Exploring the Evolution of Light-Absorption Properties of Biomass Burning Emissions in the Southeast Atlantic Region

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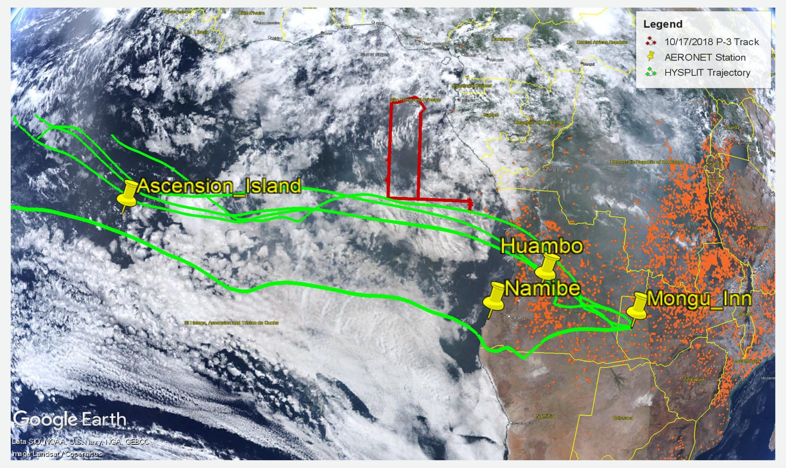
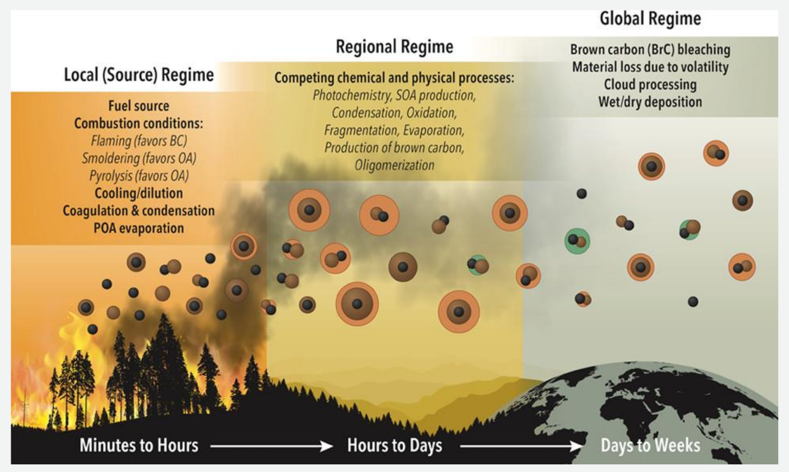
Background

- Southern Africa contributes up to 35% of global Biomass Burning (BB) emissions[1] which are transported over the Southeast Atlantic (SEA) ocean annually between June and October.
- These emissions are highly absorbing, with single scattering albedo (SSA) values between 0.7 and 0.9 from observations[2, 3].
- Over the ocean, they get entrained into the stratocumulus cloud layer due to large-scale subsidence.
- During transport, properties of BB aerosols (BBA) change due to atmospheric processing[4,5].





Knowledge Gaps

- The SEA region exhibits large differences in model estimates of aerosol-induced climate forcing[6,7].
- Improved representation of BBA properties in models, which is limited by complexities in the physical and chemical processes[6], is essential to accurately quantify their forcing.

Research Questions

Our goal here is to examine how BBA from continental Africa changes during transport in the SEA region using measurements from the NASA ORACLES campaign.

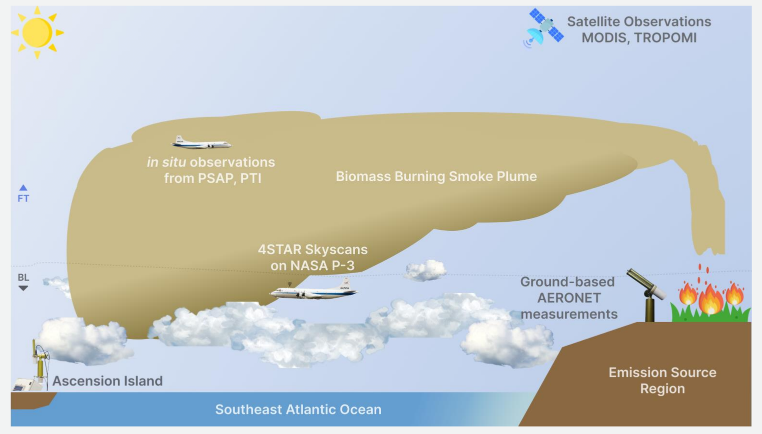
R1. What changes in BBA absorption, using SSA, can be identified across the SEA region using remote sensing observations?

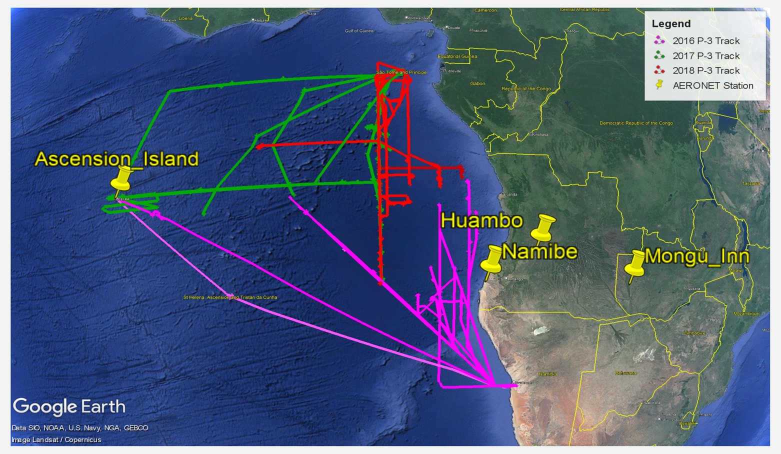
R2. To what extent does WRF-CAM5 model accurately represent SSA in the SEA?

Methodology

Data and Collocation

- The NASA ORACLES campaign conducted over 350 flight hours between 2016 – 2018 in the SEA, measuring aerosol properties aboard the P-3 aircraft[8].
- We utilized retrievals of AOD and SSA from ground based AERONET at 4 stations (3 in the BB source region, 1 over the ocean) and airborne retrievals from 4STAR.





- Adapted outputs from two models: WRF-AAM and WRF-CAM5 to spatially and temporally match with observations.
- Investigated ΔSSA of BBA with aerosol age

Aerosol Age Derivation

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

- Aerosol age is the time since emission and is estimated as the extinction-weighted age of CO tracers in WRF-AAM[9].

BBA Evolution Methodology

- Over land, BBA dominate the total column (TC), and are advected by free tropospheric (FT) winds across the SEA.
- Over the ocean, they are entrained into and mix with boundary layer (BL) aerosols, complicating the columnar retrievals.
- To isolate BL contributions to columnar observations, we combined a model-based vertical extinction separation with an extinction Ångstrom exponent (EAE) filter[9].

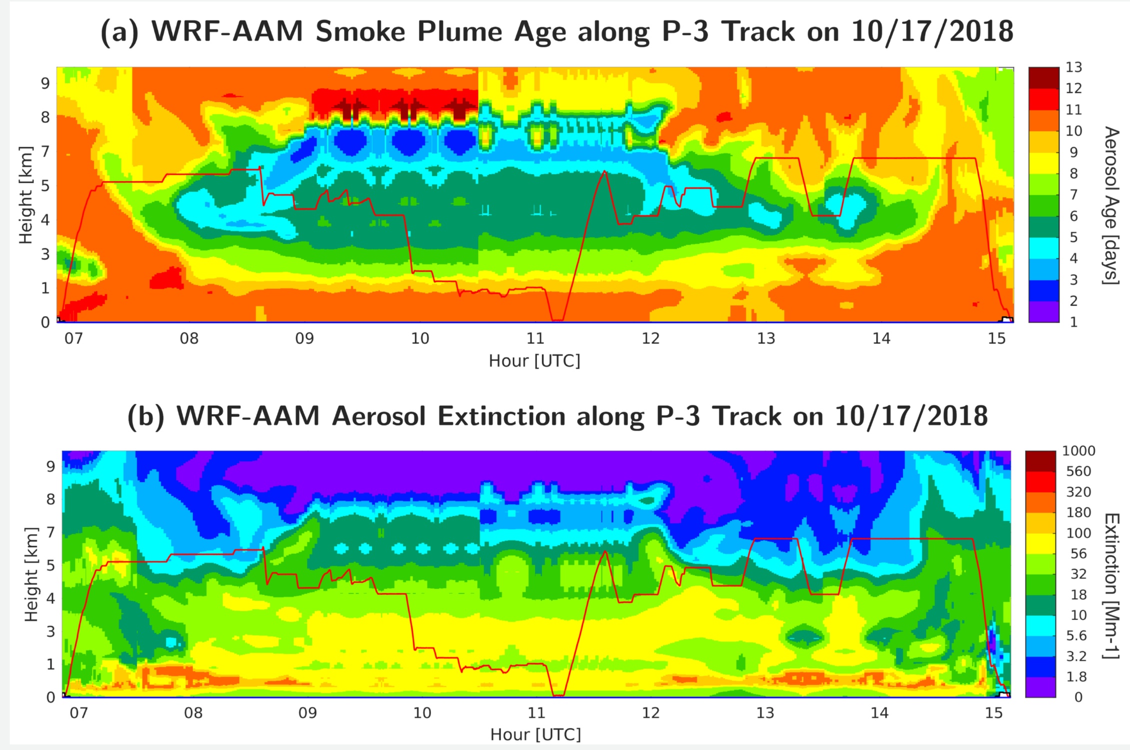
$$R_{m\_BL} = \frac{\int_{s\_elv}^{BLH} \beta_{ext} dz}{\int_{s\_elv}^{toa} \beta_{ext} dz}$$

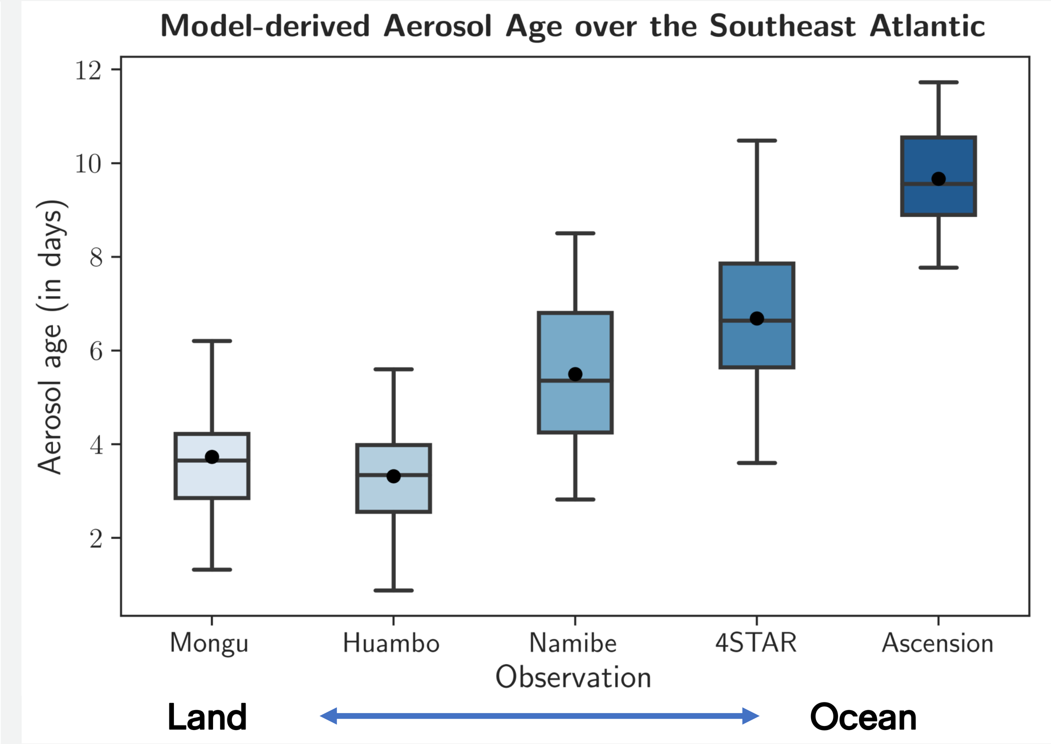
$$R_{m\_FT} = 1 - R_{m\_BL}$$

- Extinction ratio was used to estimate FT properties of BBA.
- EAE filter was applied to further exclude larger particles.

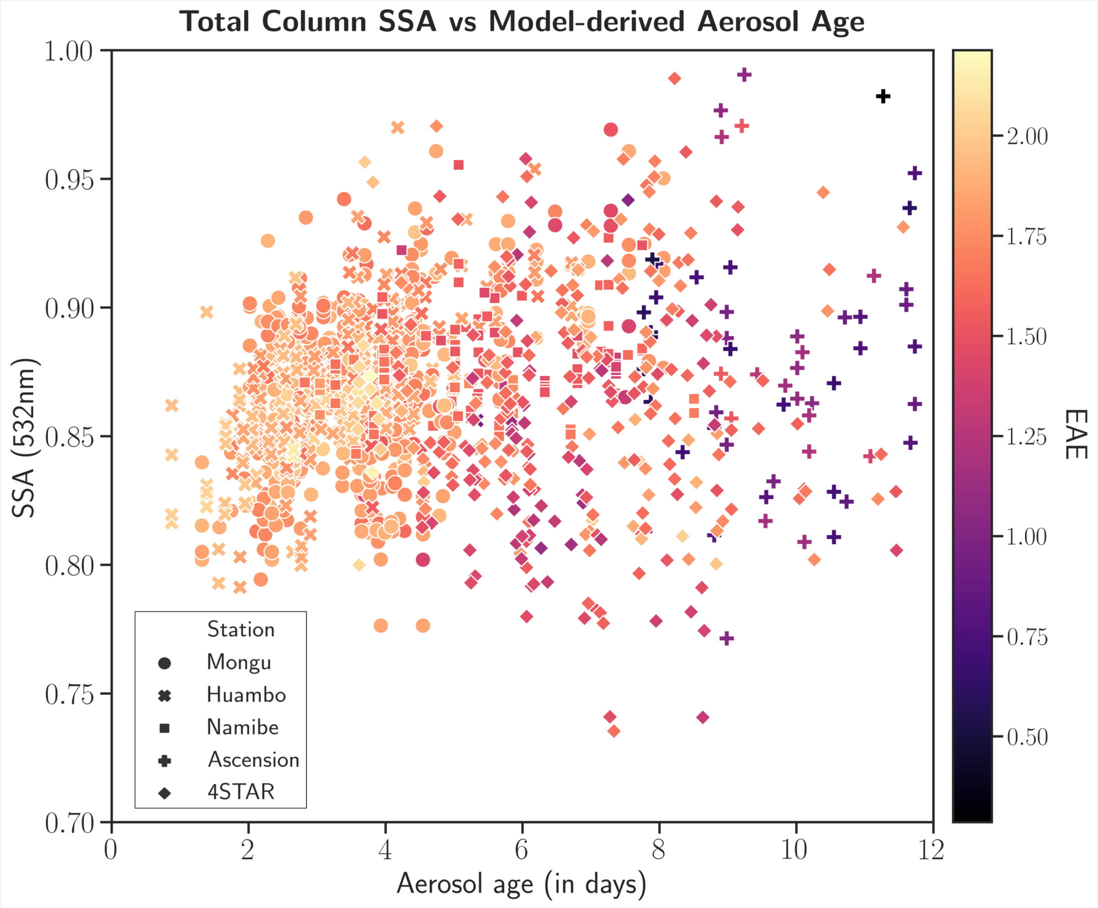
Results

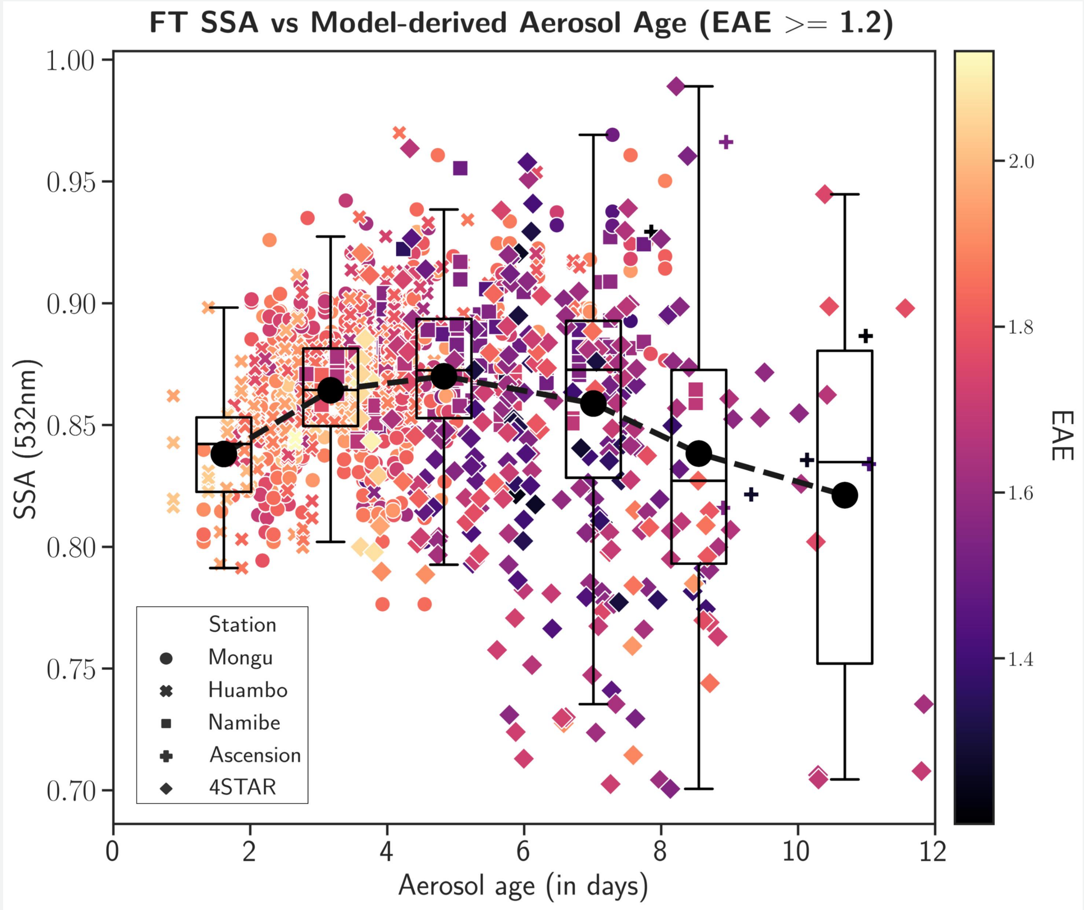
Spatial dependence of model-derived aerosol age

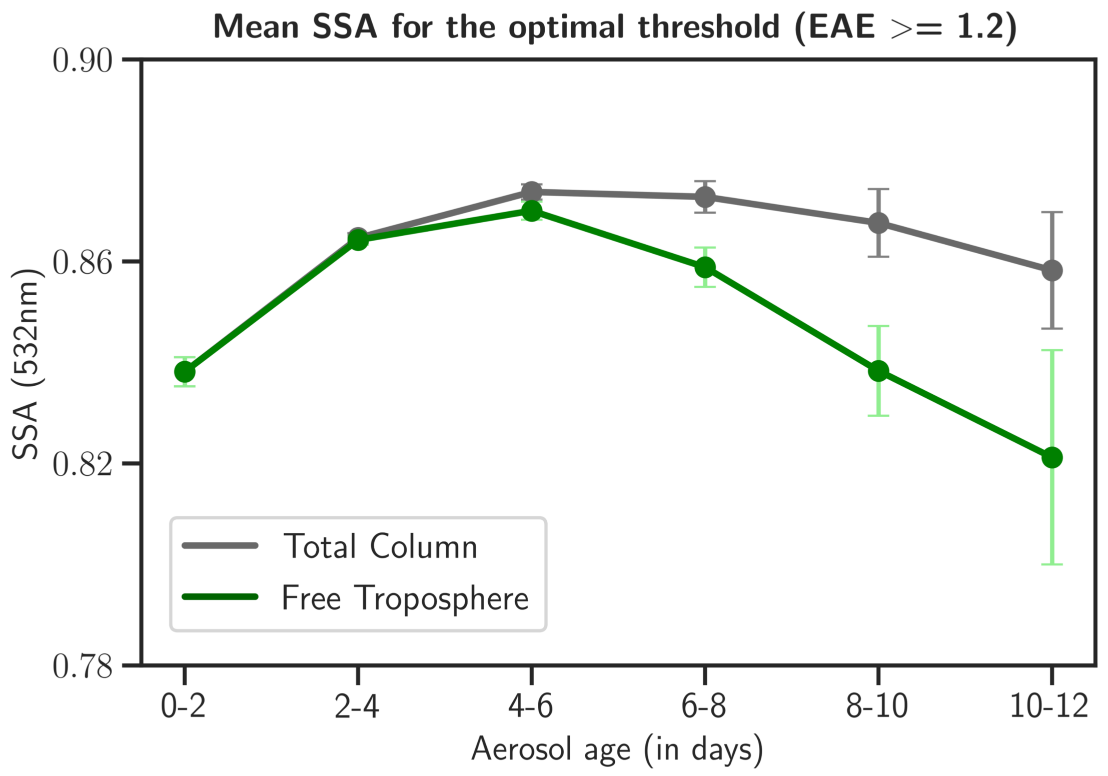




Evolution of BBA SSA with aerosol age within the TC and FT

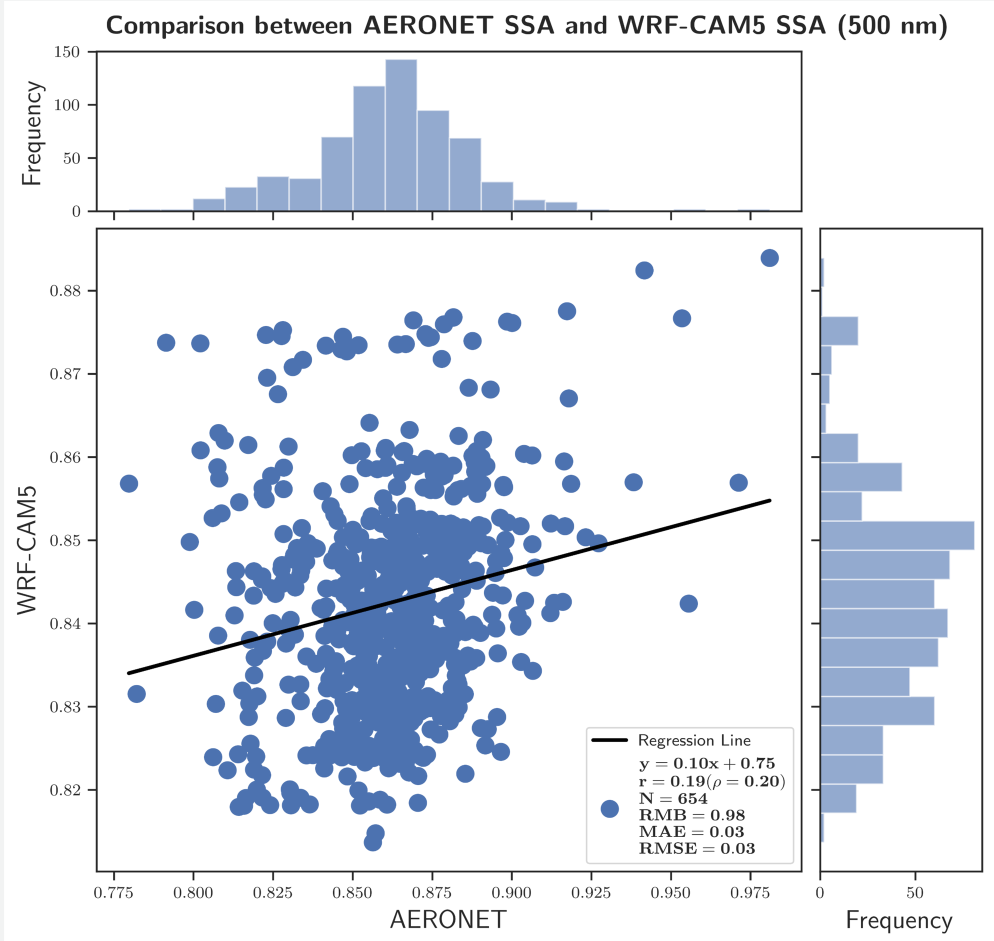


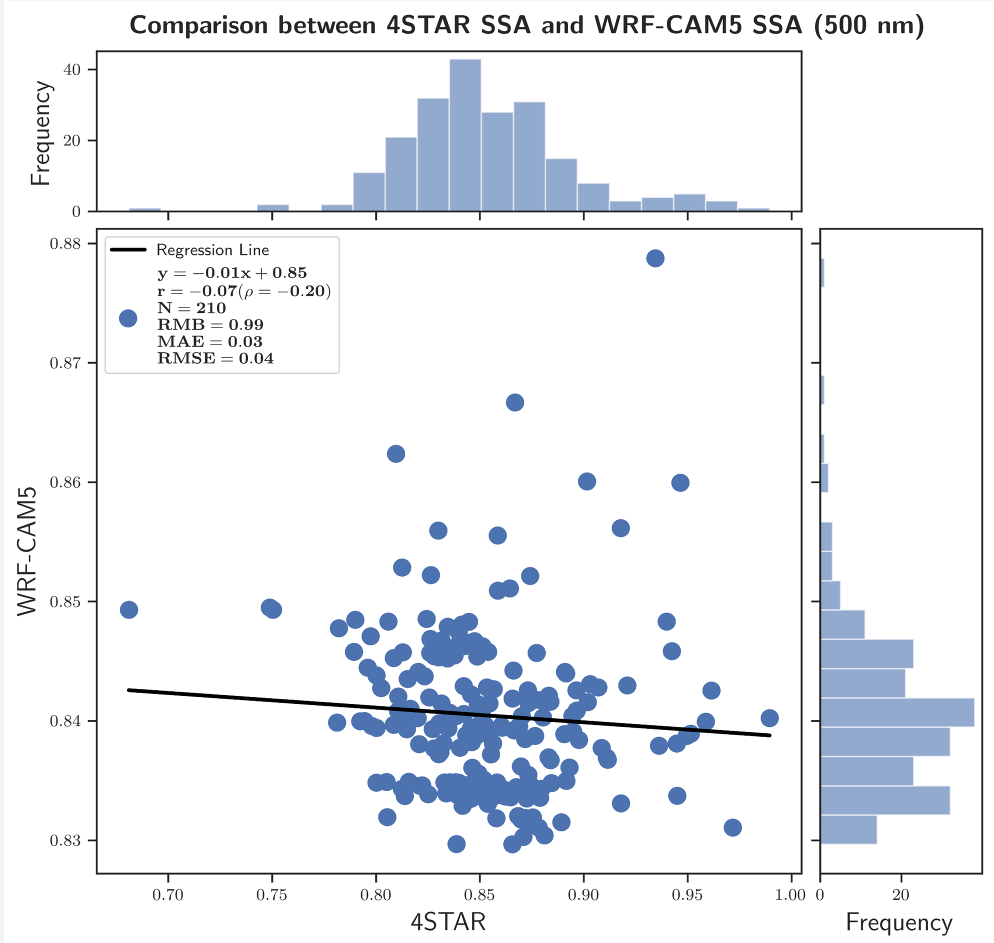




- Youngest aerosols sampled over land with oldest over the ocean. Particles within the mid FT over the ocean are directly transported by the African Easterly Jet.
- In the TC, EAE (> 1.8) shows BBA over land with mean SSA of ~ 0.85 while EAE suggest mixed particles over the ocean.
- Isolating large particles over the ocean reveals distinct changes in SSA, peaking around 4-6 days and decreasing over the ocean.
- Up to 4% ΔSSA of aged BBA in the FT relative to the TC.

Model-Observation Comparison (Early Result)





- WRF-CAM5 SSA correlated weakly against observations: r = 0.19 (AERONET) and -0.07 (4STAR).
- The model underestimates SSA on average and constrain to a narrow range of 0.82 - 0.88, compared to 0.7 - 0.98 in observations.
- The constraint is pronounced over the ocean.

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Key Takeaways, Broad Impact and Future Directions

- Upon emission, southern African BBA are highly absorptive due to abundant refractory black carbon (rBC) from flaming fires.
- The absorptivity decreases during initial transport as organic aerosols form through homogeneous nucleation. Over the ocean, there is enhanced absorptivity with heterogeneous oxidation repartitioning the emissions back to gas phase[9,10].
- We provide evidence of changes in absorptivity of BBA that can strongly perturb the radiative balance in the SEA, changing the magnitude and sign of TOA forcing.
- Extend analysis to the Western US (FIREX-AQ), North Atlantic Ocean (ACTIVATE) and Pacific (CAMP2EX)

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References: