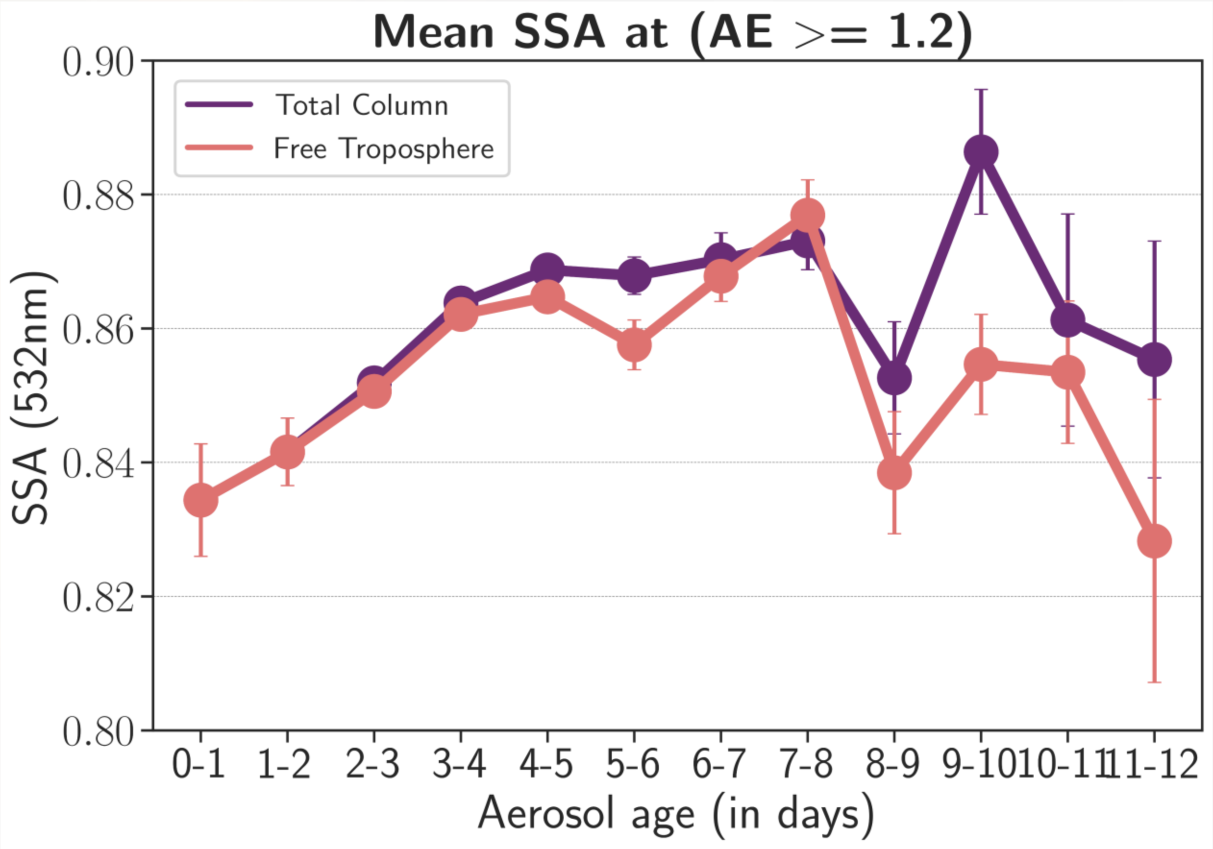




Model simulates a narrow SSA range of 0.8 - 0.9 compared to 0.7 - 0.98 in the observations

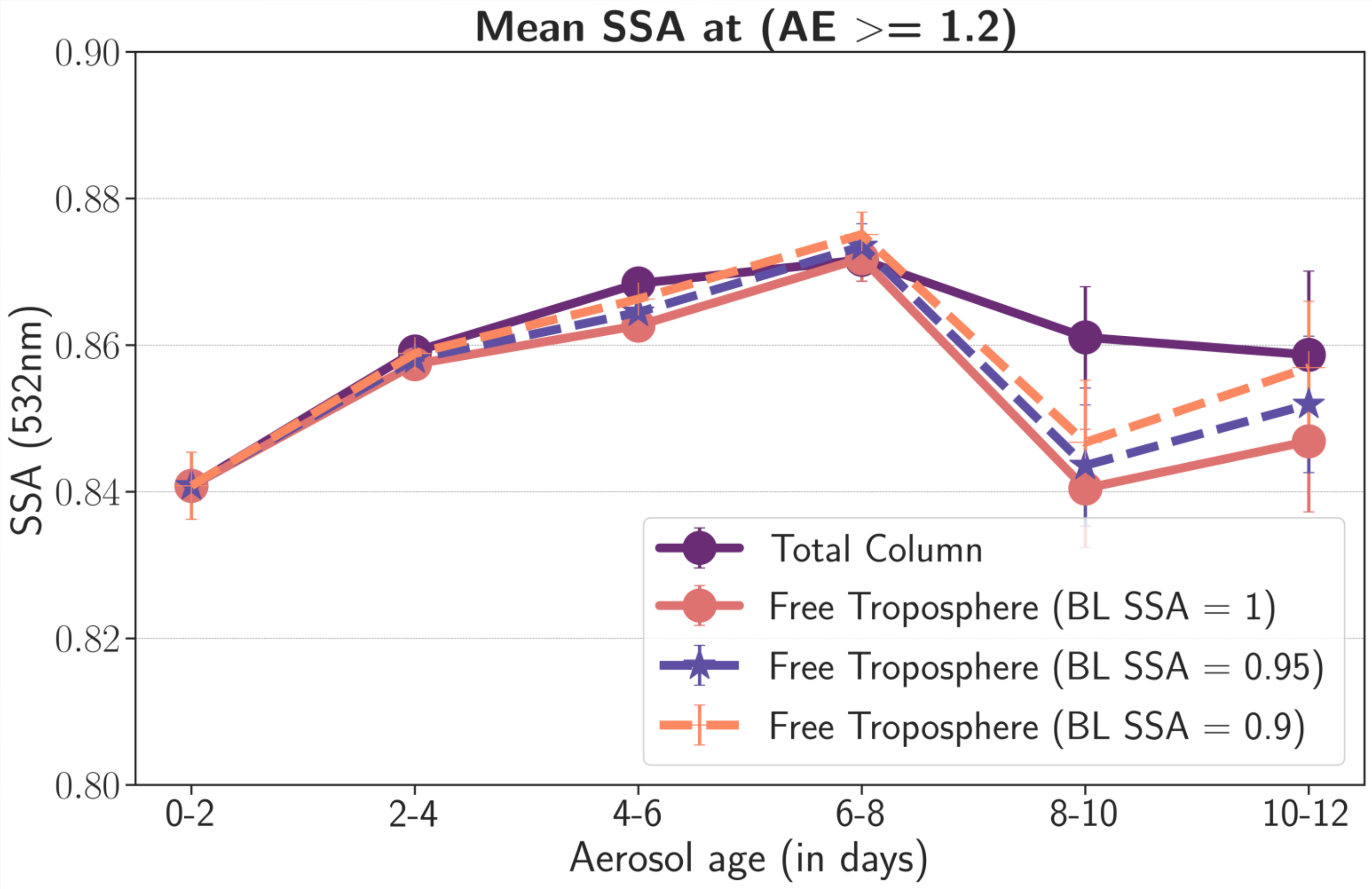
Supplementary – Sensitivity Test





Minimal sensitivity of FT SSA evolution to age binning. Overall, FT SSA decreases after 8 days meaning BBA become more absorbing after 10-12 days since emission.

Supplementary – Sensitivity Test



FT SSA evolution is sensitive to BL SSA values. BL SSA values that shows more absorption in the BL causes FT SSA overestimation.