Attribution of Sahel Rainfall Variability:

What Can Flawed Models Teach Us?

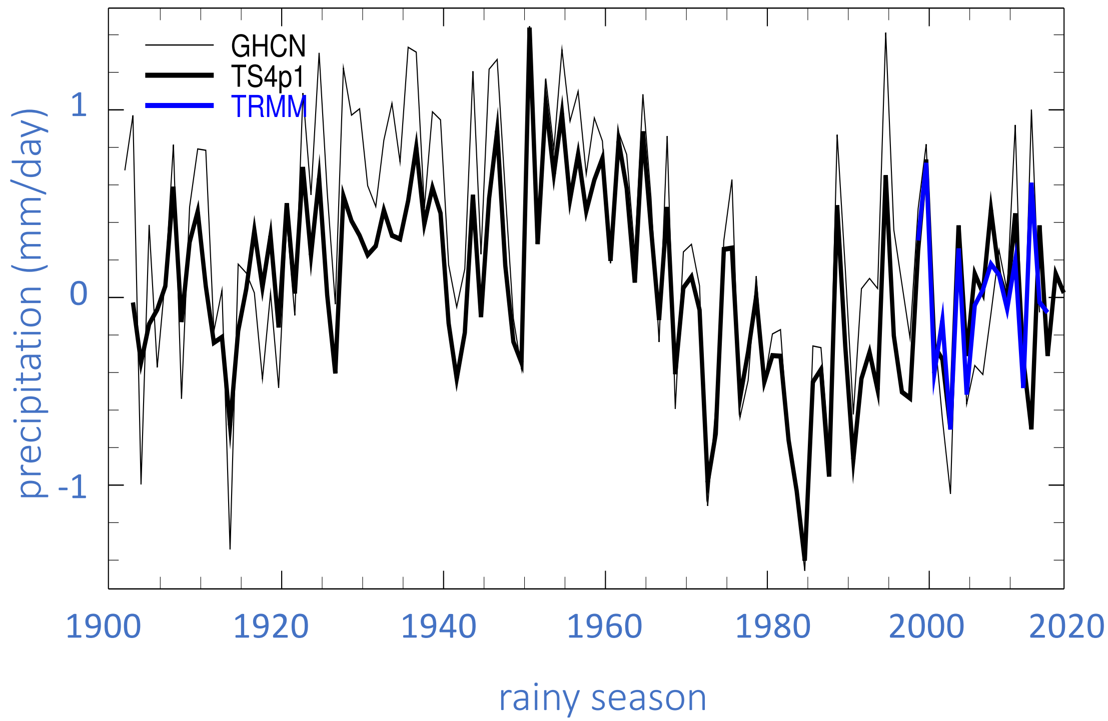
Michela Biasutti

(she/her)

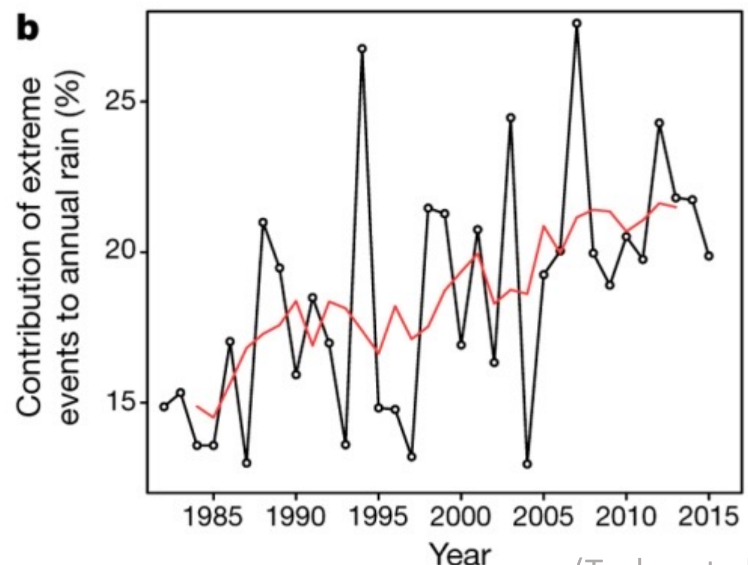
Kate Marvel, Rebecca Herman, Yochanan Kushnir, and Alessandra Giannini

AMS100

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/shifting the SHL

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

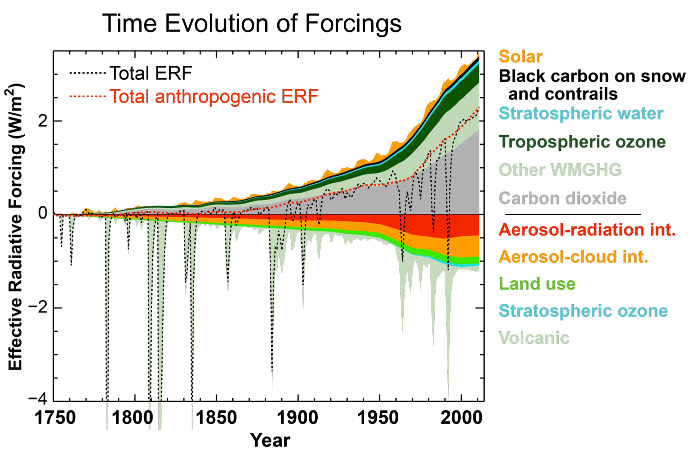
Natural External Forcing

Volcanism — Like Anthropogenic Aerosol – depending on location of eruption

Natural Internal SST Variability

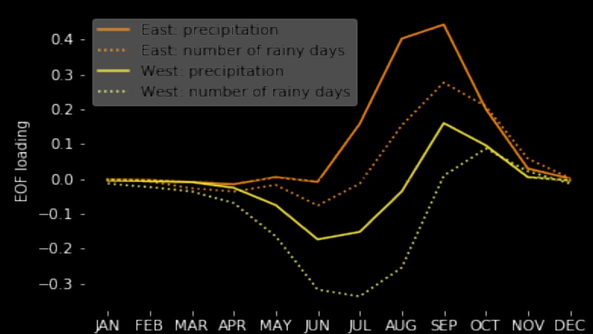
AMOC — Creates a N/S gradient in the Atlantic SST

Two approaches:



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

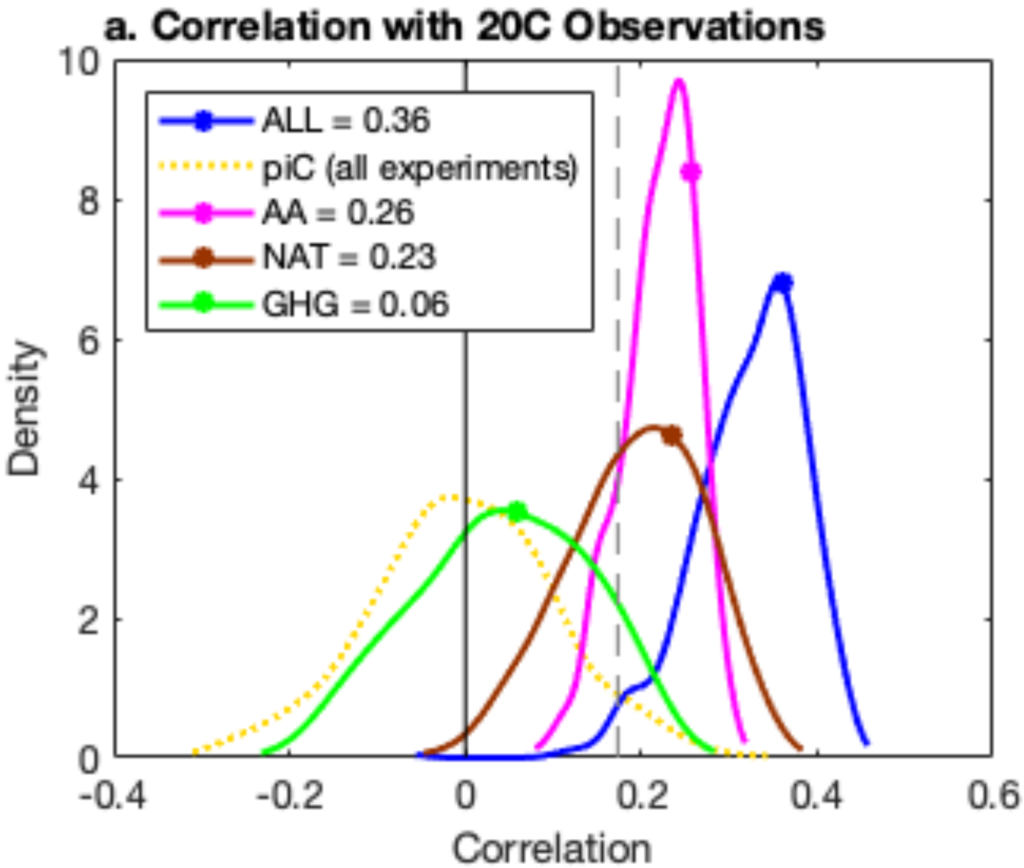
(Herman, Giannini, Biasutti, and Kushnir; Scientific Reports, 2020)



How well do observations show the fingerprint of individual forcings?

(Marvel, Biasutti, and Bonfils; ERL, 2020)

External forcings significantly shaped 20th century variations in total Sahel rainfall

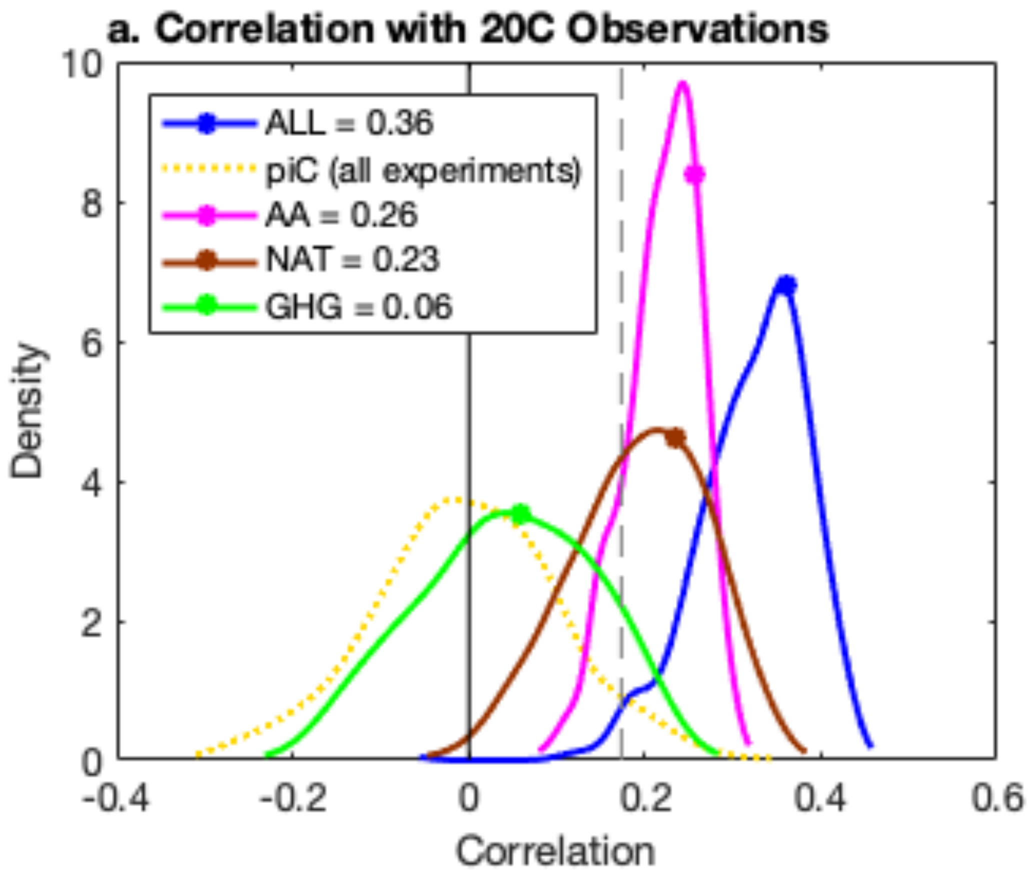


The MMM Sahel rainfall forced by all historical forcings correlates with the observed Sahel at ~ 0.4.

For comparison: AMIP runs reach at most 0.7

Bootstrapping confirms the significance.

Anthropogenic & Volcanic aerosols forcings dominated 20th century variations in total Sahel rainfall



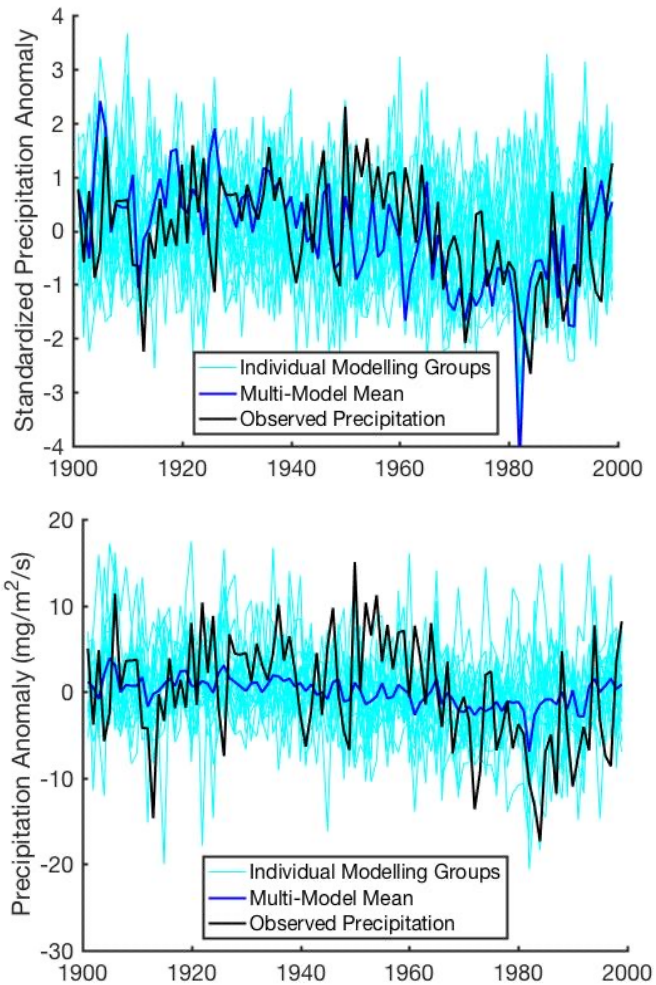
GHG-forced variations are indistinguishable from noise

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

$P_o = \alpha\, P_{MMM} + \varepsilon$

$r\,(P_o, P_{MMM}) \cong 0.4$

AND

$\sigma_o = \beta\, \sigma_{MMM}\ ,\ \beta \cong 8$

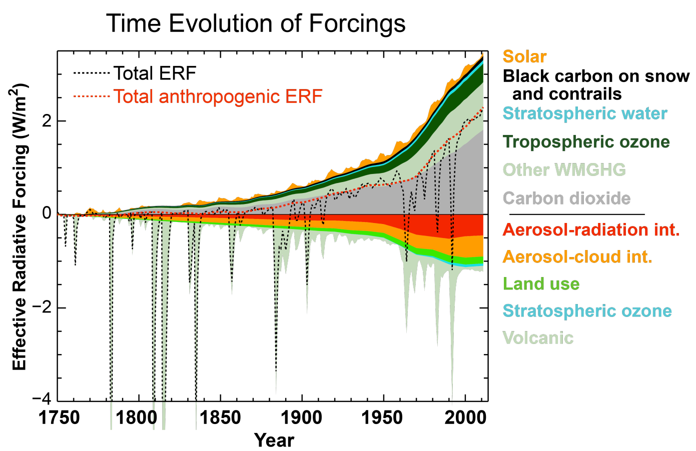
If α=1 => $r(\varepsilon, P_{MMM}) \cong 0.2$*

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

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

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

Two approaches:



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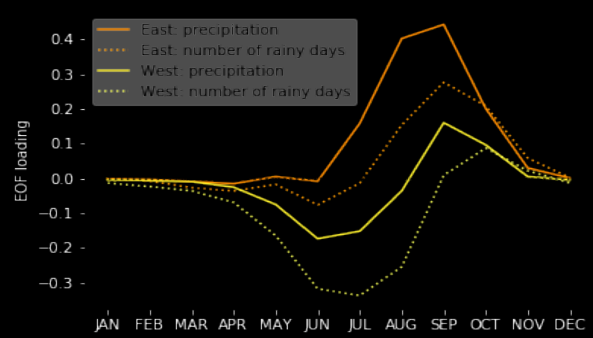


How well do observations show the fingerprint of individual forcings?
In the 20th century? In the 21st?

(Marvel, Biasutti, and Bonfils; ERL, 2020)

We build a multi-variate "fingerprint" to include characteristics of the rainy season beyond accumulation

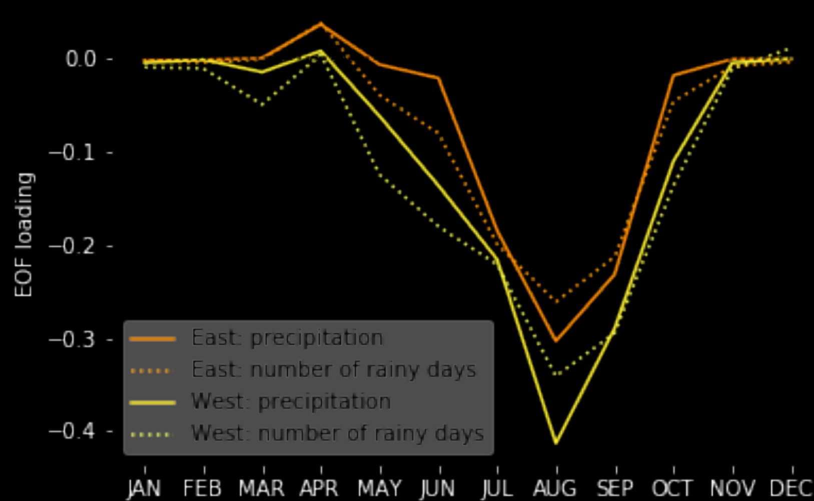
What is the distribution of rainfall across the season?
(onset/peak/cessation)

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

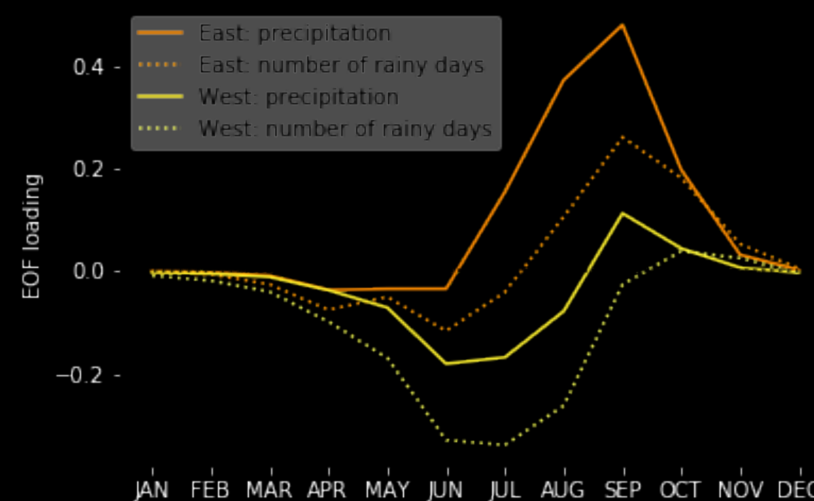
What is the day-to-day distribution of rainfall?
(wet/dry spells; frequency/intensity)

Non stationary fingerprint: split 20th and 21st centuries

20th century



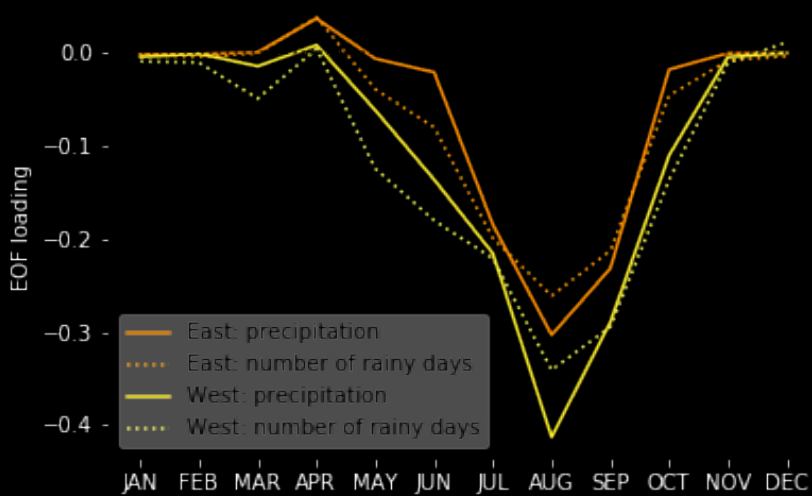
21st century



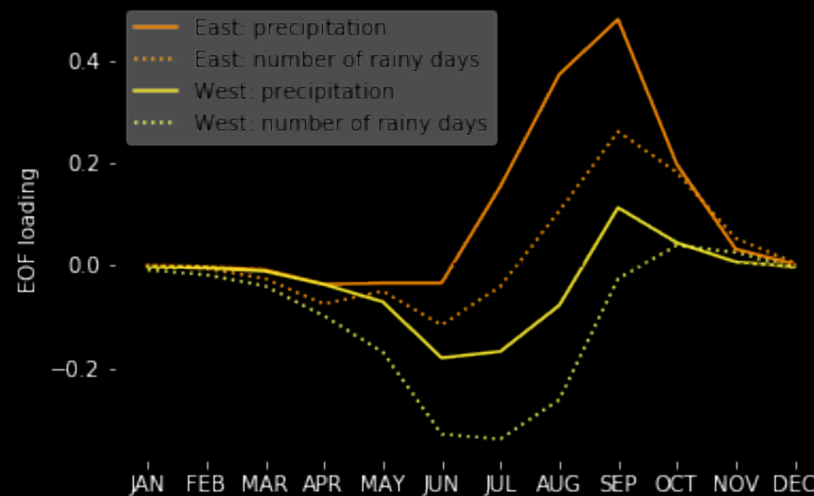
The two fingerprints are orthogonal: correlation <0.05

Each captures the effect of a single forcing

20th century



21st century



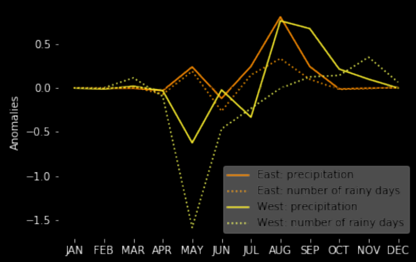
dominated by aerosols

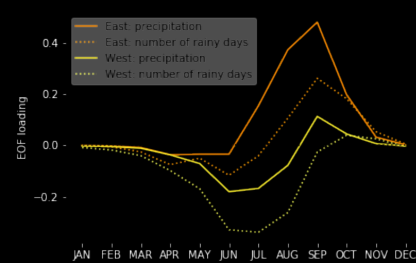
dominated by greenhouse gases

(confirmed using single forcing experiments)

Finding the signal in one realization (or observations)

Realization/Observations





Projection onto model fingerprint

Slides courtesy of Ben Santer, LLNL

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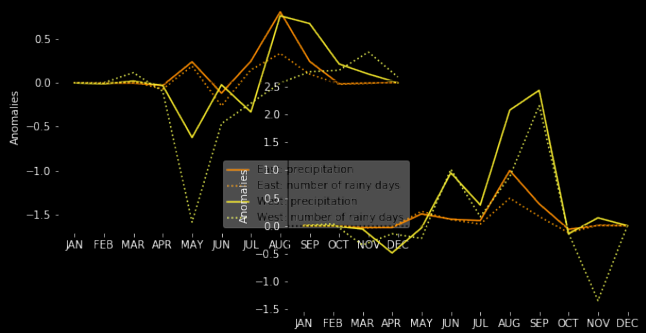

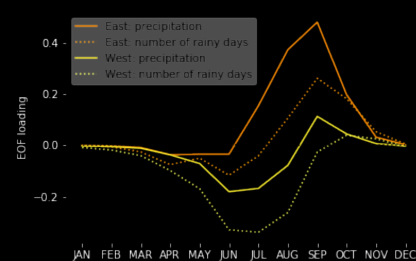

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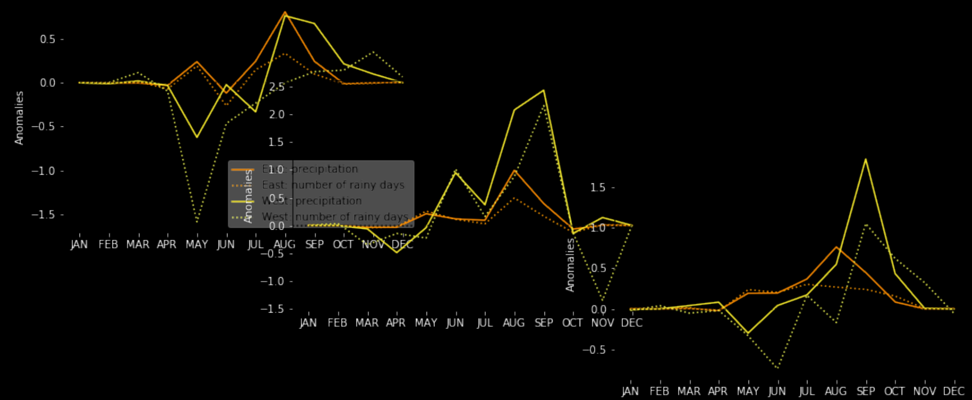

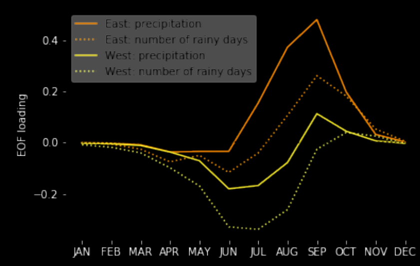

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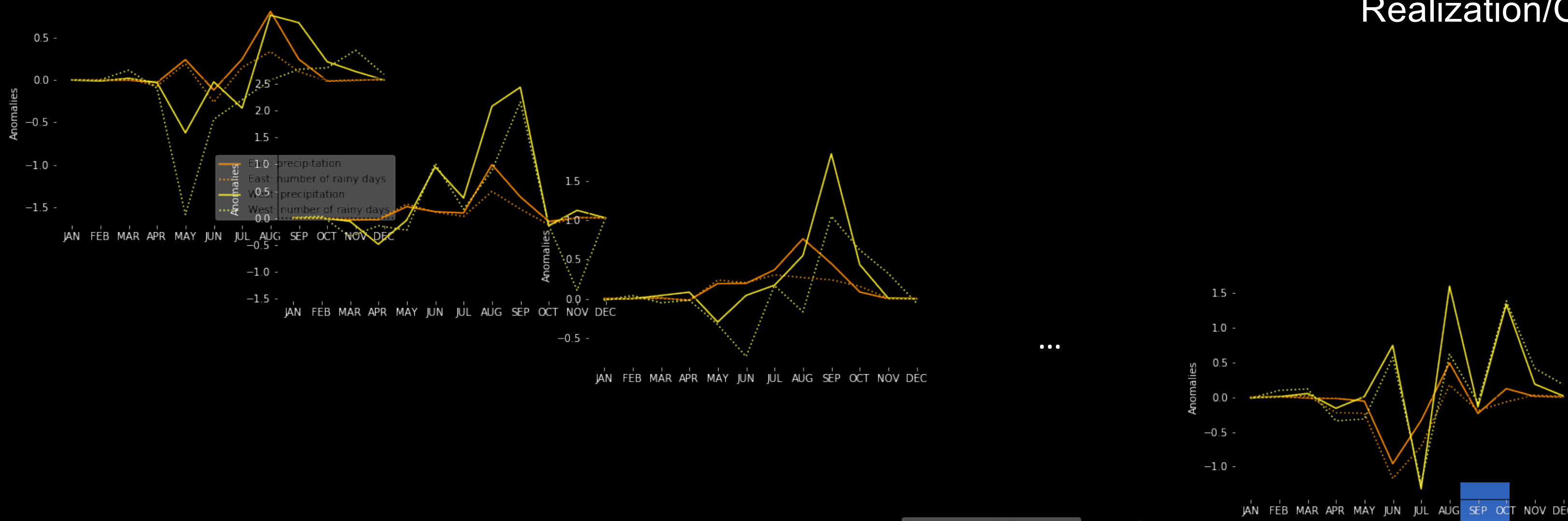

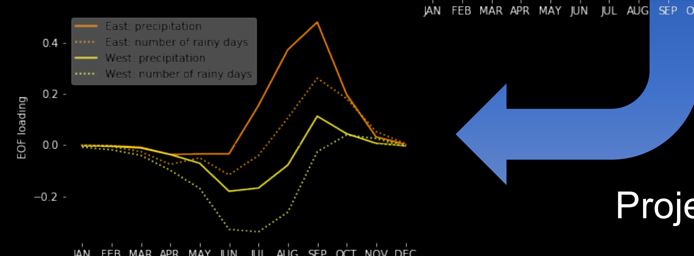

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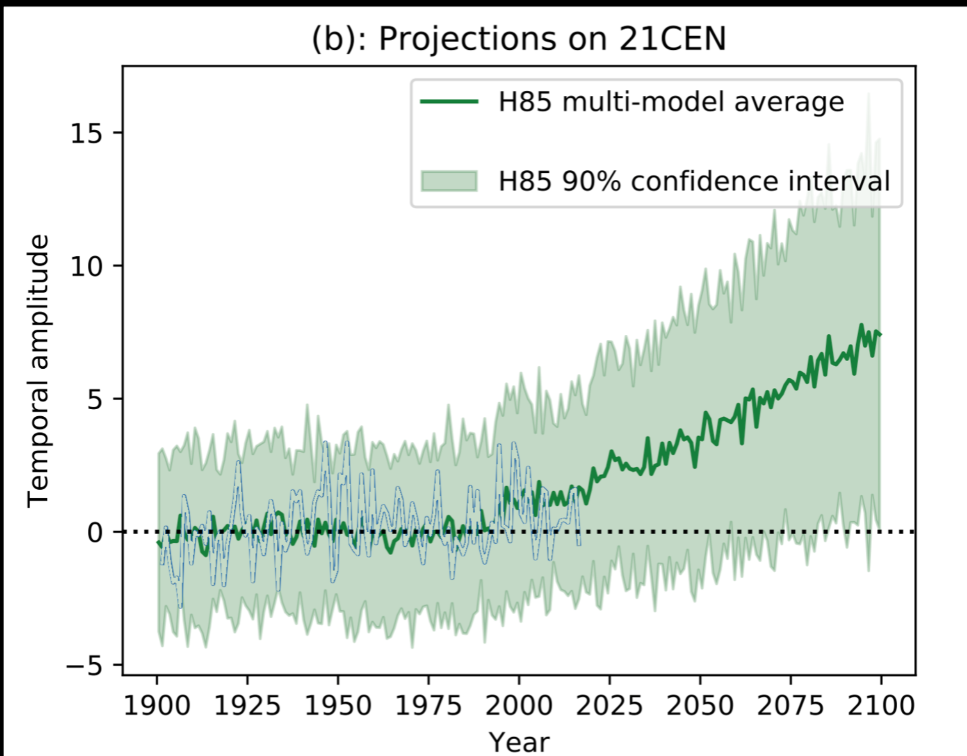
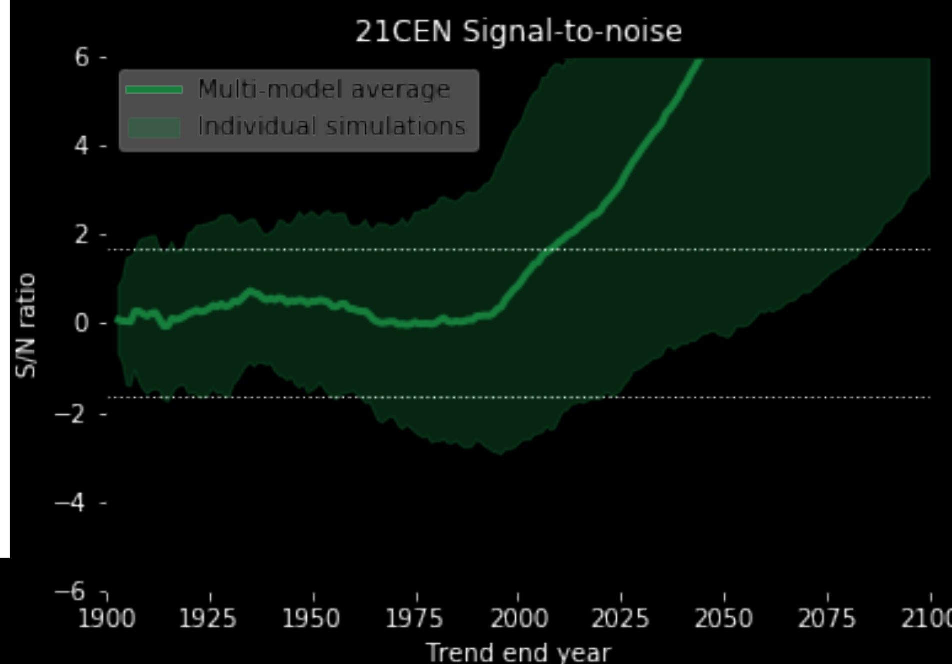
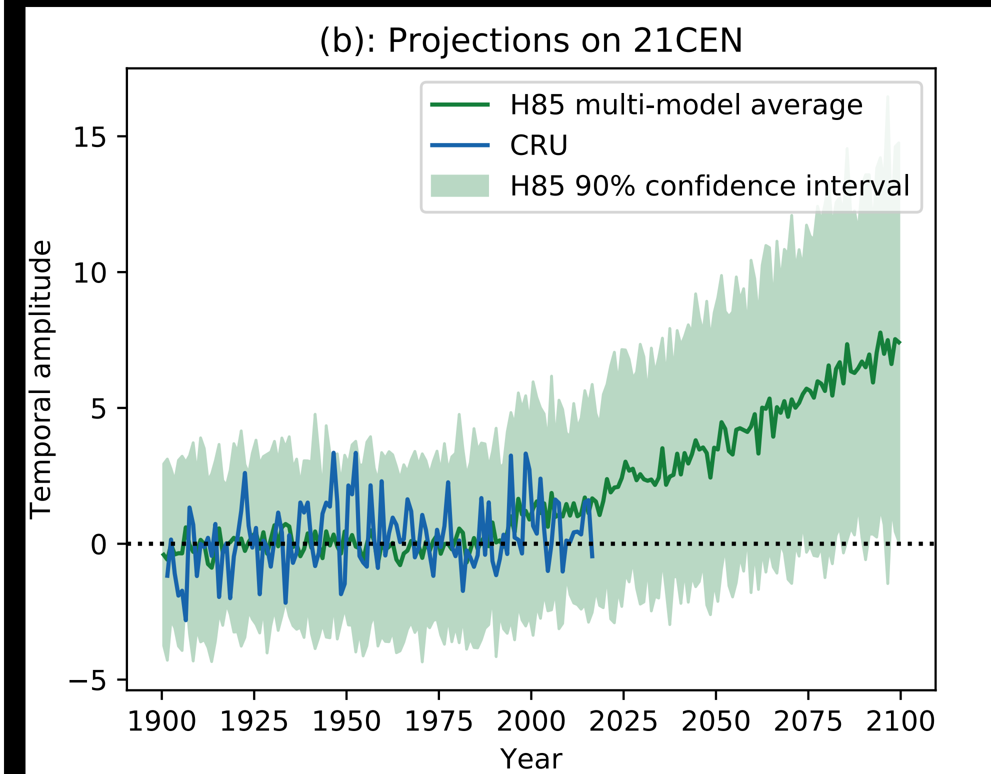
The signature of GHG forcing in CMIP5



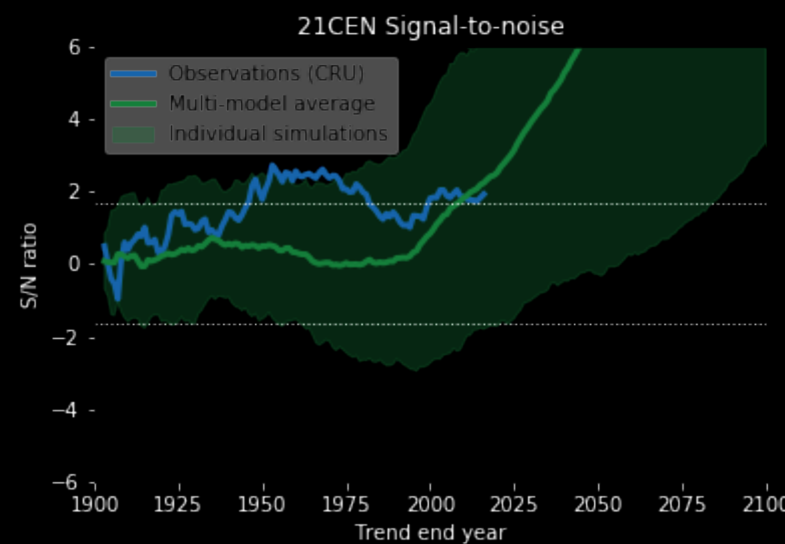
- The trends in the projection on the GHG fingerprint should have emerged from noise in 2017.



The signature of GHG forcing in observations

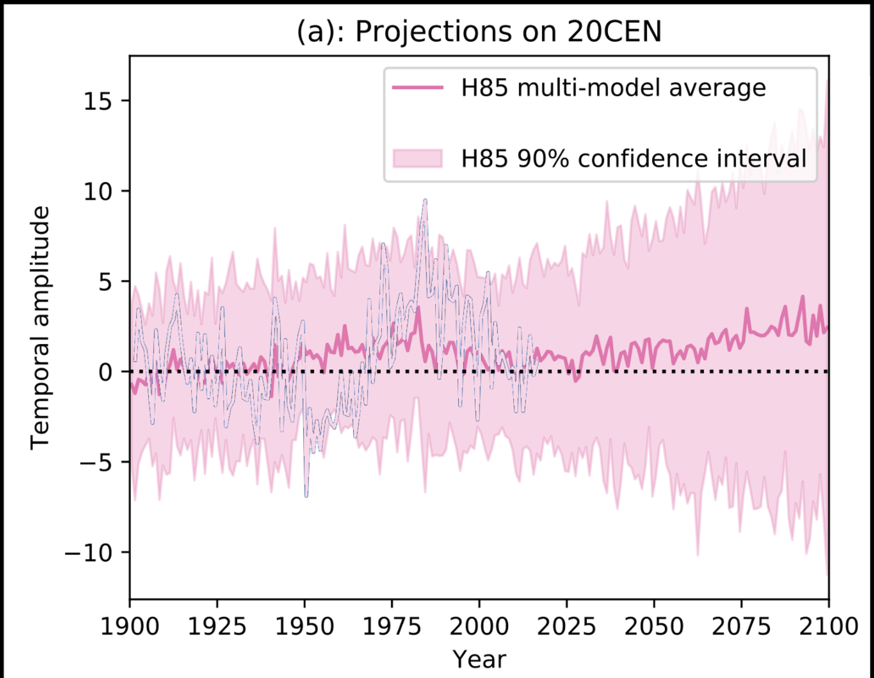


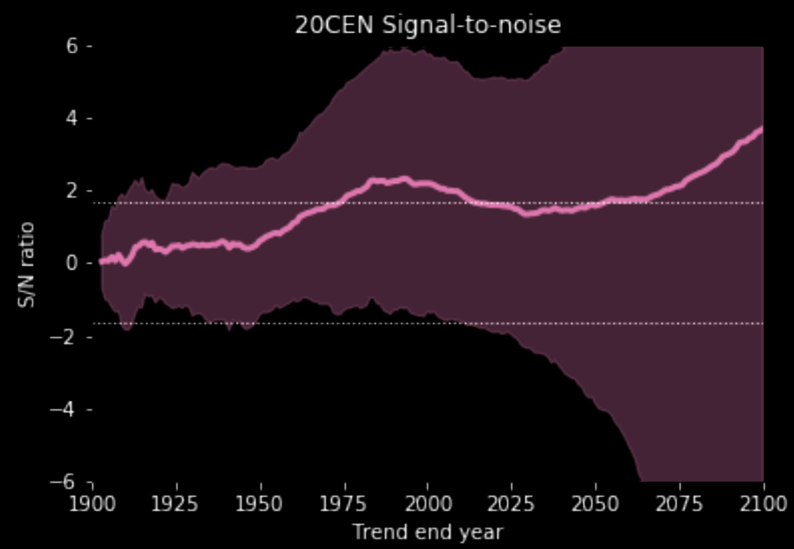
- The Observations show an influence of the GHG forcing much earlier.



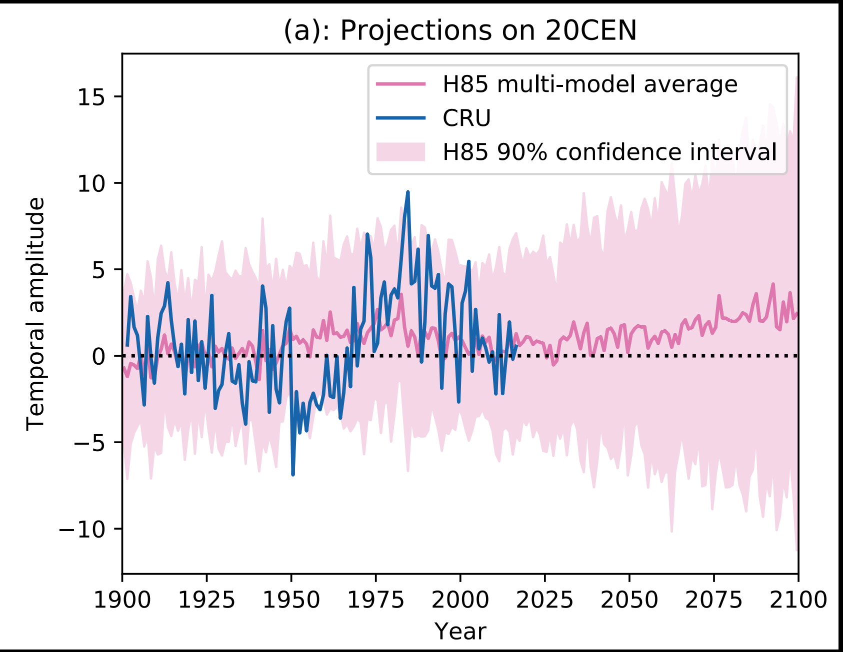
The signature of Aerosols forcing in CMIP5

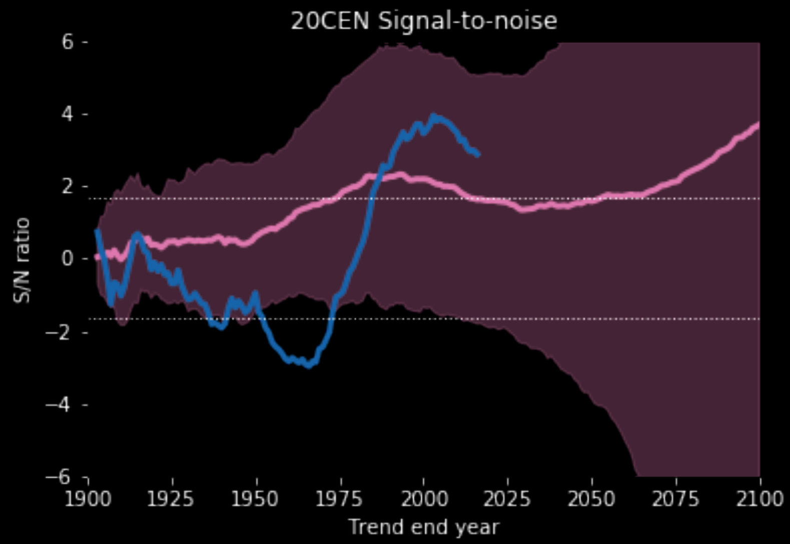
- The Aerosol fingerprint in CMIP% gets more prominent up to the 70s-80s.
- It becomes detectable in 1982
- uncertainty grows in the 21st century (as the forcing weakens)





The signature of Aerosols forcing in Observations





- The Observations response to aerosols is outside the CMIP5 envelope
- We can’t say if noise or response is underestimated (degenerate fingerprints)

Conclusions

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!