A Mechanism for the AMO: Positive Feedback between SST and Dust Aerosol via Sahel Rainfall

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2012 U.S. AMOC PI Meeting
Boulder, CO
August 15-17, 2012

Wang, C., S. Dong, A. T. Evan, G. R. Foltz, and S.-K. Lee, 2012: Multidecadal covariability of North Atlantic sea surface temperature, African dust, Sahel rainfall and Atlantic hurricanes. *J. Climate*, 25, 5404-5415.

NOAA
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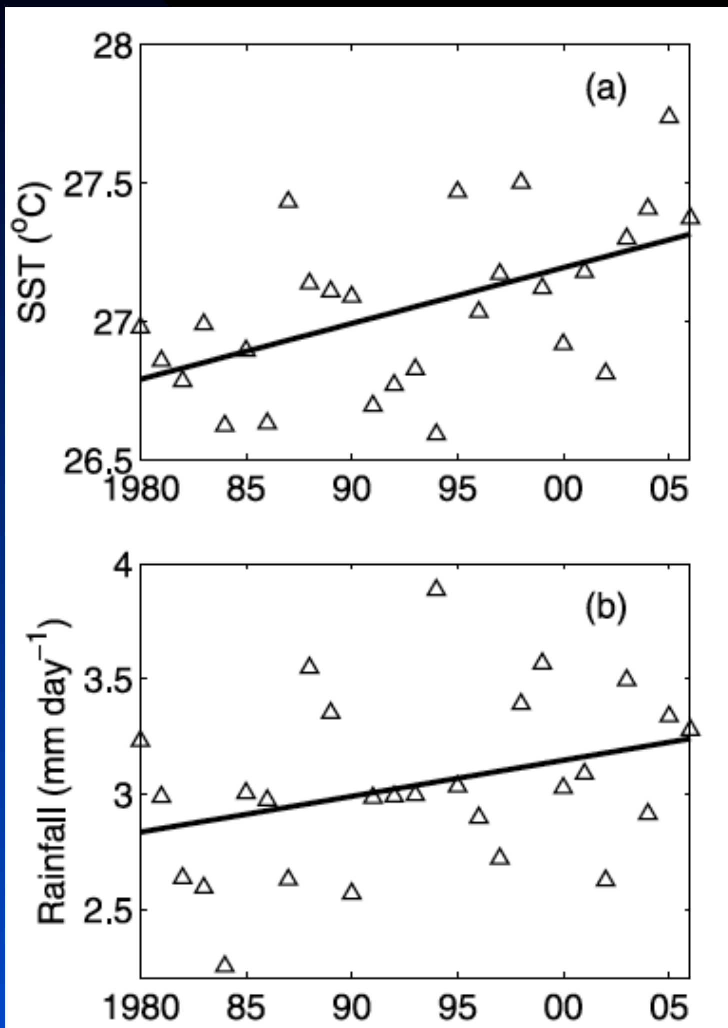
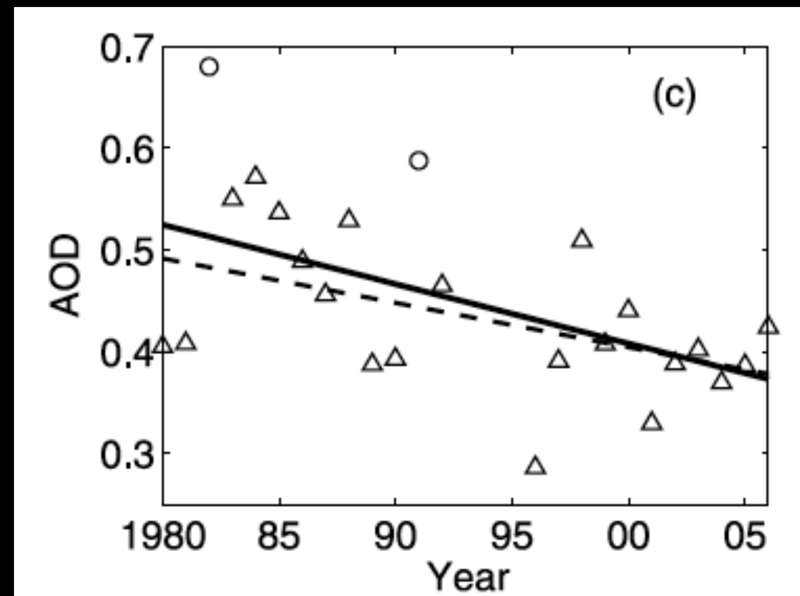
National Oceanic & Atmospheric Administration

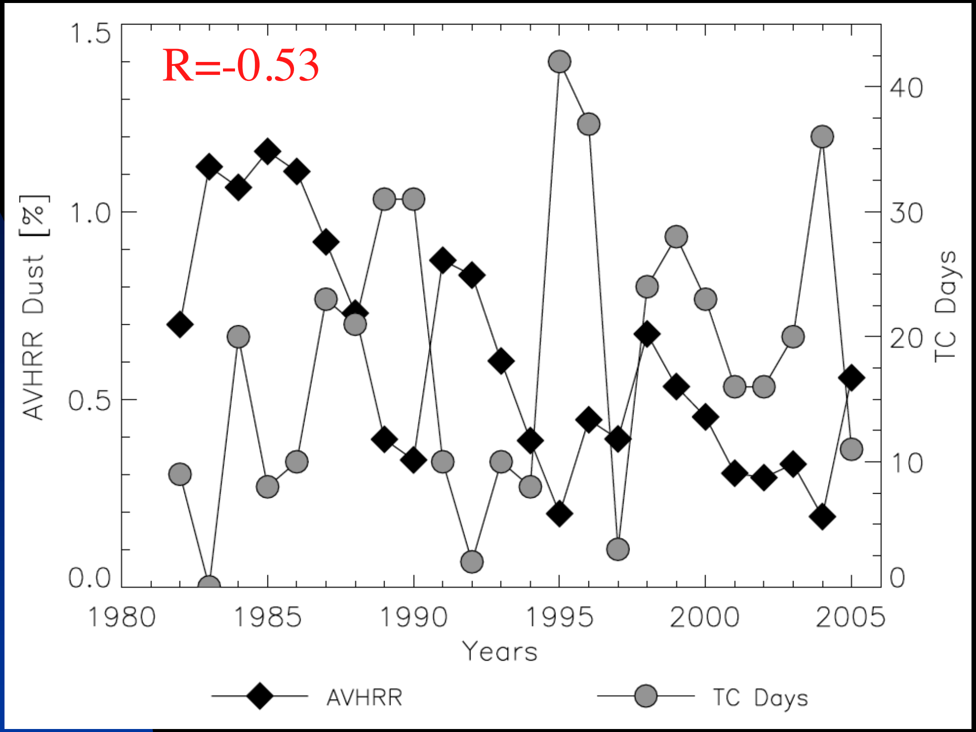
Climate: Previous studies have limited to a short period since the satellite era (1980 onward), precluding the examination on longer timescales.





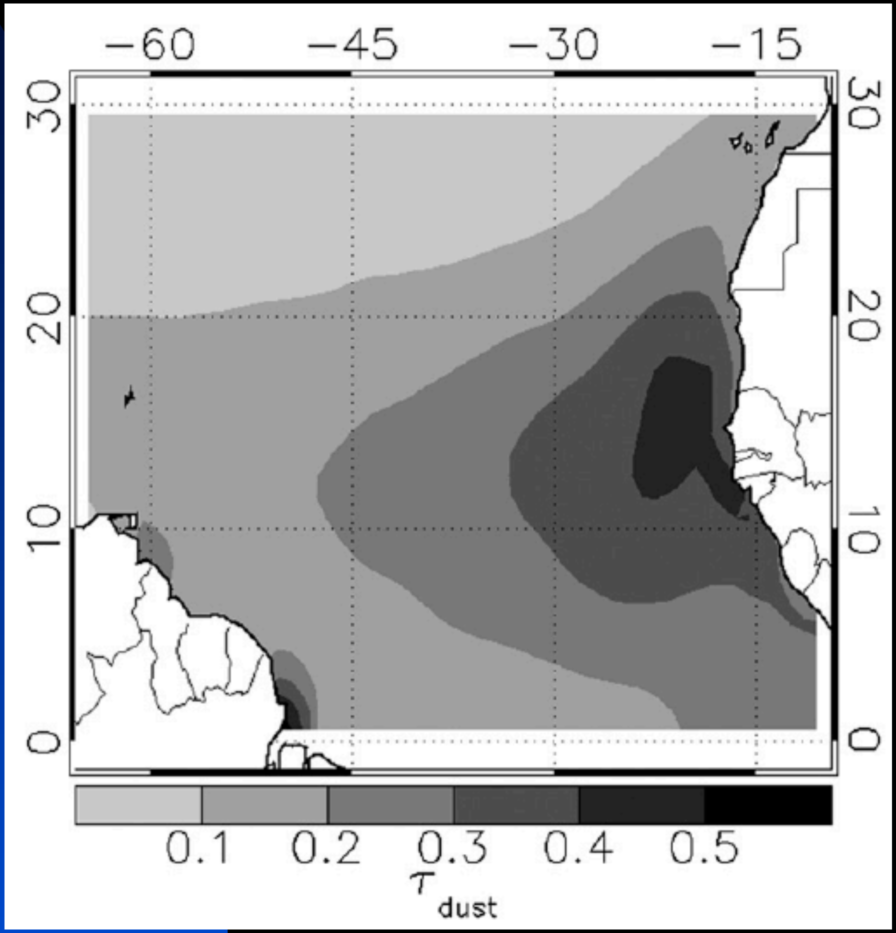
The data from 1980-2006 show trends of Sahel rainfall and dust during the most recent upswing of the AMO (Foltz & McPhaden 2008, *GRL*).

Hurricanes: **Previous studies have limited to a short period since the satellite era (1980 onward), precluding the examination on longer timescales.**



Evan et al. (2006, *GRL*) have demonstrated a negative relation between interannual variations in Atlantic TC days and dust measured by satellite during 1982-2005.

Dust data used in this study: Evan and Mukhopadhyay (2010) extended satellite-retrieved dust optical depth over the TNA from 1955-2008, using modern/historical data and a proxy record (crustal $^{4}H_{e}$ from a Porites coral) for atmospheric dust.

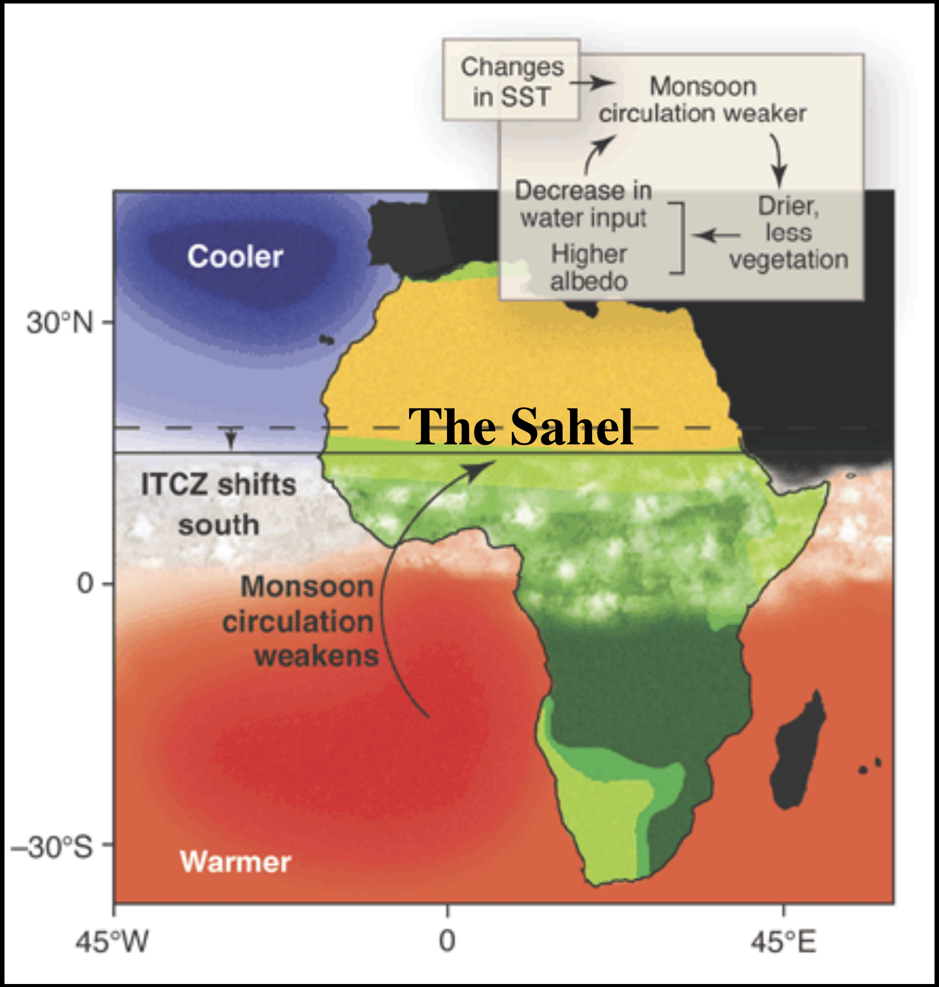


Climatology of dust for the period of 1955-2008

Other Data Sets Used in This Study

- Extended Reconstructed SST (ERSST) version 3.
- NCEP-NCAR reanalysis.
- ERA-40 reanalysis.
- The 20^{th} Century Reanalysis (20CR).
- Wind station data observed in the Western Sahel.
- Global Precipitation Climatology Centre (GPCC).
- Hurricane data based on HURDAT reanalysis.

The Sahel region (10°N-20°N, 20°W-40°E)



The Sahel is a semi-arid tropical region

Sahel rainfall is forced by monsoon circulation associated with SST.

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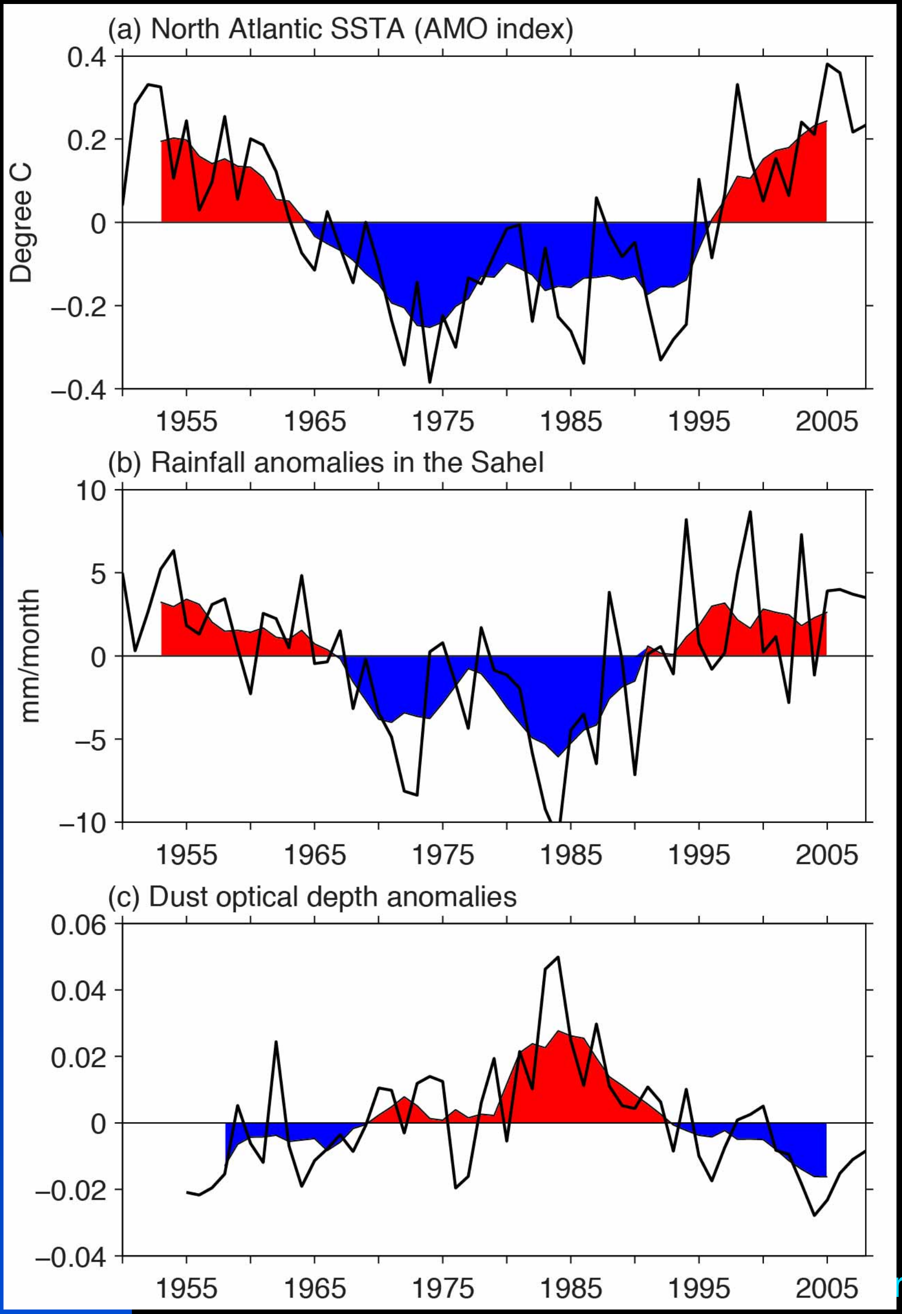
Co-variability of the AMO, dust and Sahel rainfall



AMO

Sahel rainfall

Dust in TNA

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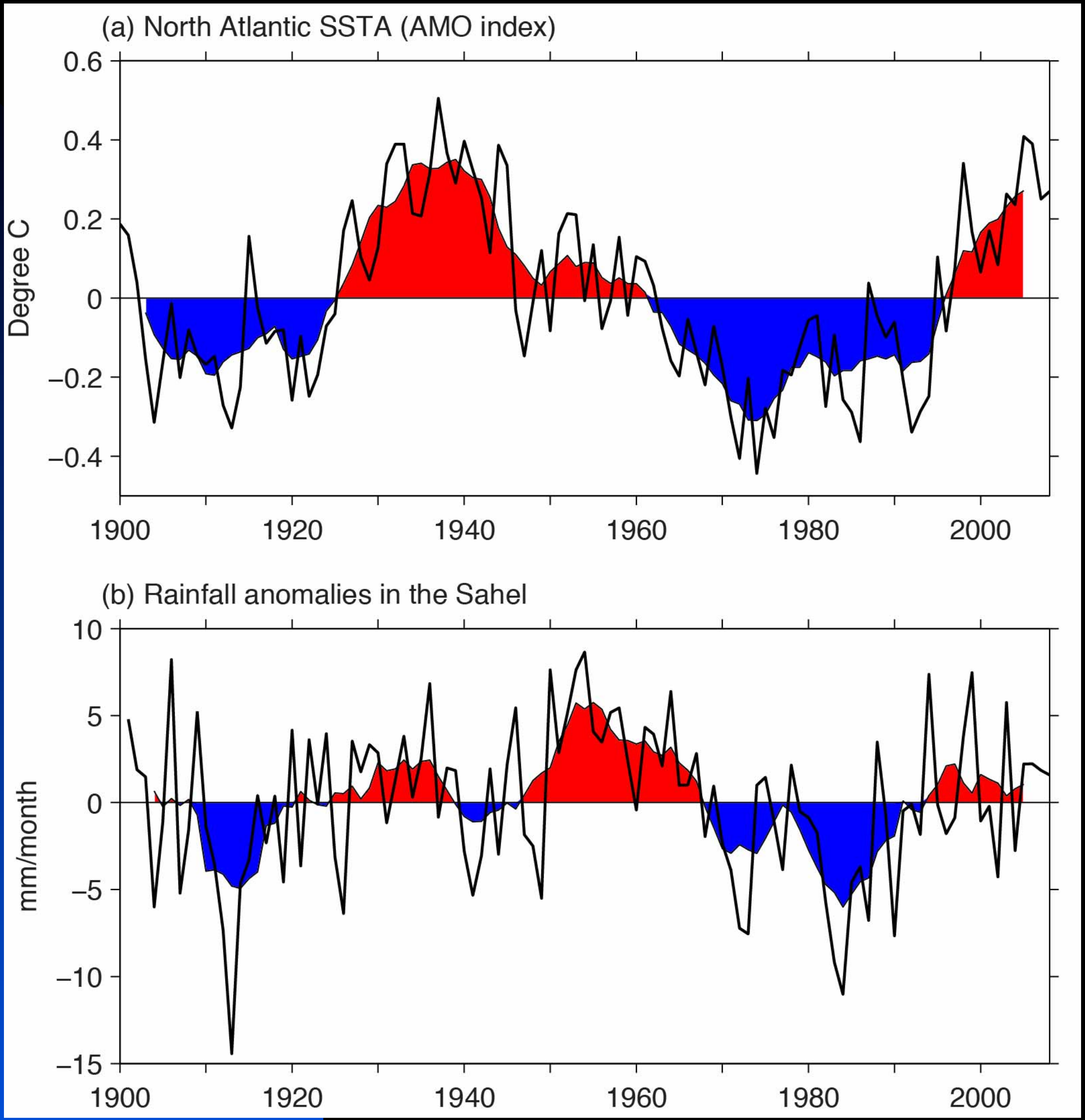
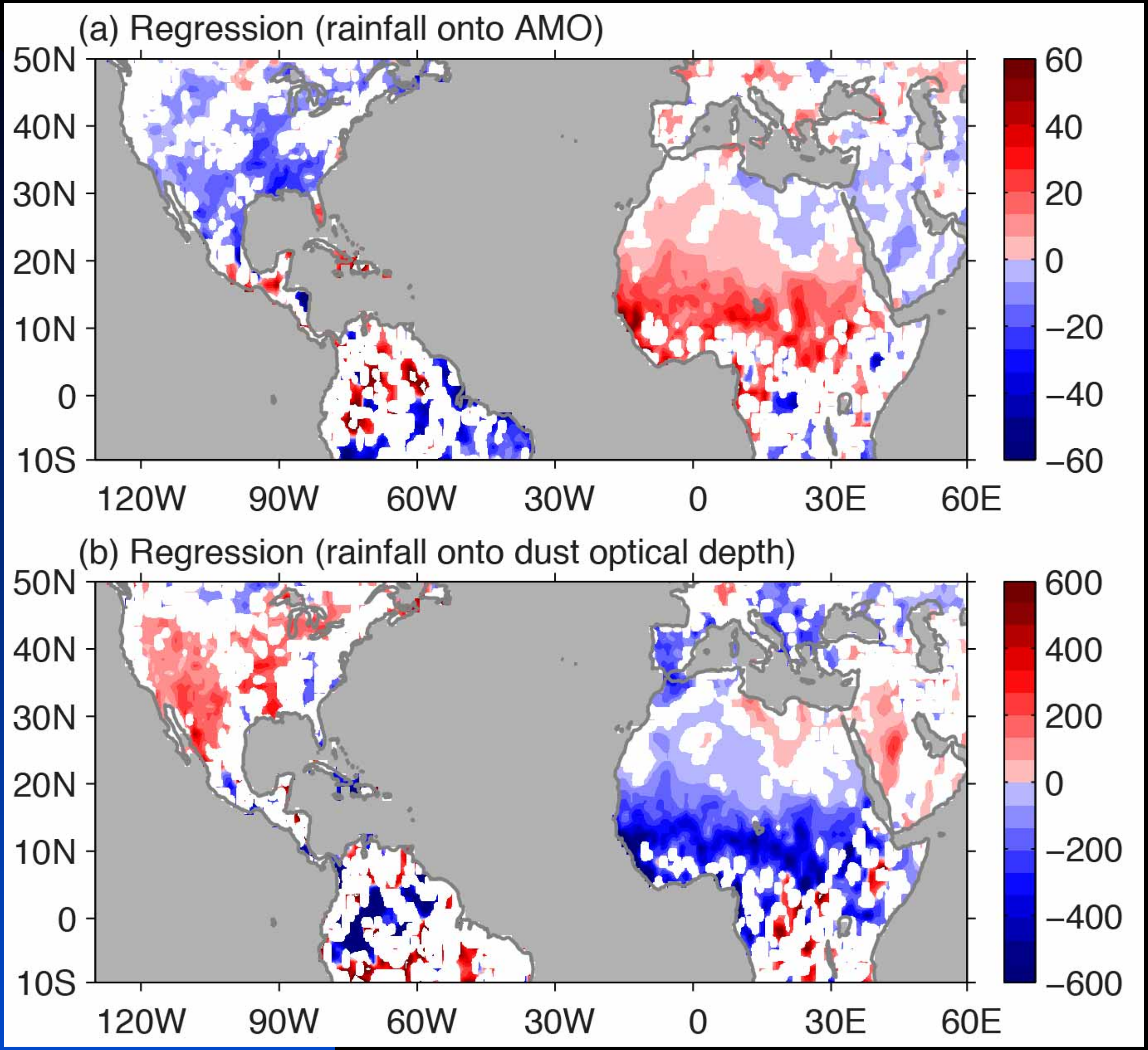
The relationship still holds for the entire 20th century



AMO

Sahel rainfall

The spatial rainfall patterns related to the AMO and dust aerosol in the TNA



Rainfall related to the AMO

Rainfall related to TNA dust

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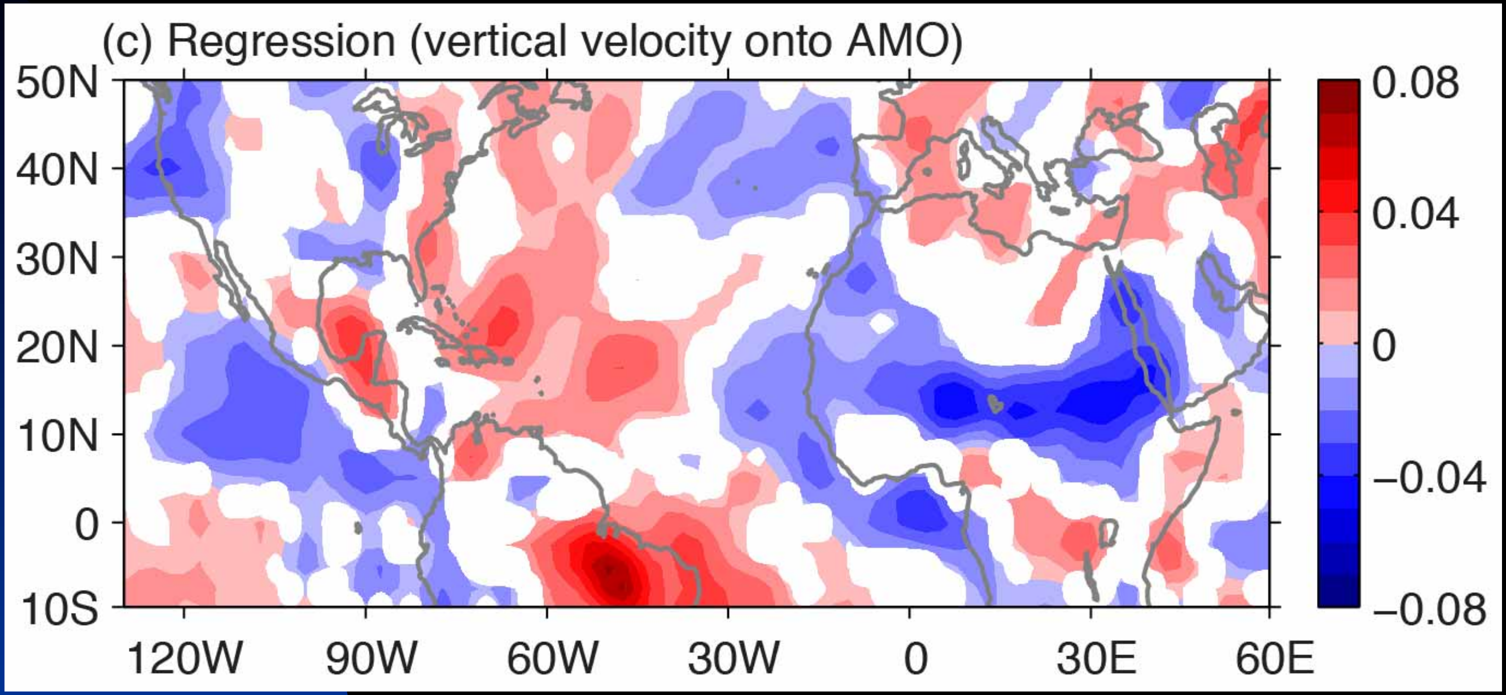
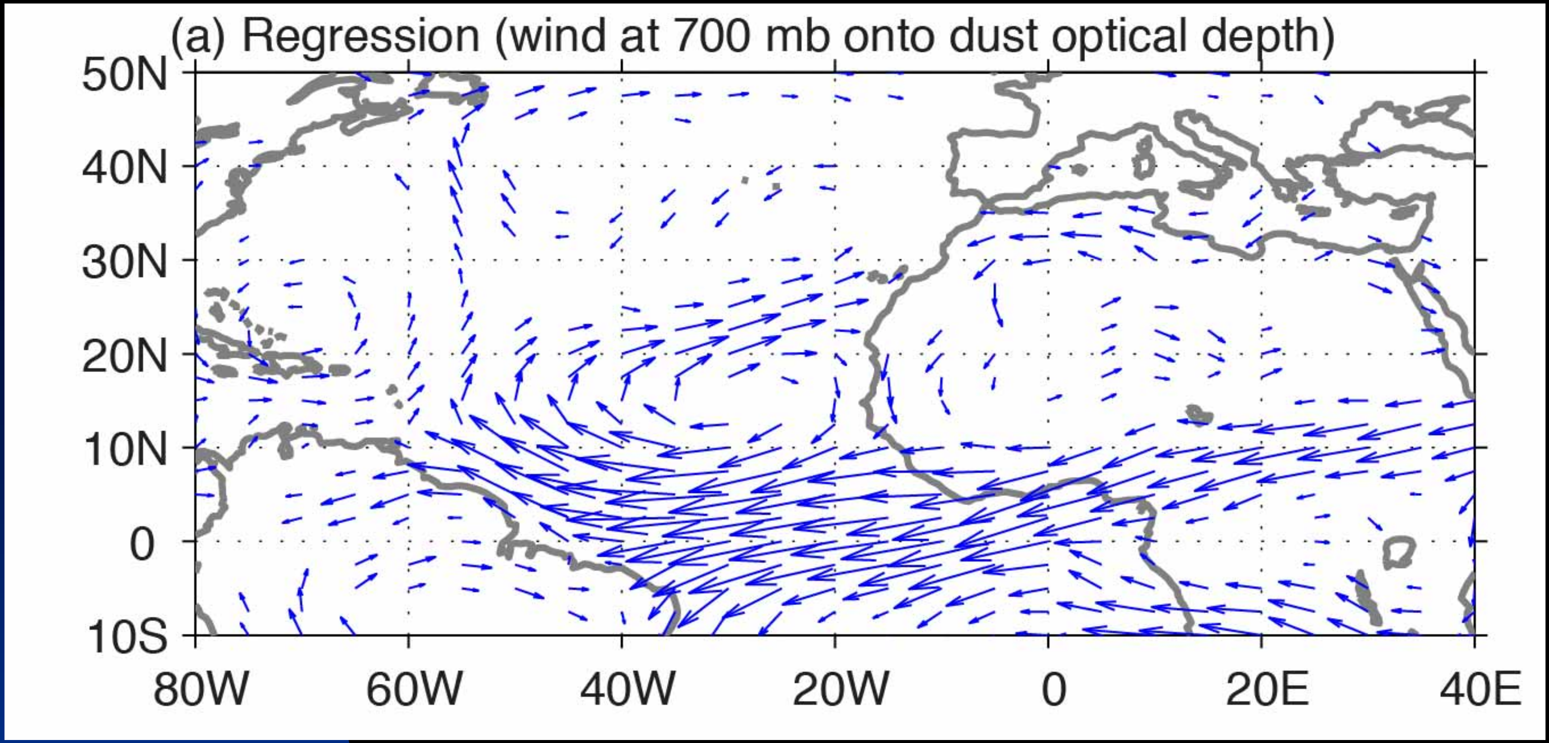
Vertical velocity (at 500-hPa) associated with the AMO



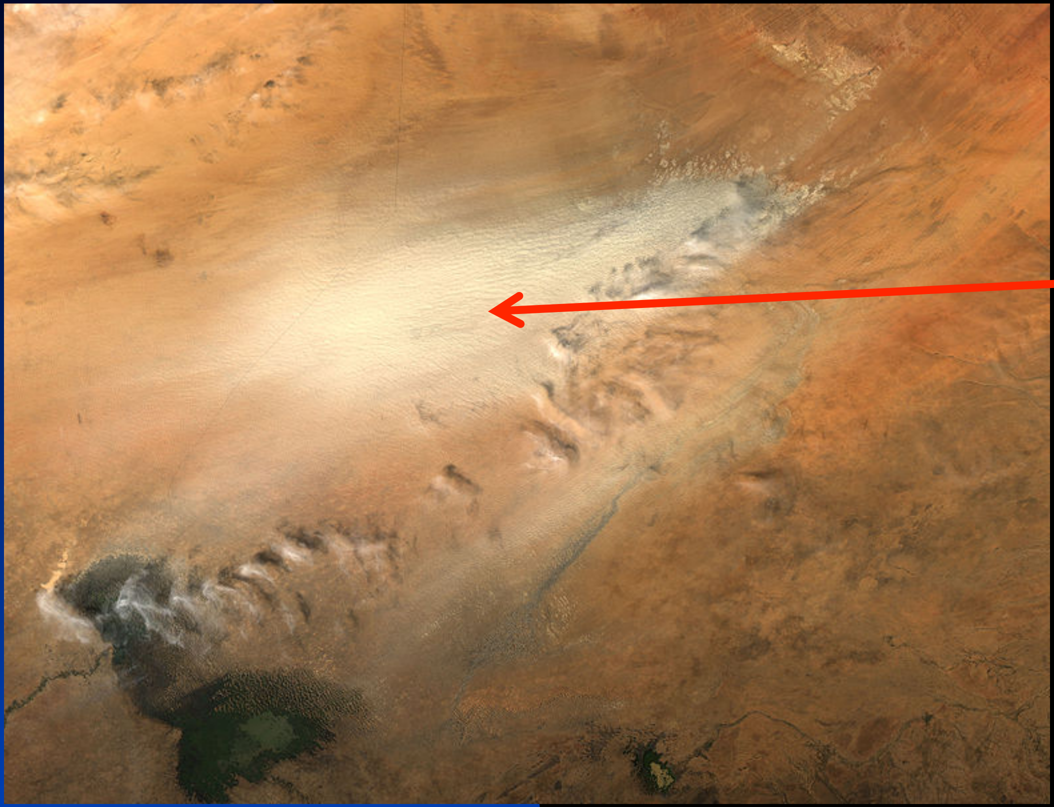
A positive phase of the AMO leads to a northward shift of the ITCZ which is associated with a strengthening of the southwesterly monsoon and an upward motion in the Sahel.

Relationship of winds at 700-hPa with dust aerosol



- **The position inconsistency suggests that the dust changes in TNA could not be due to wind anomalies.**
- **We hypothesize that dust in TNA could be more due to (1) enhanced dust production in the Sahel and (2) transport by the mean zonal wind (instead of anomalies).**

The Bodélé Depression (an area of 40,000 km^2 near 16°N, 18°E), located at the southern edge of the Sahara Desert in north central Africa, is the lowest point in Chad and the planet's largest single source of dust.



The Bodélé Depression

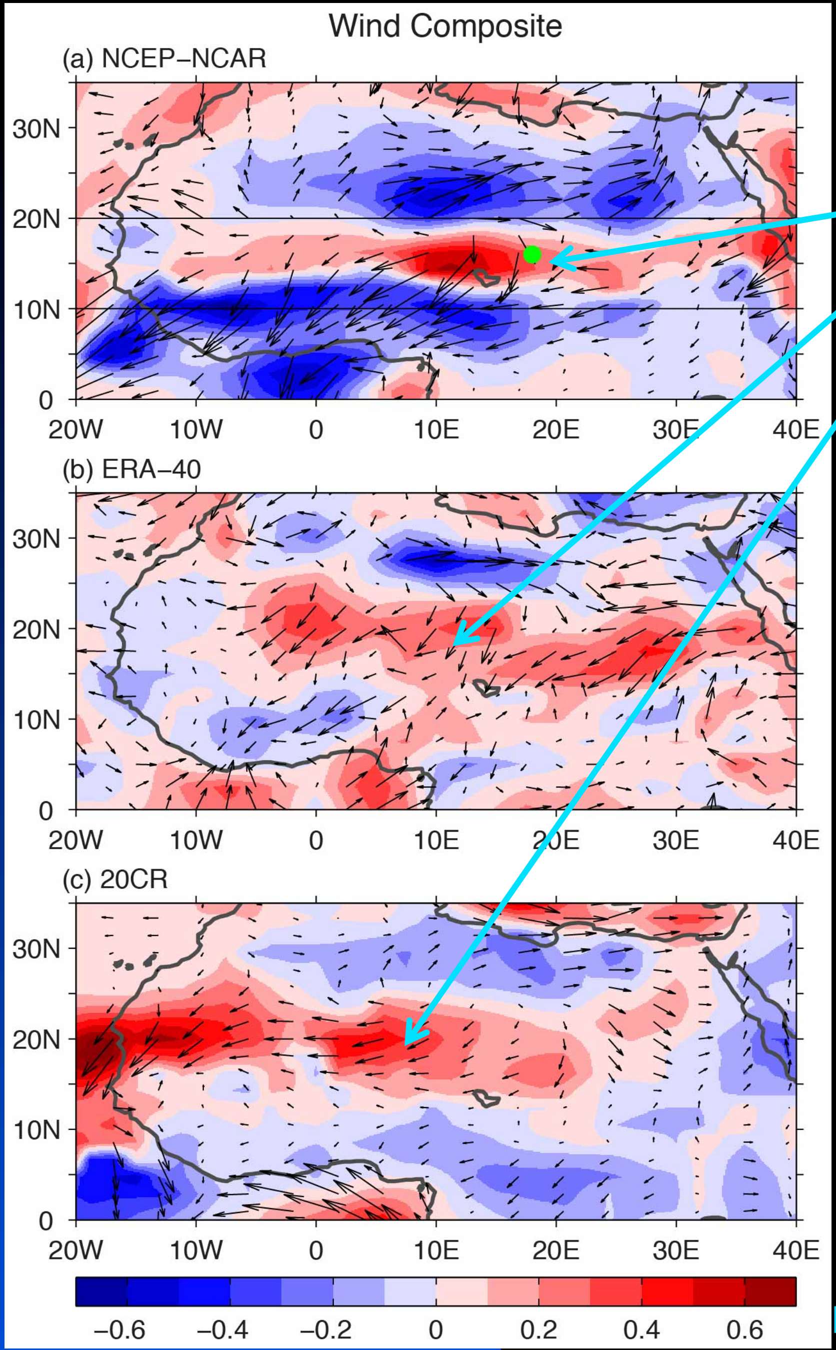
Dust storm was blowing on the afternoon of 18 November 2004 from the MODIS.

Two key requirements for deflation:

(1) strong surface winds,

(2) erodible sediment.

Wind difference between high & low dust years



An increased surface wind speed across the Sahel (deflation is proportional to wind speed cube).

These indicate that dust production is enhanced in the Bodélé Depression.

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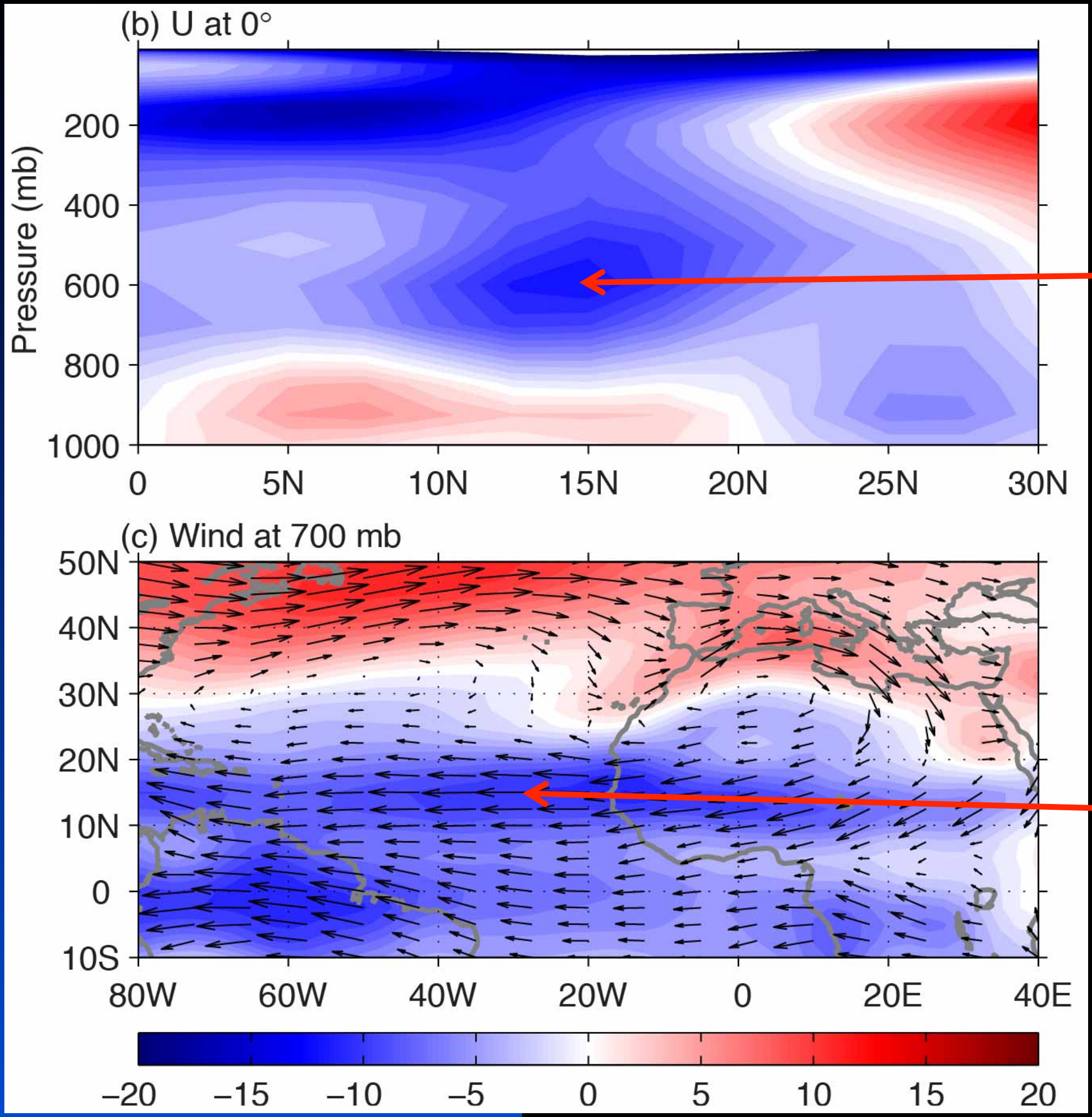
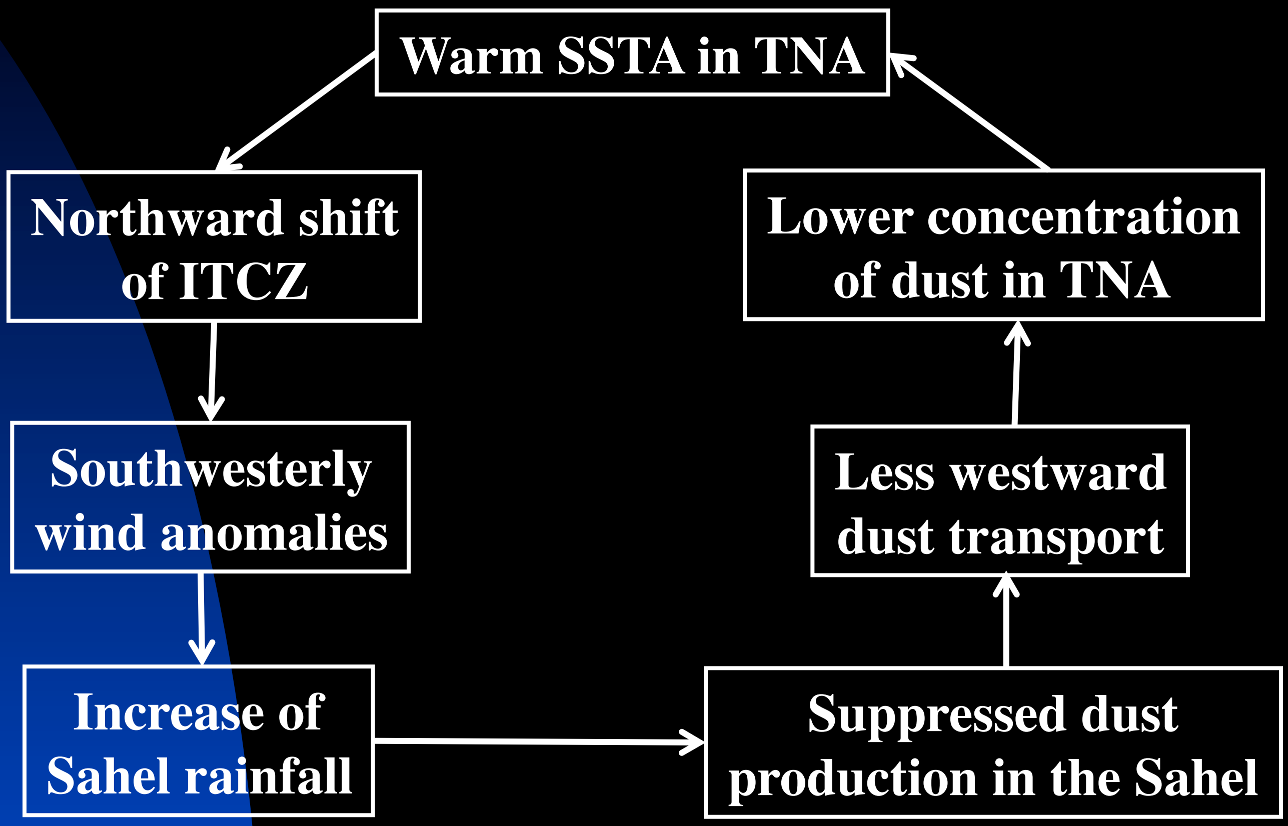
Dust in the Sahel is transported to the TNA by the mean zonal winds (instead of wind anomalies)



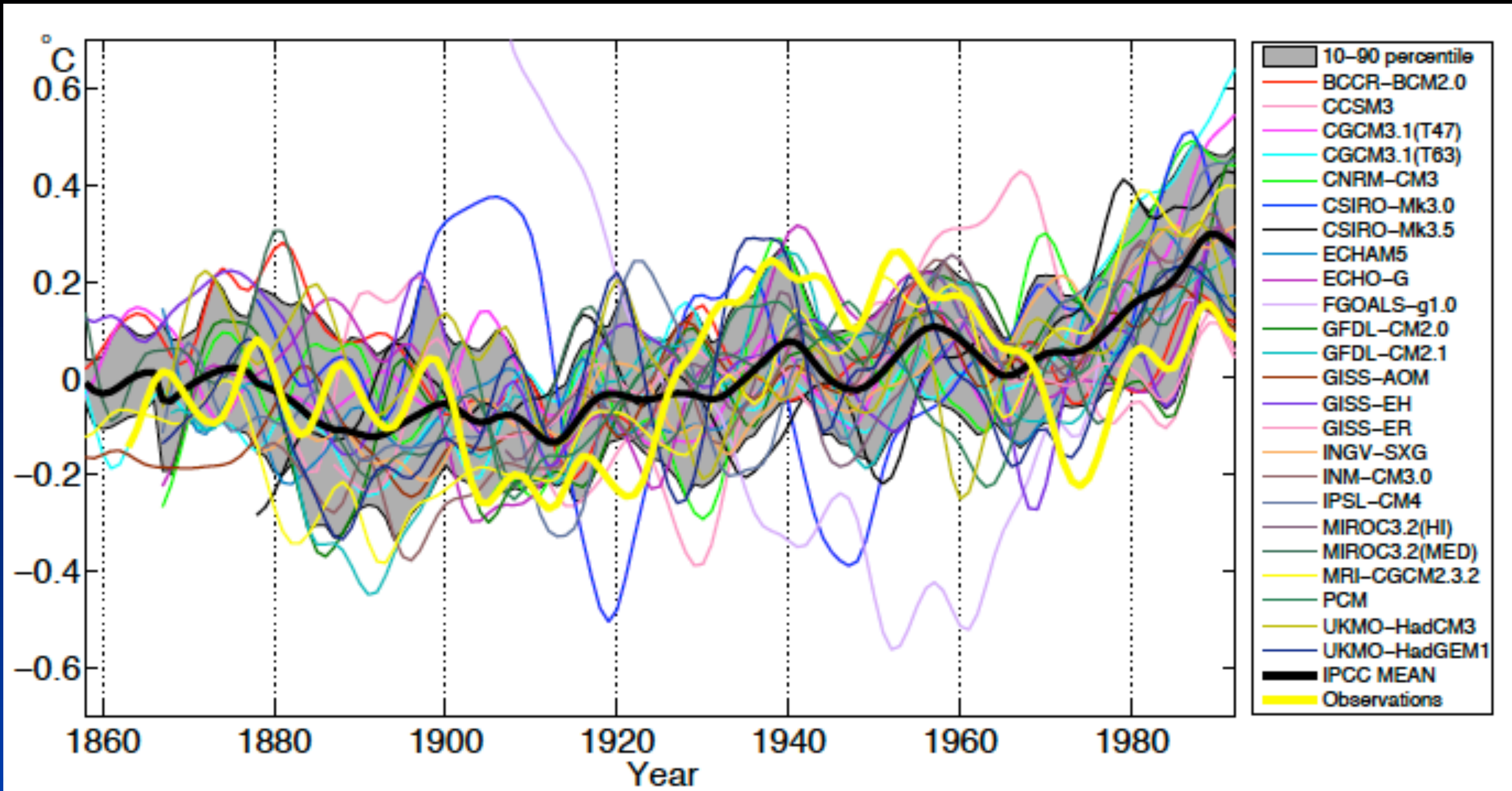
African easterly jet (AEJ)

Strong winds are across the entire TNA and consistent with the maximum dust band between 10°N-20°N.

A positive feedback between the AMO and dust via Sahel rainfall variability

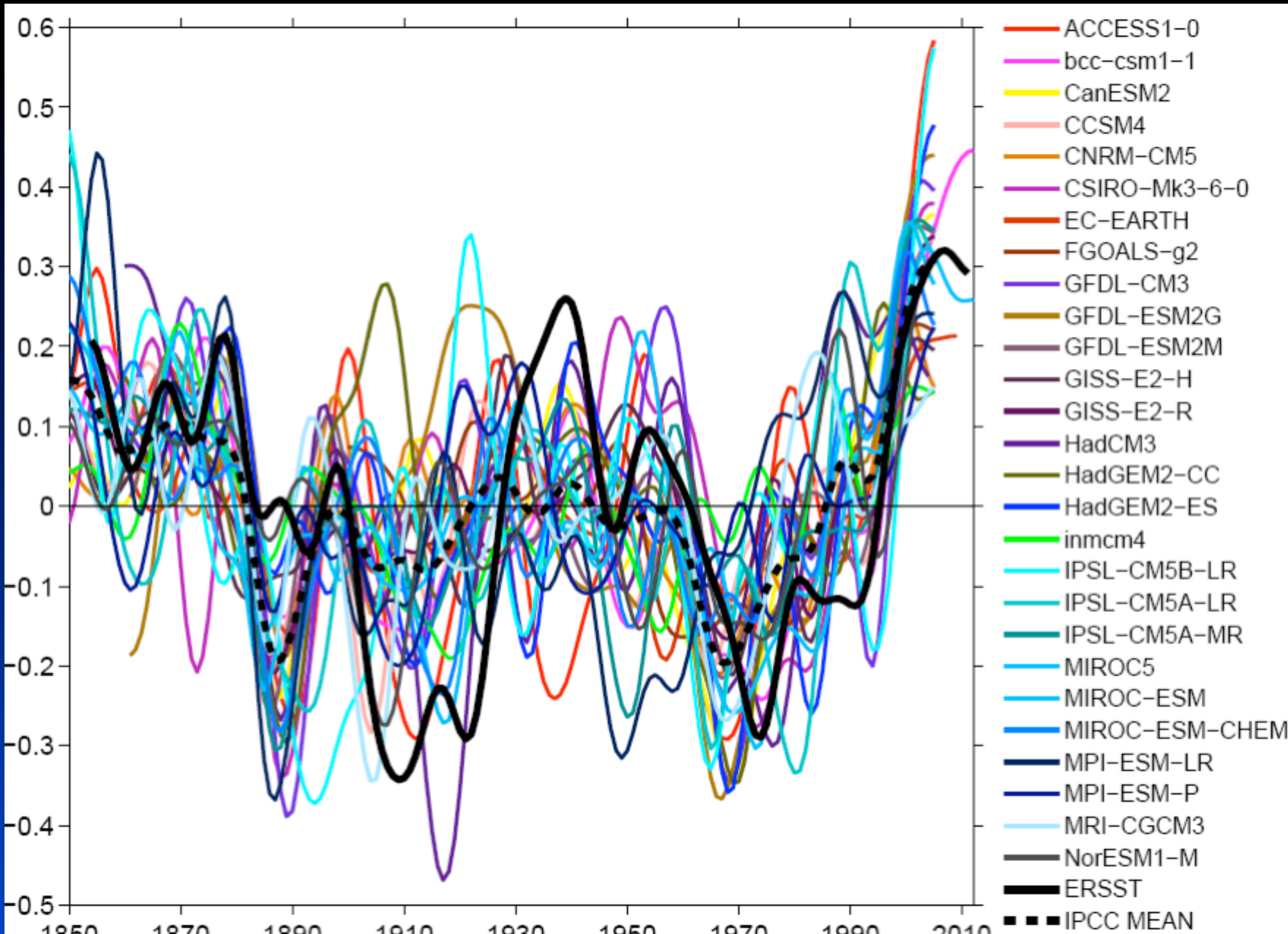


The AMO Simulated from 24 IPCC-AR4 Models (1850-2000)



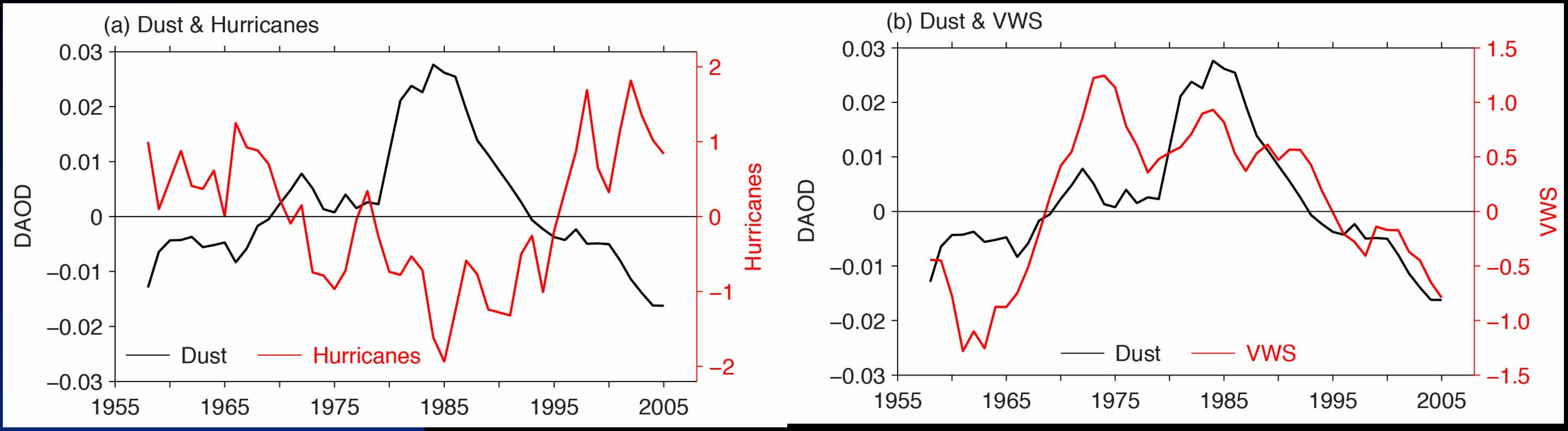
Medhaug and Furevik (2011, *OS*)

The AMO Simulated from 27 IPCC-AR5 Models



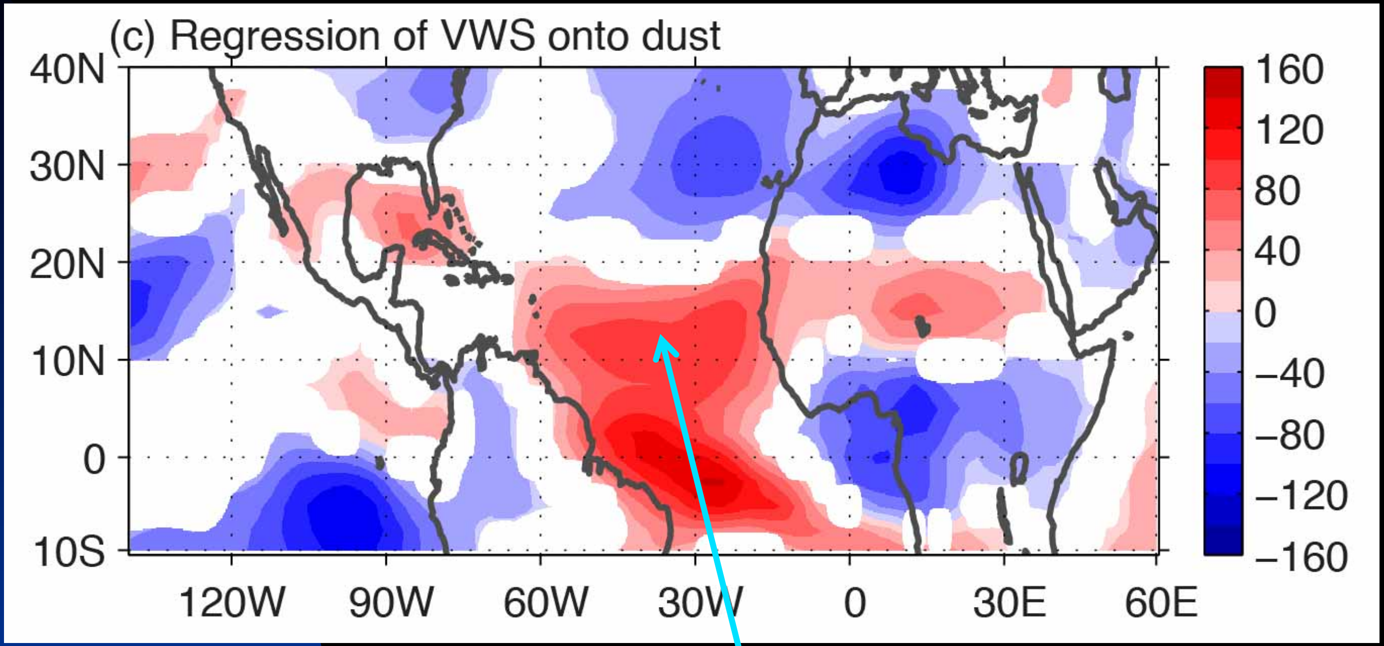
Zhang and Wang (to be submitted)

Dust and Hurricanes on Multidecadal Timescales



- **When dust concentration in TNA is low (high), the number of Atlantic hurricanes is more (less).**
- **This is because dust changes meridional air temperature gradient via dust-radiation processes and alters zonal winds (thermal wind balance) and then vertical wind shear (VWS).**

Dust and Hurricanes on Multidecadal Timescales



Strong VWS in the hurricane main development region (MDR)

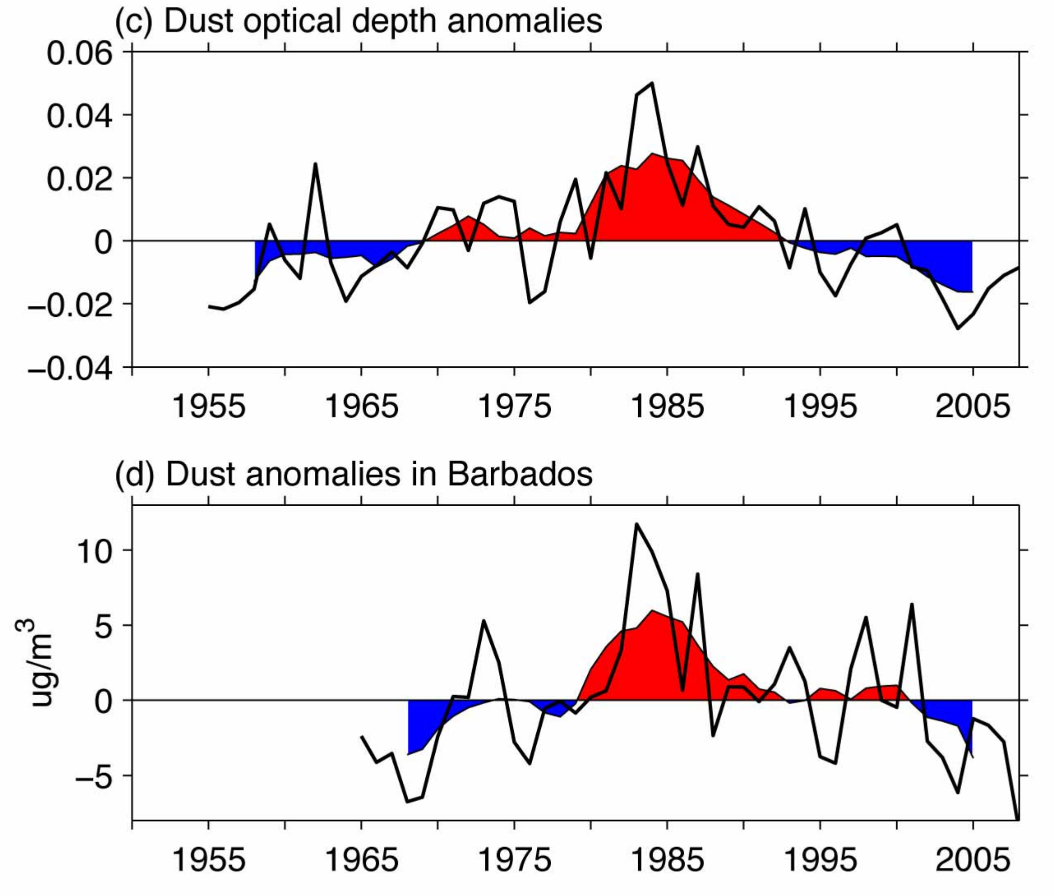
Summary

- This study shows a multidecadal co-variability of the AMO, dust in the TNA and rainfall in the Sahel.
- It suggests a novel mechanism for NA SST variability on multidecadal timescales: A positive feedback between the AMO and dust via Sahel rainfall.
- Dust varies inversely with the number of Atlantic hurricanes on multidecadal timescales due to dust-related VWS in the hurricane MDR.
- An implication of this study is that coupled models need to be able to simulate this aerosol-related feedback.
- Can climate models (IPCC-AR5) simulate this feedback?

Indirect Influences of Dust on Vertical Wind Shear

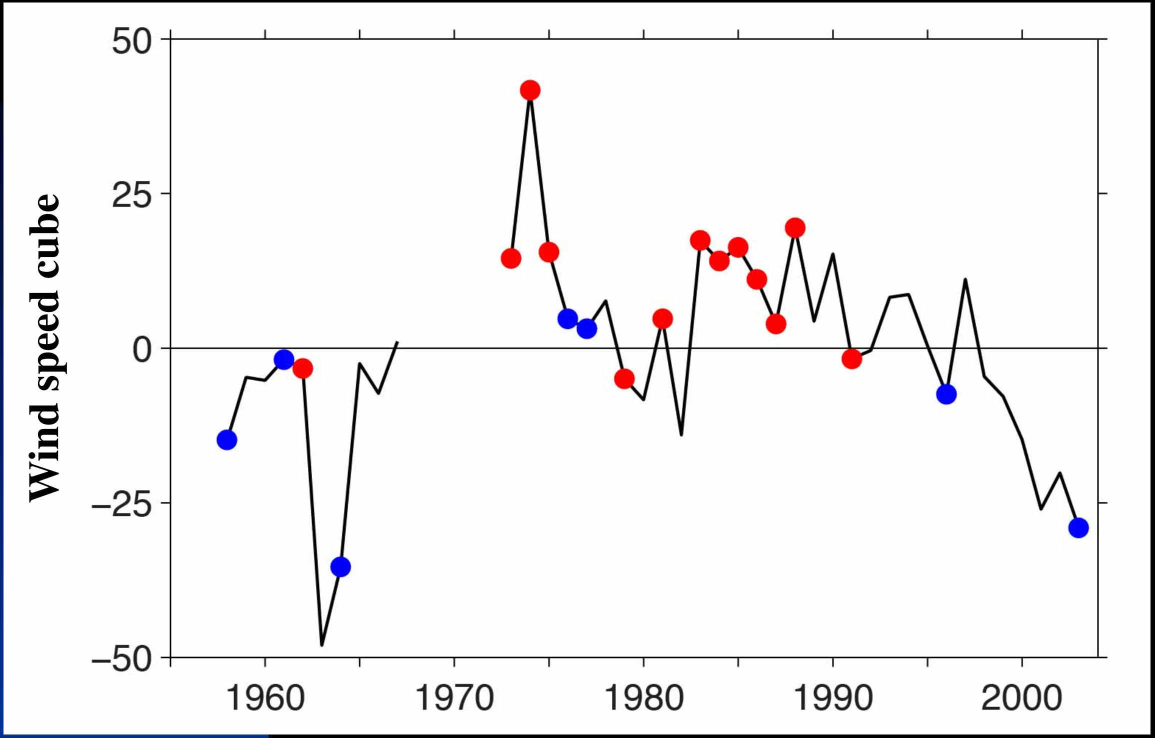
- Sahel rainfall (Landsea & Gray 1992).
- The Saharan air layer (Dunion & Velden 2004).
- North Atlantic SST (Goldenberg et al. 2001).
- Atlantic warm pool (Wang et al. 2006).
- Atlantic meridional mode (Vimont & Kossin 2007).

A comparison with the station dust time series observed on the island of Barbados since 1965



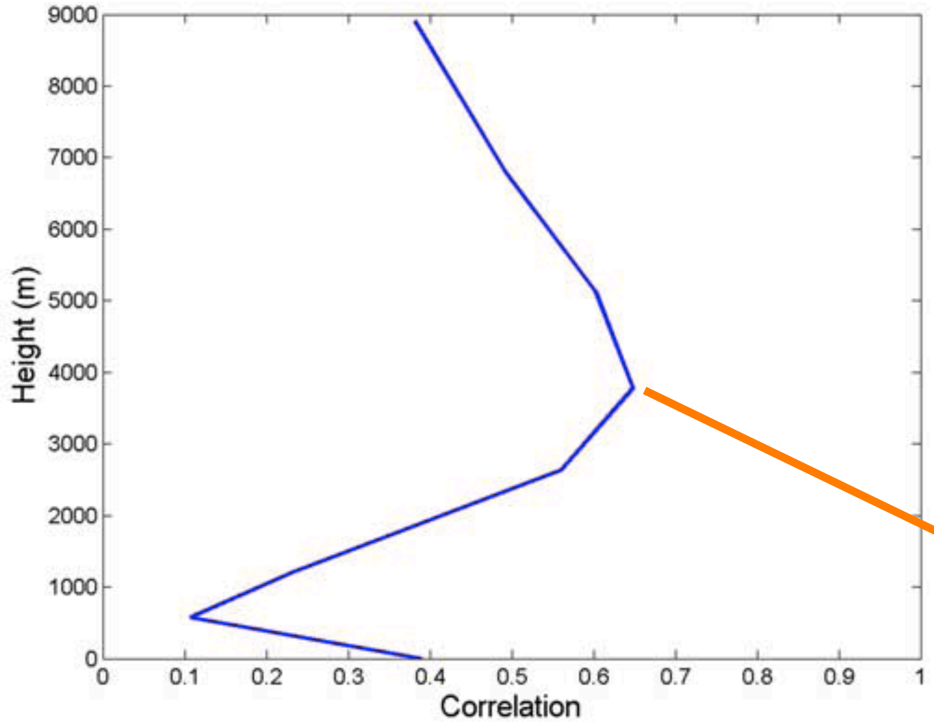
Correlation is 0.70 for the yearly data and 0.84 for the 7-yr running mean

Annual average of the wind speed cube from the observed station data in the Western Sahel (dust production $\propto W^3$)



It also shows the AMO signal, consistent with the reanalysis products. All of these indicate that an increased wind speed (associated with the negative AMO and high TNA dust phases) produces more dust in the dust source region.

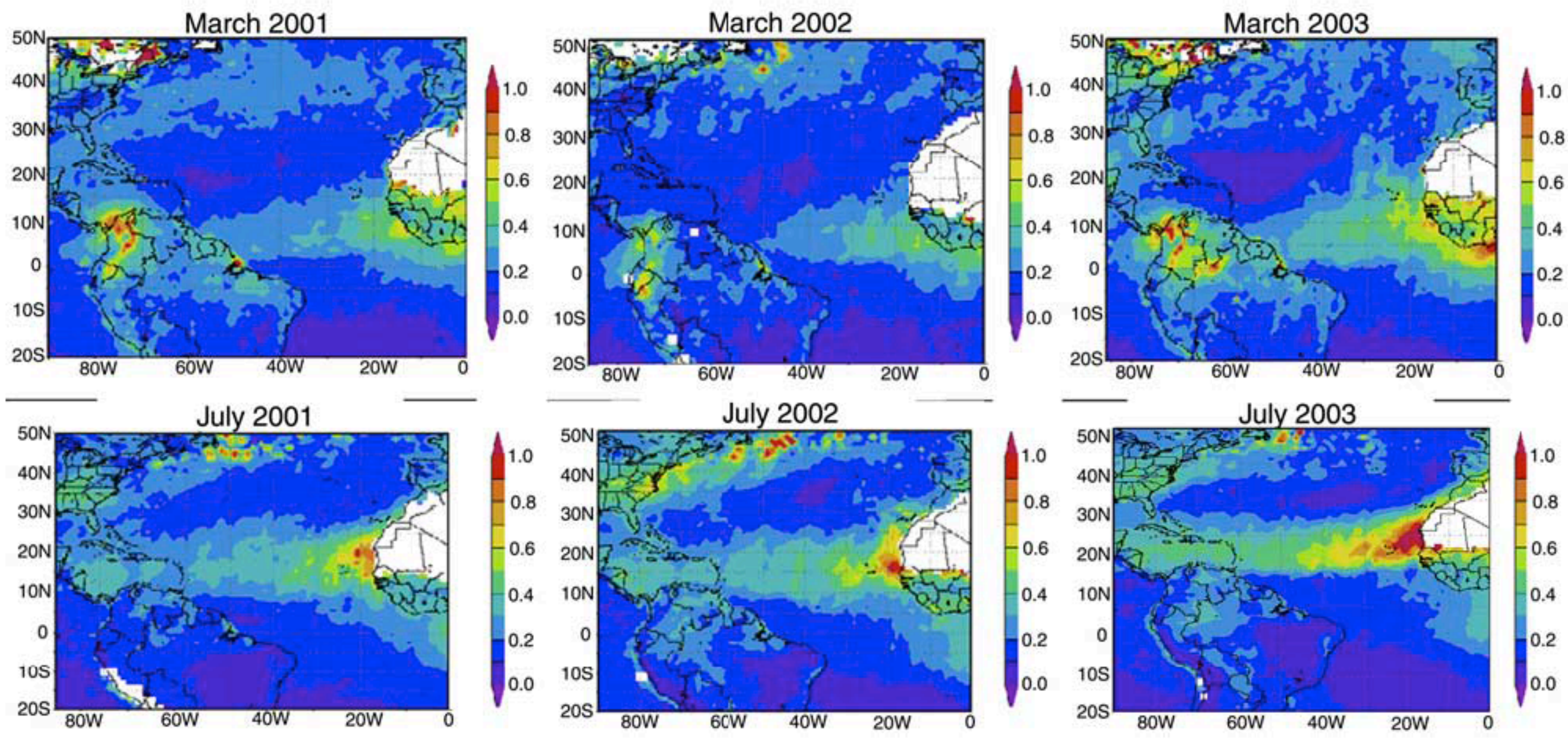
Kaufman et al. (2005, *JGR*) showed that transport of Saharan dust is most strongly correlated with winds at 700-hPa.



about 700-hPa

Figure 11. Correlation between the wind and dust optical thickness time series measured in Capo Verde during the summer months. One hundred and fifteen measurements were used in the analysis. The correlation coefficient is drawing a profile of the wind driven aerosol. Dust was at the layer of 3–5 km, and sea salt was in the lowest 500 m. This correlation profile serves as a virtual lidar that draws the concentration of the wi ven aerosol.

Observations of the Aerosol Optical Depth (AOD) in the Atlantic by the Moderate Resolution Imaging Spectroradiometer (MODIS)



Kaufman et al. (2005, *JGR*)

Where does dust in the TNA come from? Africa.
What is mechanism? Our contribution: Enhanced dust production in the Sahel and the importance of mean winds.

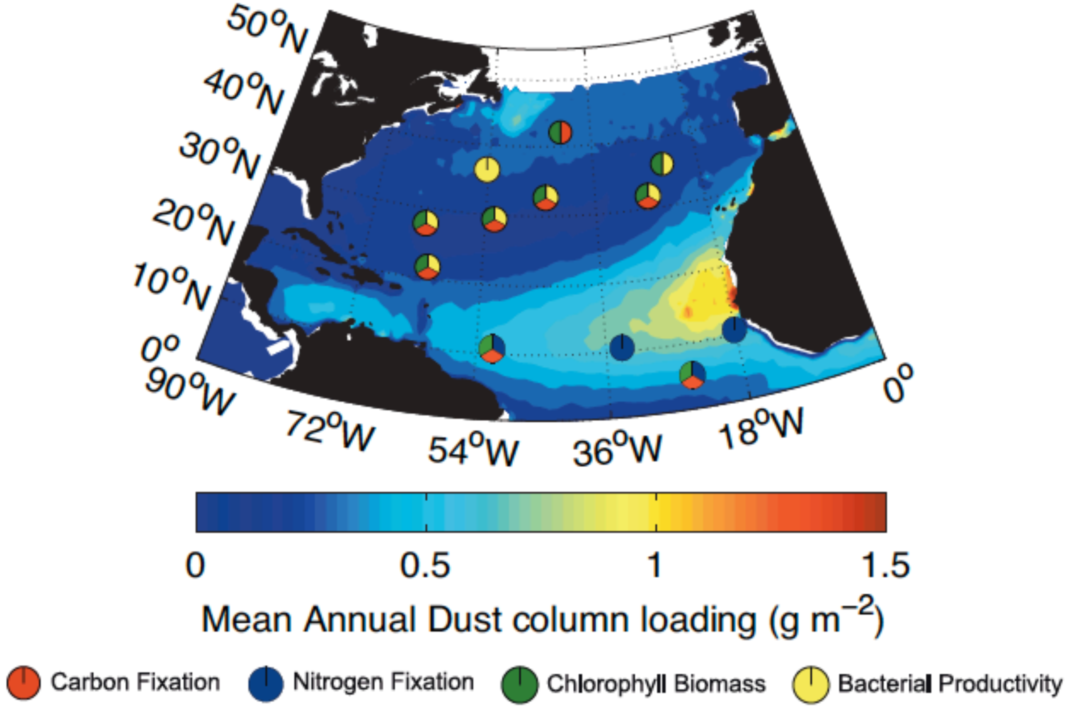
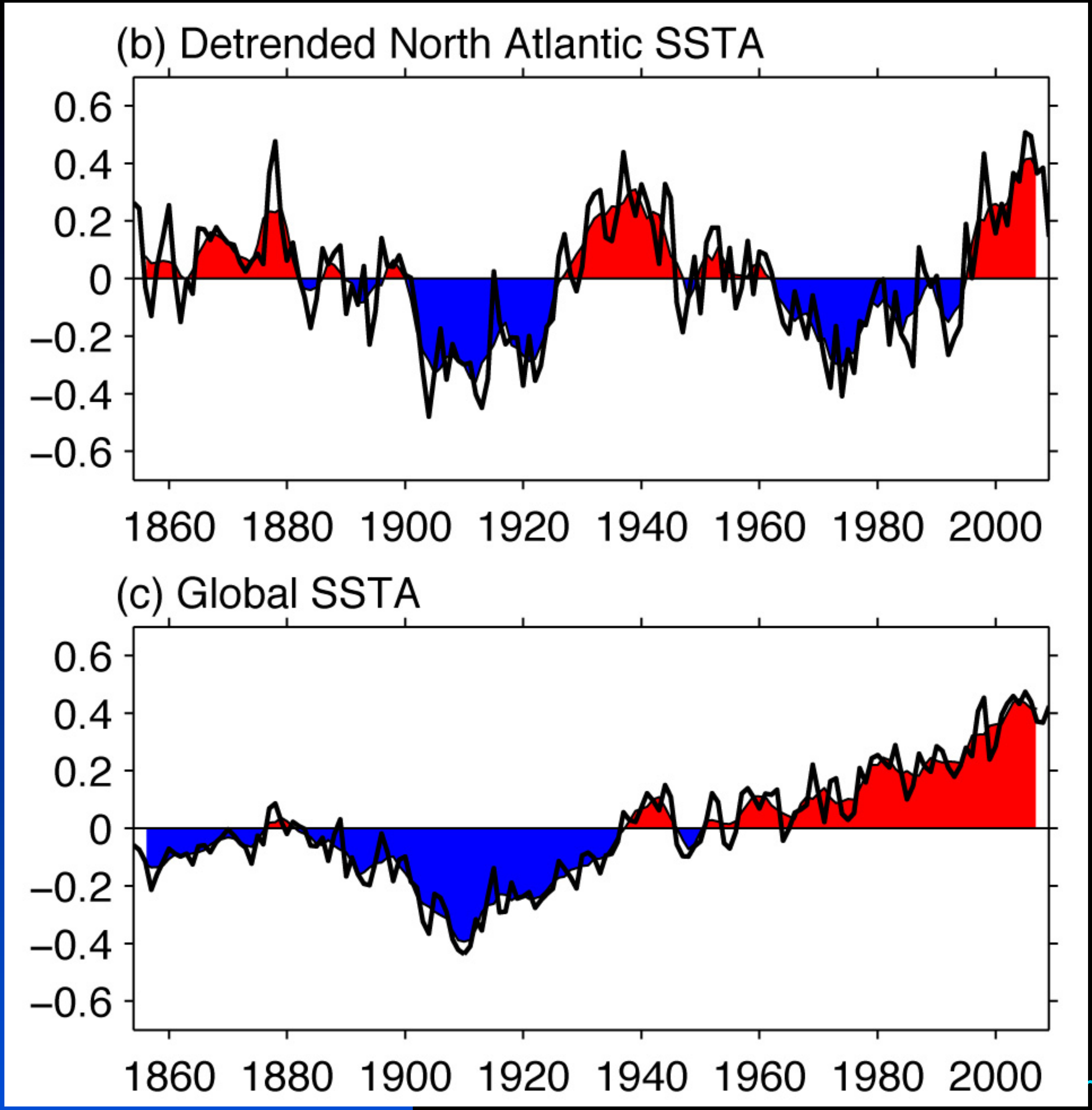


Figure 3: Mean annual dust column loading to the North Atlantic calculated using MODIS aerosol optical thickness data from April 200 – March 2004. Overlayed on the map are the sites of the nutrient enrichment bioassay experiments with colors indicating the presence of a stimulation of CO_2 fixation (red), N_2 fixation (blue), chlorophyll biomass (green), and bacterial productivity (yellow) by dust. Note: Sample analysis for N_2 fixation have been completed for sites south of 20°N.

Mills & LaRoche (2004)

Do dust aerosols play a role in climate changes?



AMO (Atlantic Multidecadal Oscillation)

Global SST

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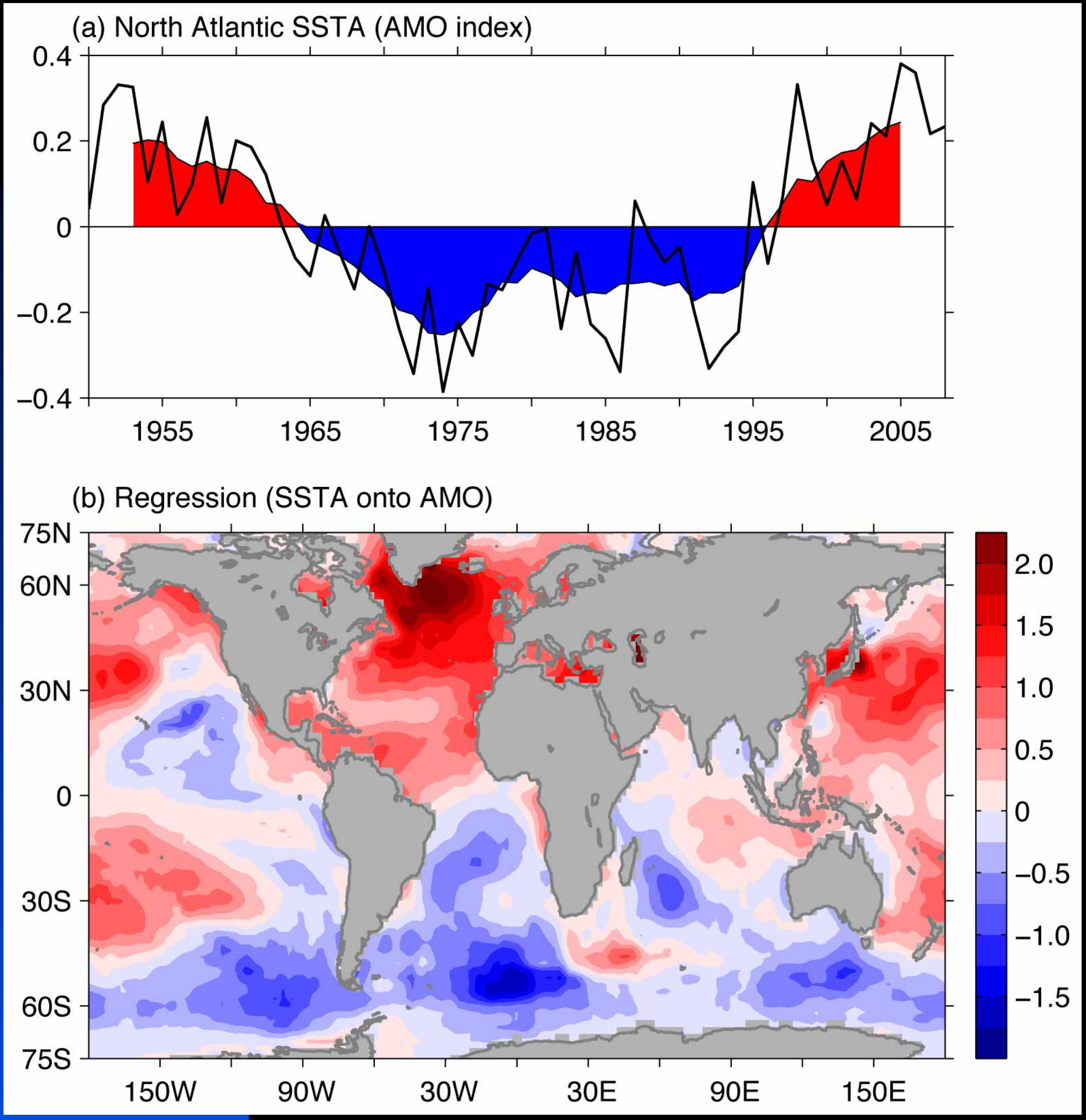
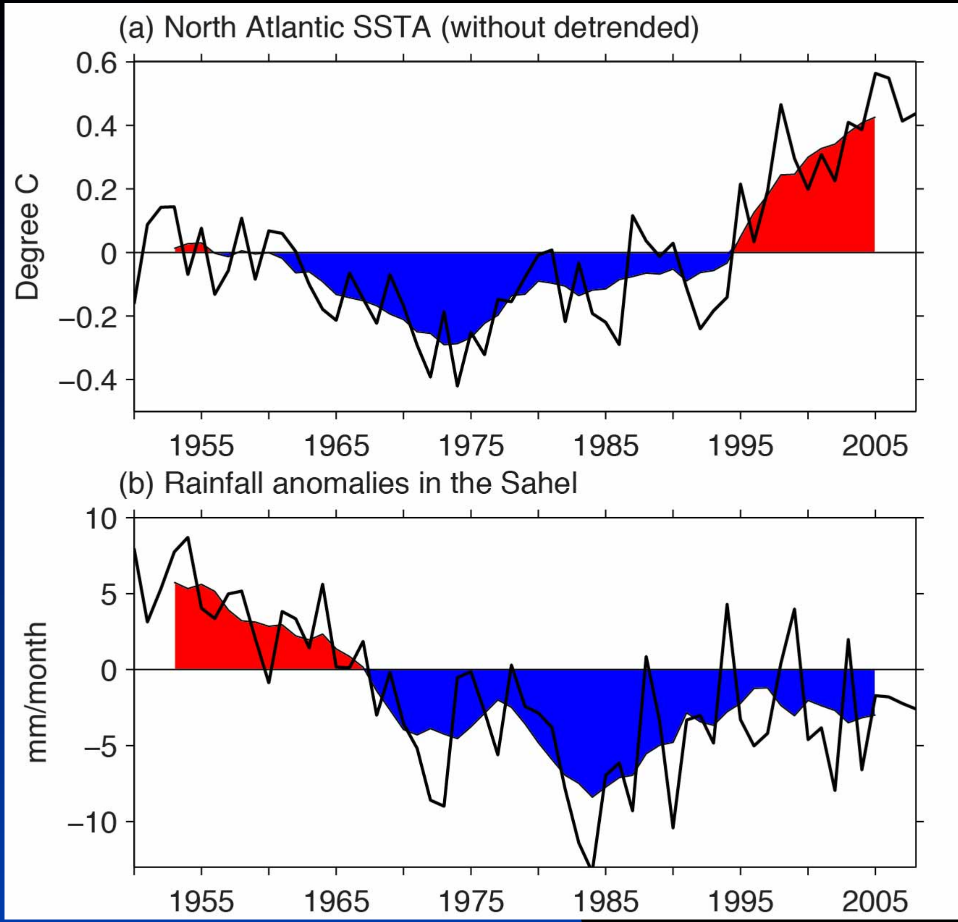
Influence of the AMO on global SST

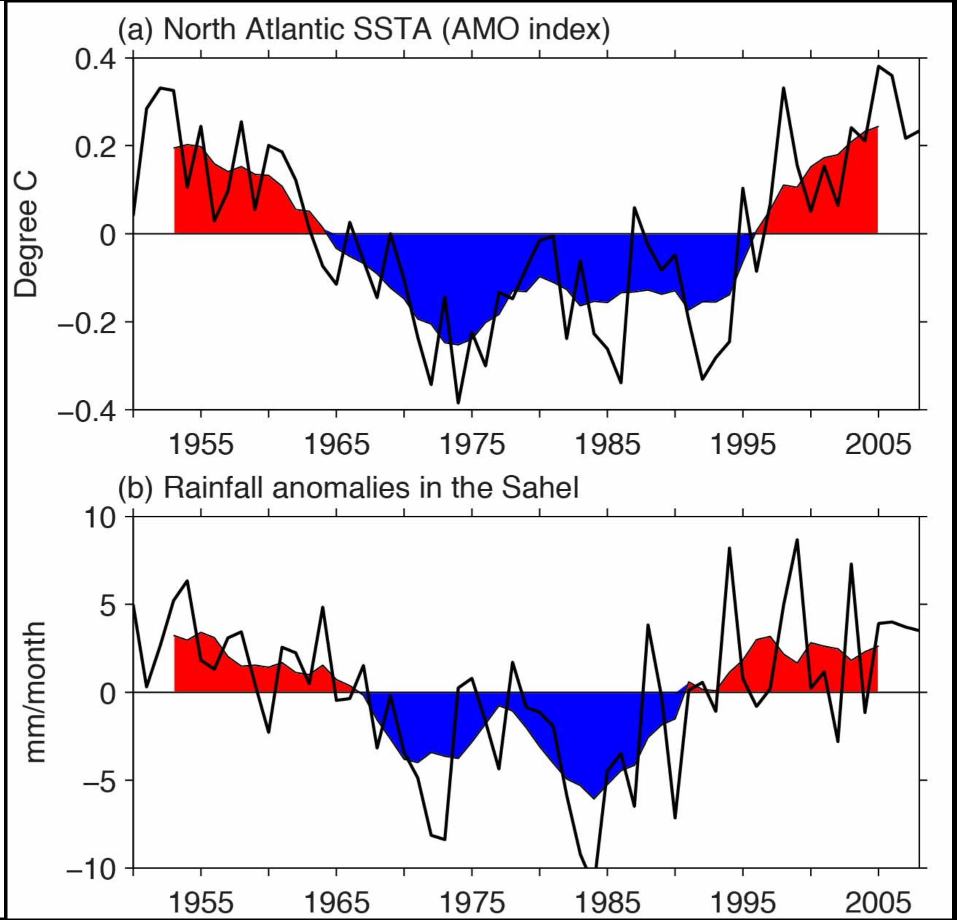


What are roles of global warming?

Linear trends included



Linear trends removed



The warming trend is associated with a reduction of Sahel rainfall, whereas the warm phase of the AMO after the early 1990s tends to increase Sahel rainfall.

What are roles of global warming?

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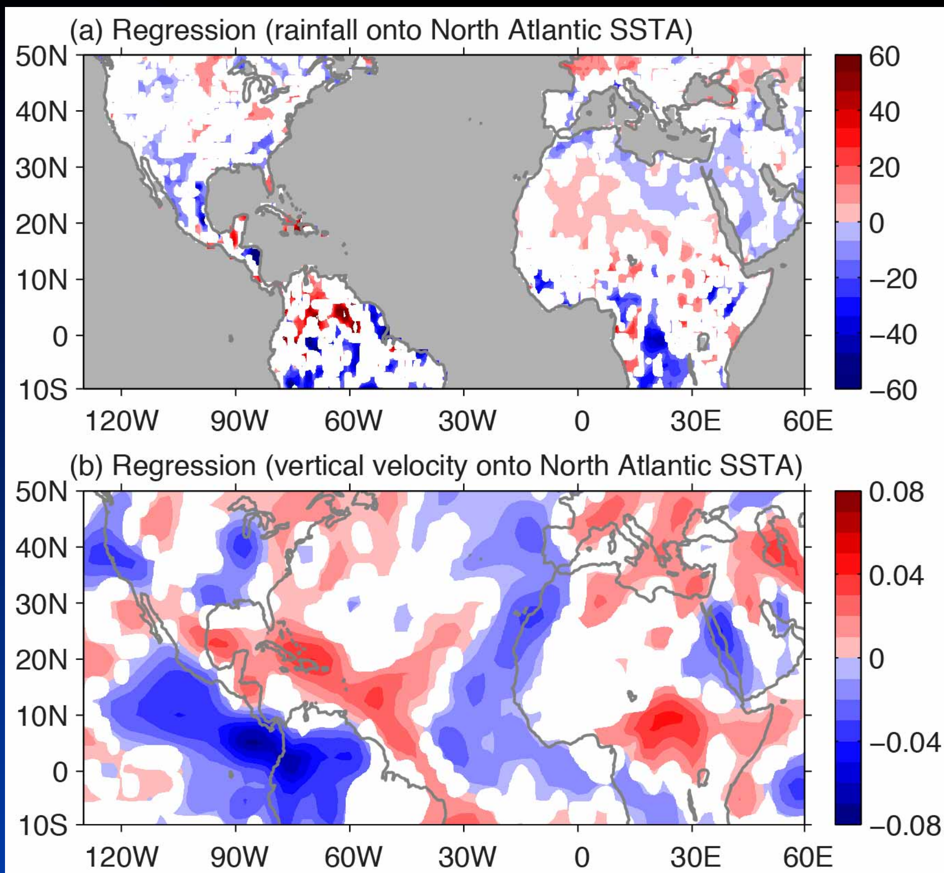
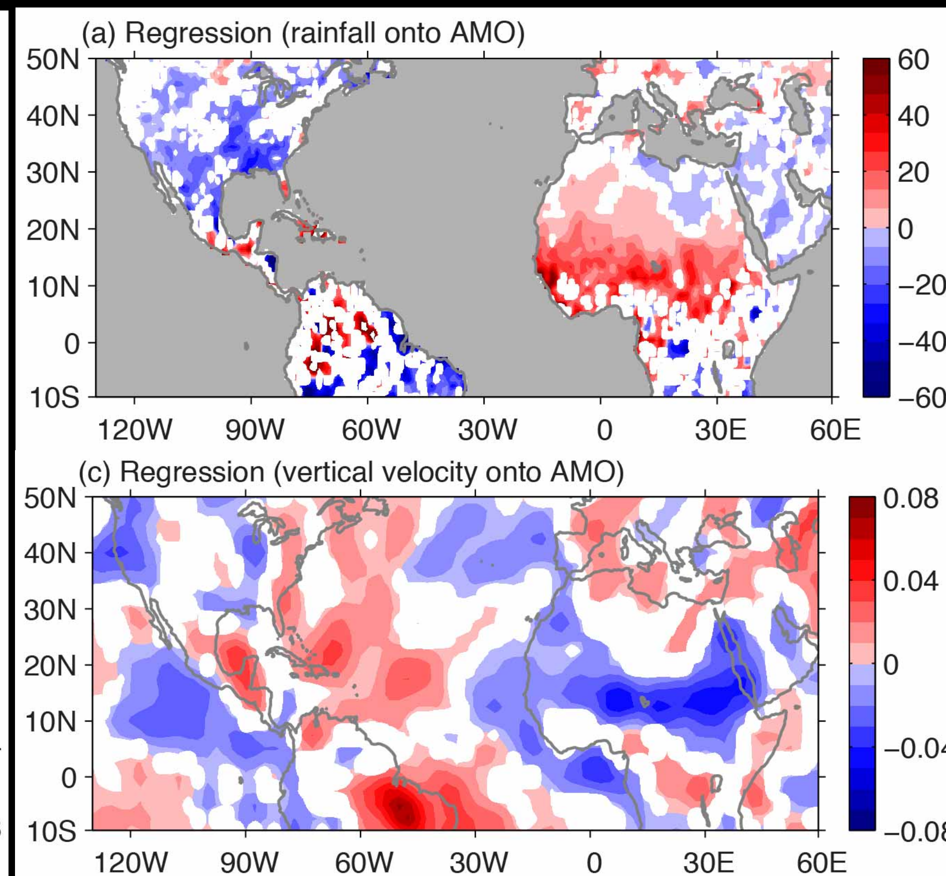
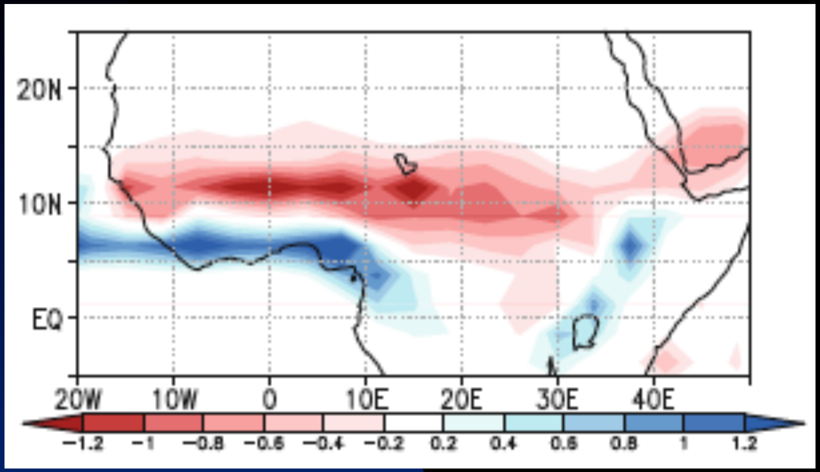


Linear trends removed

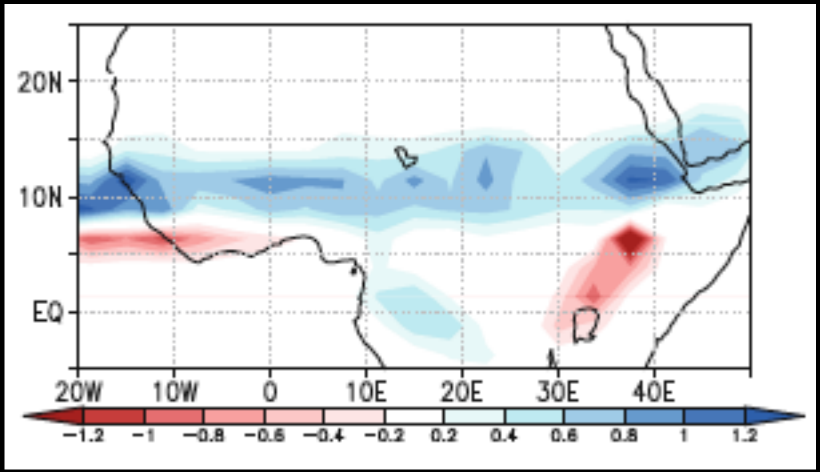


The warming trend is associated with a reduction of Sahel rainfall, whereas the warm phase of the AMO after the early 1990s tends to increase Sahel rainfall.

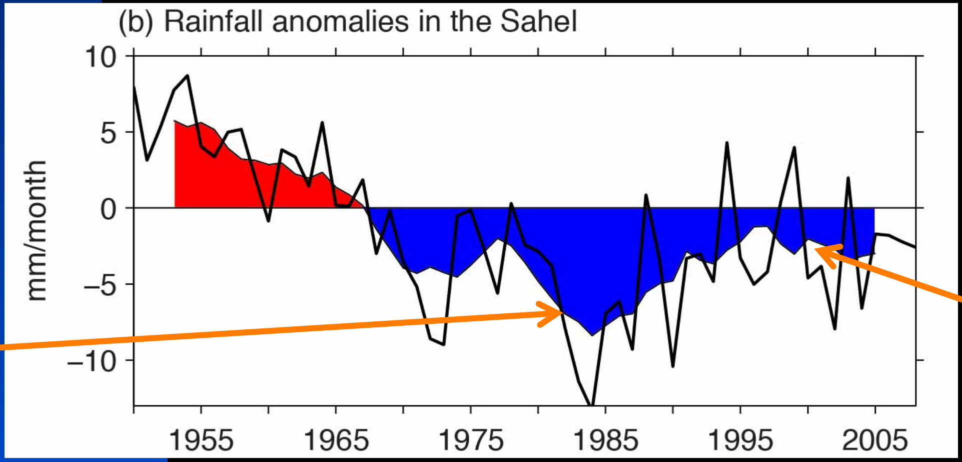
A recent modeling study of SST contribution to 1980s drought (mid-1990s recovery) in West Africa (Mohino et al. 2011, *CD*)



GW: 10% (-20%)



AMO: 50% (80%)



1980s drought

mid-1990s recovery

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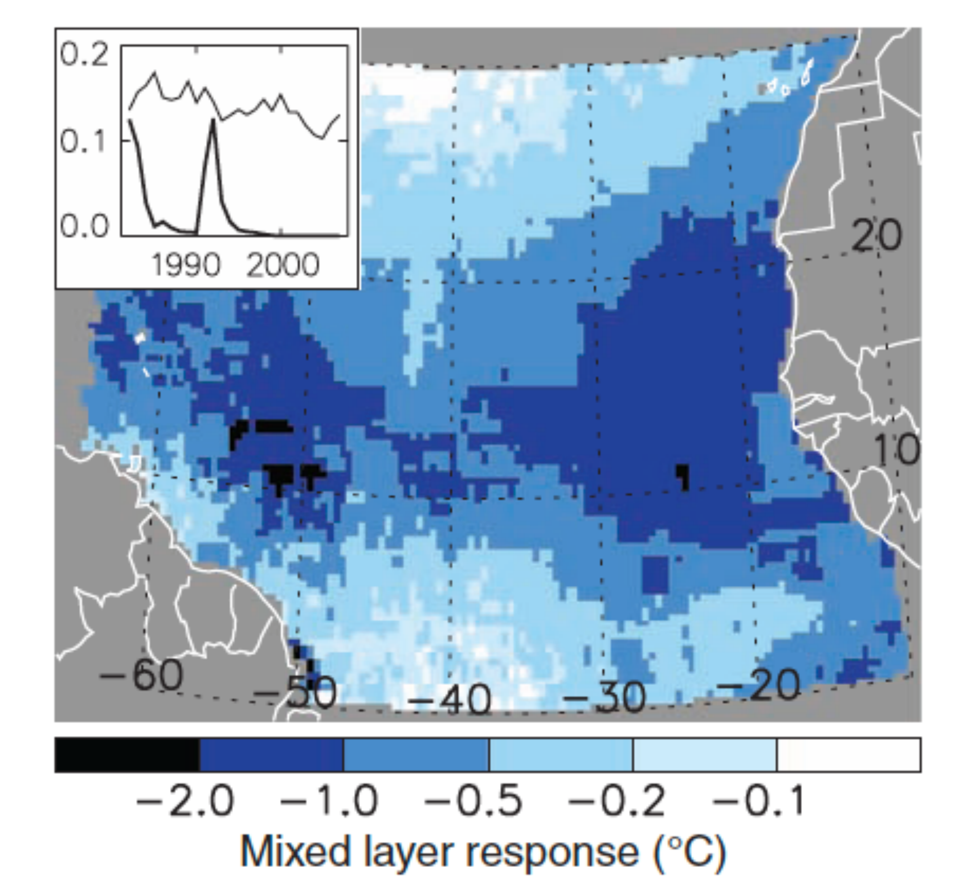
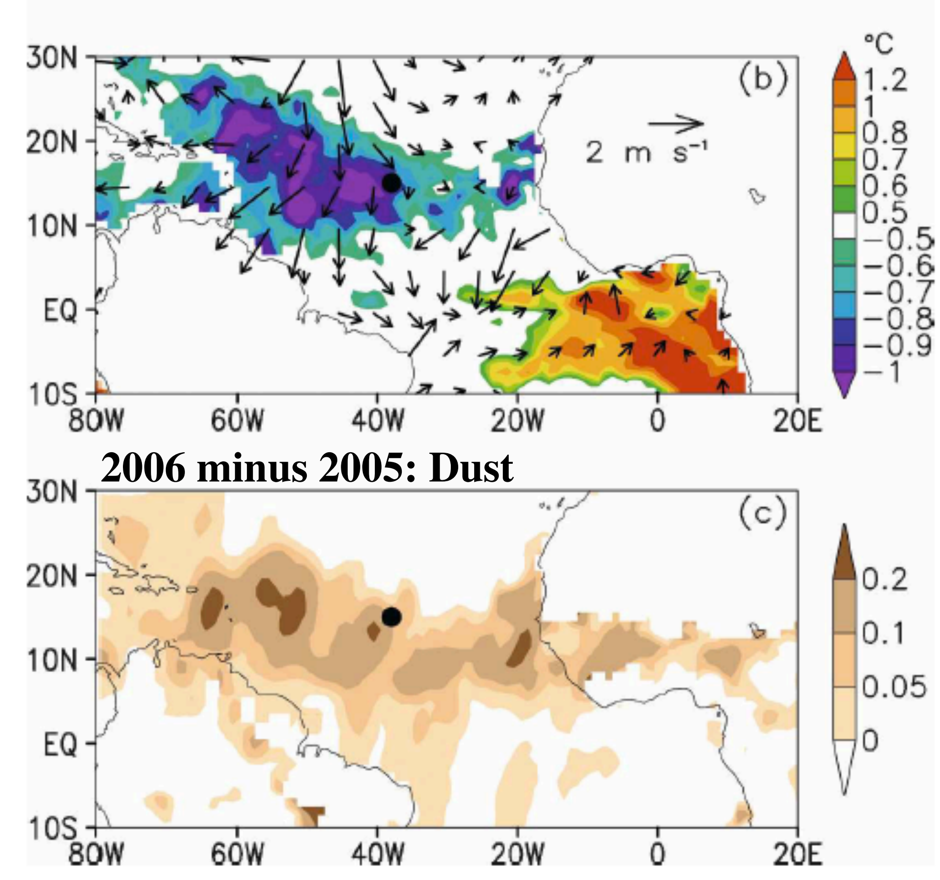
Role of dust in the ocean: Some studies show that high (low) concentration of dust in the TNA cools (warms) the TNA.



Evan et al. (2009, *Science*)



Foltz & McPhaden (2008, *JC*)

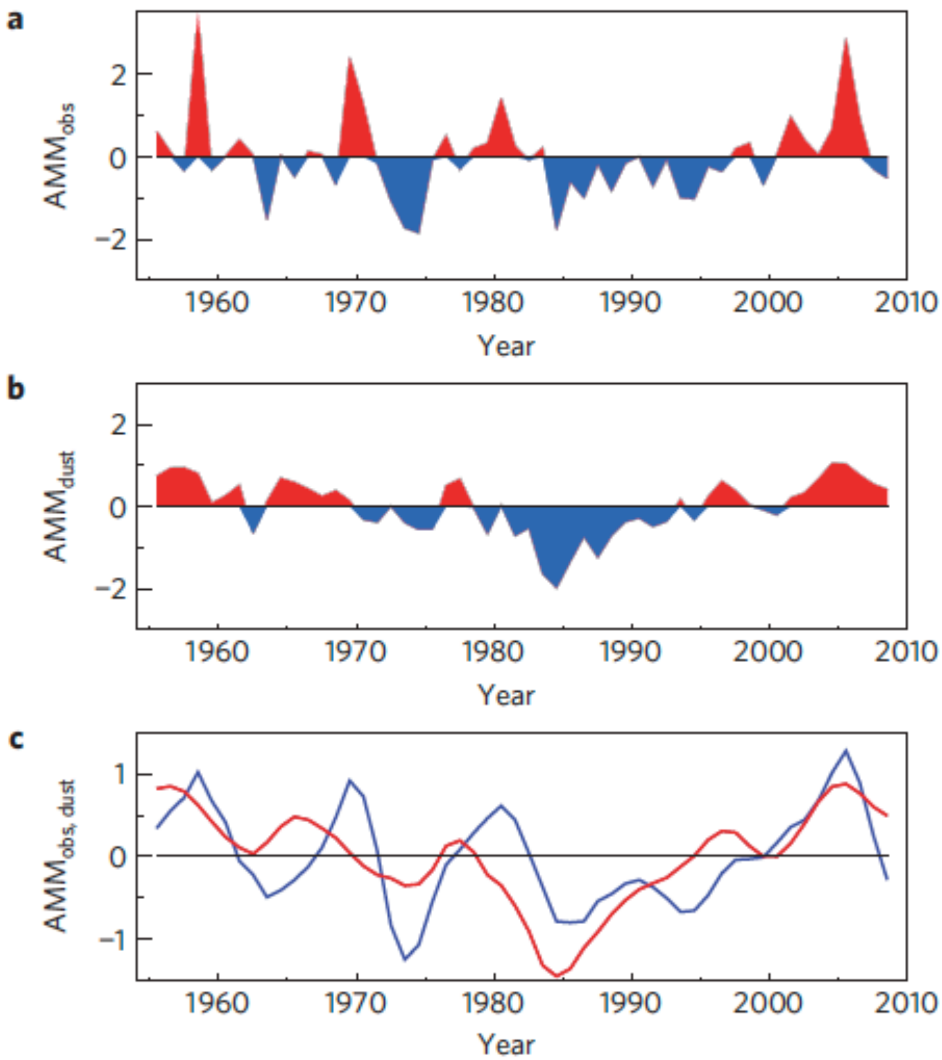
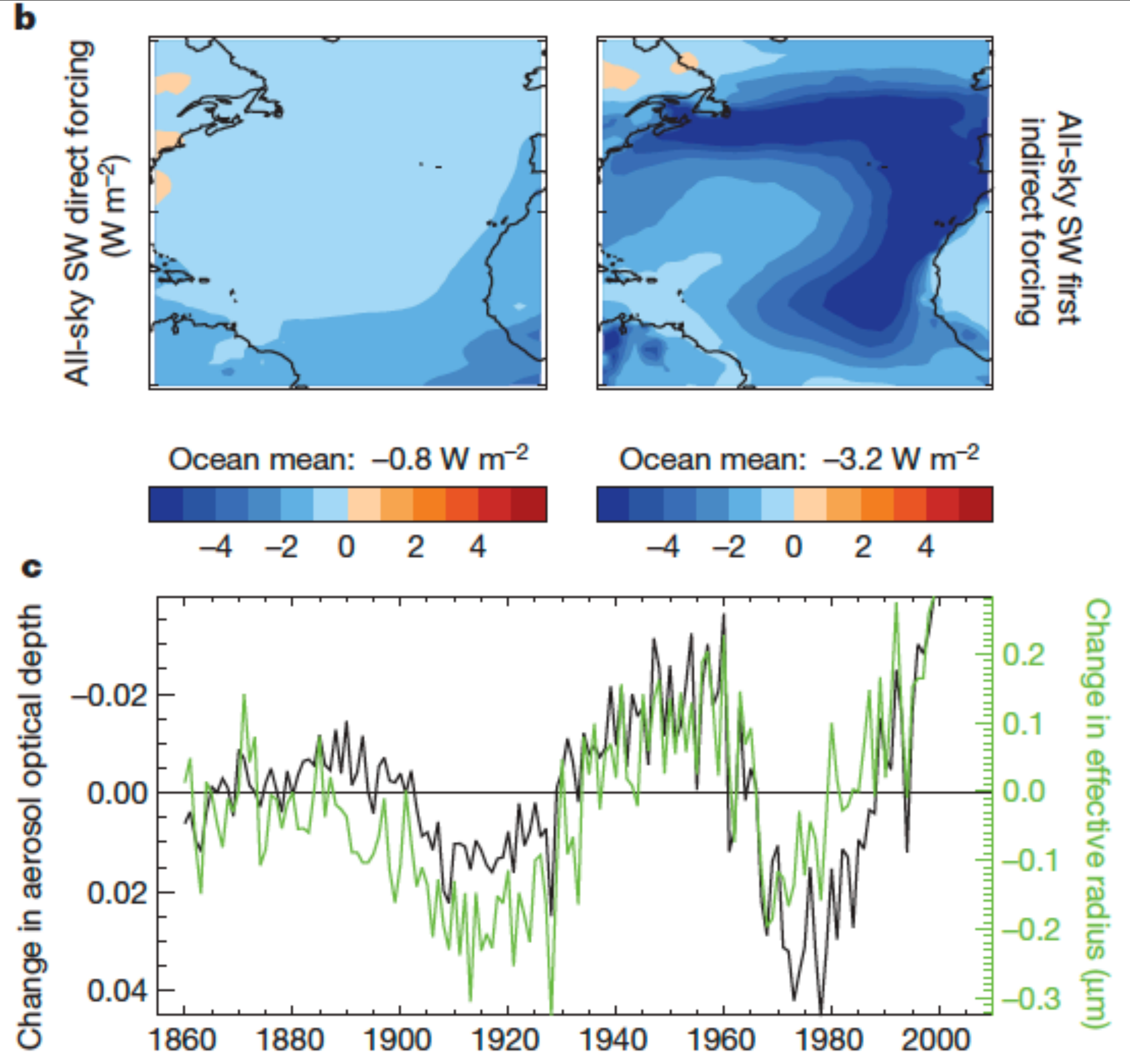


Figure 3 | Observed and dust-forced component of the AMM time series. **a–c**, The annually averaged observed AMM time series (**a**), the dust-forced component of the AMM (**b**) and the 5-year low-pass-filtered observed (blue) and dust-forced component (red) of the AMM (**c**). Both time series have the same normalization so that similarity between the observed and dust-forced AMM indicates direct forcing of the AMM by African dust outbreaks.

Role of dust in the ocean: The simulated Atlantic meridional mode (AMM) by an ocean GCM (Evan et al. 2011, *Nature Geo*.).

Using HadGEM2-ES climate model, Booth et al. (2012, *Nature*) focus on the forcing by volcanoes and anthropogenic aerosols. They argue that the AMO is not an internal variability.

SW forcing induced by **direct** effect (absorb & scatter radiation)



SW forcing induced by first **indirect** effect (aerosols-cloud)

However, the simulations by Booth et al. (2012, *Nature*) fail to capture dust concentration in the North Atlantic on multidecadal timescales, i.e., no the AMO signal. The authors state that this is due to the lack of a common coherent dust response in the model.