Regional drivers of Sahel Precipitation Response to Anthropogenic Aerosols

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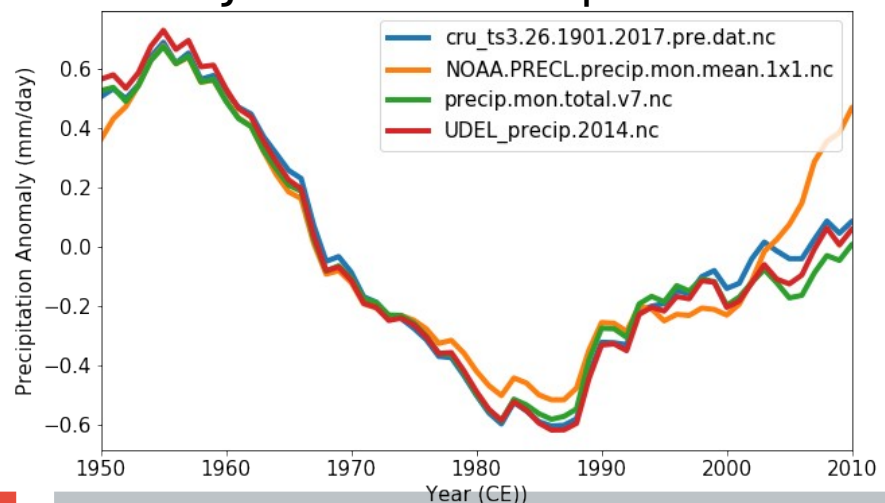
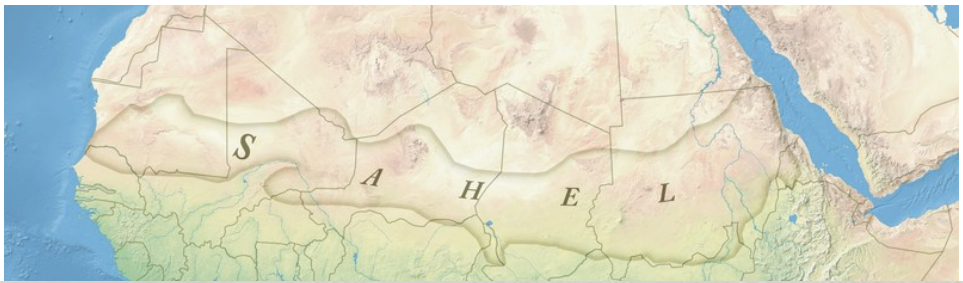
20th century drought and recovery of Sahel Precipitation

- Observed JAS Sahel precipitation underwent a large swing during the late-20th century.
- The extent of human influence on the drought and recovery is a long-running question.

JAS Sahel Precipitation



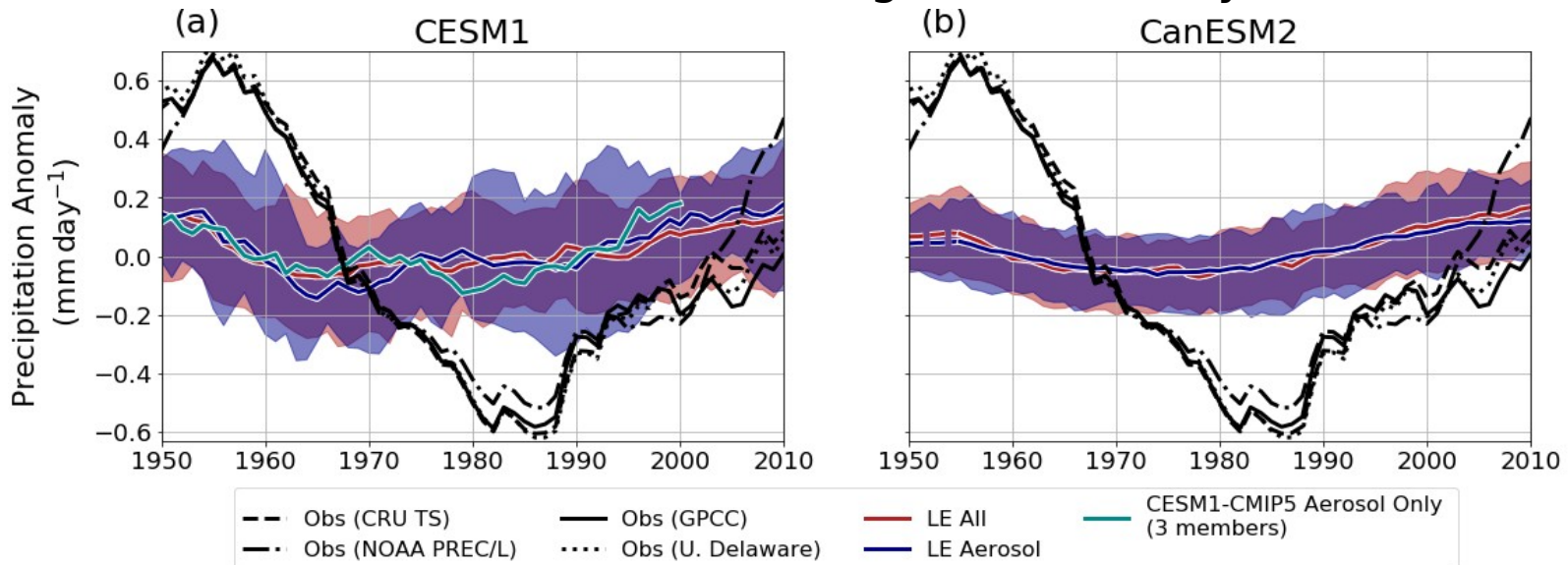



In Africa, a Natural Disaster Made Worse by Man

King, S. 1984 New York Times

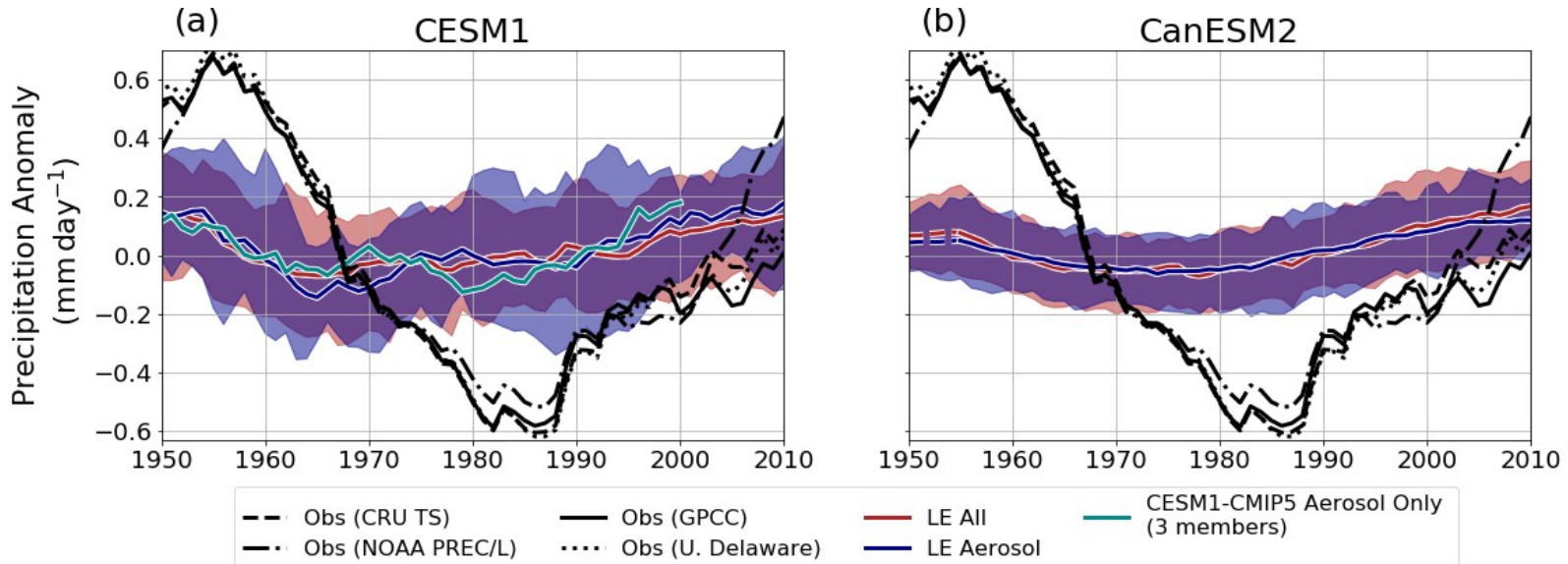
Analysis of Coupled GCM Large Ensembles

- We analyze the CESM1 and CanESM2 Single Forcing Large Ensembles to isolate the effect of aerosols.
  - CESM1 : All but Industrial Aerosols (XAER)
  - CanESM2 : Industrial and Biomass Burning Aerosols Only



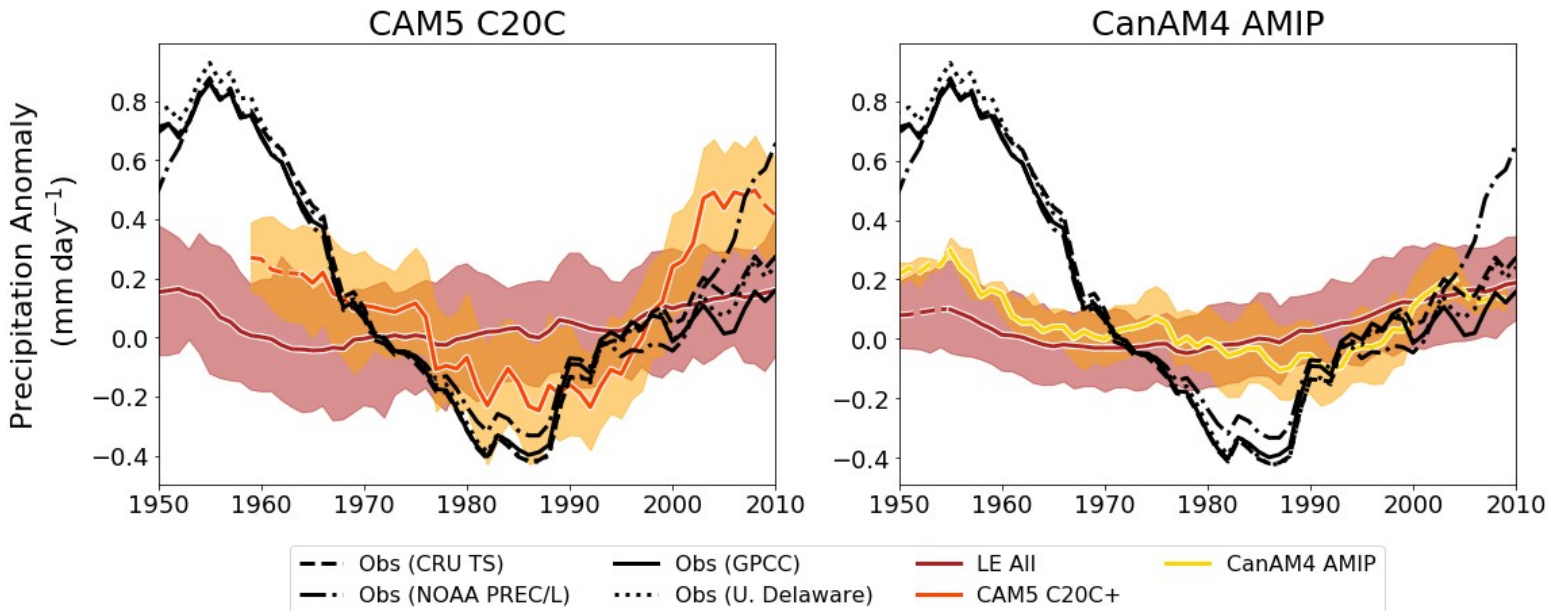
Anthropogenic Aerosol Forcing drives Forced African Precipitation Change

- CESM1 and CanESM2 heavily underestimate the magnitude of multi-decadal change.
- Much of the forced component of the response is due to Anthropogenic aerosols in CESM1 and CanESM2



Comparing AMIP to LE simulations

- CAM5 C20C captures much of the multidecadal variability, more than the CESM1 LE
- CanAM4 AMIP has much lower variability than observations, similar to the CanESM2 LE.

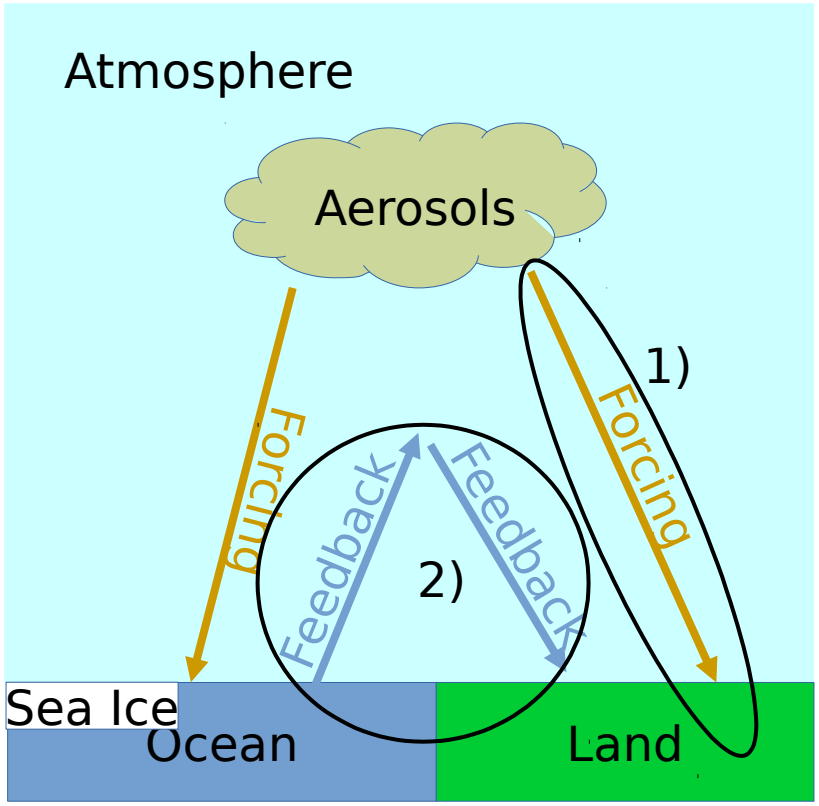


How do aerosols affect Sahel Climate?

The **Total Coupled Climate Response** can be conceptually divided into the**:**

1) Direct atmospheric response which is directly due to the radiative forcing

2) Ocean Mediated response which is mediated through slower forced SST and Sea Ice changes.



This Decomposition in Previous Work

Direct-Atmospheric

- Increasing local reflectance causes downwelling (e.g. Charney 1975)
- Teleconnected response to Asian emissions via Walker Circulation change (Dong et al., 2014)

Ocean-mediated

- Cooling of North Atlantic causes southward shift of the ITCZ (e.g. Biasutti and Giannini, 2006)
- Relative cooling of North Atlantic relative to global tropical oceans reduces convection (e.g. Biasutti and Kaplan, 2019)

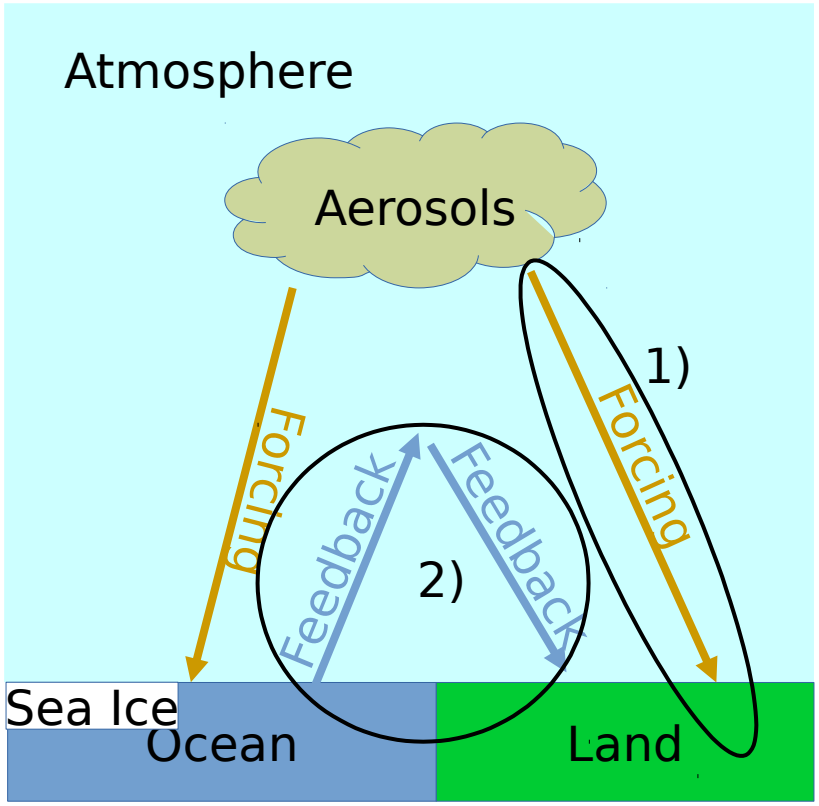
CAM5 AGCM Experiments

We run a set of time-slice CAM5 simulations and isolate the

1) Direct atmospheric response by changing aerosol emissions while keeping SST/SIC fixed

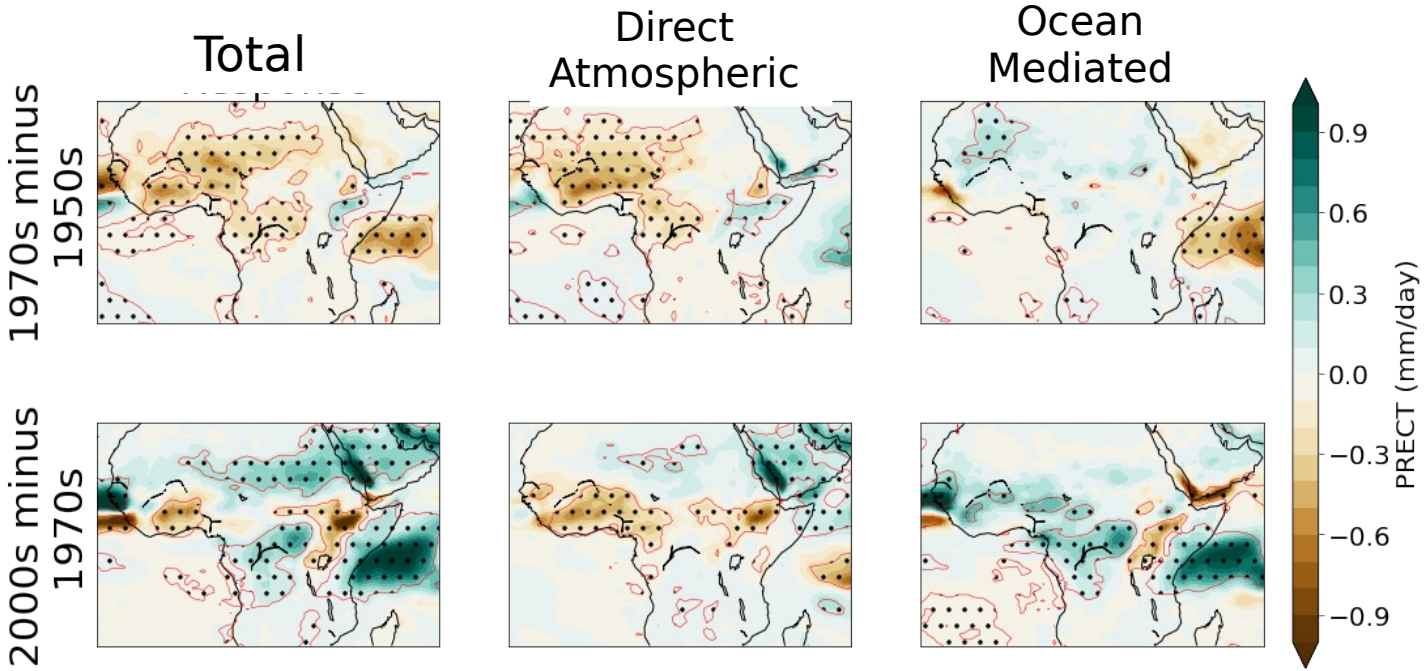
2) Ocean Mediated response by perturbing AGCM SSTs using the LE AER SST/SIC anomalies, while keeping emissions fixed.

For the 1970s minus 1950s and the 2000s minus 1970s



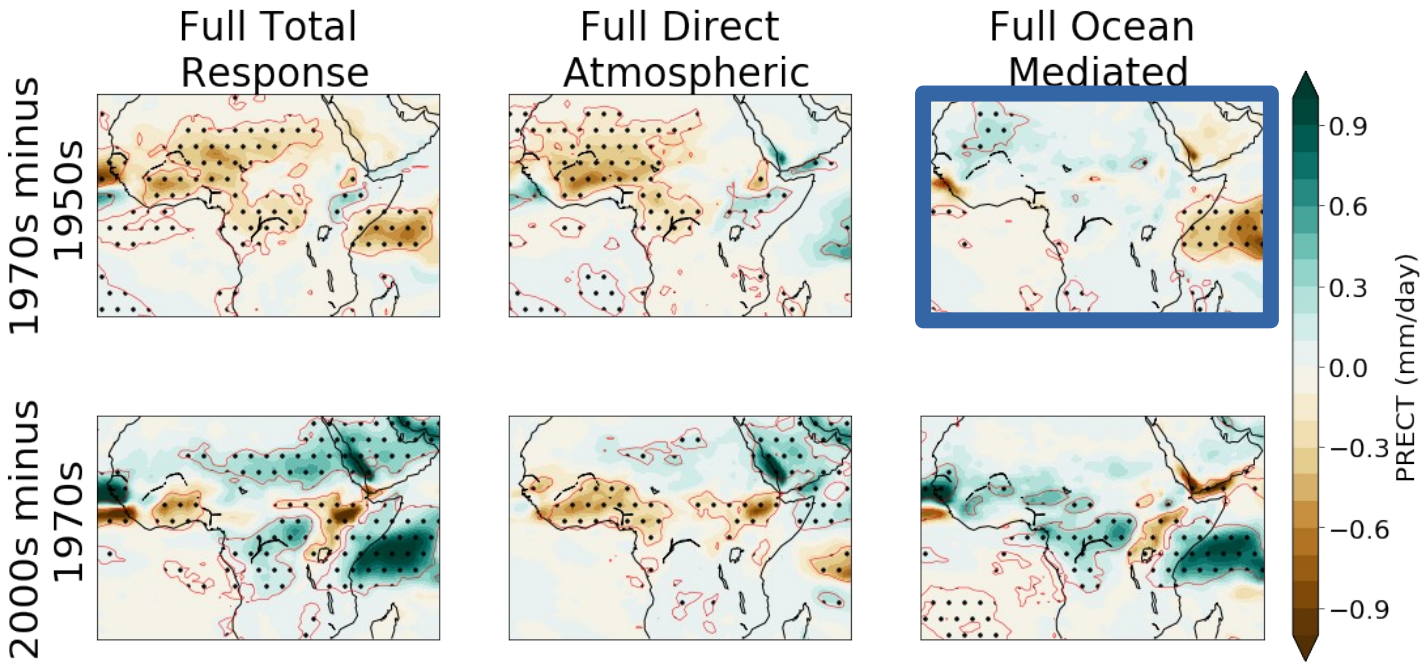
Decompose CESM1 Response using CAM5 AGCM simulations

- In CAM5, the 1970s minus 1950s drying direct-atmospheric and the 2000s minus 1970s recovery is ocean-mediated.



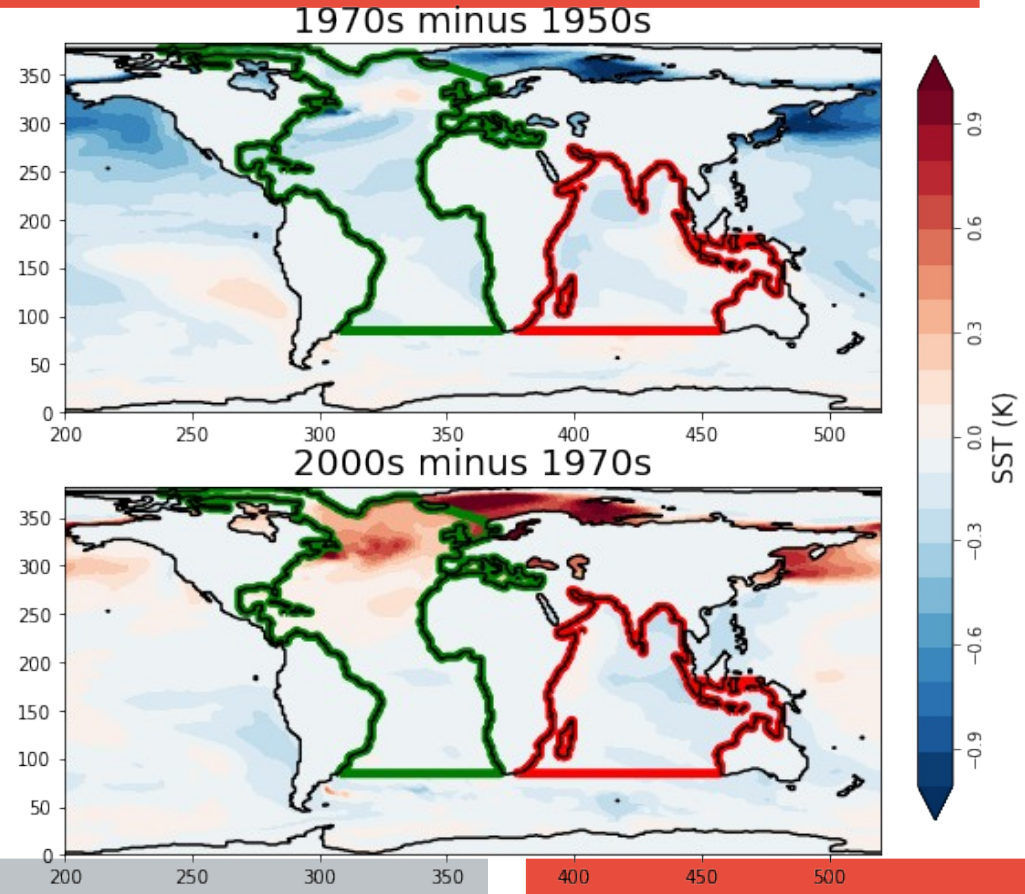
Puzzling CAM5 Results

- There is a notably weak 1970s minus 1950s Ocean-mediated response in spite of substantial SST change.



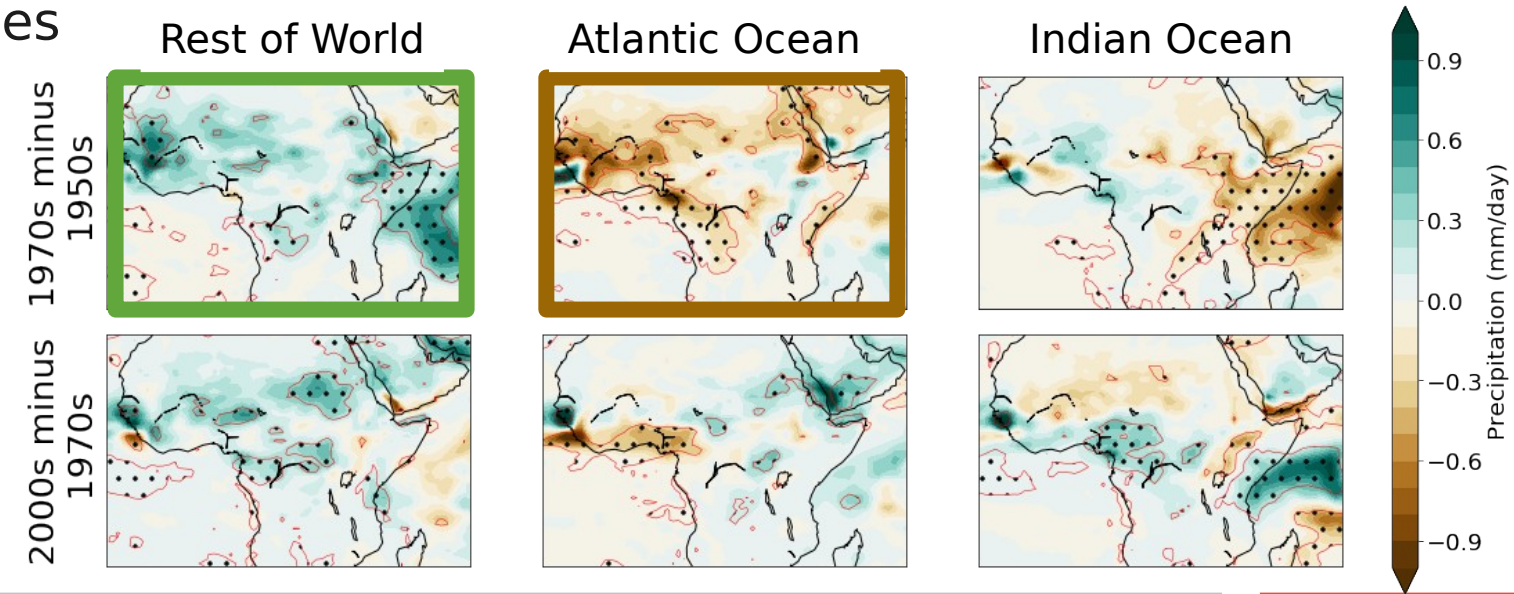
Response to Regional SST Anomalies

- We decompose the Ocean-Mediated response into the response to AA-forced SST anomalies in the
  - Atlantic (ATL, in Green)
  - Indian (IND, in Red)
  - Rest of World (ROW)



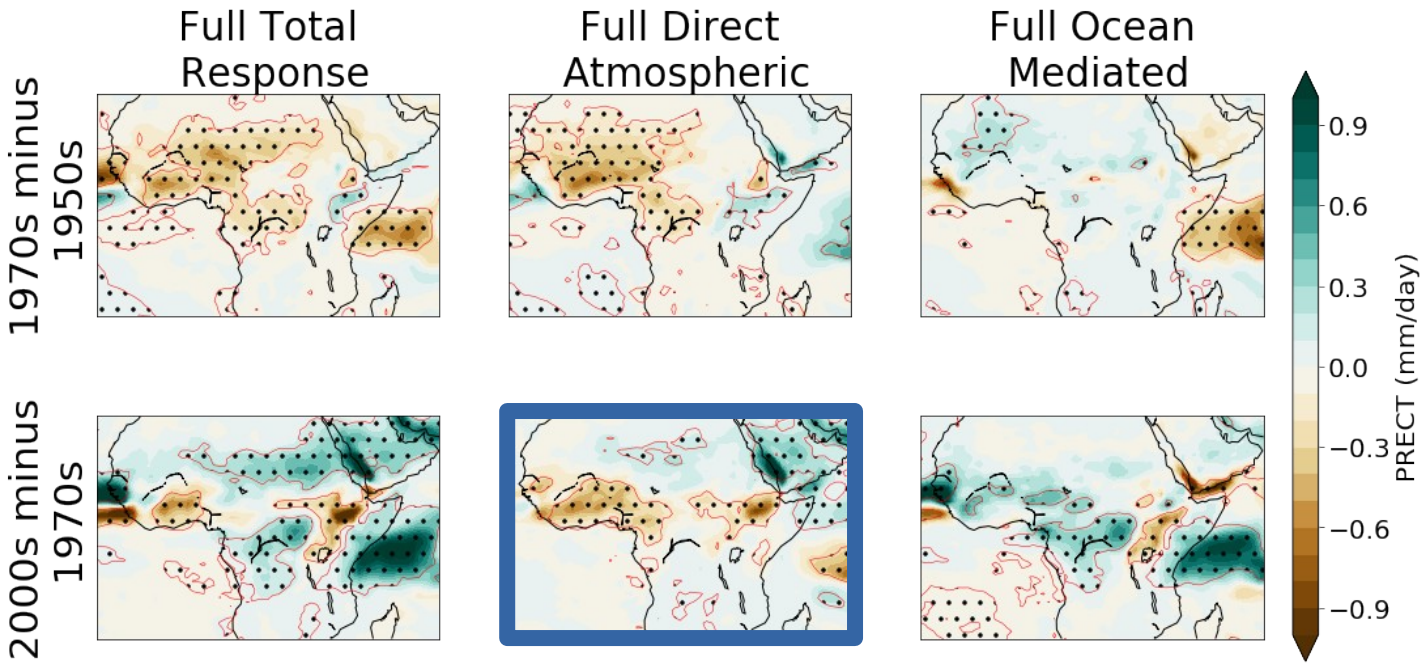
Why is there a weak 1970s minus 1950s Ocean-Mediated Response?

- Cancelling responses to Atlantic and Rest of the World (mainly Pacific) aerosol-forced SST anomalies anomalies
- Later 2000s minus 1970s recovery is mainly due to Pacific SST anomalies



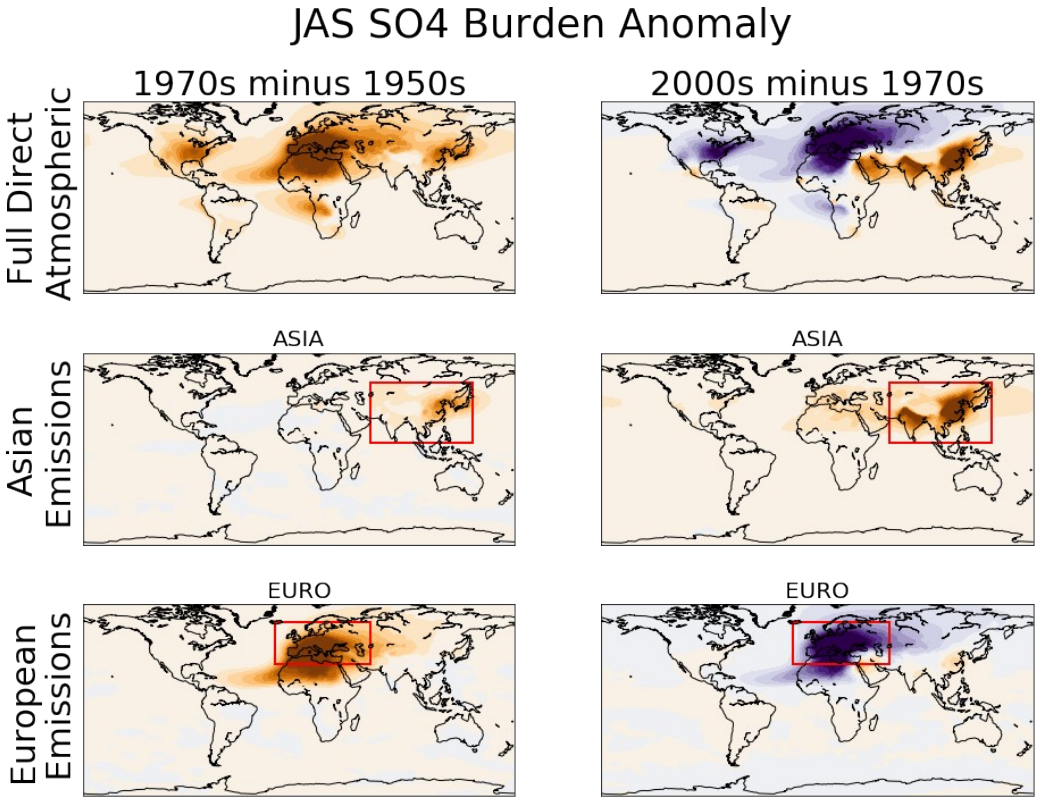
Second Puzzling CAM5 Results

- Direct-Atmospheric drying for the 2000s minus 1970s in spite of large decreases in European and North American emissions.



Response to Regional Emission Change

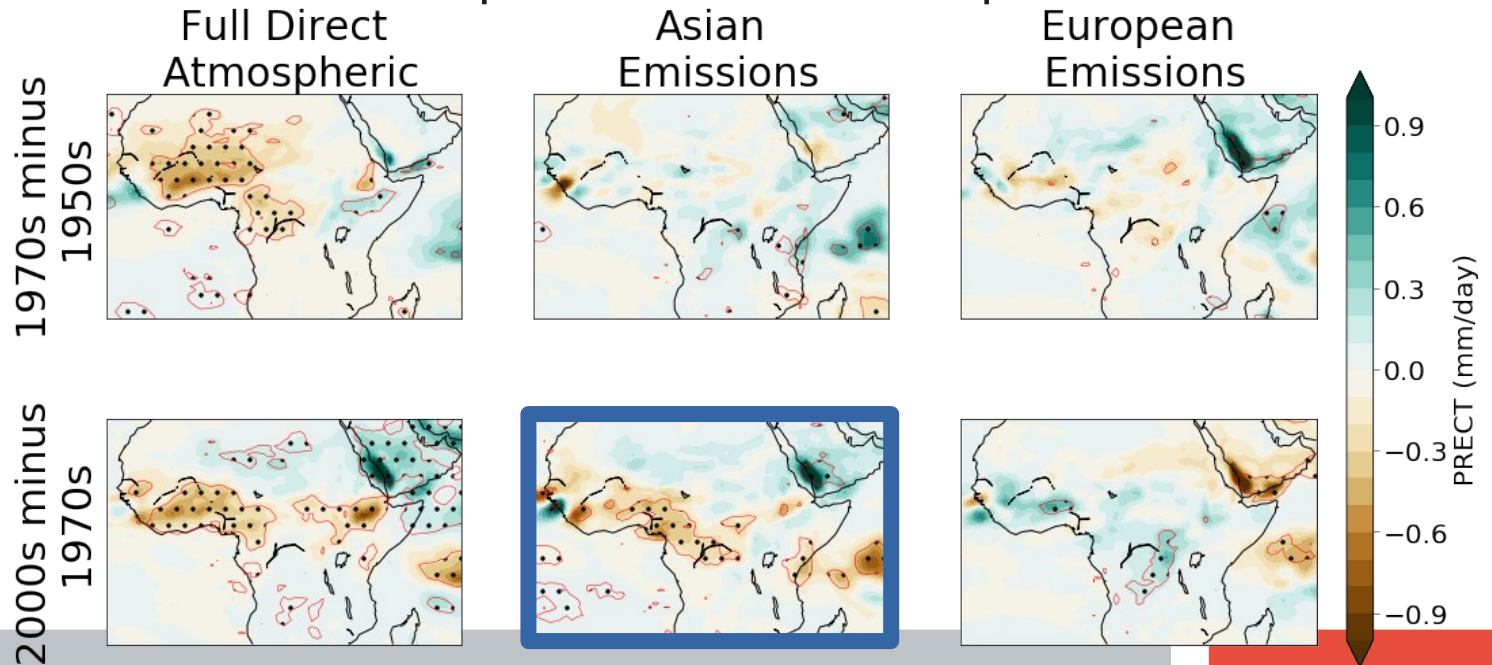
- We next isolate the Direct-Atmospheric response into the response to emissions from:
  - Asia
  - Europe



What are the effects of Asian and European Emissions?

2000s minus 1970s JAS drying in Coastal West Africa is indeed due to rising Asian Emissions.

Lack of 1970s minus 1950s response to Asian/European emissions.



Conclusions

- Aerosol forcing has a substantial influence on past Sahel precipitation in CESM1 and CanESM2.
- 1970s minus 1950s:
  - Drying is primarily a direct-atmospheric response, but source is as yet unclear
  - Lack of ocean-mediated effect due to cancellation from Atlantic and Pacific anomalies.
- 2000s minus 1970s:
  - Wetting is primarily an ocean-mediated response due to Pacific SST anomalies
  - Continued direct-atmospheric drying due to Asian emission increase

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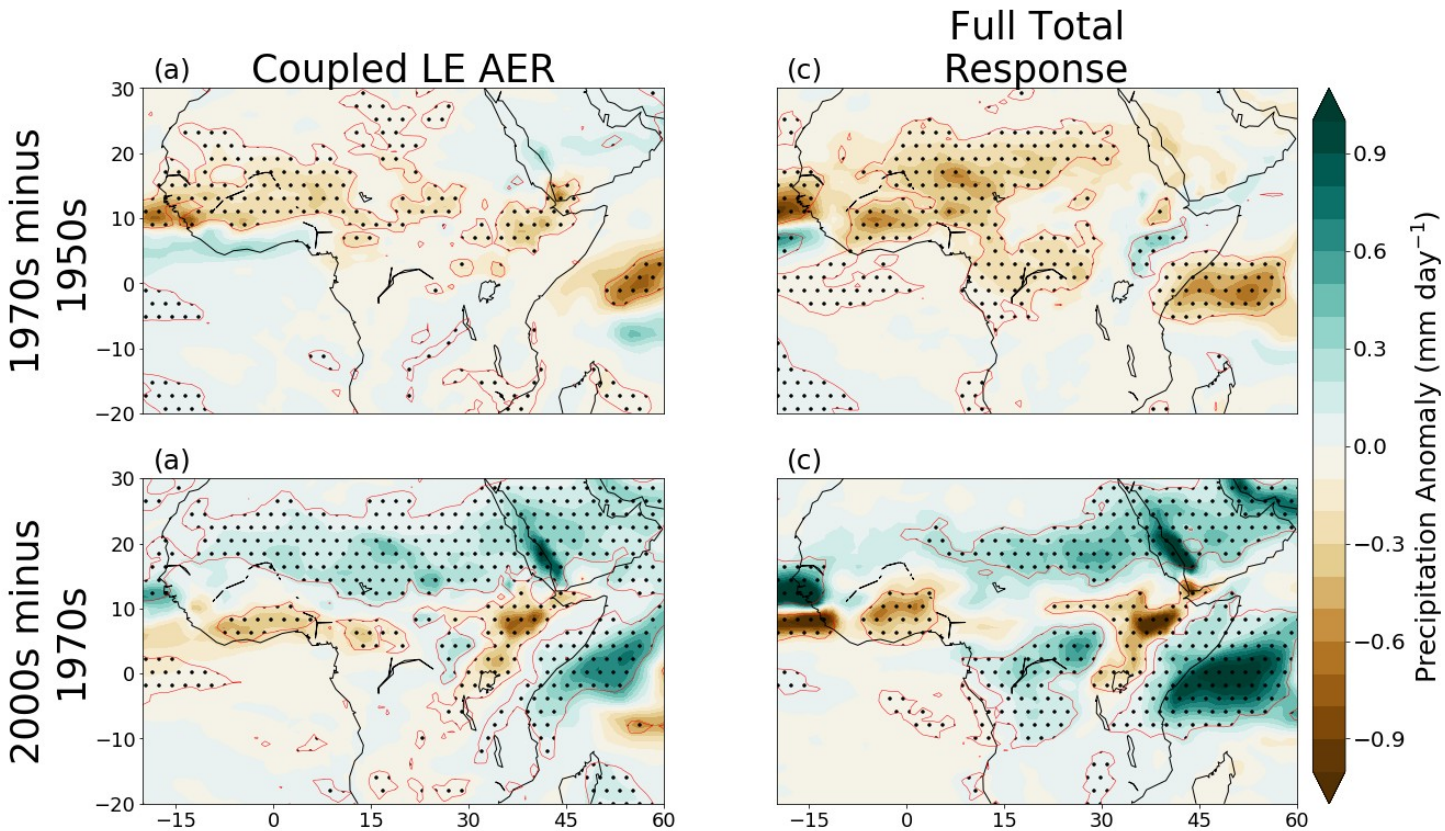
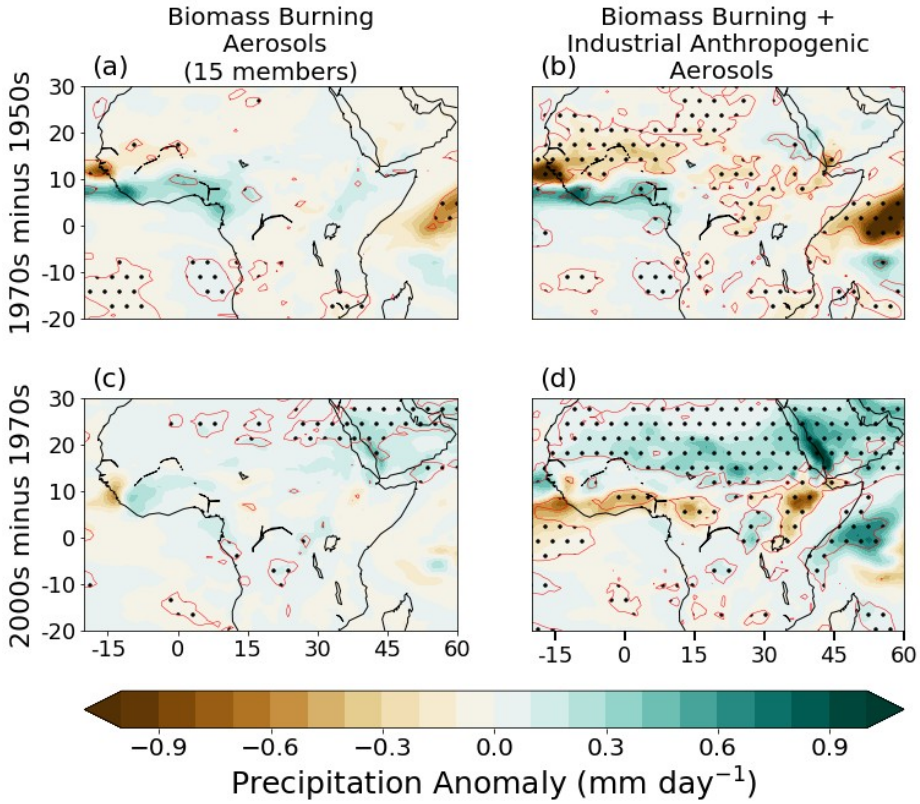
AGCMs Reasonably Reproduce LE Response



Effect of BMB Aerosols

BMB aerosols have a minor effect on the Sahel and largely act to amplify the effect of industrial aerosol forcing



CanAM4 results