Climate Change in the Sahel: the past and the future

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Image: NASA

Climate Change in the Sahel:

The past

How did the climate of the Sahel vary over the last century?

What were the proximate causes of droughts and pluvials of the 20th century?

What was the ultimate cause: natural variability or anthropogenic forcing?

The future

What are the projections of Sahelian climate?

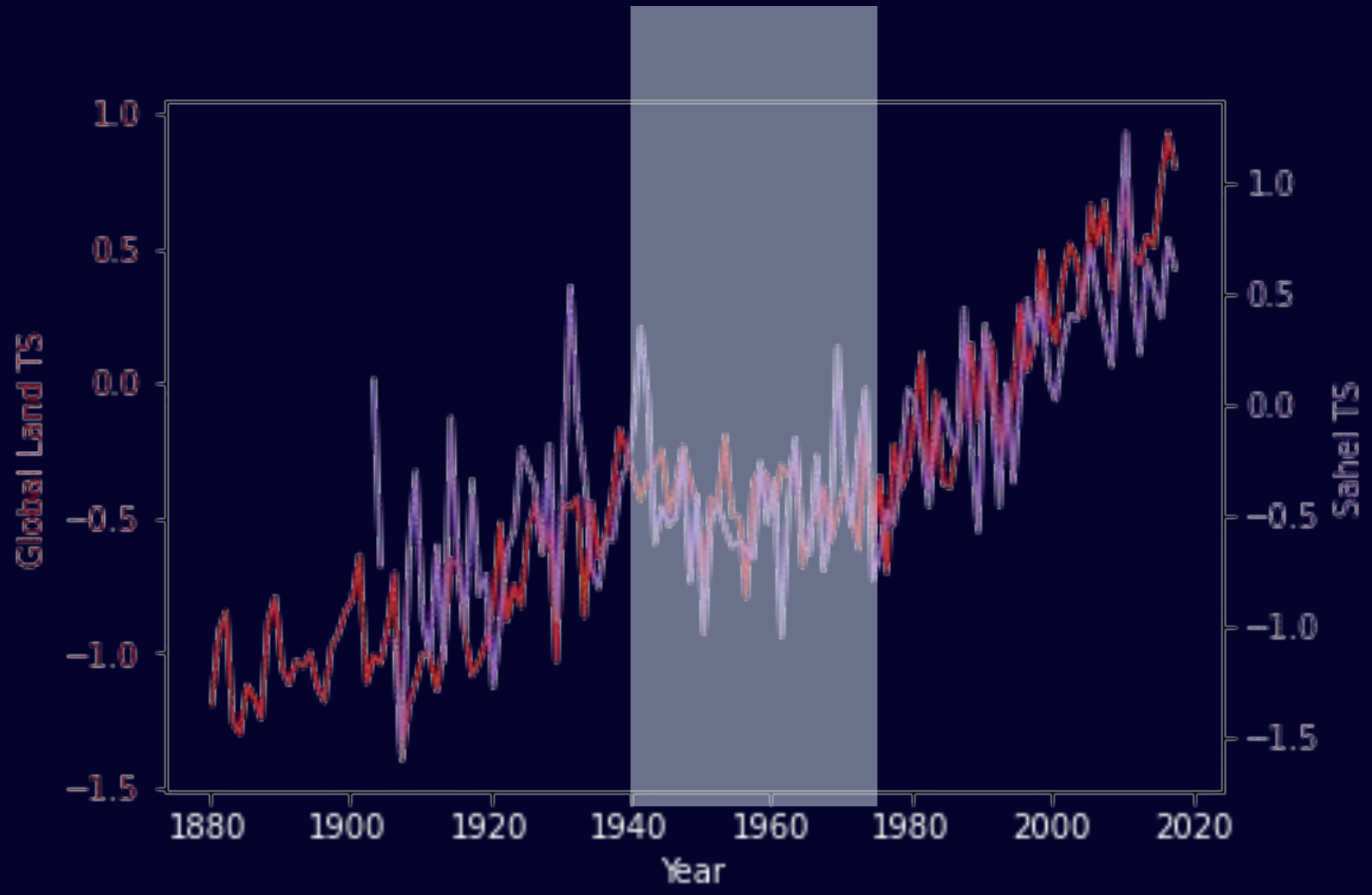
The response

How can we make progress?

Observed Sahel Surface Temperature Anomalies

SAHEL

GLOBAL LAND

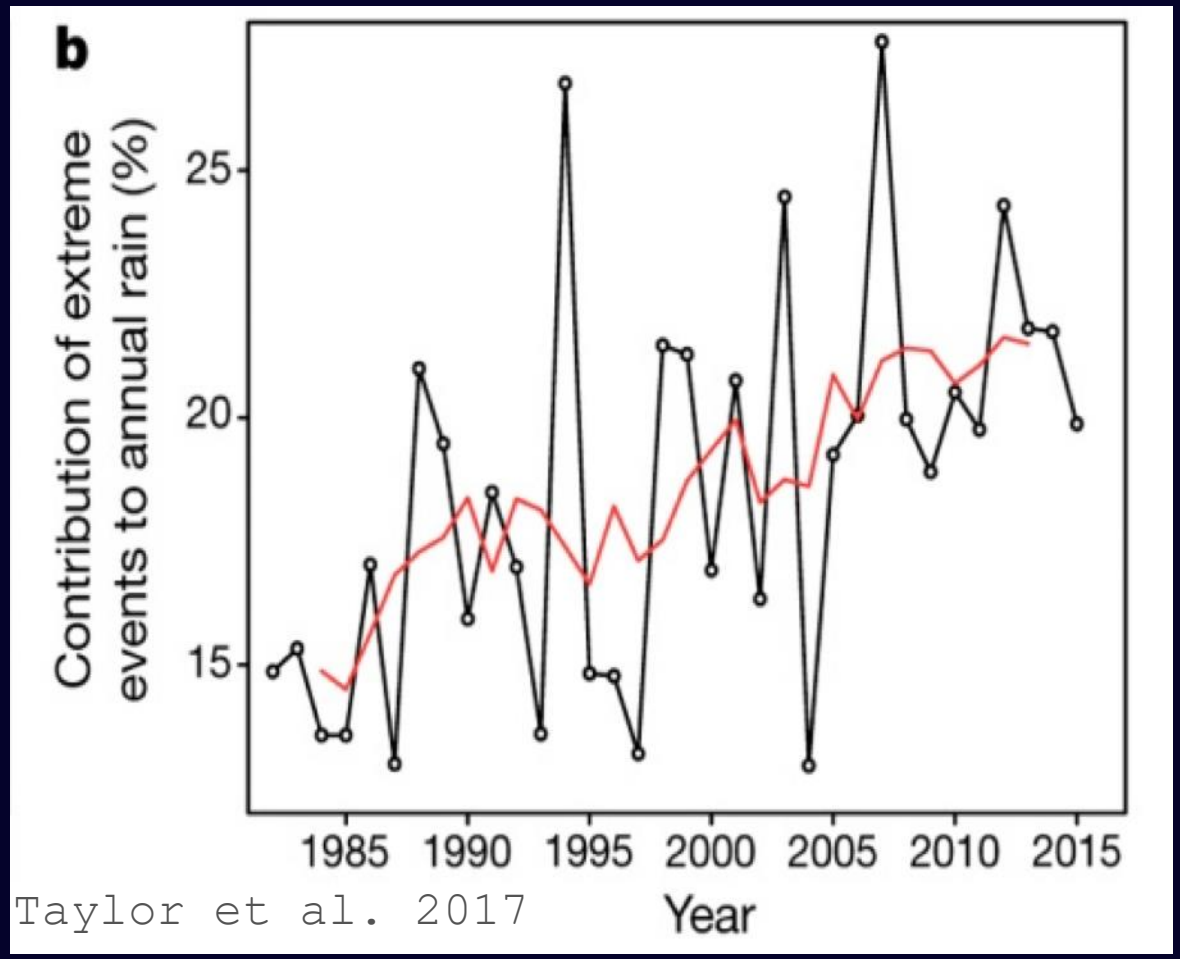


Berkeley Earth Surface Temperature

Observed changes in extreme rainfall

Frequency of extreme Sahelian storms (as indicated by very cold cloud tops) tripled since 1982 in satellite observations.

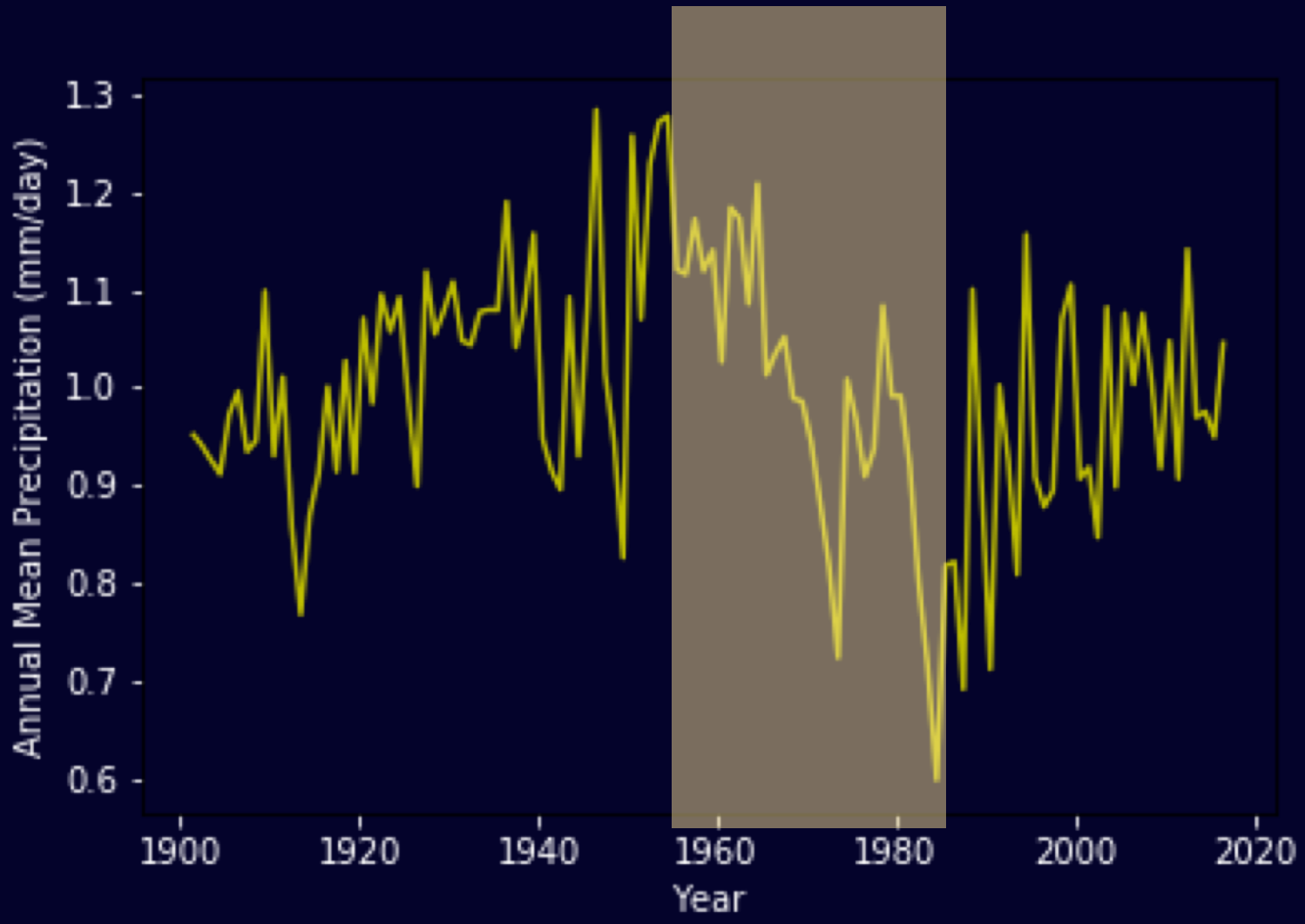
Extreme events now account for 25% of total rainfall.



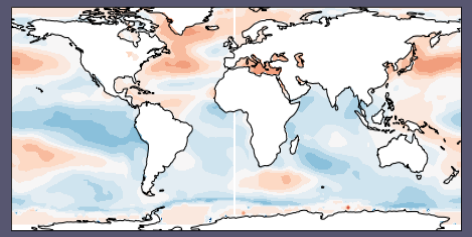
Taylor et al. 2017

Observed Sahel Rainfall Anomalies

What can explain the multi-decadal swings?



The decadal swings in Sahel rainfall are well matched by the CMIP6-generation of AGCMs



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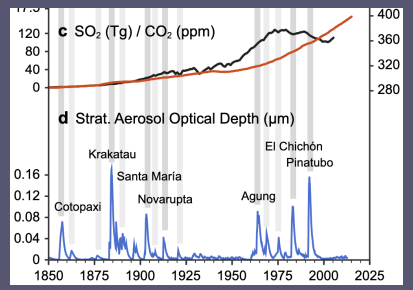
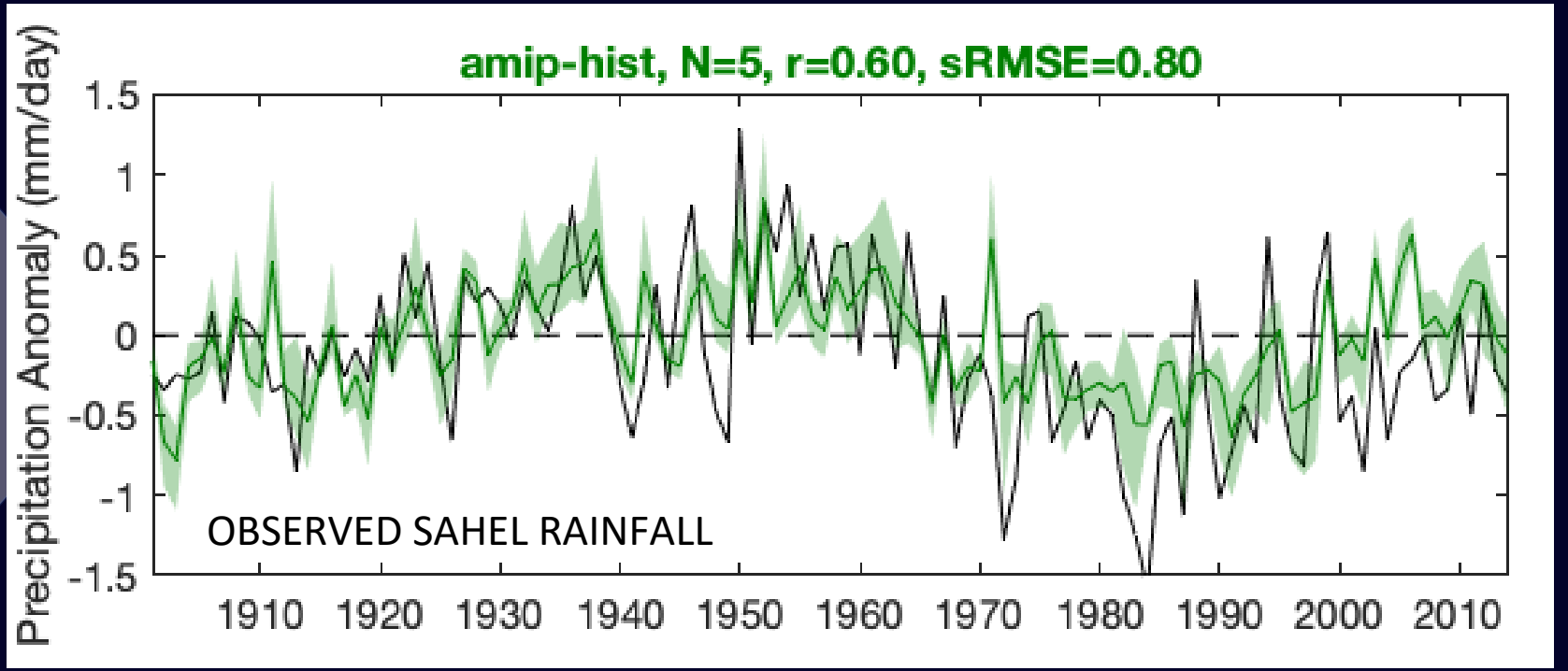
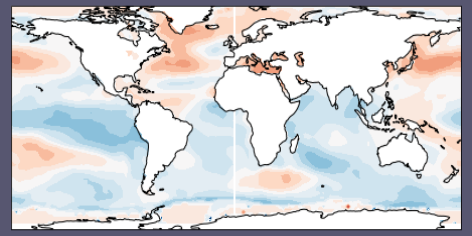




Herman, Biasutti, Kushnir, 2023, Climate Dynamics.

The role of SST alone



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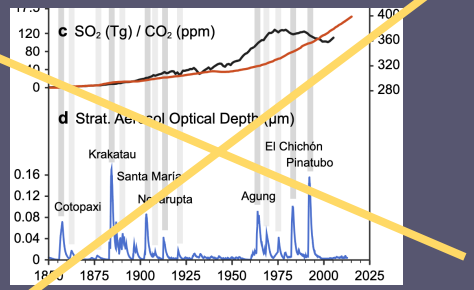

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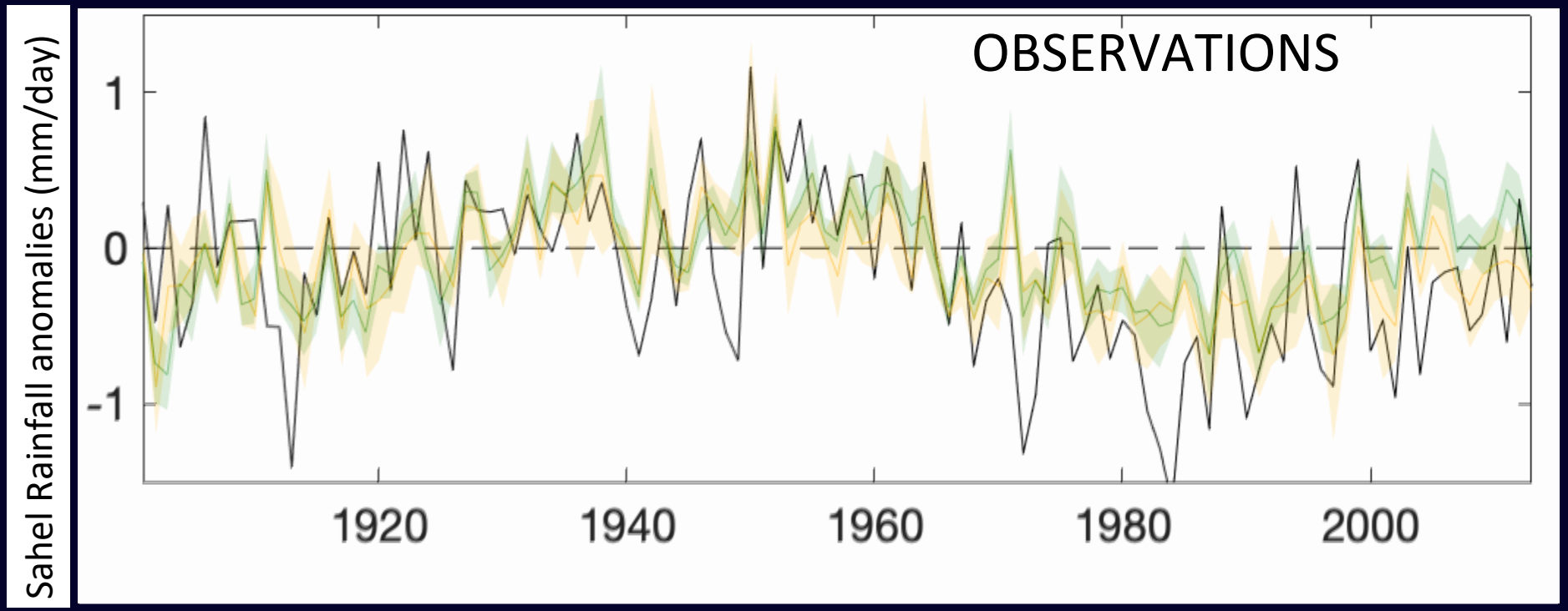
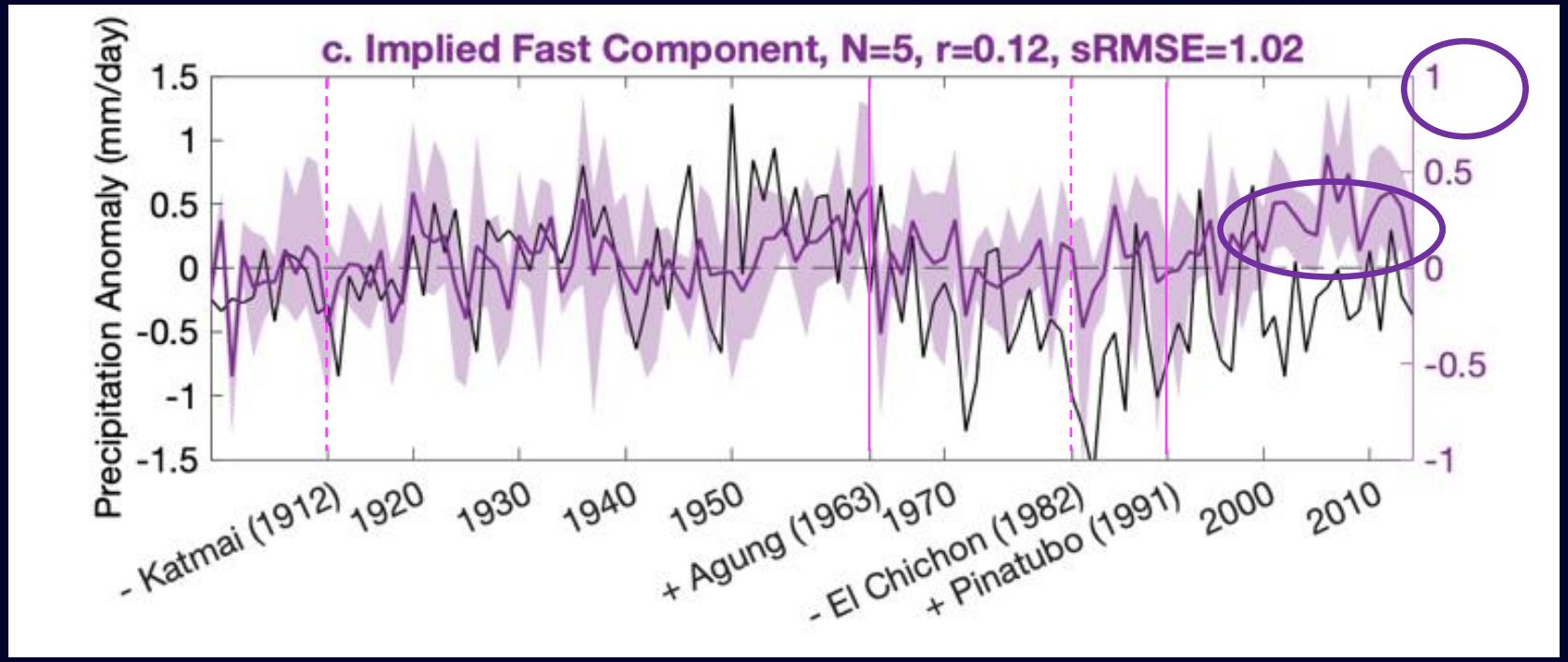
Rainfall swings are determined by the global ocean



With SST and radiative forcing

With SST only

The direct effect of radiative forcing (fast response)



With SST and radiative forcing

minus

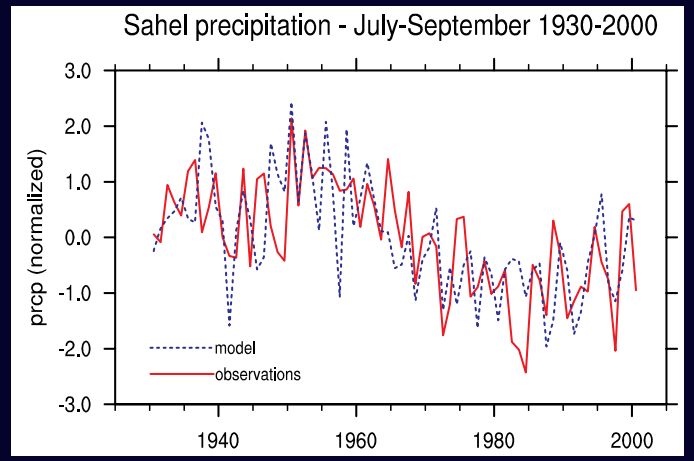
With SST only

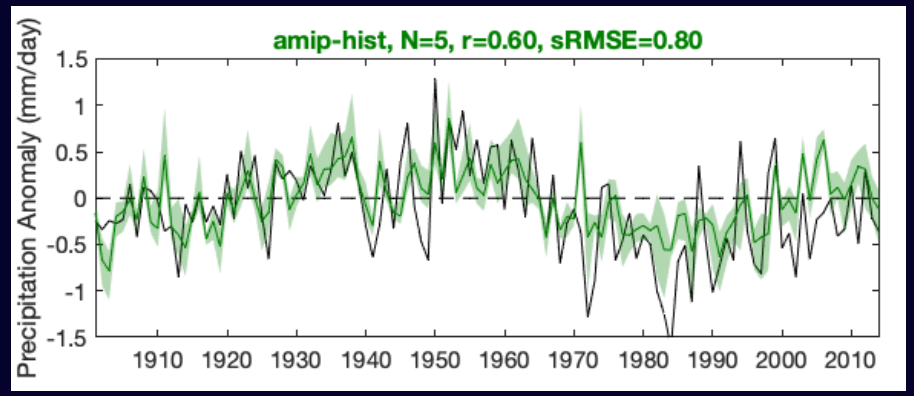
The difference (direct response) is small, but indicates

- Effect of volcanic eruptions and
- extra wetting in recent decades (as GHG ↑ and Aerosols ↓).

The effect of 20 years of model development

PAST AMIP performance:





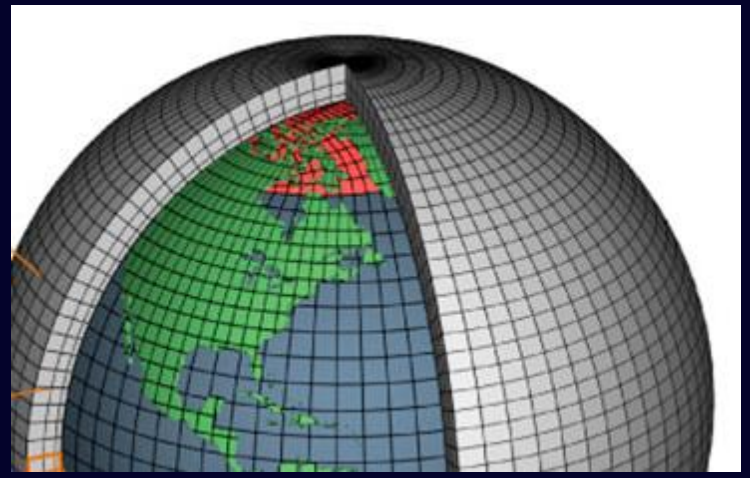
2003: Giannini et al.:
"The ratio of observed to ensemble-mean standard deviations in the Sahel is 4"

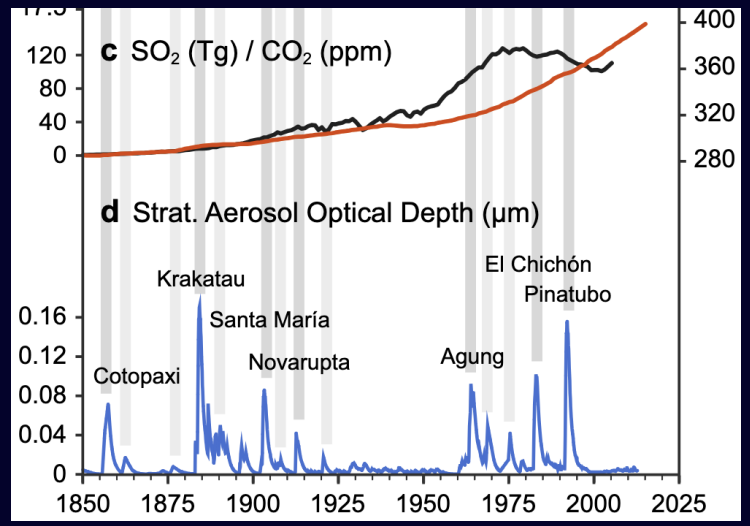
2008: Scaife et al (C20C)

2015: Rodriguez-Fonseca et al

Timing and (most of the) magnitude of Sahel rainfall anomalies are captured, if the SST is prescribed

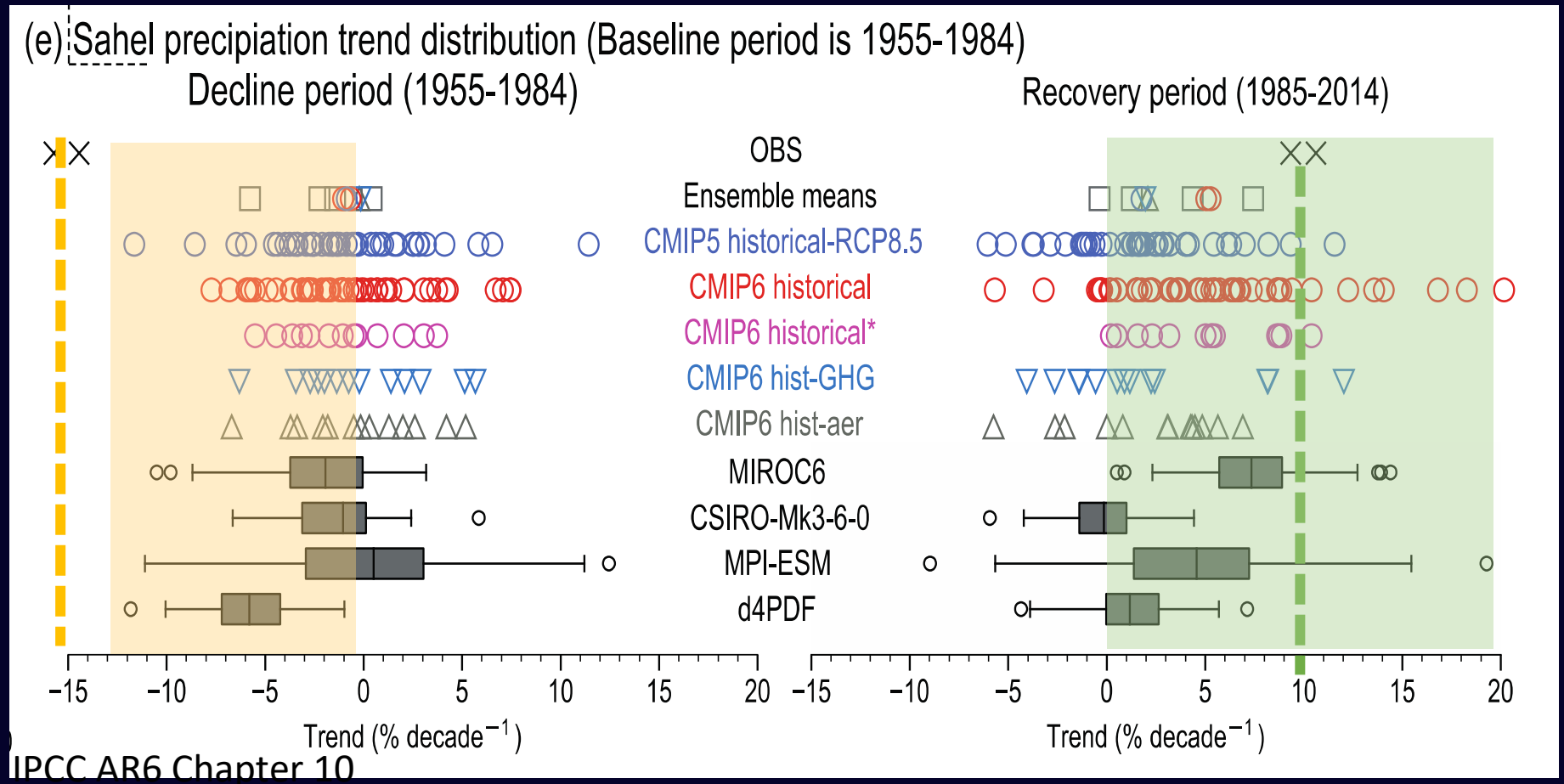
We use Coupled GCMs to determine the ultimate cause of observed SST & rainfall changes





COUPLED ATMOSPHERE-OCEAN GCMs:
Impose the history of external forcings
(atmospheric pollution, solar output and volcanic eruptions)
and simulate the response of the entire climate system
(atmosphere and ocean).

The full extent of drought is not captured in CMIP

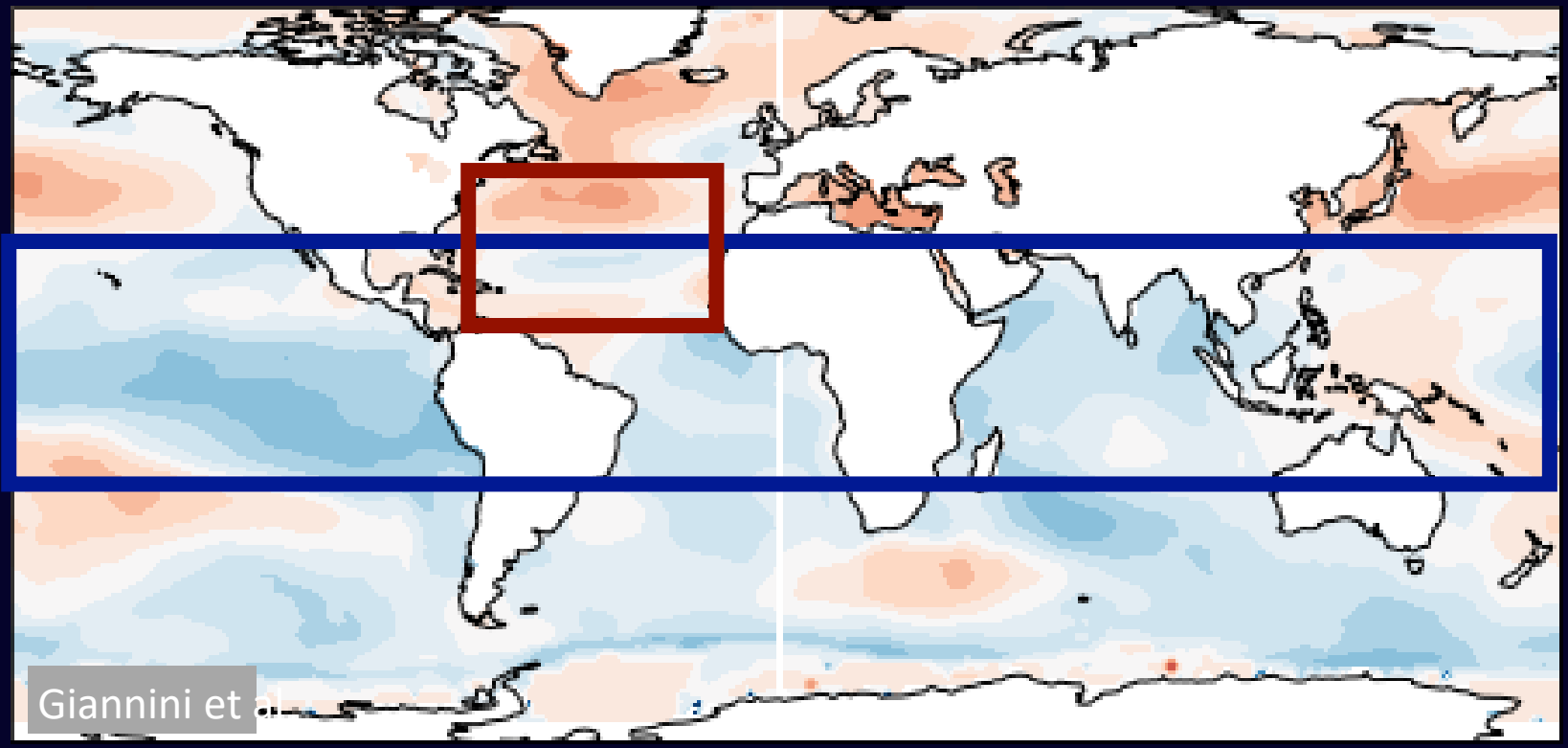


- The signal has the right sign
- The signal + internal variability is too small

Is this a problem with SST?

We use a simple index to summarize teleconnection of Sahel rainfall with global SST

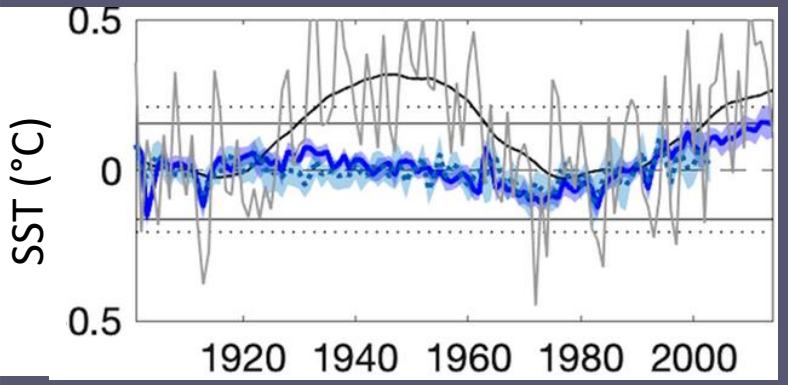
North Atlantic Relative SST Index



NARI = [box] - [box]

NARI means to capture the stabilizing effect of warming tropical SST and the destabilizing effect of local moisture influx.

CMIP models get the wrong SST, hence the wrong Sahel

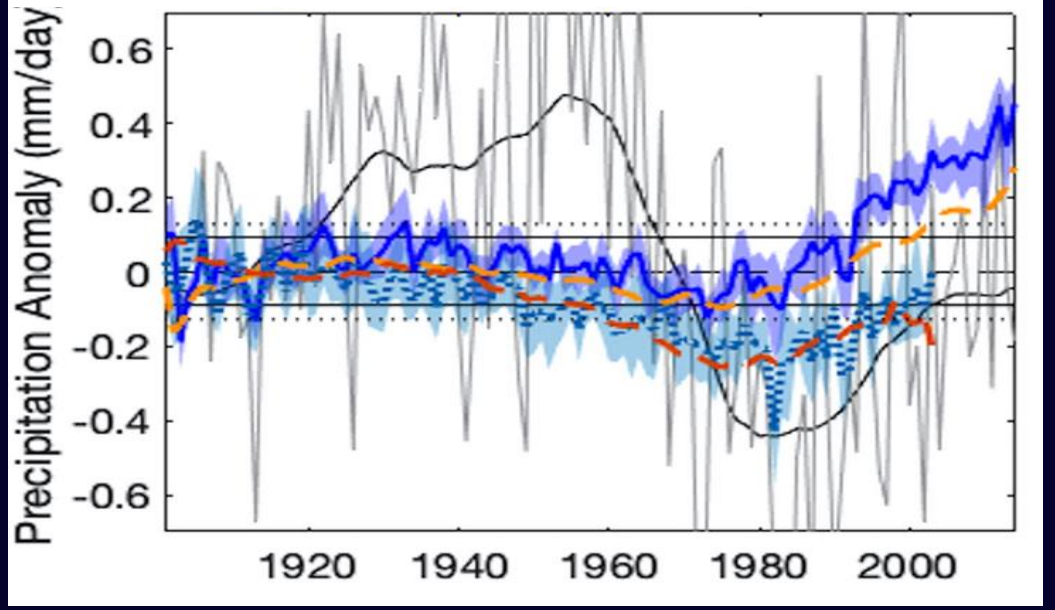


OBS NARI

CMIP6 NARI

CMIP5 NARI

OBS, CMIP5 and CMIP6 Sahel rainfall

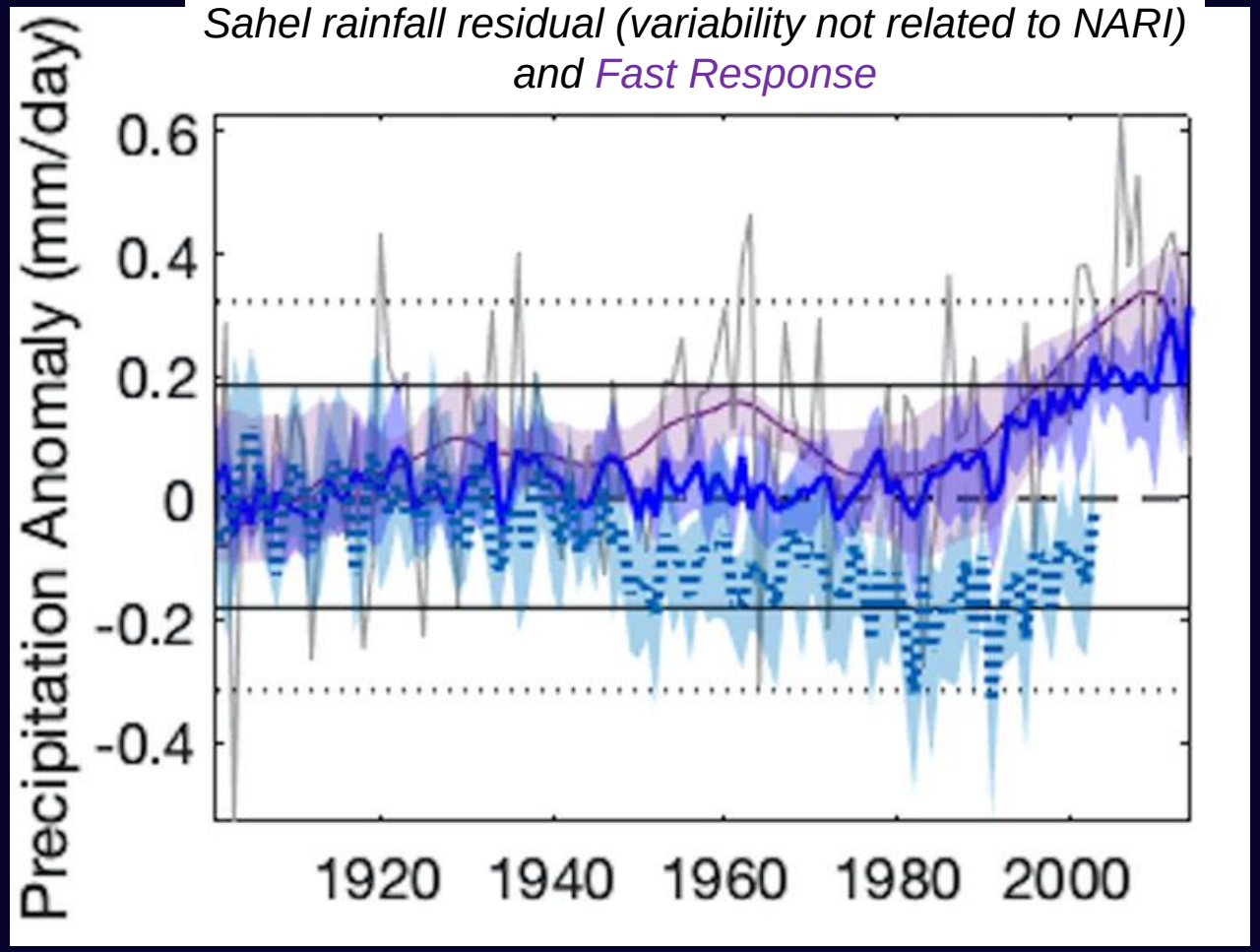


CMIP6 UN-Correlated with OBS

CMIP5 Correlated at 0.4 with OBS

Why is CMIP6 worse than CMIP5?

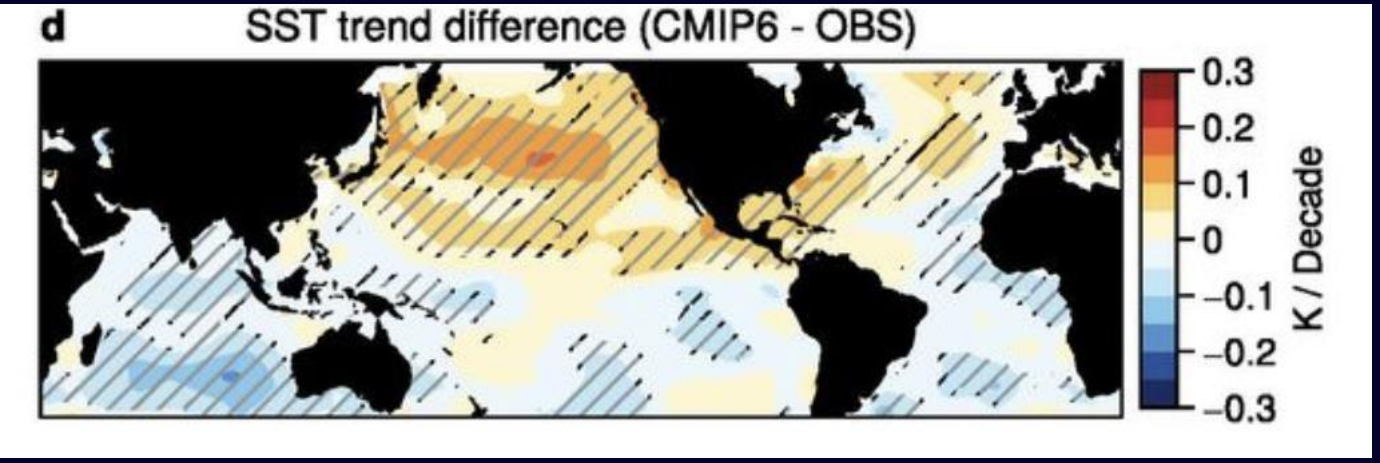
CMIP5 and CMIP6
Sahel rainfall residual (variability not related to NARI)
and Fast Response



- extra wetting from the direct radiative forcing further degrades the CMIP6 simulations
- CMIP5 and CMIP6 have different sensitivities.
- CMIP5 and CMIP6 don’t have the same forcing!

He et al: CMIP6 produces a spurious gradient

He et al 2023



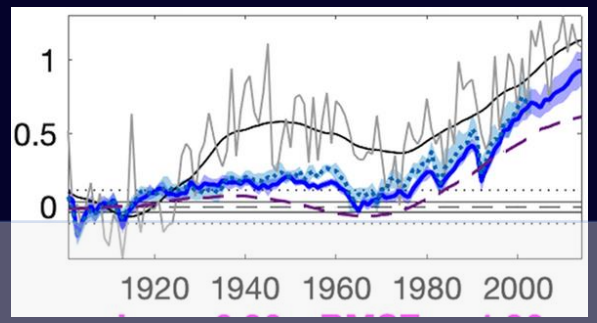
GHG force an erroneous “trend” in inter-hemispheric gradient in CMIP6.

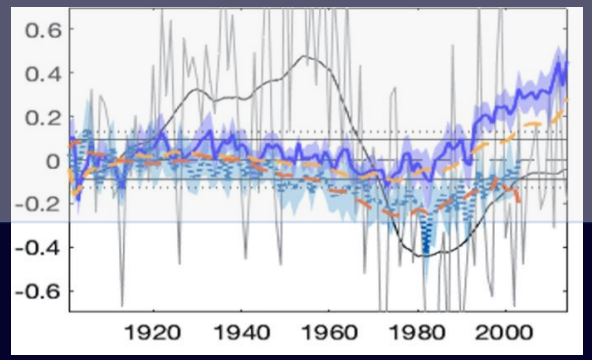
- Does this pattern of SST affect Sahel rainfall in addition to NARI?
- Is the direct effect confounded with SST?

https://www.nature.com/articles/s41586-023-06489-4

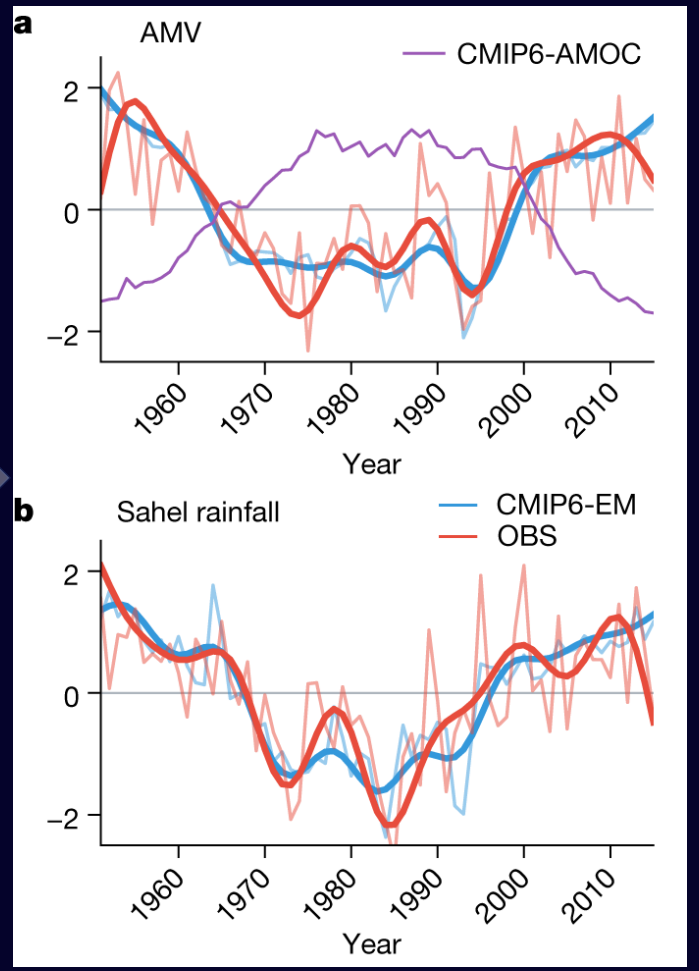
He et al: CMIP6 underestimates the response to aerosols

He et al 2023





DETREND (spurious gradient)
AND RESCALE
(Atlantic signal/noise)



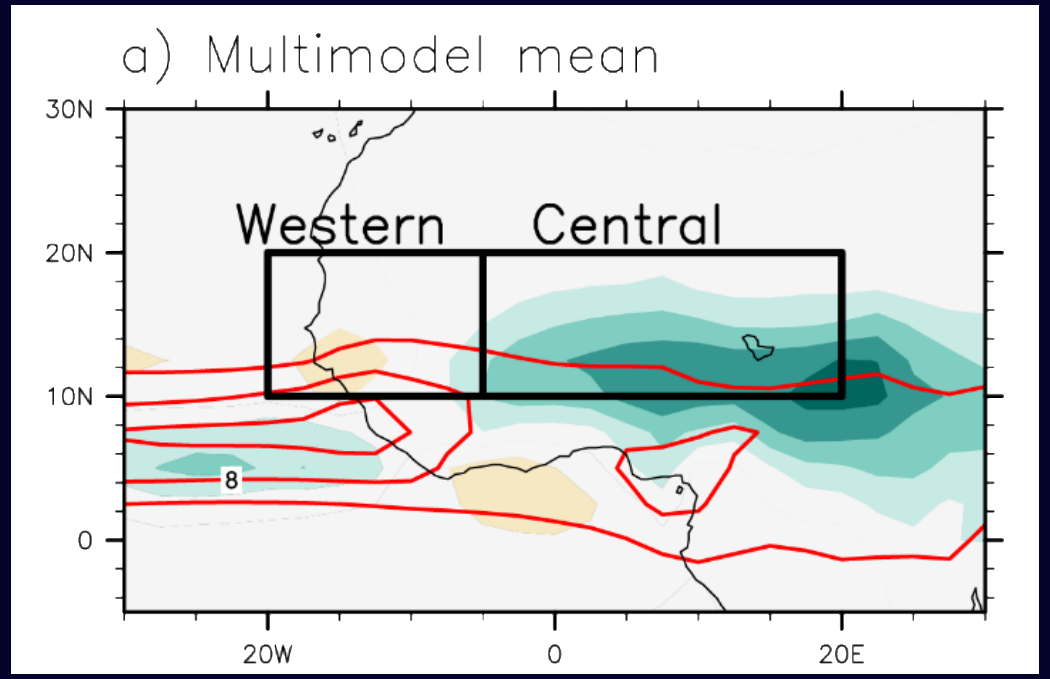
He et al., 2023

What happened? Ultimate causes of rainfall swings.≈

What will happen?

Rainfall projections are complex

CMIP6 CHANGES IN SEASONAL TOTAL

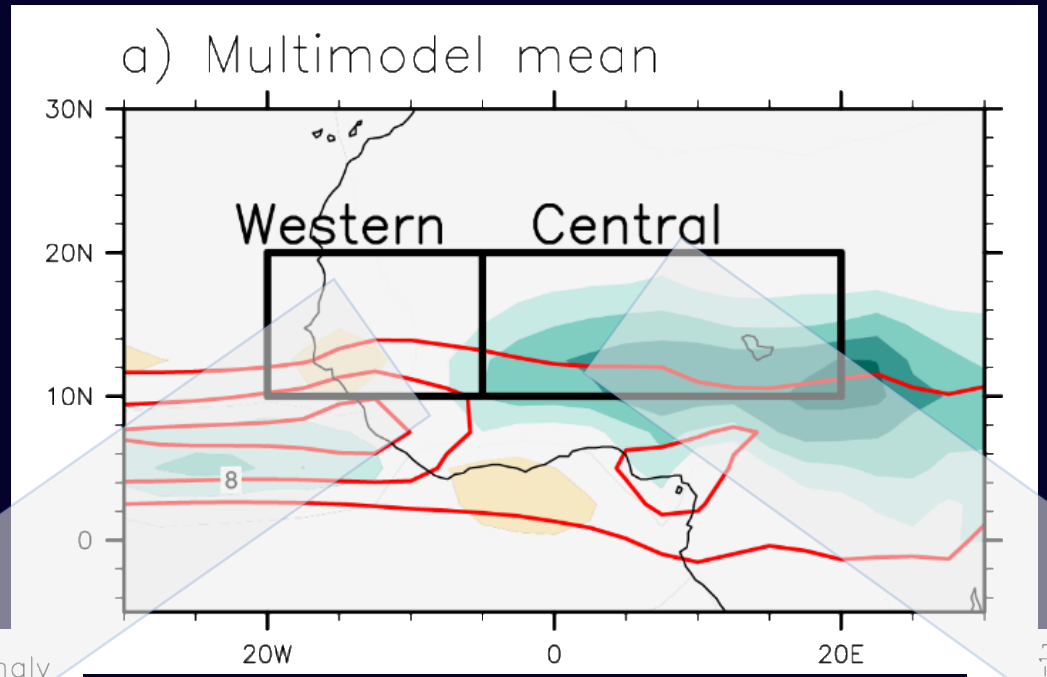


- West and East have different anomalies

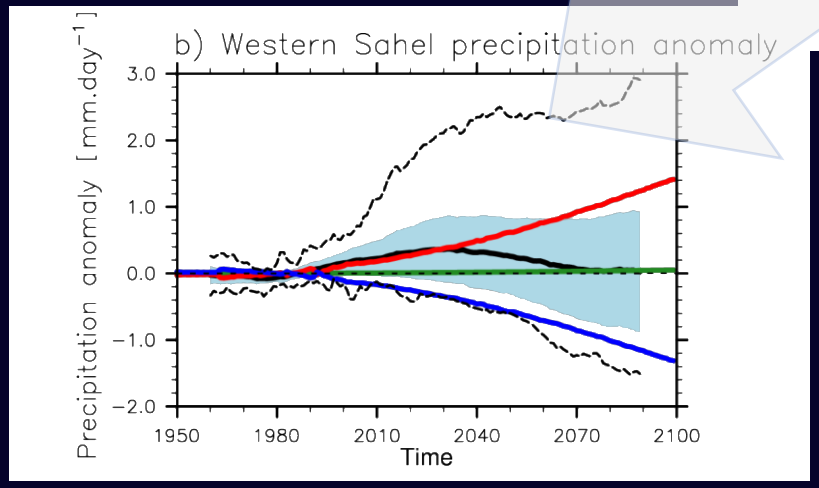
Monerie et al 2024, JGR

Rainfall projections are uncertain

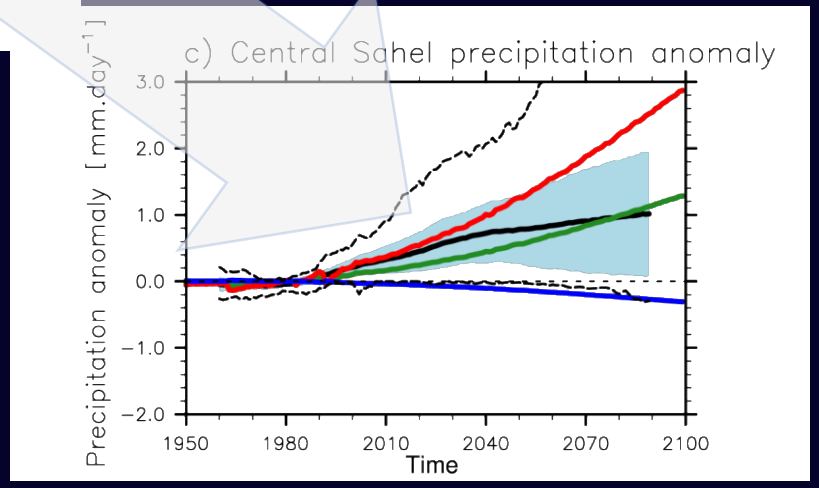
- The projections for the Western Sahel range from quite a bit drier to much wetter



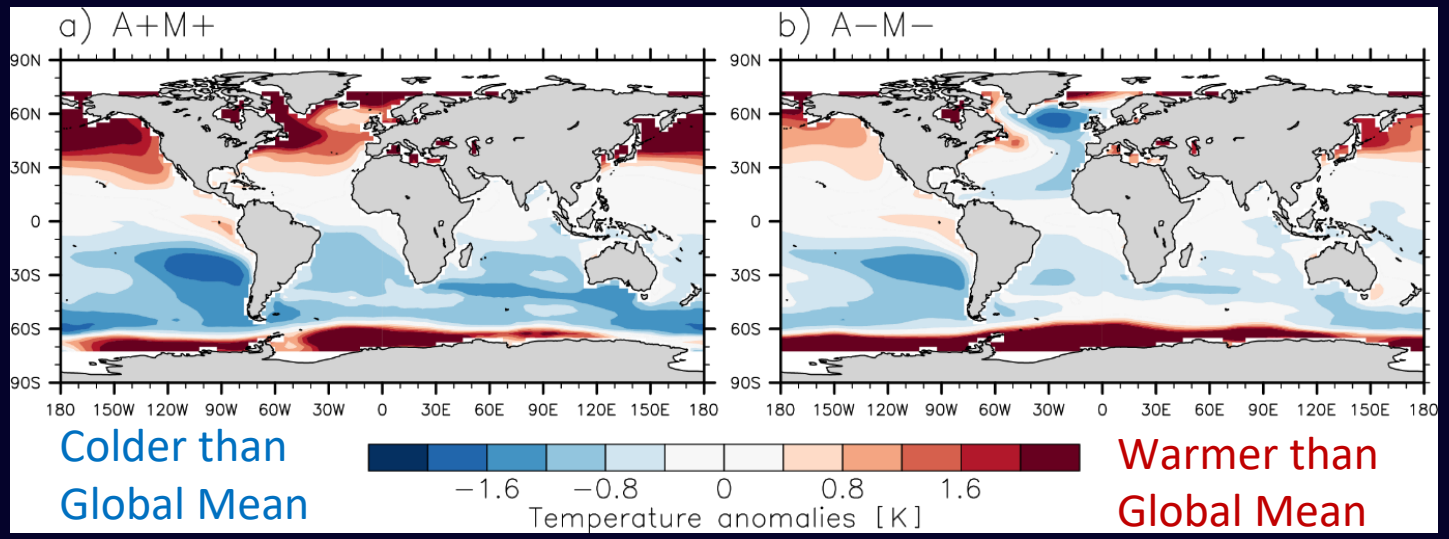
- The projections for the Central/Eastern Sahel range from no change to much wetter

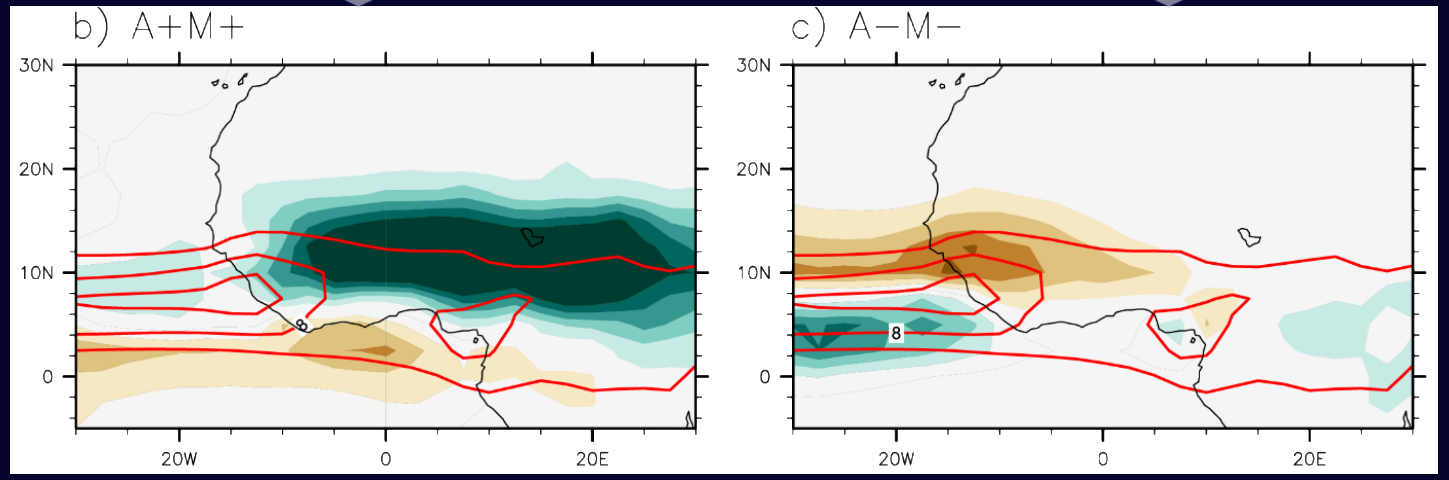


Monerie et al, 2023 JGR



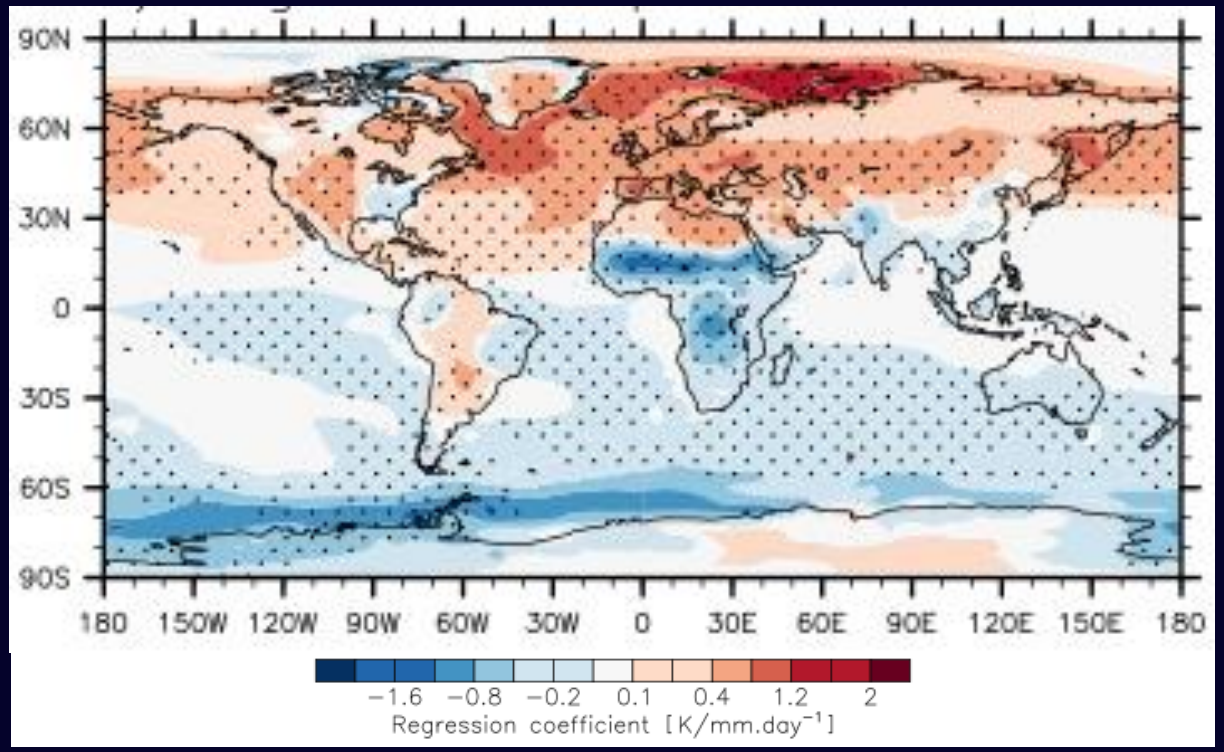
SST pattern uncertainty causes rainfall uncertainty





- CMIP6 models that simulate an especially warm North Atlantic and Mediterranean (or a more positive inter-hemispheric temperature gradient) tend to wet the Sahel.
- Models with a relative cooling of North Atlantic dry the Sahel

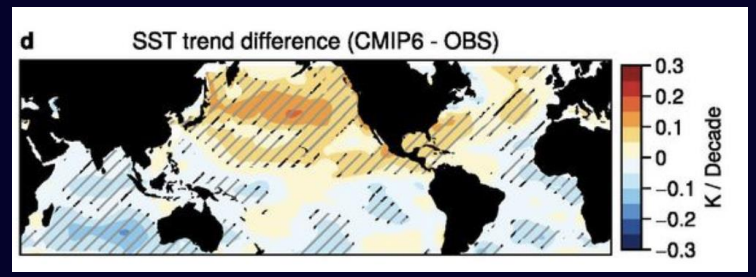
SST pattern uncertainty causes rainfall uncertainty



The SST trends linearly related to the uncertainty in Sahel projections

- Atlantic vs. Global Tropics
- Inter-hemispheric gradient

This is a problematic pattern!



What have we learned about GCM simulations of Sahel rainfall?

1. Sahel rainfall is sensitive to the pattern of SST changes
2. Current AGCMs capture this sensitivity fairly accurately
3. But the CGCMs cannot capture the SST response to past forcings:
    * overestimated inter-hemispheric gradient
    * underestimated Atlantic SST changes
4. Uncertainty in how this same SST pattern will evolve drives uncertainty in Sahel rainfall.

What do we do now?

Adaptation

Climate Research

How can we make progress?

Adaptation

"If we can learn to substitute evolution-from-what-we-know for evolution-toward-what-we-wish-to-know, a number of vexing problems may vanish in the process."

(Thomas Kuhn, via Ted Shepherd)

Focus on adaptations that address heat, downpours, and drought at the same time.

Adaptive decision making with monitoring, benchmarks, and decision points.

?

Climate Research

- "better" climate simulations
  - Can we reduce uncertainty in 20th century forcings?
  - Can we solve the signal-to-noise paradox?
- Observational constraints:
  - What is the range of natural variability in the Sahel?
  - What is the response to volcanic aerosols?

Climate Research

Drought atlases in existence

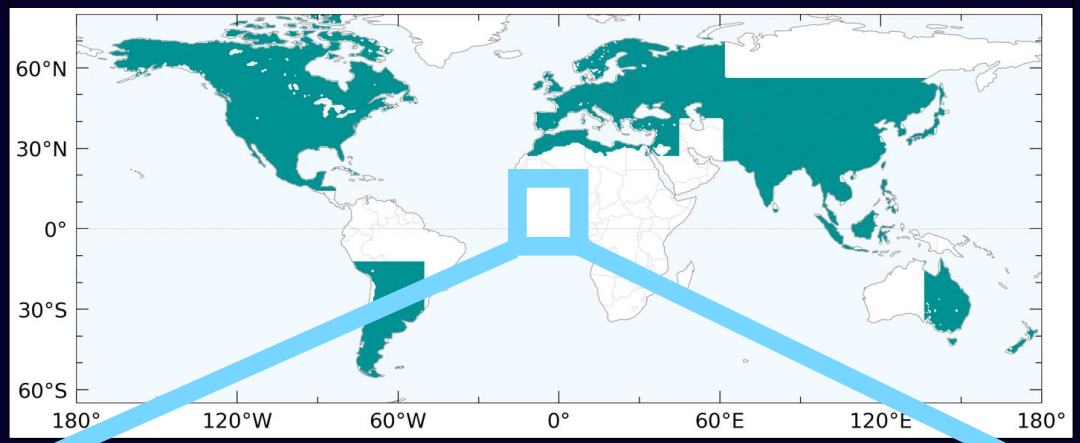


Figure 2. Two views of a section of *Pterocarpus erinaceus* from Senegal collected in March 2007 by D. Blanas showing visible ring structure.

- "better" climate simulations
- Observational constraints:
  - What is the range of natural variability in the Sahel?
  - What is the response to volcanic aerosols?

CONCLUDING ANSWERS

What happened?

Changes in the global oceans caused 20th century pluvials and droughts, and the 21st century recovery. Volcanoes add to interannual variability.

Attribution of rainfall changes to anthropogenic Aerosols and Greenhouse Gases in 20th century rainfall remains uncertain, but the balance of evidence suggests a larger forced response than simulated by CMIP models.

What will happen?

More warming and more intense rainfall
Drought will persist in the Western Sahel, the East will continue to wet… maybe!

What should we do?

Focus adaptation on solutions robust to uncertainty in the mean rainfall change
Better understand/model the gradient in SST response
Collect new data to build a paleo record of Sahel rainfall

MORE QUESTIONS: CONTACT ME VIA EMAIL: biasutti@ldeo.Columbia.edu