Attribution of Sahel Rainfall Variability: What Can Flawed Models Teach Us?

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Sahel Rainfall Variability/Trends

Continental & multidecadal changes in rainfall accumulation and characteristics

(Taylor et al. 2017)
What are the Causes of Sahel Rainfall Variations?

**Anthropogenic Forcing**

**GHG**
- Overall warming and moistening
- Regional warming: Mediterranean (+); North Atlantic (+); Indian (−)
- Warming land: Strengthening/shift the SHL

**Aerosol**
- Overall cooling and drying
- Hemispheric cooling: Reflecting solar energy off the Northern Hemisphere
- Cooling land: Weakening/shift the SHL

**Natural External Forcing**

**Volcanism**
- Like Anthropogenic Aerosol – depending on location of eruption

**Natural Internal SST Variability**

**AMOC**
- Creates a N/S gradient in the Atlantic SST
Two approaches:

How well do the single-forcing CMIP5 experiments capture the evolution of Sahel summer rainfall?

(Herman, Giannini, Biasutti, and Kushnir; Scientific Reports, 2020)

How well do observations show the fingerprint of individual forcings?

(Marvel, Biasutti, and Bonfils; ERL, 2020)
External forcings significantly shaped 20$^{th}$ century variations in total Sahel rainfall.

The MMM Sahel rainfall forced by all historical forcings correlates with the observed Sahel at $\sim 0.4$.

For comparison: AMIP runs reach at most 0.7

Bootstrapping confirms the significance.
Anthropogenic & Volcanic aerosols forcings dominated 20\textsuperscript{th} century variations in total Sahel rainfall

GHG-forced variations are indistinguishable from noise

Variations forced by Anthropogenic Aerosols or by Natural Forcing are significantly correlated with observed history.

We confirm with the full CMIP5 ideas in: Rotstayn & Lohmann, 2002; Biasutti & Giannini, 2006; Ackerley et al., 2011; Booth et al., 2012; Hwang et al., 2013; Heywood et al. 2013
Good correlation, but much lower variance.

1. Standardized forced anomalies show a good match to drying and recovery

2. The variance of the (dimensional) forced anomalies is very small
Good correlation, but much lower variance... is an odd combination

\[ P_o = \alpha P_{\text{MMM}} + \varepsilon \]

\[ r(P_o, P_{\text{MMM}}) \cong 0.4 \]

**AND**

\[ \sigma_o = \beta \sigma_{\text{MMM}}, \beta \cong 8 \]

If \( \alpha = 1 \) => \( r(\varepsilon, P_{\text{MMM}}) \cong 0.2^* \)

Either the noise is correlated with the forced signal at 0.2 by chance

If \( r(\varepsilon, P_{\text{MMM}}) = 0 \) => \( \alpha \cong 2.8 \)

Or the forced signal is underestimated by CMIP5 by a factor of 3.
Two approaches:

How well do the single-forcing CMIP5 experiments capture the evolution of Sahel summer rainfall?

(Herman, Giannini, Biasutti, and Kushnir; Scientific Reports, 2020)

How well do observations show the fingerprint of individual forcings?
In the 20th century? In the 21st?

(Marvel, Biasutti, and Bonfils; ERL, 2020)
We build a multi-variate “fingerprint” to include characteristics of the rainy season beyond accumulation.

What is the distribution of rainfall across the season? (onset/peak/cessation)

What is the distribution of rainfall across the Sahel? (east/west)

What is the day-to-day distribution of rainfall? (wet/dry spells; frequency/intensity)
The two fingerprints are orthogonal: correlation <0.05
Each captures the effect of a single forcing

**20th century**

dominated by aerosols

(Confirmed using single forcing experiments)

**21st century**

dominated by greenhouse gases

(Confirmed using single forcing experiments)
Finding the signal in one realization (or observations)

Projection onto model fingerprint

Realization/Observations

Slides courtesy of Ben Santer, LLNL
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The signature of GHG forcing in CMIP5

- The trends in the projection on the GHG fingerprint should have emerged from noise in 2017.
The signature of GHG forcing in observations

- The Observations show an influence of the GHG forcing much earlier.
The signature of Aerosols forcing in CMIP5

• The Aerosol fingerprint in CMIP% gets more prominent up to the 70s-80s.
• It becomes detectable in 1982
• Uncertainty grows in the 21st century (as the forcing weakens)
The Observations response to aerosols is outside the CMIP5 envelope

We can’t say if noise or response is underestimated (degenerate fingerprints)
It’s significant: Sahel rainfall over the 20th century has responded to
volcanic eruptions
anthropogenic aerosols
greenhouse gases (**only clear from multi-variate analysis)
The GHG is getting stronger in the 21st century

The aerosol signal is detectable (outside internal variability) but not
attributable (incompatible with models).

CMIP5 underestimates the response to forcings (or it has weak internal
variability AND observed noise correlated with Aerosol forcing).

CMIP6 models have the same problem – we need a smarter approach!