Importance of Dust Radiative Feedback on the Trans-Atlantic Evolution of the Saharan Air Layer

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Introduction: The Saharan Air Layer (SAL; Figure 1) is a hot, dry, dusty air mass that forms over North Africa and moves westward over the Atlantic [1]. Models estimate that approximately 170 Tg yr^{-1} of Saharan dust are transported across and deposited over the Atlantic basin [2]. Additionally, dust produces a wide range of earth system and societal impacts, including human health [3], hydrometeorological changes via by cloud microphysics [4], and thermodynamic changes via direct radiative interactions with incoming solar radiation. However, the effect of the latter on synoptic SAL evolution is not well understood.

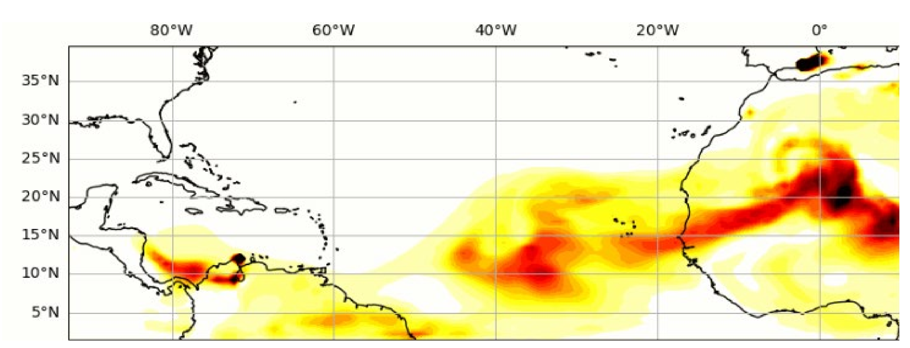

Figure 1: Example of long-range Saharan dust transport across the north Atlantic on June 8, 2022.

Research question: How does the direct, radiative aerosol effect (Figure 2) influence trans-Atlantic SAL trajectories?

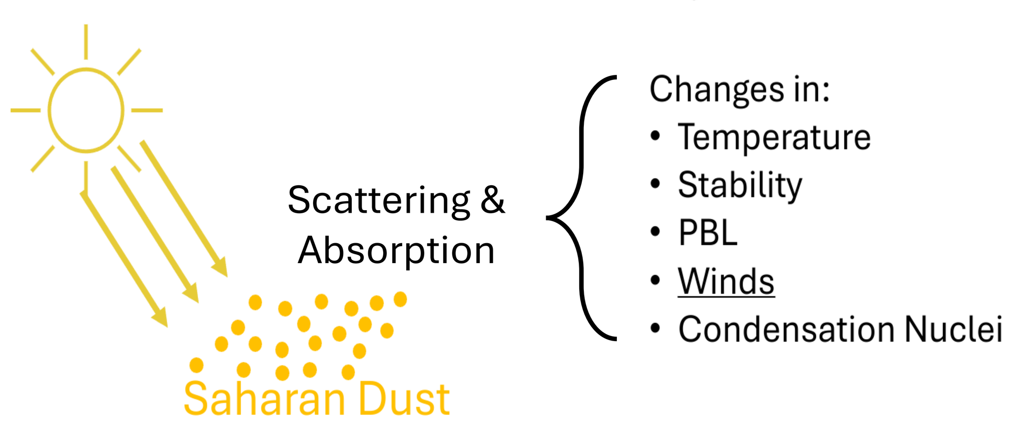

Figure 2. Diagram of radiation, Saharan Dust, and feedback effects

Methods: Twenty-five dust events (Table 1) were selected from a recently developed SAL database [5] and simulated with WRF-Chem to evaluate SAL trajectories with and without aerosol radiative (AER-RAD) interactions.

Table 1. Example of the 25 selected dates from [5].

Start simulation	Start event	End event	End simulation	DUCMASS (g/m^2)
1984-07-06	1984-07-16	—	1984-07-18	0.71
2000-05-20	2000-05-30	2000-05-31	2000-06-02	0.92
2001-06-10	2001-06-20	2001-06-21	2001-06-23	0.63
2002-06-20	2002-06-30	—	2002-07-02	0.64
2003-06-15	2003-06-25	—	2003-06-27	0.75

For each SAL, particle trajectories were generated from the WRF-Chem output using HYSPLIT for both the AER-RAD ON and OFF cases, yielding ~2000 paths (50 simulations x 36 sources; Fig. 3).

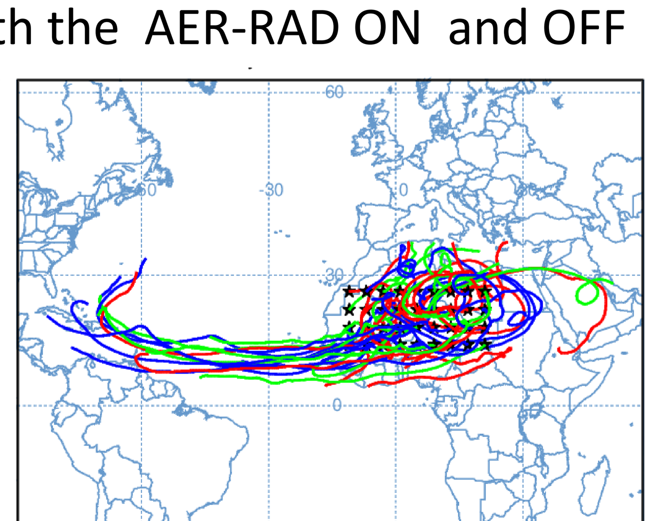

Figure 3. The thirty-six HYSPLIT trajectories generated from a WRF-Chem SAL hindcast from May 22, 2000.

Radiative interactions between solar energy and dust may promote faster and more direct transport across the Atlantic.

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Results: Changes to SAL evolution were measured by comparing the speed, distance, and curvature of all HYSPLIT trajectories as a function of AER-RAD interactions. There were no significant differences between AER-RAD ON and OFF (Figure 4).

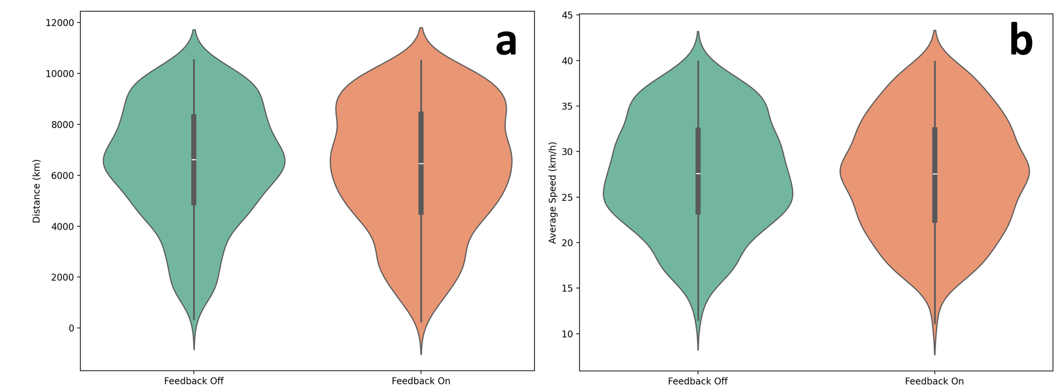

Figure 4. Violin plots comparing AER-RAD OFF and ON simulations for (a) migration distance and (b) average speed.

However, when the top decile of speed, distance, and curvature was evaluated, the fastest and least curved trajectories were disproportionately associated with the AER-RAD ON group (Table 2).

Table 2. Frequency table for Chi-square analysis of trajectory distance, speed, and curvature. Top 10% and bottom 90% are shown for AER-RAD ON and OFF. ***Bold*** indicates Chi-square $p < 0.05$.

	Top 10%		Bottom 90%		
Metric	OFF	ON	OFF	ON	Chi-square
Distance	86	105	886	831	0.09
Speed	83	108	889	828	***0.03***
Curvature	112	79	860	857	***0.03***

Discussion and Conclusions: Previous studies report mixed responses of Saharan dust radiative feedback on atmospheric circulation, with some indicating a weakening of transport [6], while others suggest a strengthening of the flow [7]. In this study, simulations with radiative interactions enabled (AER-RAD ON) exhibit statistically significant changes in SAL transport among the top decile. Analysis of the upper percentiles of SAL parcel trajectories, based on speed and curvature, indicates that active dust radiative feedback is associated with faster and more direct transport, characterized by higher speeds and reduced curvature across the Atlantic. Future work will examine the evolution of dust loading and its role in modulating these differences between AER-RAD ON and OFF experiments.

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