Opposing, then complementary effects of Aerosol forced Atlantic and Pacific SST anomalies in 20th century Sahel precipitation

Haruki Hirasawa\textsuperscript{1}, Paul Kushner\textsuperscript{1}, Michael Sigmond\textsuperscript{2}, John Fyfe\textsuperscript{2}, and Clara Deser\textsuperscript{3}

\textsuperscript{1}University of Toronto
\textsuperscript{2}Canadian Centre for Climate Modeling and Analysis
\textsuperscript{3}National Center for Atmospheric Research
The Sahel in the 20th Century

- The Sahel is an arid region of North Africa
- Most rainfall occurs during the West African Monsoon, peaking in July-August-September (JAS)
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Aerosol Forcing Effect on the Sahel

- Historical aerosol forcing reduces rainfall in the Sahel region of Africa in coupled GCMs.
- This aerosol-forced drying is often interpreted as a response to hemispheric differences in SST cooling. [Ackerley et al., 2011]
- Sulphate forcing can cause drying even without SST change [Dong et al., 2014]
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Direct-Atmosphere vs. Ocean-Mediated Response

- We seek to clearly determine the effects of the:
  - **Ocean-mediated** (slow) response to aerosol forced SST change without emission changes
    - e.g. effect interhemispheric SST gradient
  - **Direct-Atmospheric** (fast) response to the aerosol emission changes without sea surface temperature (SST) change
    - e.g. rapid atmospheric response to European emissions
    - Radiation + cloud interactions, etc
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We conduct **timeslice CAM5** simulations to separately test the roles of these components of the response for the 1950s to 1970s and 1970s to 2000s.
**Timeslice Experiment Perturbations**

**Ocean-Mediated Response:**
Aerosol-forced JAS SST anomalies

- SST and SIC anomalies obtained from CESM1 ALL – XAER simulation
- Looking at short period, so LE is important to filter internal variability

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**Direct-Atmospheric response:**
JAS SO4 anomaly
Timeslice Experiment Perturbations

Ocean-Mediated Response: Aerosol-forced JAS SST anomalies

- All anthropogenic aerosol emissions are modified to target decade levels
- Includes sulphate and black carbon
- Omit fire emissions

Direct-Atmospheric response: JAS SO4 anomaly

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Direct Atmospheric Drying and Ocean-Mediated Recovery

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- The 2000s-1970s recovery is mainly ocean-mediated with some direct-atmospheric contribution.
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Breakdown of Direct-Atmospheric Response into Emission Regions

- We perform additional timeslice to separately test the effect of aerosol emissions from:
  - North America (Blue)
  - Europe (Purple)
  - Asia (Red)
  - Africa (Green)
Breakdown of Ocean-Mediated Response into Ocean Basin Anomalies

- We perform additional timeslice to separately test the effect of aerosol-forced SST + SIC anomalies in the:
  - Atlantic + Arctic Oceans (Orange)
  - Indian + Southern Oceans (Green)
  - Pacific Ocean (Purple)
- Focusing on the 1970s-1950s
- Showing results from selected experiments
1970s - 1950s Direct Atmospheric Drying

- 1970s-1950s emissions increase generally, with the strongest SO4 anomalies from Europe.
- BC declines in North America and West Europe, but increases in the rest of the world.
1970s - 1950s Drying is Due to North American Emissions

- European emissions have little effect on precipitation, despite causing SO4 increases over N Africa
- Instead, North American emissions cause the most drying
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Weak Shortwave Effect over the Sahara?

- European emissions have relatively weak impacts on clearsky SW radiation over the Sahara.
1970s - 1950s Weak Ocean Mediated Response

- General cooling due to SO4 forcing that is strongest in NH extratropics
- Strongest anomalies in Pacific ocean and weakest in Indian/Southern ocean.
Opposing influences of Atlantic and Pacific Cooling

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- Pacific cooling causes wettening
- Thus there is a cancelling effect of SST anomalies in the two basins
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Why does Pacific Cooling Increase Sahel Precipitation?

- Atlantic cooling reduces humidity input into the monsoon, reducing precipitation
- Wetting driven by Pacific cooling suggests an “upped-ante” like mechanism [Giannini et al., 2013]
  - Tropical Pacific Cooling
  - Cooling of tropical upper troposphere
  - Reduced threshold for convection in Africa
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Summary of 1970s - 1950s Sahel Precipitation Responses

- The sum of the Sahel averaged responses from the regional simulations is similar to the total simulation response.
- However, the sum is quite noisy.
Summary of 2000s-1970s Sahel Precipitation Responses

- In the 2000s – 1970s, African emissions reduces Sahel precipitation.
- Atlantic SST warming now causes increased precipitation.
- Continued increases due to Pacific SST, perhaps due to cooling in the tropical west Pacific.
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Summary

- Mechanisms of aerosol-forcing effect on Sahel precipitation change with time and spatial pattern.

- 1970s - 1950s drying is direct-atmospheric and is mainly caused by remote North American emissions.

- Opposing effects of Atlantic and Pacific anomalies in the 1970s – 1950s

- Complementary effects from the basins in the 2000s-1970s.
References


Supplementary: Definitions for ocean basin regions
Sahel Averaged Anomalies

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All Regional SST Perturbation Precipitation Responses

Regional SST Perturbation JAS Precipitation

1970s minus 1950s

Total

Atlantic

Indian

Pacific

2000s minus 1970s

Precipitation (mm/day)
MSE for all basins

Regional SST Perturbation Zonal Mean JAS MSE

Total

Atlantic

Indian

Pacific

1970s minus 1950s

2000s minus 1970s

Precipitation (mm/day)

MSE (°C)
Regional SST Additivity

• Summing the response to different basins does not reproduce the overall response, but this may be due to internal variability
All emission regions
Effect of timeslice run length on Sahel regional average
Changing Sign as Atlantic SSTs Warm

For the 2000s-1970s, aerosol forcing warms the North Atlantic SST, reversing the previous drying signal.
Why does Pacific Cooling Increase Sahel Precipitation?

- In the 2000s-1970s, the warming North Atlantic results in greater moisture supply to the monsoon.
- The western tropical Pacific sees additional though weak cooling which may be driving more Sahel wetting.

- 2000s-1970s Guinean Coast drying occurs as a teleconnected response to increasing Asian emissions
- Southwest Sahel drying occurs due to local African emission increase