Enhanced Water Vapor in the Dusty Saharan Air Layer: Radiative Impacts

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Abstract

Traditionally, the Saharan Air Layer (SAL) is defined as an elevated dry layer, frequently containing mineral dust transported from North Africa. The presence and characteristics of the SAL have an impact on tropical Atlantic climate and also on tropical cyclone development. However, recent observations from airborne campaigns in the Eastern Tropical Atlantic have found that under heavier dust loadings, water vapor content is increased in the SAL, rather than decreased as expected. This work will present airborne in-situ profile observations of dust loading and water vapor in the SAL from the AER-D field campaign during August 2015 in the tropical East Atlantic. The radiative impact in the shortwave and longwave spectra of the enhanced water vapor in the SAL will quantified and compared to that from mineral dust in the SAL. Trends in SAL water vapor over recent decades from satellite observations will be presented to assess the representativity of the aircraft data.

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Introduction

Traditionally the Saharan Air Layer (SAL) is considered to be a 'dry, dusty, elevated' layer. However, recent aircraft observations suggest enhanced, rather than reduced moisture, under very heavy dust conditions. Here we present these aircraft observations and asses their radiative impact.

Background

The SAL is typically considered 'dry and dusty,' e.g. Dunion & Velden (2004), Carlson & Benjamin (1980)

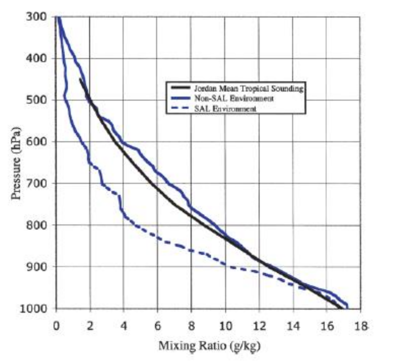

Figure 1. Jordan mean tropical sounding, compared to typical SAL and non-SAL soundings of WV (Dunion & Velden, 2004)

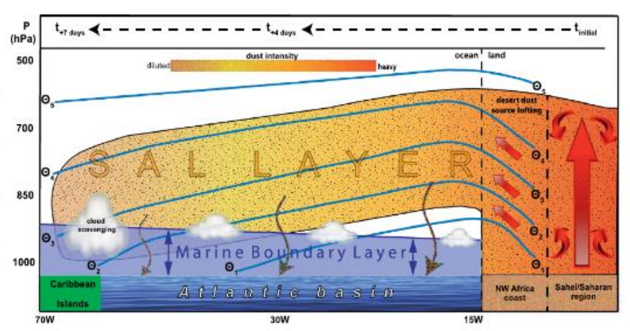

Figure 2. Schematic of the SAL from Kuciauskas et al (2018)

Aircraft Observations

- Recently, airborne observations were made over the Eastern Tropical Atlantic in August 2015 during the AER-D (AERosols in ICE-D) experiment with the FAAM BAe146
- Observations of aerosol properties and meteorological parameters were taken during 29 profiles (Ryder et al., 2018, ACP)

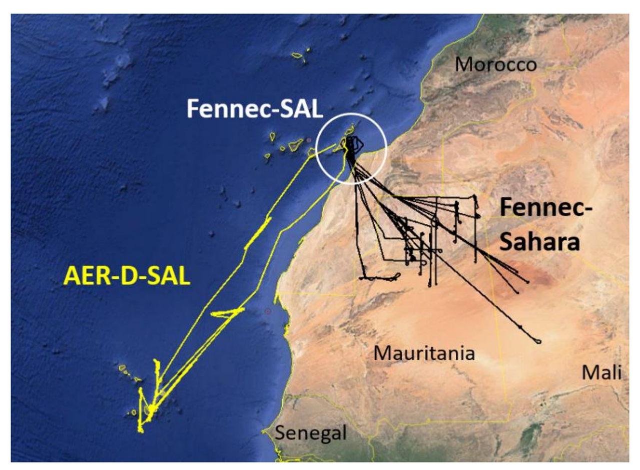

Figure 4. Locations of AER-D airborne fieldwork (August 2015), also showing Fennec-Sahara and Fennec-SAL (figure from Ryder et al., 2019, ACP)

Figure 3. FAAM BAe146 research aircraft

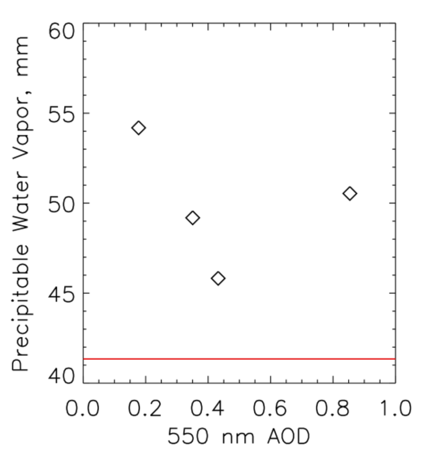

Figure 5. AOD of each category, vs precipitable water vapour. Initially PWV decreases with AOD as the SAL strengthens. However, for very dusty cases, WV increases.

Water Vapour and Dust Observations

- Measurements show:
  - Higher moisture content compared to the tropical standard atmosphere
  - AOD<0.6: decreased column water vapour (WV) with increasing AOD
  - AOD>0.6 increased column WV and more WV at higher altitudes

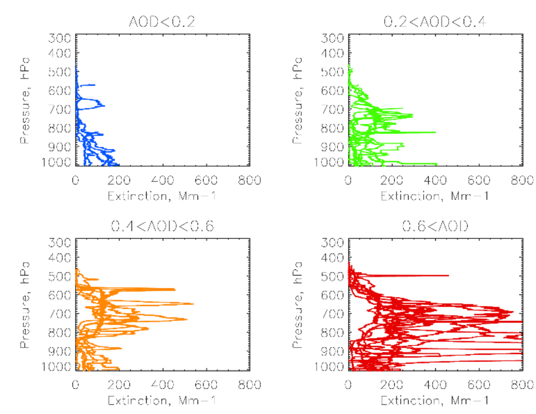

Figure 6. Aircraft measurements of extinction, categorized by AOD. Extinction measured by in-cabin nepheometer (scattering) and PSAP (absorption), represents d<2.5µm

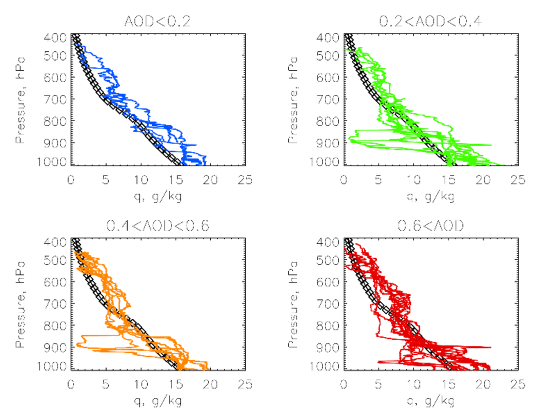

Figure 7. Aircraft measurements of water vapour mixing ratio, categorized by aerosol optical depth (AOD)

Radiative Transfer Calculations

- Profiles are grouped by AOD and medians for each category used as input in a radiative transfer code (SOCRATES)
- Overhead sun assumed in SW
- Dust SSA=0.92 at 550nm, LW MEC ~0.3g/m2 & SSA~0.6 at 10 µm, spherical particles
- Scattering and absorption by dust in SW and LW represented

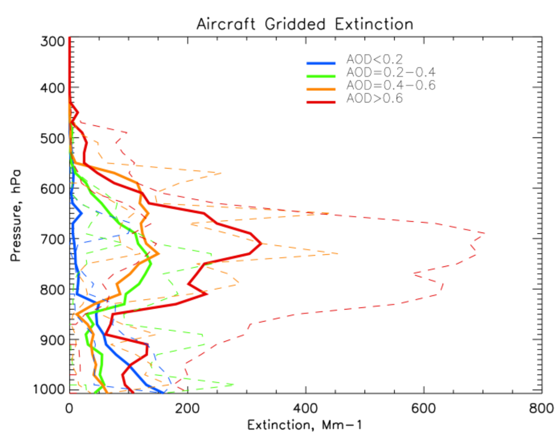

Figure 8. Aircraft extinction profiles for each AOD category, vertically regridded for SOCRATES. Bold lines show median, dashed show $10^{th}/90^{th}$ percentiles.

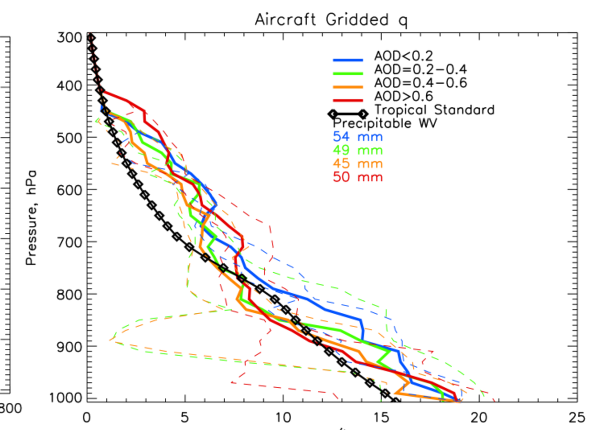

Figure 9. Aircraft measured water vapour mixing ratios for each AOD category. Bold lines show median, dashed show $10^{th}/90^{th}$ percentiles. Black line/diamonds show tropical standard atmosphere

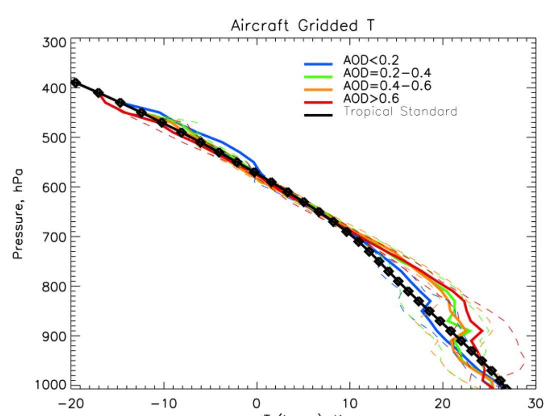

Figure 10. Aircraft measured temperature profiles for each AOD category. Bold lines show median, dashed show $10^{th}/90^{th}$ percentiles.

Experimental Setup

- 4 experiments, one for each AOD category
- Control: tropical standard WV profile, no dust
- Replaced with aircraft observations for dust/WV/dust+WV experiments
- Results show radiative impact of aircraft-observed dust or WV relative to a non-dusty tropical standard atmosphere, as dustiness and structure of SAL change

AOD	Control	Dust	Water Vapour	Dust+WV
AOD<0.2	No dust q_{trop_std} $T_{\tau<0.2}$	$Dust_{\tau<0.2}$ q_{trop_std} $T_{\tau<0.2}$	No dust $q_{\tau<0.2}$ $T_{\tau<0.2}$	$Dust_{\tau<0.2}$ $q_{\tau<0.2}$ $T_{\tau<0.2}$
AOD=0.2-0.4	No dust q_{trop_std} $T_{\tau=0.2\text{-}0.4}$	$Dust_{\tau=0.2\text{-}0.4}$ q_{trop_std} $T_{\tau=0.2\text{-}0.4}$	No dust $q_{\tau=0.2\text{-}0.4}$ $T_{\tau=0.2\text{-}0.4}$	$Dust_{\tau=0.2\text{-}0.4}$ $q_{\tau=0.2\text{-}0.4}$ $T_{\tau=0.2\text{-}0.4}$
AOD=0.4-0.6	No dust q_{trop_std} $T_{\tau=0.4\text{-}0.6}$	$Dust_{\tau=0.4\text{-}0.6}$ q_{trop_std} $T_{\tau=0.4\text{-}0.6}$	No dust $q_{\tau=0.4\text{-}0.6}$ $T_{\tau=0.4\text{-}0.6}$	$Dust_{\tau=0.4\text{-}0.6}$ $q_{\tau=0.4\text{-}0.6}$ $T_{\tau=0.4\text{-}0.6}$
AOD>0.6	No dust q_{trop_std} $T_{\tau>0.6}$	$Dust_{\tau>0.6}$ q_{trop_std} $T_{\tau>0.6}$	No dust $q_{\tau>0.6}$ $T_{\tau>0.6}$	$Dust_{\tau>0.6}$ $q_{\tau>0.6}$ $T_{\tau>0.6}$

Table 1. Radiative Transfer calculation experiments

Results: Shortwave

- Radiative effect of WV is small
- Dust dominates DRE compared to WV, for atmospheric radiative divergence, DRE at surface, and DRE at TOA
- For AOD>0.6 profiles:
  - Dust DRE = $-39Wm^{-2}$ at TOA, $-112Wm^{-2}$ at SFC
  - WV DRE = $0.7Wm^{-2}$ at TOA, $-10Wm^{-2}$ at SFC

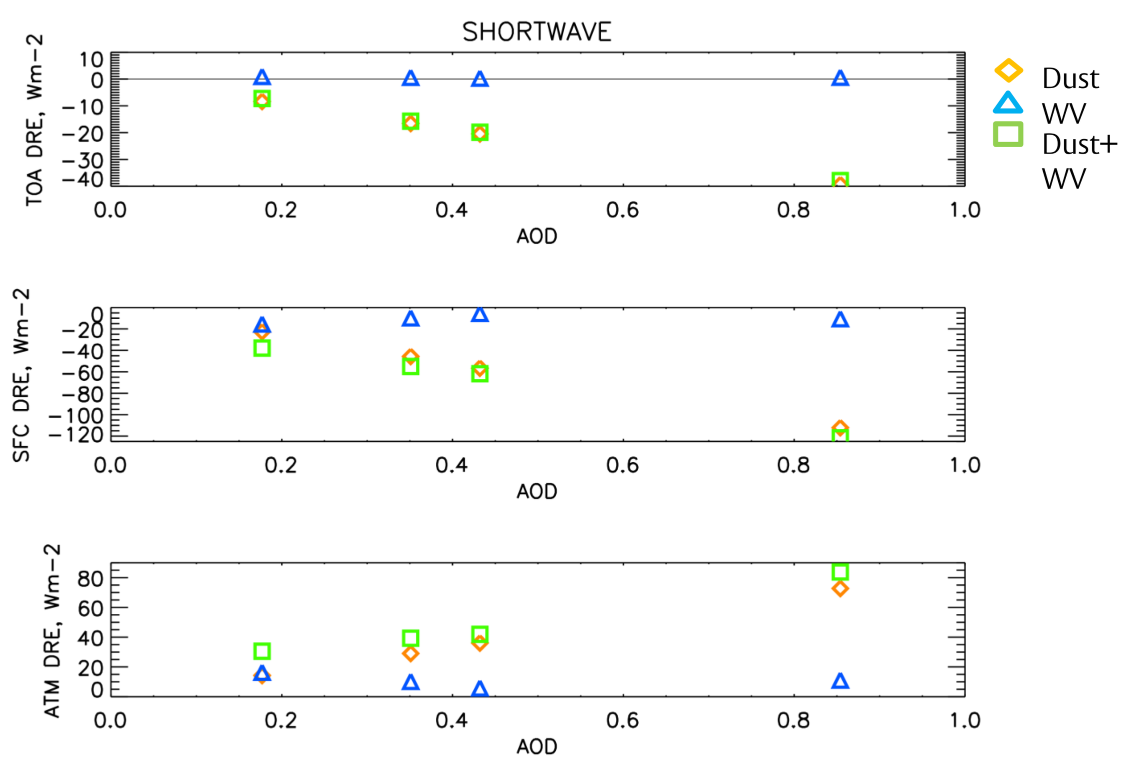

Figure 11. Shorwave Direct Radiative Effect for different AOD categories, due to dust only (orange), water vapour only (blue) and dust+water vapour (green), relative to the control (tropical standard WV, no dust).

Results: Longwave

- Dust and DRE magnitudes comparable when AOD>0.4
- As AOD increases from <0.2 to 0.4-0.6 (while PWV decreases):
  - dust DRE_TOA, DRE_SFC and atmospheric divergence transition from being dominated by WV to equally dependent on dust and WV
- For AOD>0.6 profiles (PWV same as AOD=0.2-0.4 case, but WV at higher altitudes):
  - DRE from dust and enhanced water vapour are comparable
  - Enhanced WV causes slight atmospheric warming

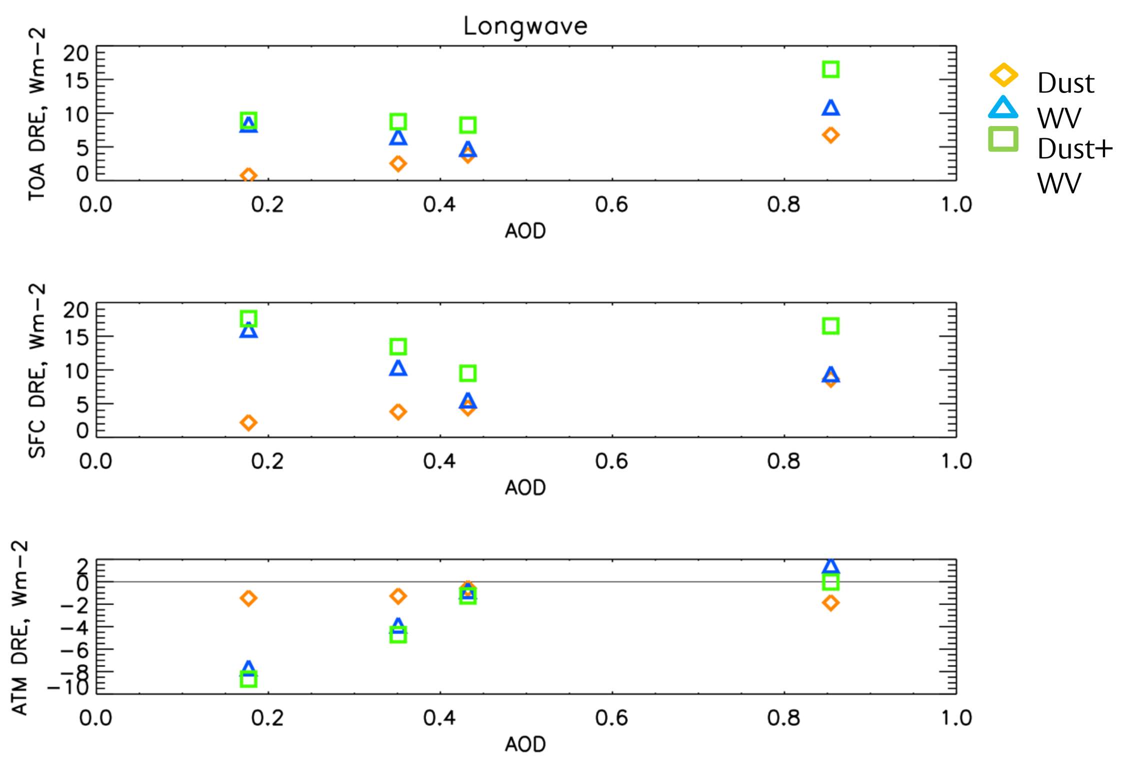

Figure 12. Longwave Direct Radiative Effect for different AOD categories, due to dust only (orange), water vapour only (blue) and dust+water vapour (green), relative to the control (tropical standard WV, no dust).

Conclusion

- For AOD<0.6, water vapour content decreases with increasing dustiness. However, very dusty cases (AOD>0.6) displayed enhanced water vapour
- At the TOA, the LW DRE_WV ($11Wm^{-2}$) is larger than LW DRE_dust: ($7Wm^{-2}$) for AODs.>0.6
- At the SFC, LW DRE for dust and WV are about the same ($9Wm^{-2}$) for AODs>0.6
- In the SW, the DRE is dominated by dust, with much larger magnitudes than the LW (for overhead sun; diurnal values will be lower)

Enhanced WV in the dusty SAL significantly perturbs the radiation balance

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