# The influence of the oceans on West African climate

*ANACIM/ICTP summer school*
ERNAM, Dakar – 24 November 2016

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# Outline of this talk

**the role of the oceans in the variability of West African climate**

including future projections of change in the Sahel [and limitations of the explanation]

Applications of this idea/interpretation to:

- An [indirect] *attribution* argument for anthropogenic influence in late 20th century drought and recovery in the Sahel
- Interpretations of trends in the sub-seasonal *character of precipitation*

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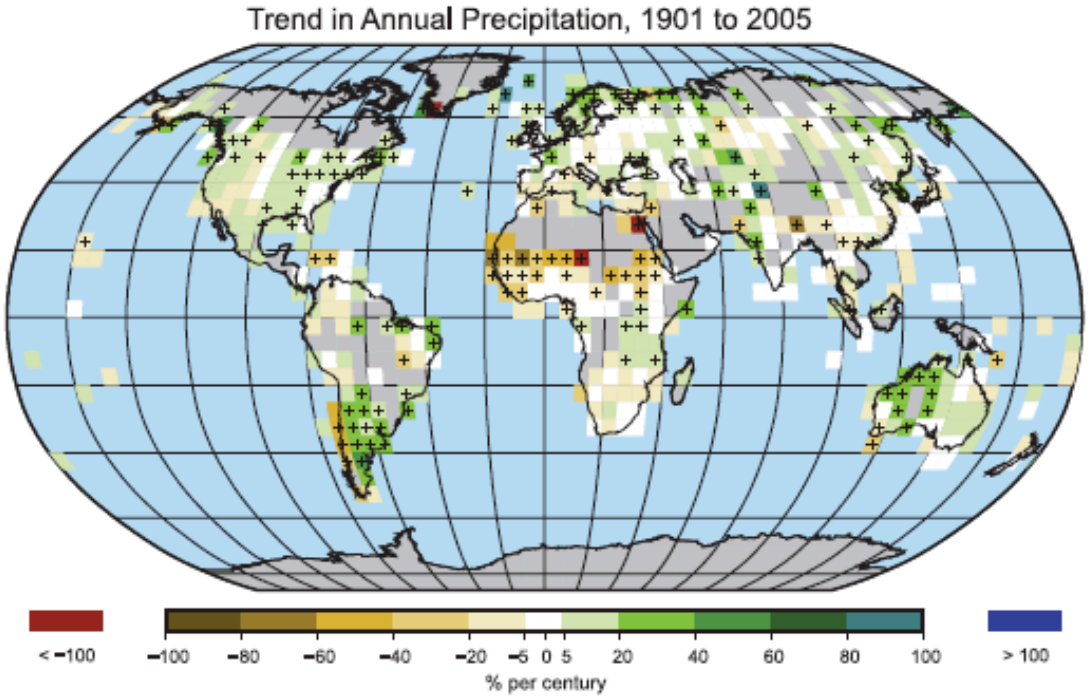
[This is the work of ~15 years of research, and ongoing, so if there is one lesson here, it is that in research you have to be persistent – ***perseverance, and some intellectual support, can take you there***]

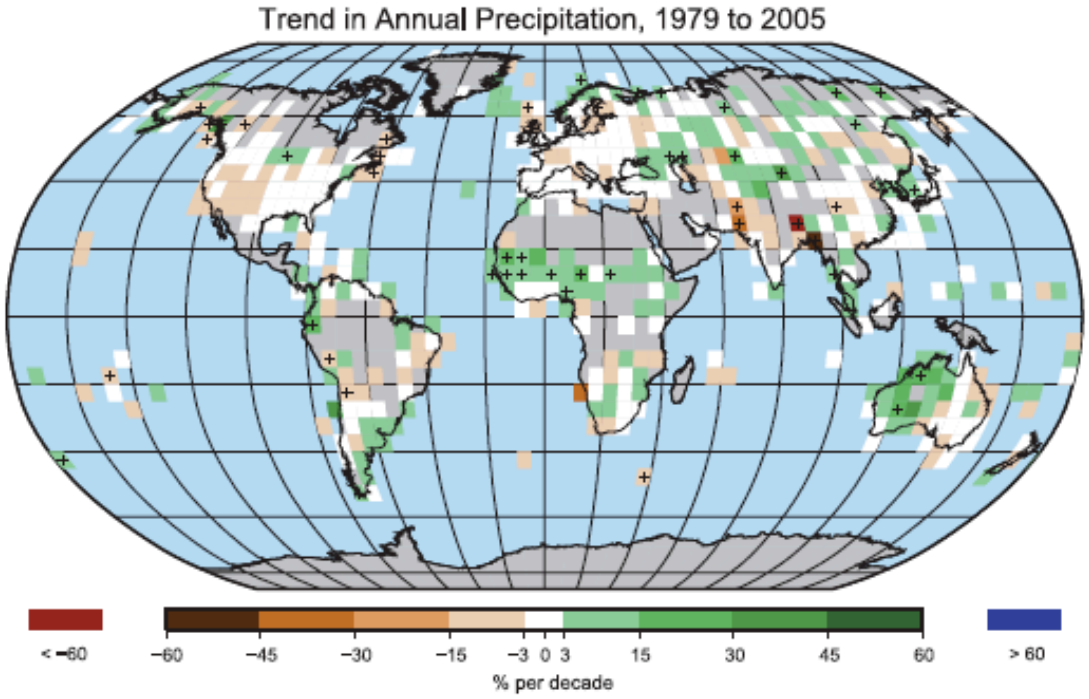
[This presentation is about research results, but also about **methods in climate research**. As we go through it, note what elements may be relevant to your research. We can delve deeper in them in the lab session on the IRI Data Library.]

# Observed trends in annual precipitation

*1901-2005*




*1979-2005*




**IPCC/AR4/WG1, Ch.3**
(Trenberth *et al*, 2007)

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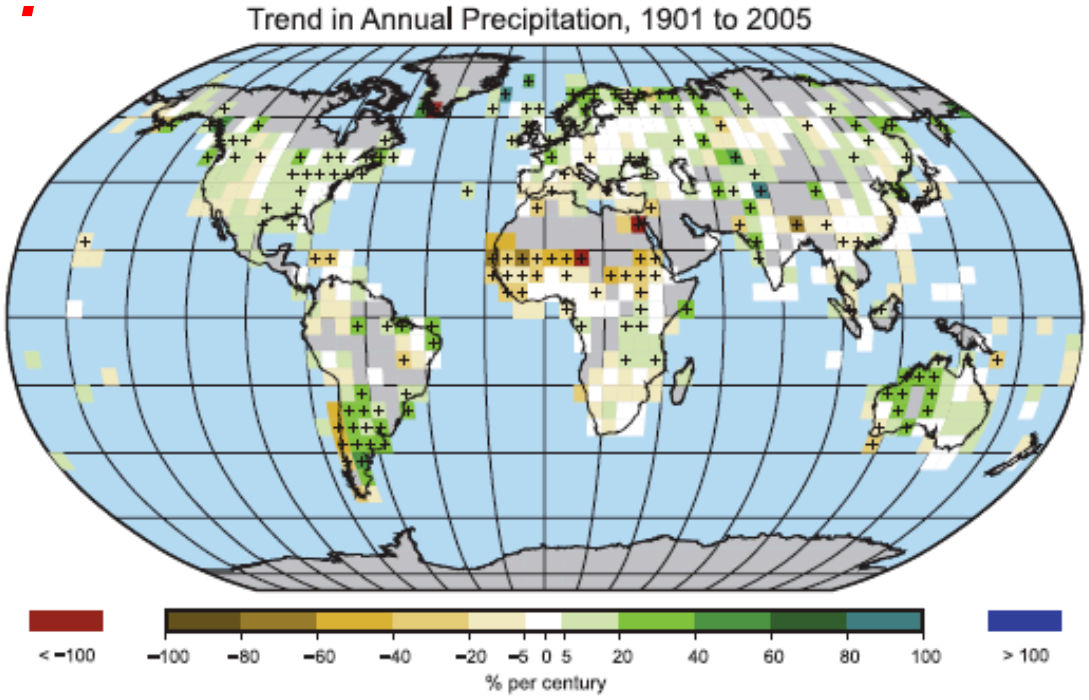
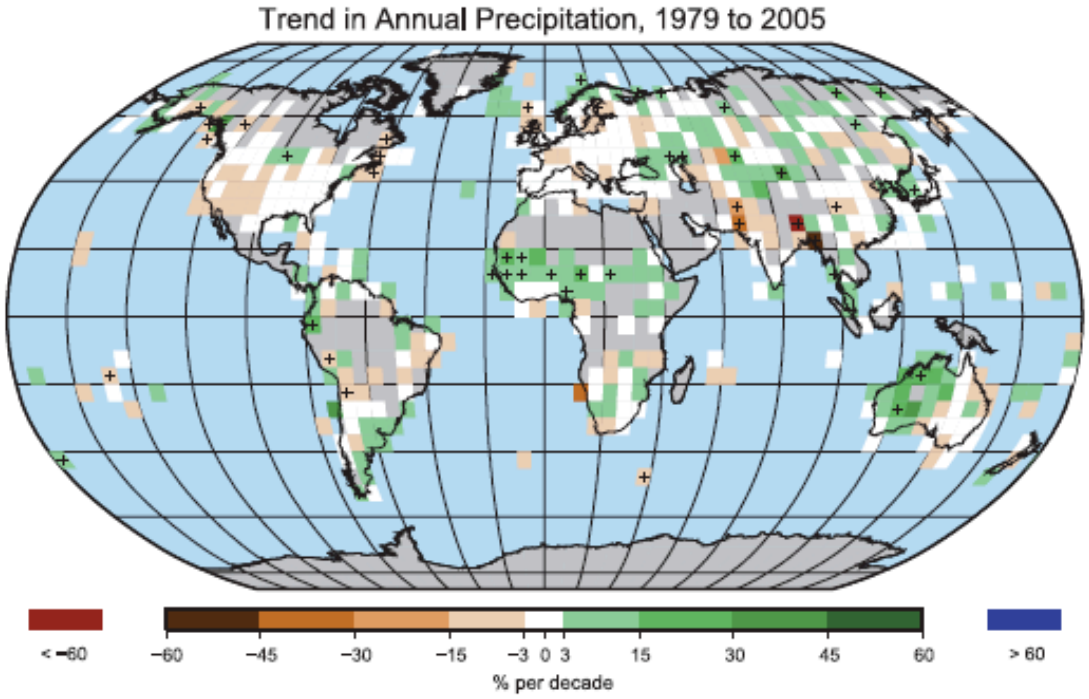
# *Where is the Sahel?*

*1901-2005*




*1979-2005*

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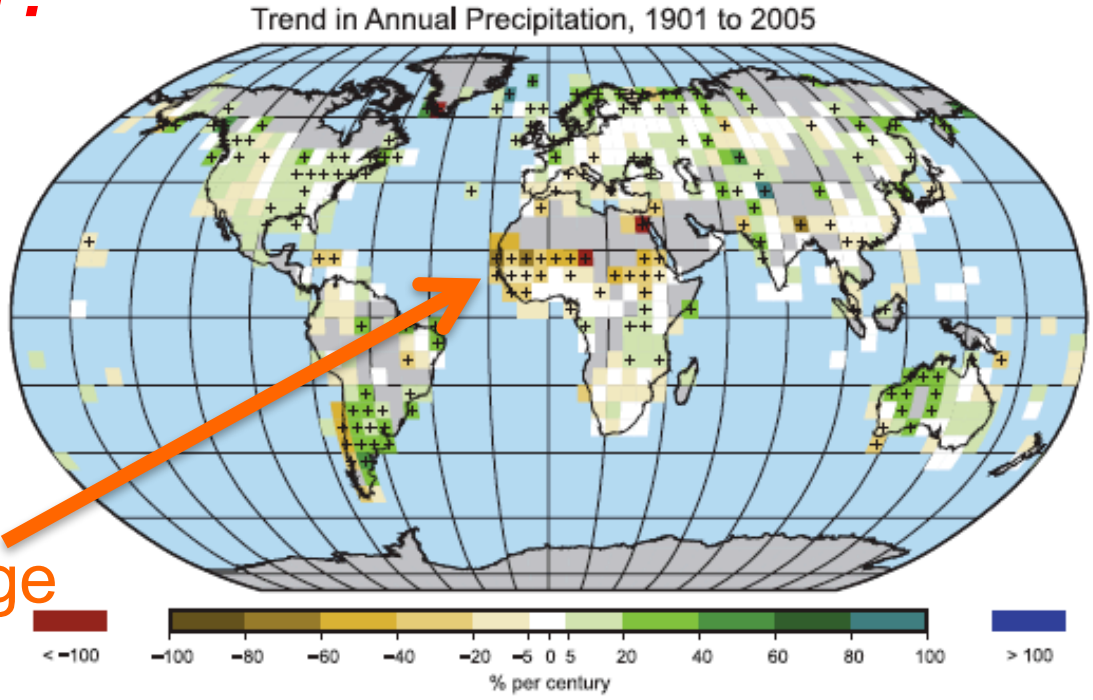
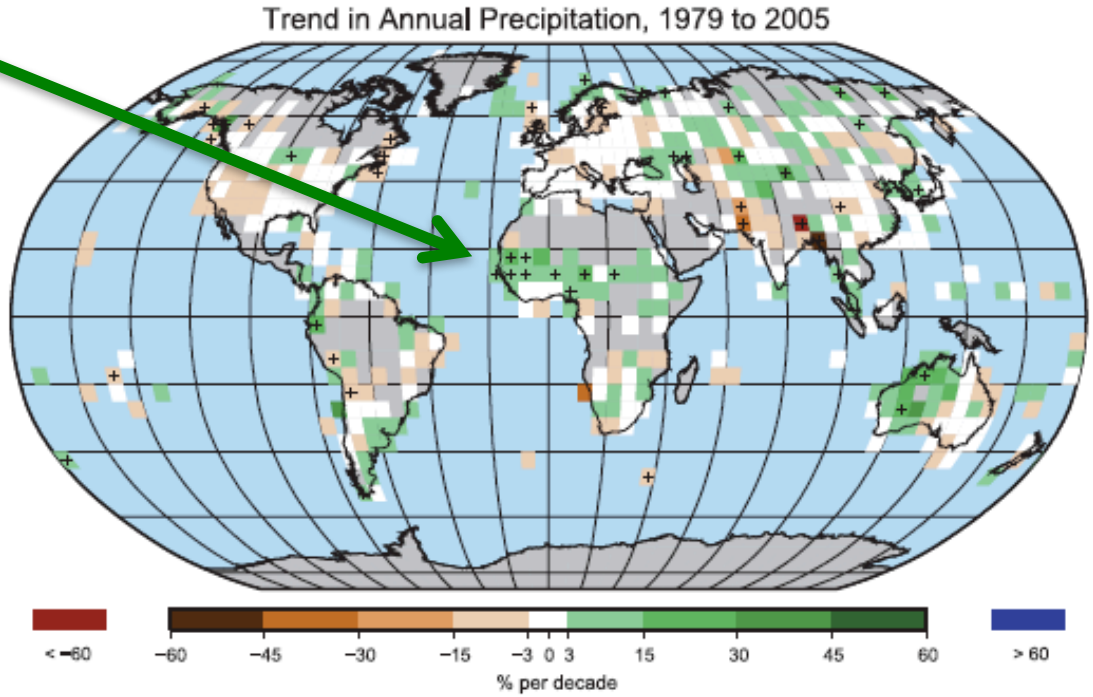



If this most outstanding trend
is anthropogenic climate change

then what about "recovery?

*1979-2005*




**IPCC/AR4/WG1, Ch.3**
(Trenberth *et al*, 2007)

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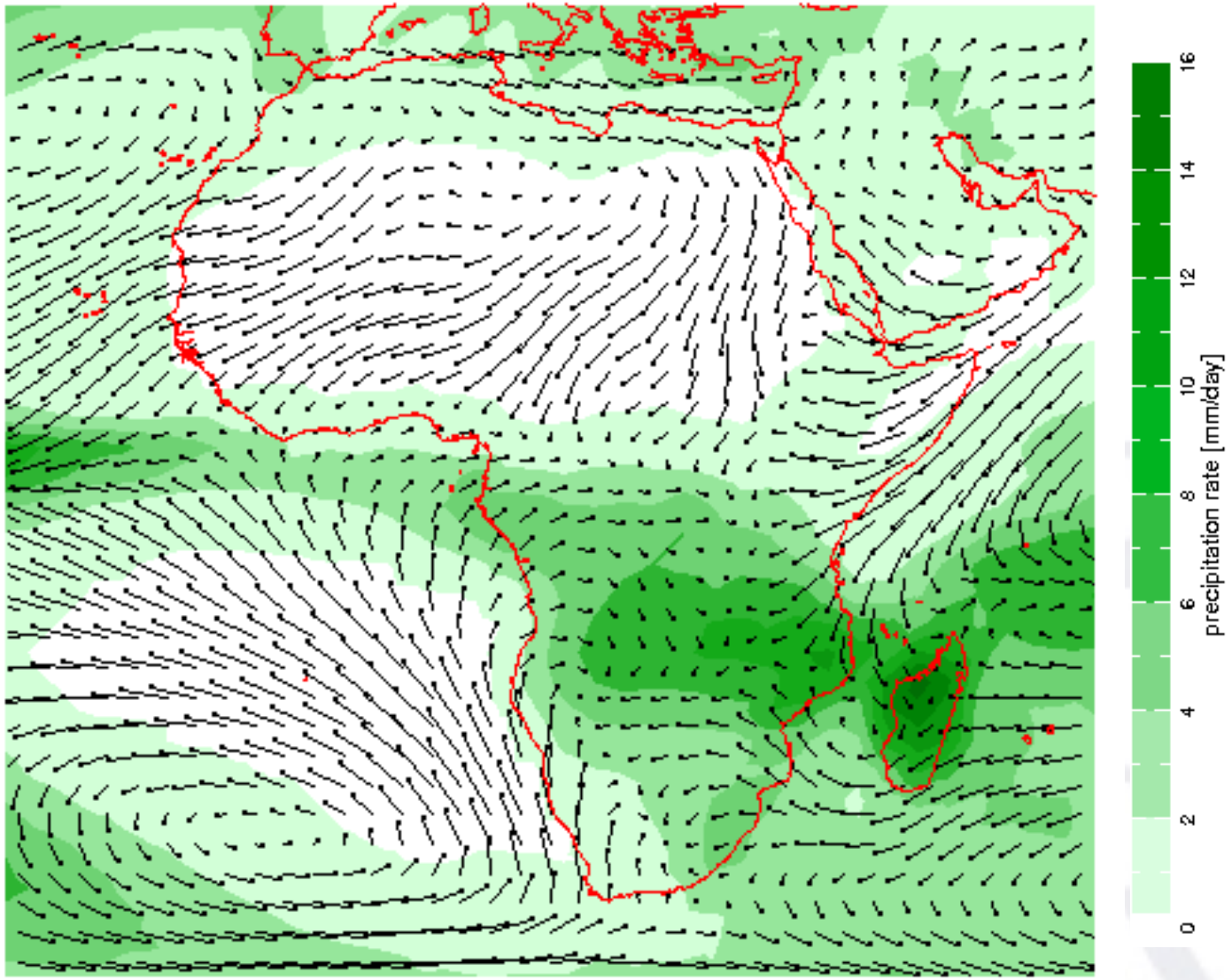
# The climate of sub-Saharan Africa

## is dominated by [seasonality in] precipitation

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Time Jan Pressure Level 925.0 mb

**the role of the oceans in the variability of West African climate**

[this is the basis for seasonal climate prediction, *and much more*]

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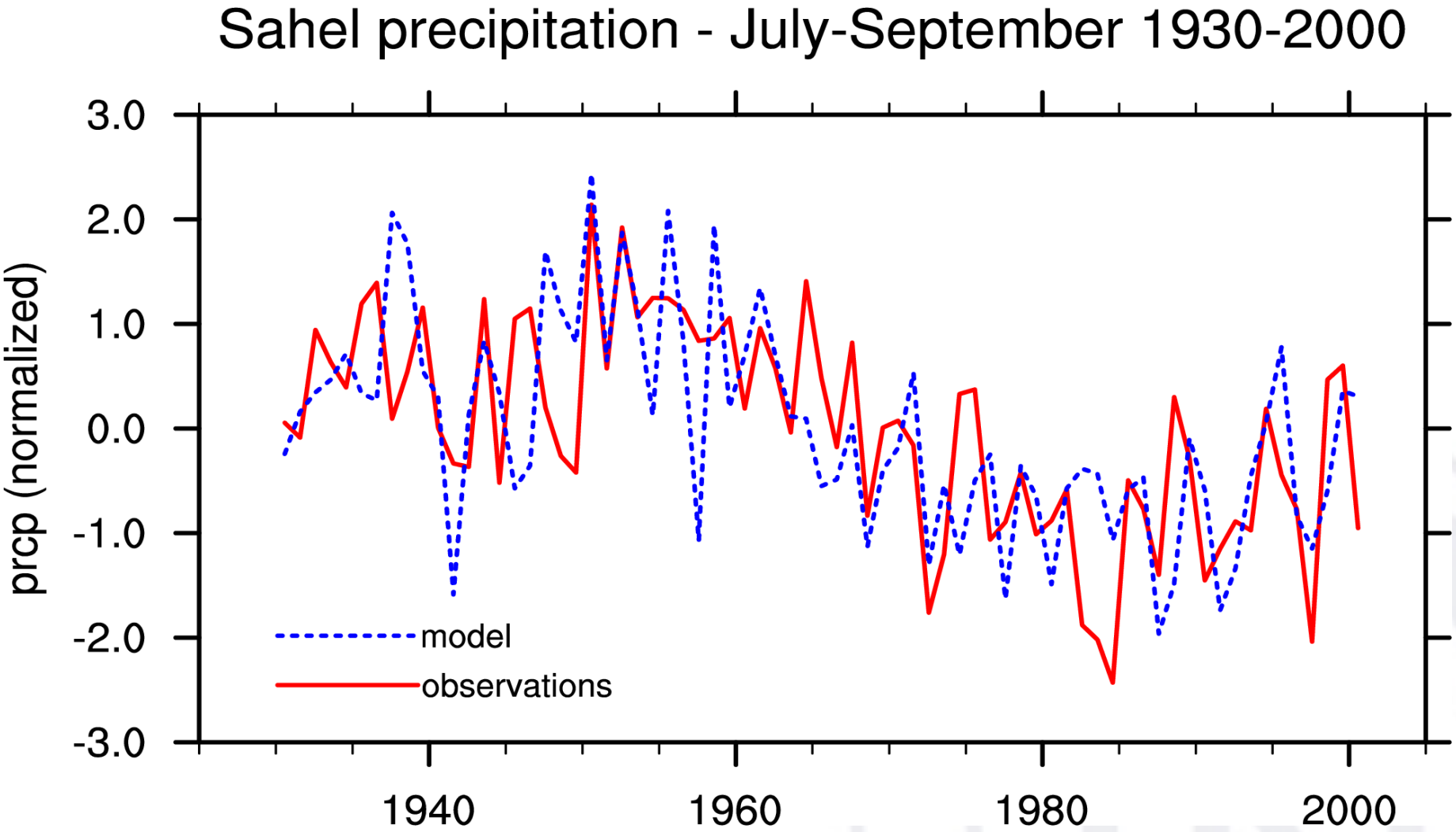
# Oceans caused 20th century Sahel drought

## land surface-atmosphere interaction a positive feedback




**Giannini, A, R Saravanan, P Chang, 2003. Science, 320, 1027-1030**

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# An ensemble of simulations...

the same model is run many times with the same boundary conditions, but different initial conditions [to sample chaos or uncertainty in the system]

- The ensemble average/mean, approximates the *externally forced* response
- Deviations from it approximate *internal variability*
  - Cases of climate prediction [S2S, SI, decadal]
  - Case of climate change projections

# An application of Principal Component Analysis [or Empirical Orthogonal Function analysis] to the study of the variability of *July-September* precipitation over tropical Africa

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# [What is an anomaly?]

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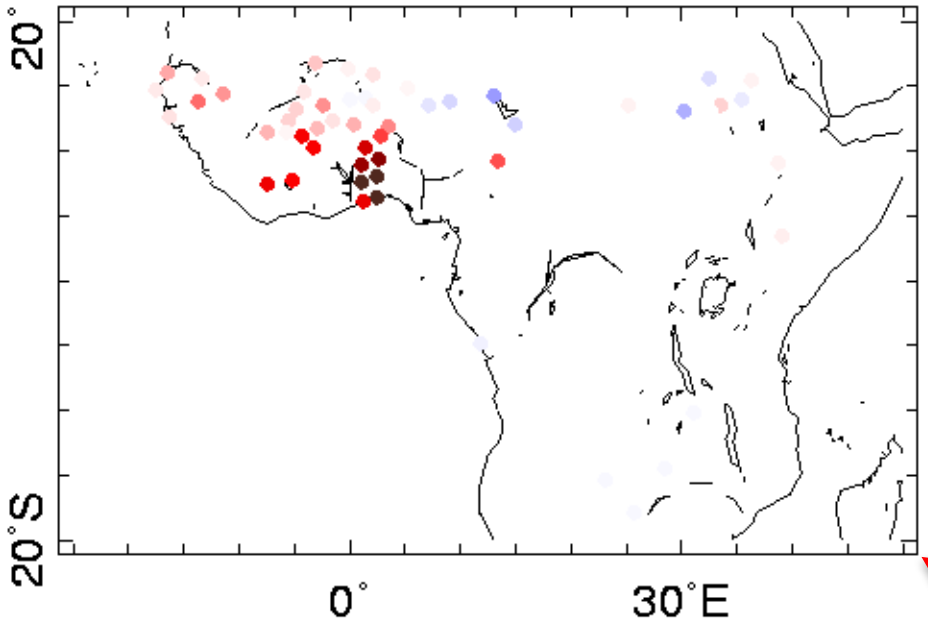
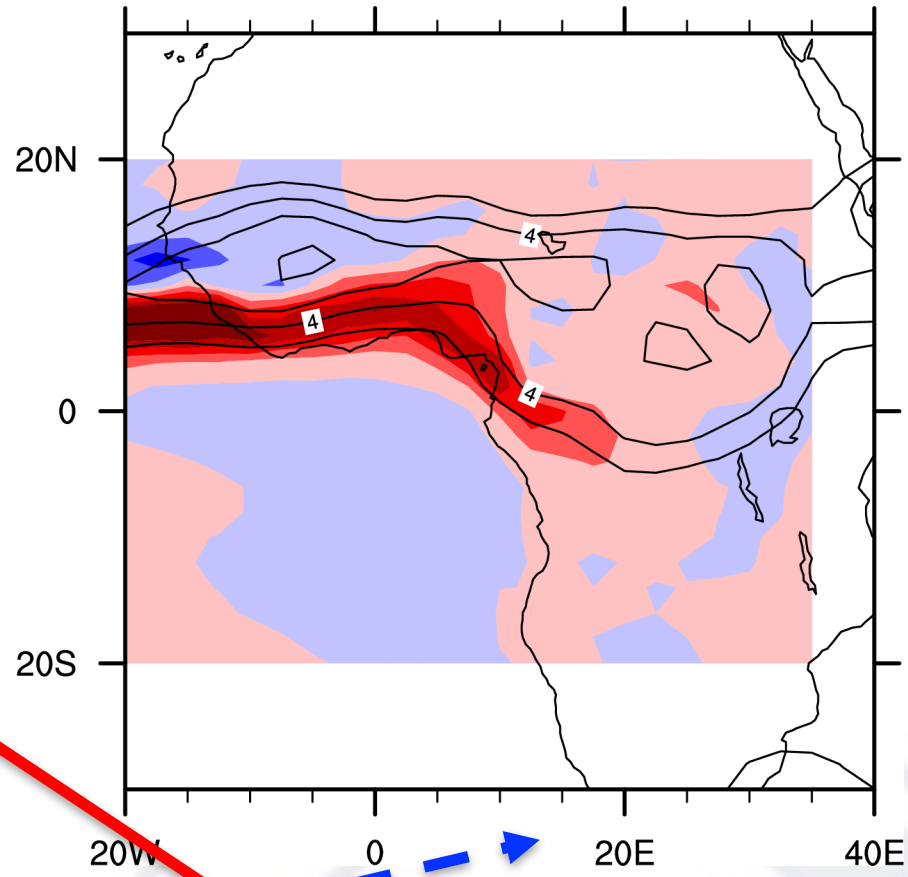
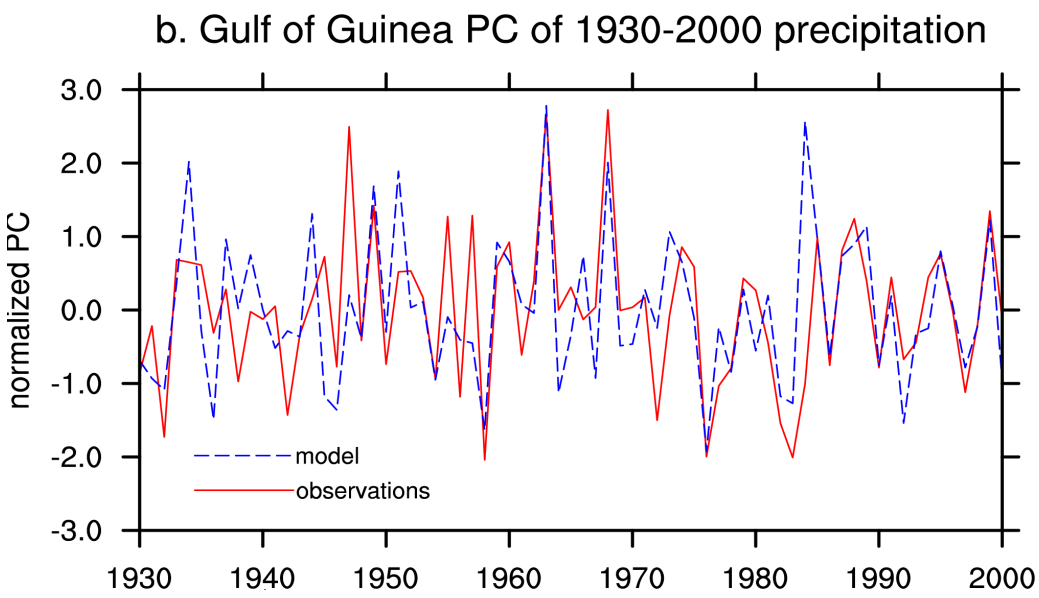
# Variability in Gulf of Guinea rainfall – the oceanic ITCZ

*(15% in obs, 32% in ens-mean)*




EOFs, or eigenvectors

PCs, or time series

**Giannini, A, R Saravanan, P Chang, 2005 in Clim. Dyn.**

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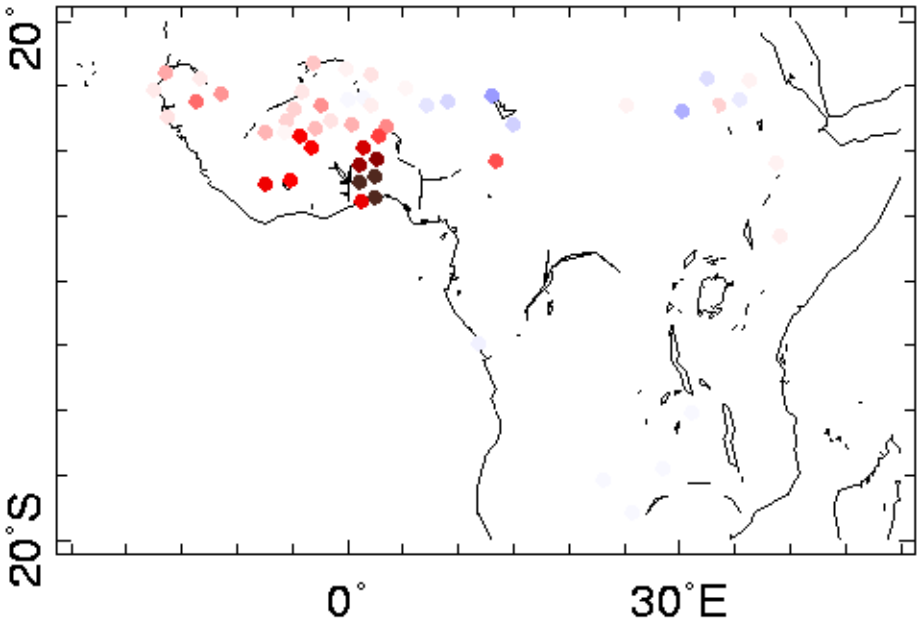
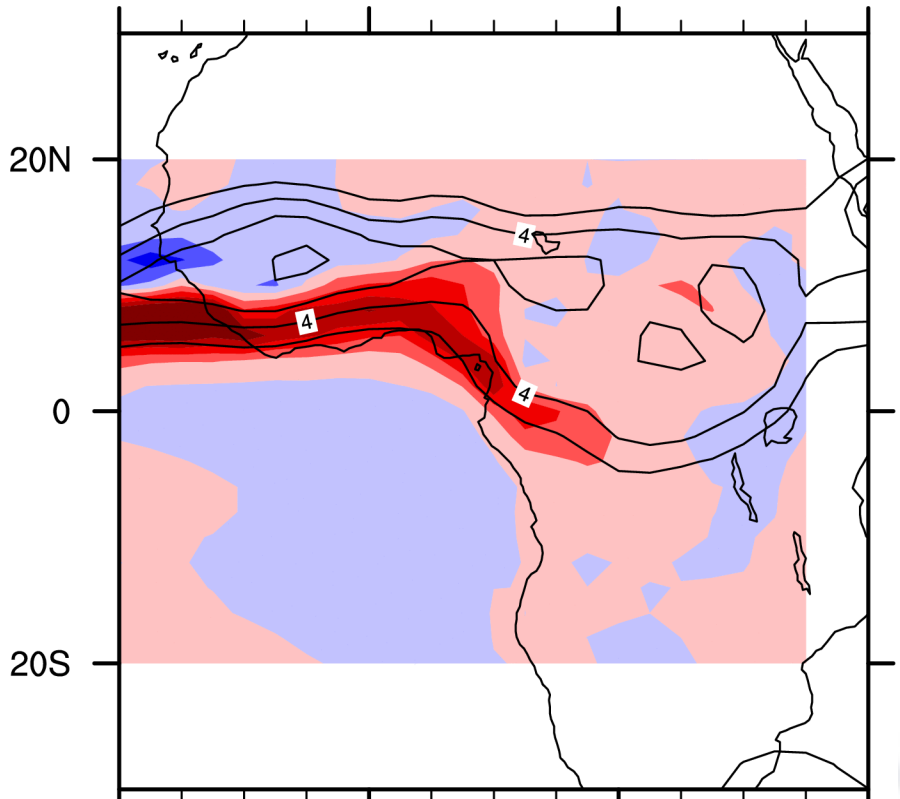
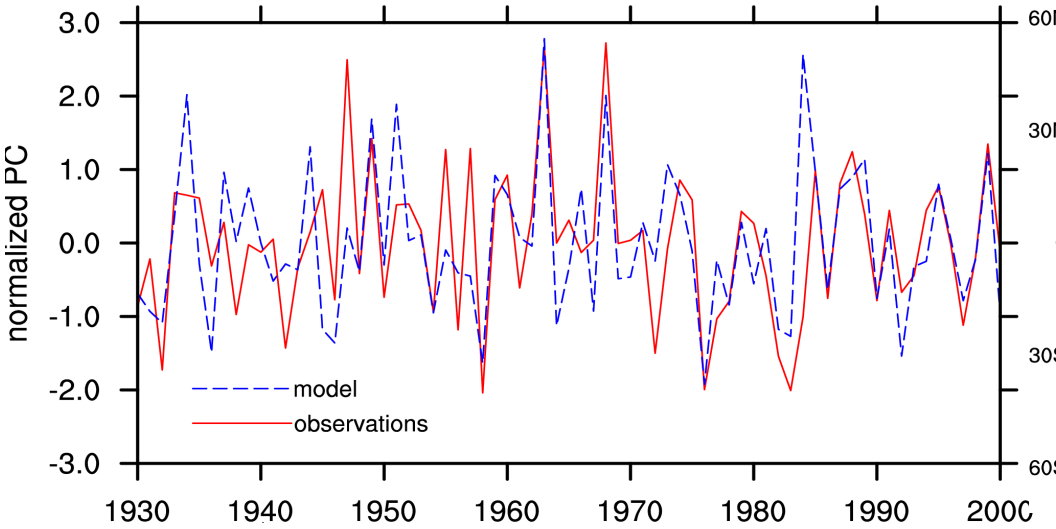
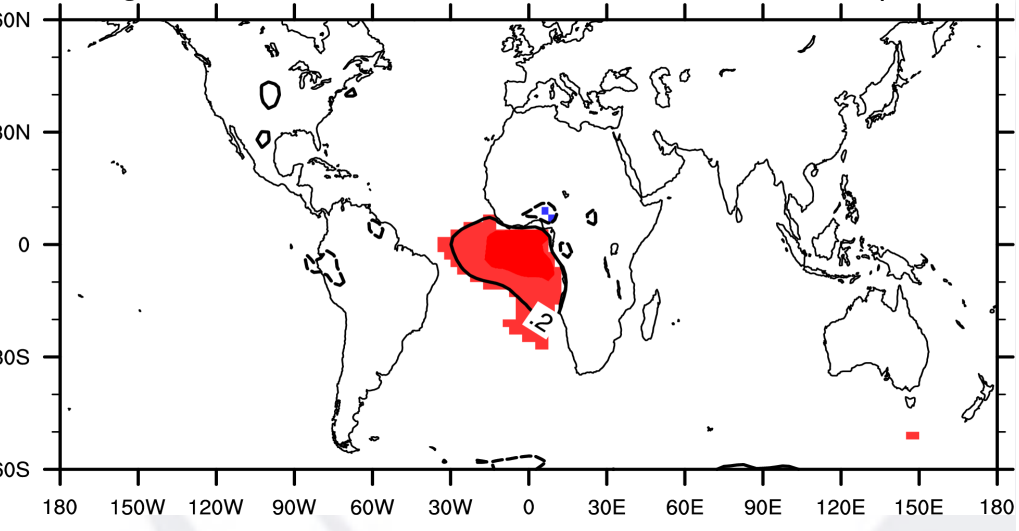



b. Gulf of Guinea PC of 1930-2000 precipitation



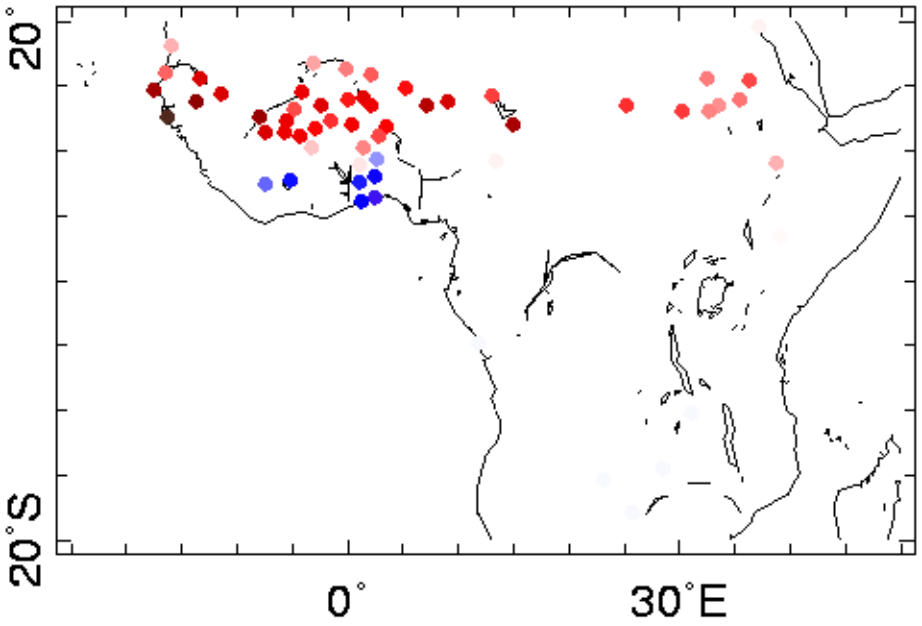

c. regression of the model's Gulf of Guinea PC on sfc temperature

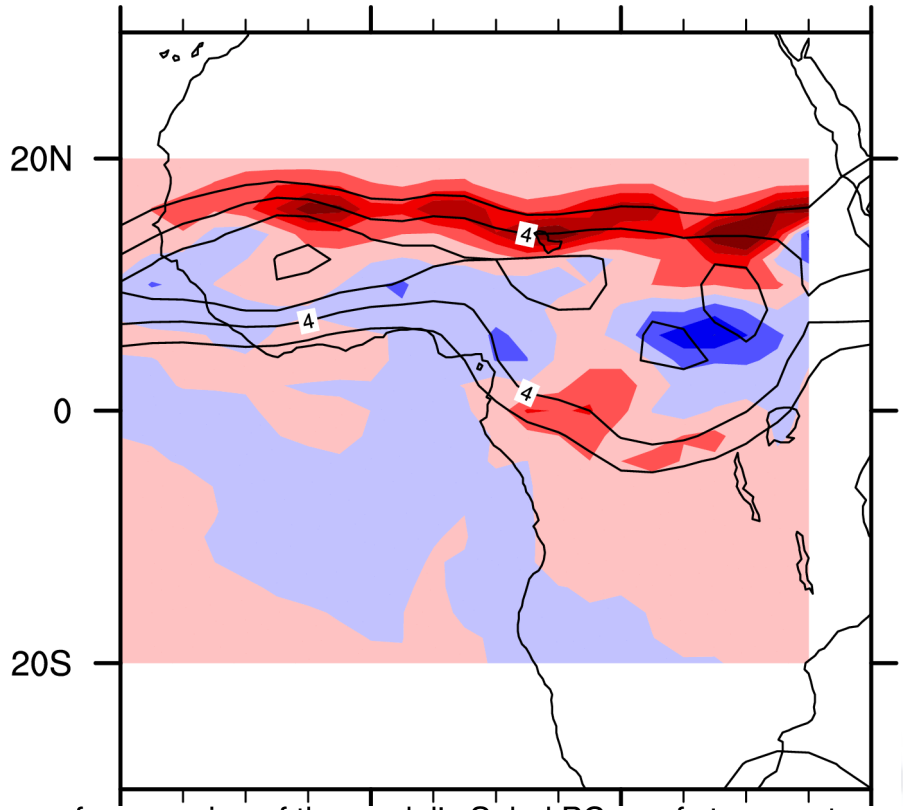



**Giannini, A, R Saravanan, P Chang, 2005 in Clim. Dyn.**

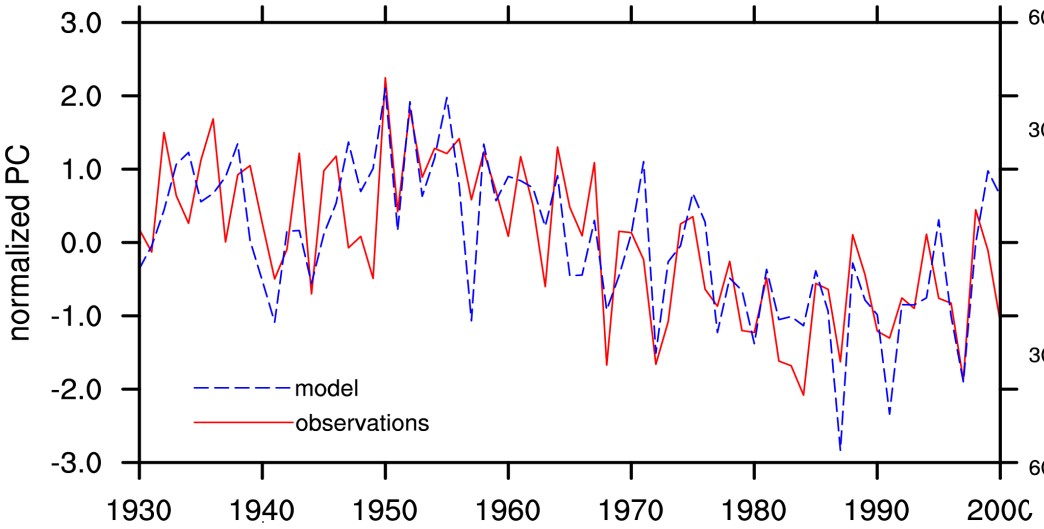
# Variability in Sahel rainfall – the West African monsoon

*(25% in obs, 21% in ens-mean)*

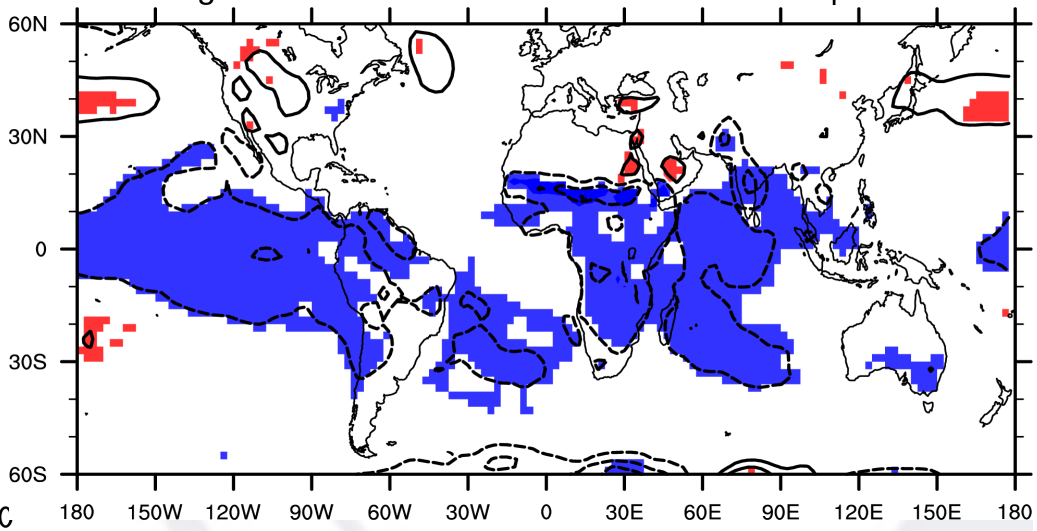



e. Sahel PC of 1930-2000 precipitation

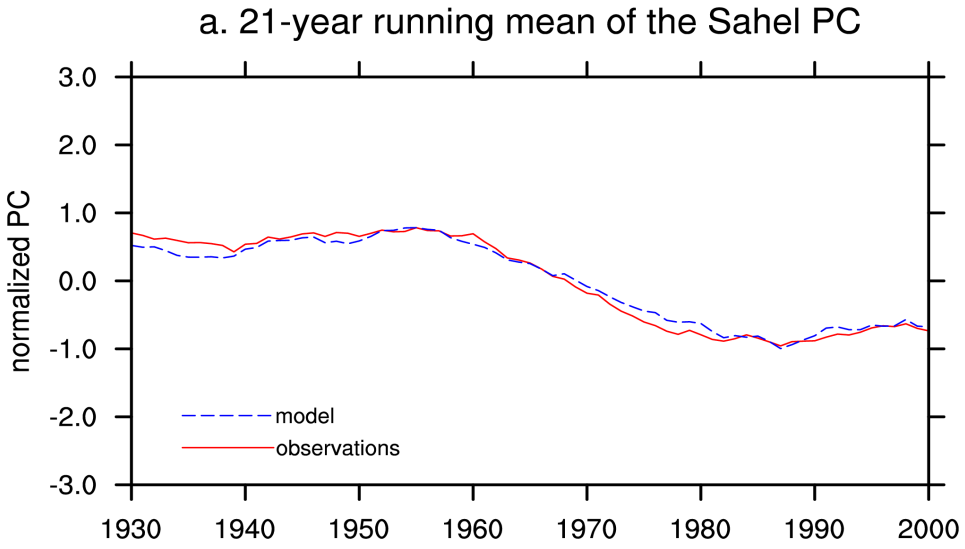


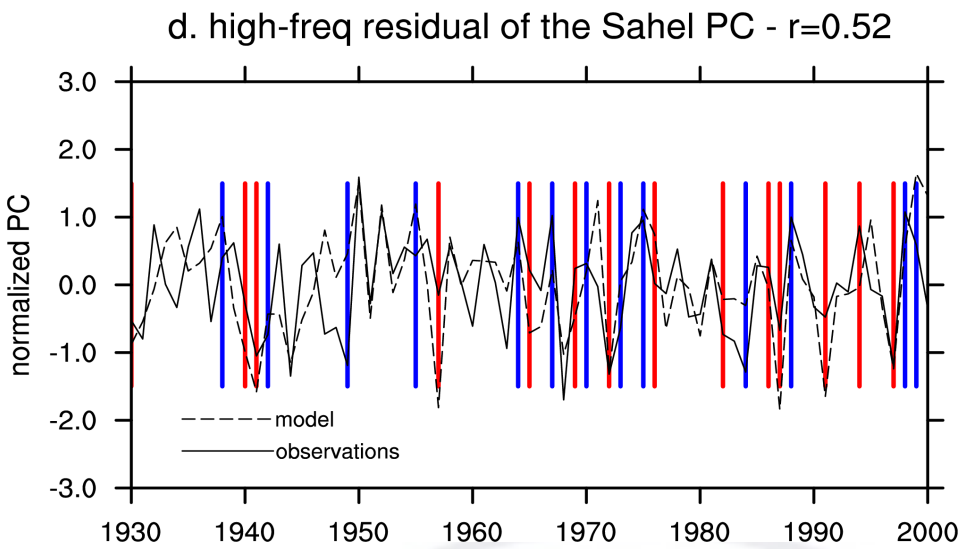

f. regression of the model's Sahel PC on sfc temperature

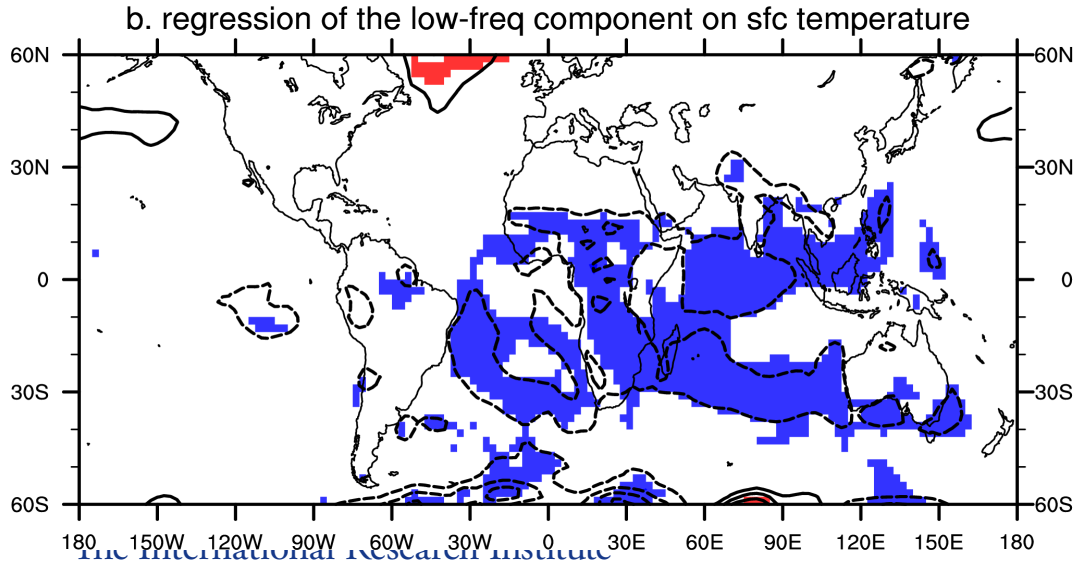


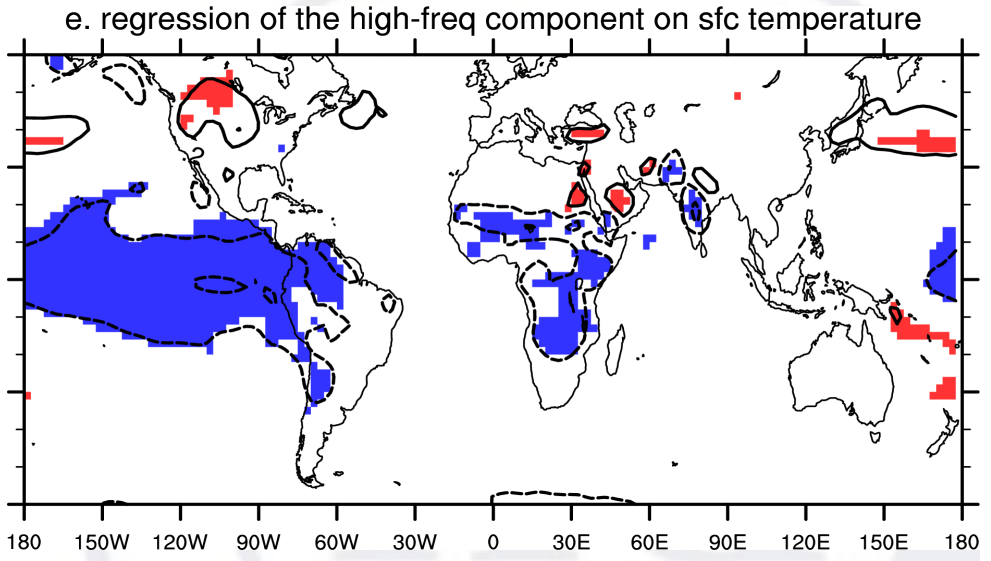

**Giannini, A, R Saravanan, P Chang, 2005 in Clim. Dyn.**

# Variability in Sahel rainfall: separation of interdecadal and interannual time scales





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**Giannini, A, R Saravanan, P Chang, 2003 in Science**

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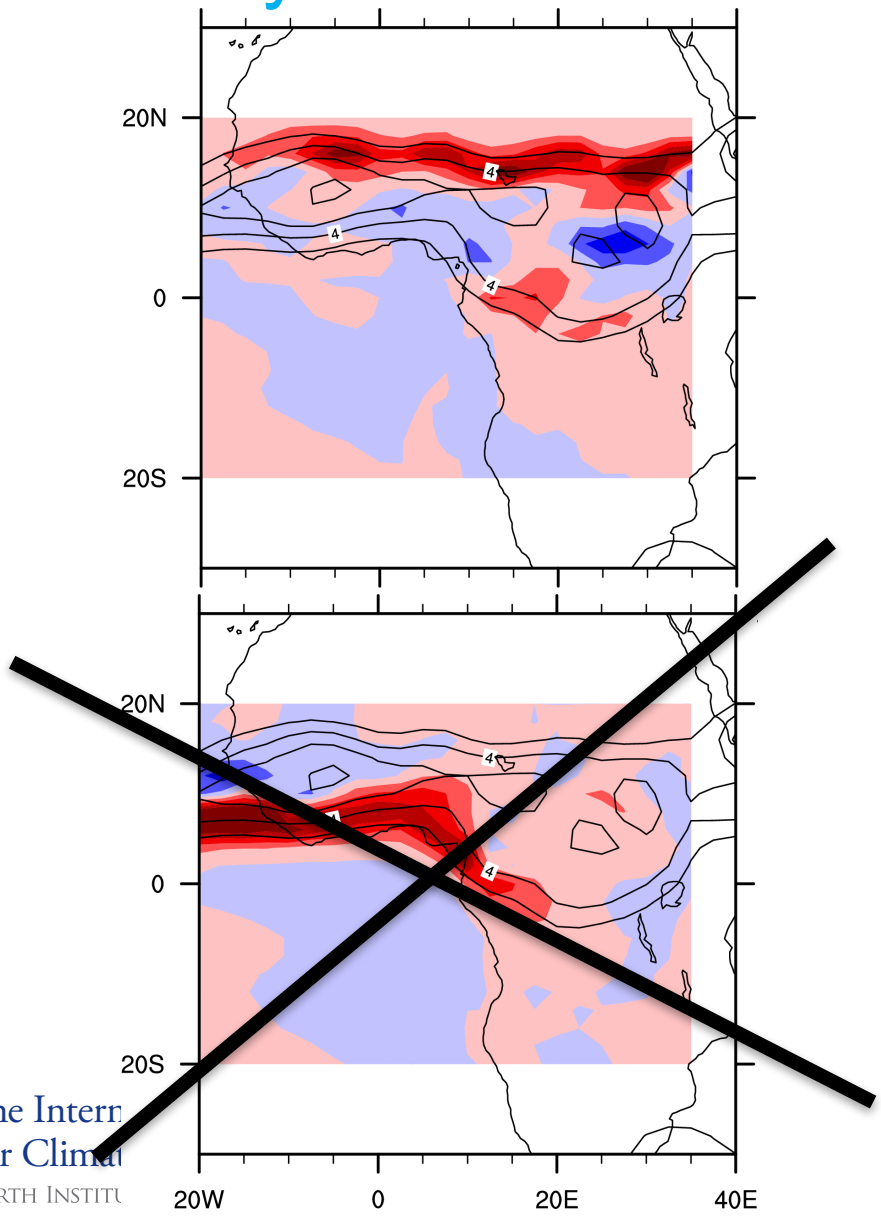
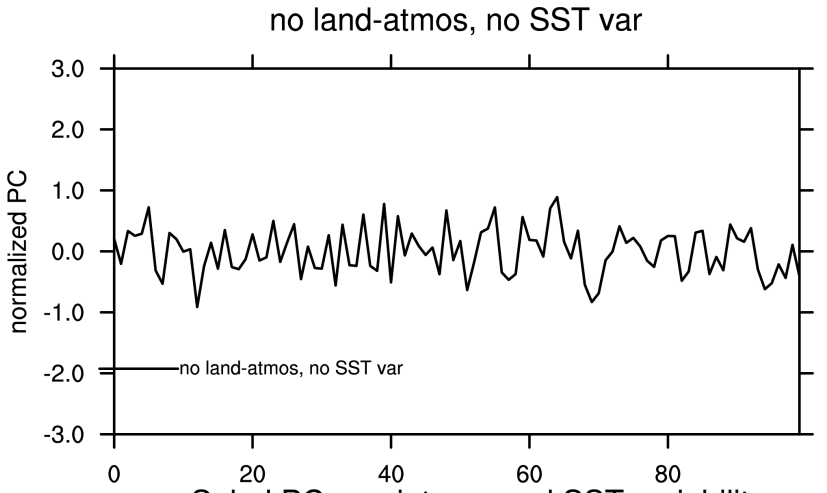
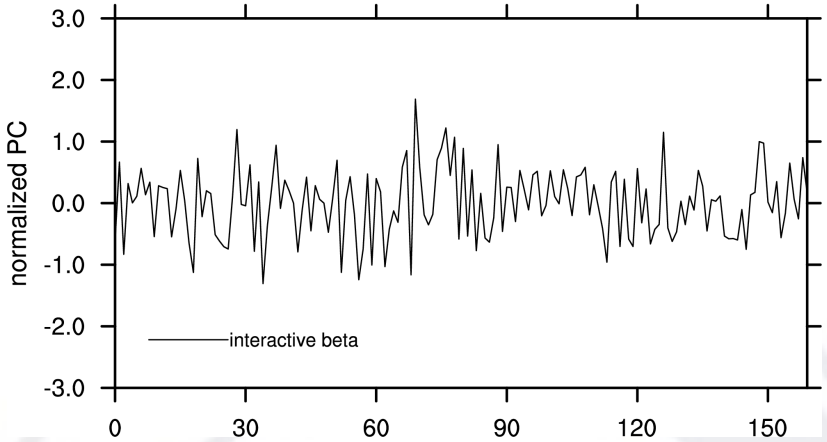
# The "Sahel" pattern is also an internal mode of atmospheric variability

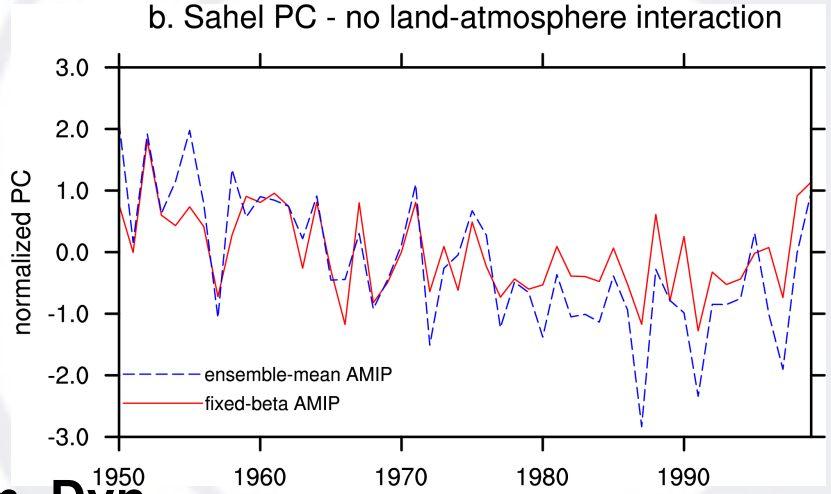



a. Sahel PC - no interannual SST variability




b. Sahel PC - no land-atmosphere interaction

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**Giannini, A, R Saravanan, P Chang, 2005 in Clim. Dyn.**

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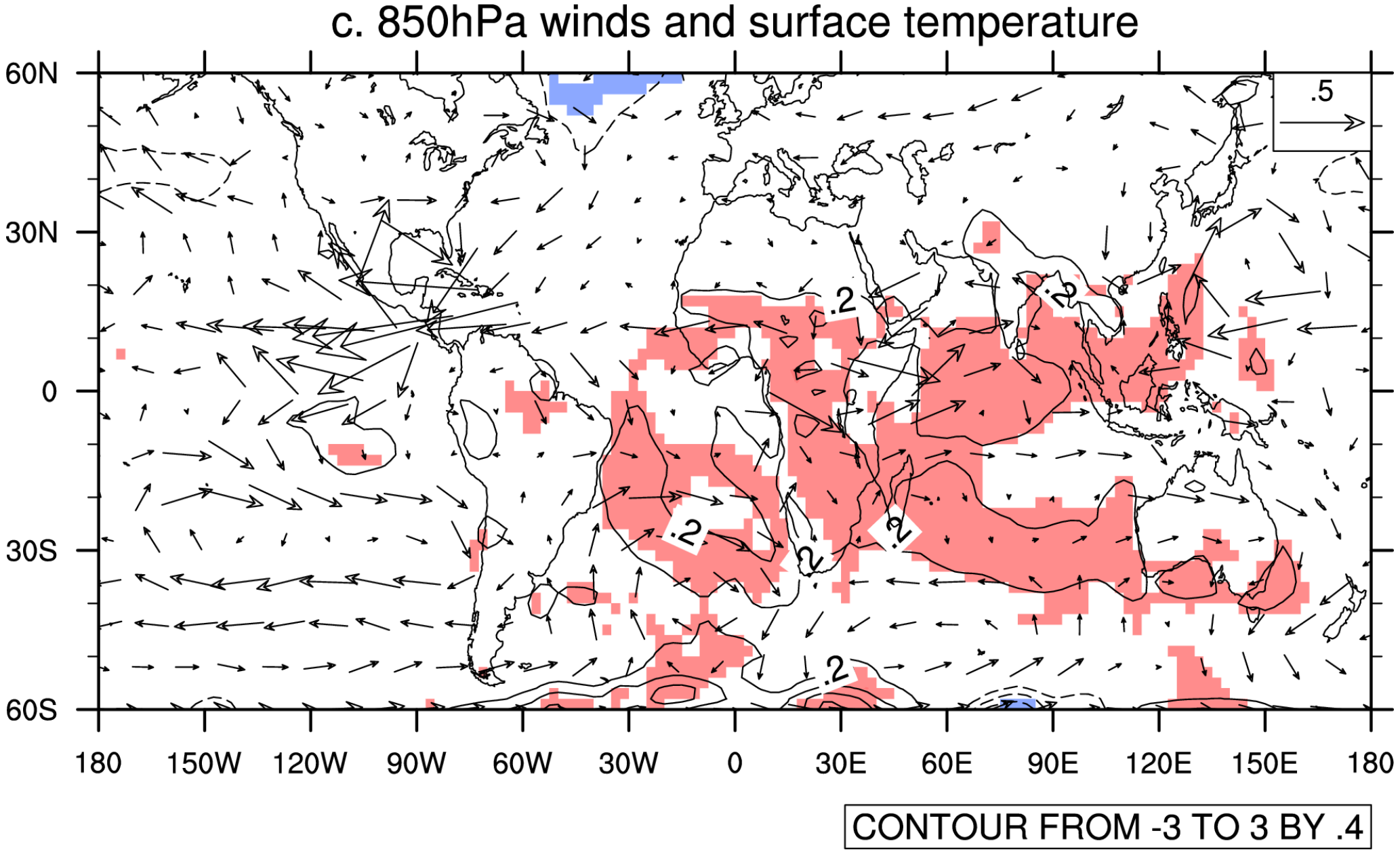
# diagnosing the dynamics of ocean influence through regression



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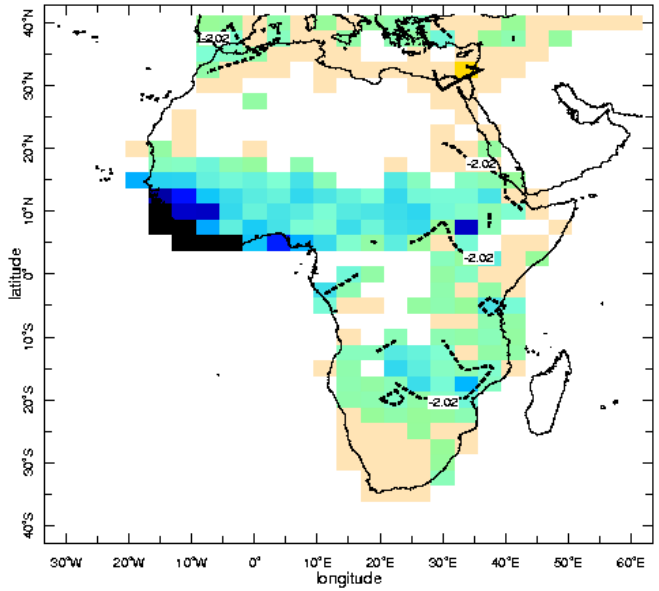
# Dominant patterns of observed rainfall variability

## Jul-Jun [annual average] 1930-1995

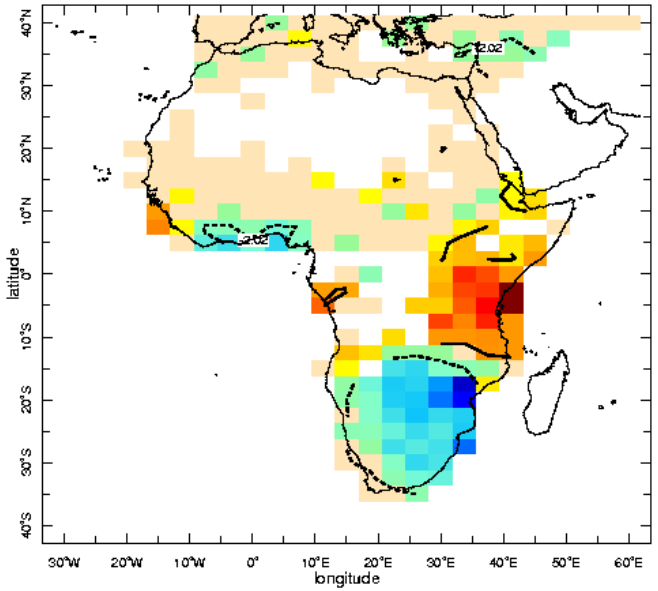
**Giannini, Biasutti, Held and Sobel 2008, in *Climatic Change***




1.

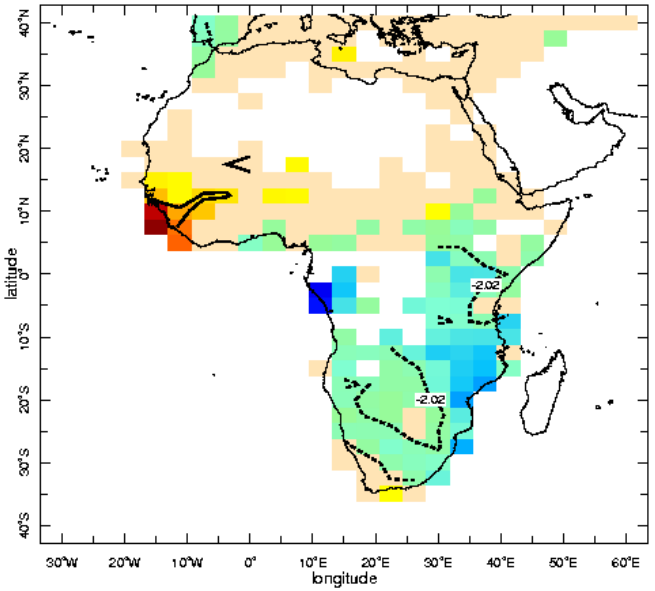
17% of Jul-Jun variance

EOF1 of Apr-Jun (11%)
EOF1 of Jul-Sep (24%)




9% Jul-Jun variance

EOF1 of Oct-Dec (17%)
EOF1 of Jan-Mar (18%)




3.

7% of Jul-Jun variance

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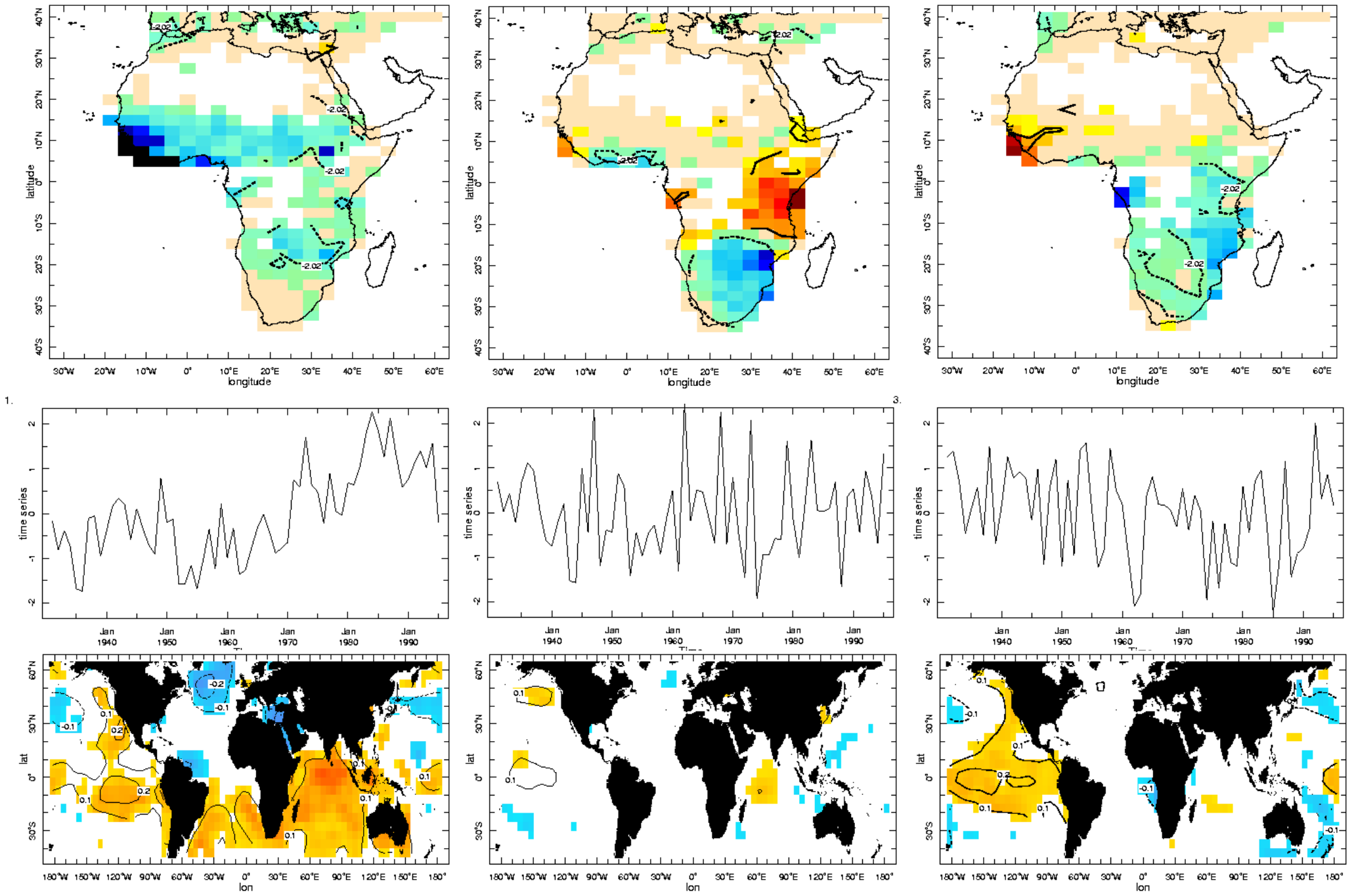
# Predictability of precipitation comes from the oceans

## Giannini, Biasutti, Held and Sobel 2008, in *Climatic Change*



## Oceans' influence explains past persistent drought:

multi-decadal changes in the oceans around Africa, Atlantic and Indian, explain the persistence of drought

the monsoon is distinct from the (oceanic) ITCZ

# **How** do oceans affect the climate of the Sahel?

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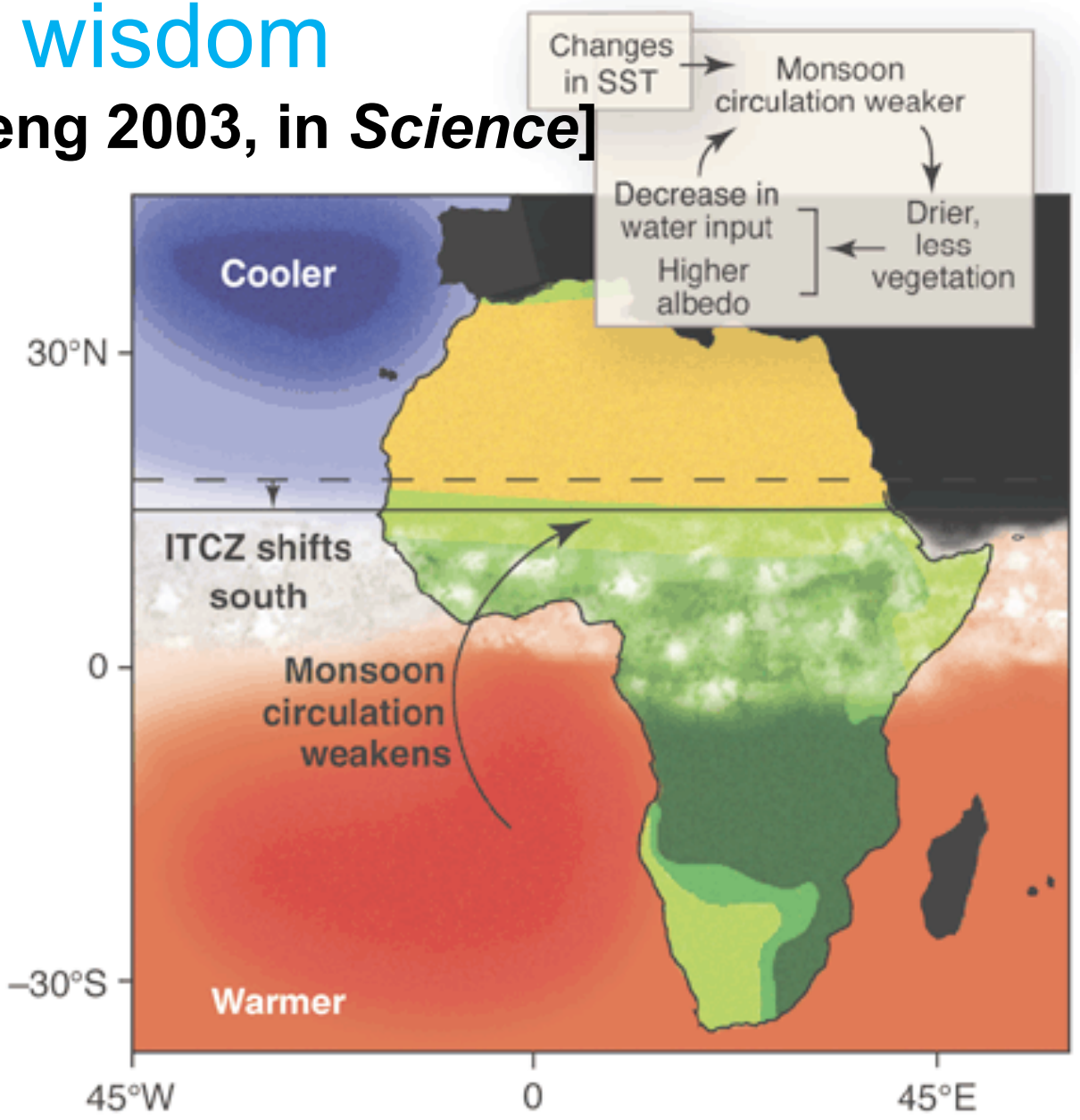
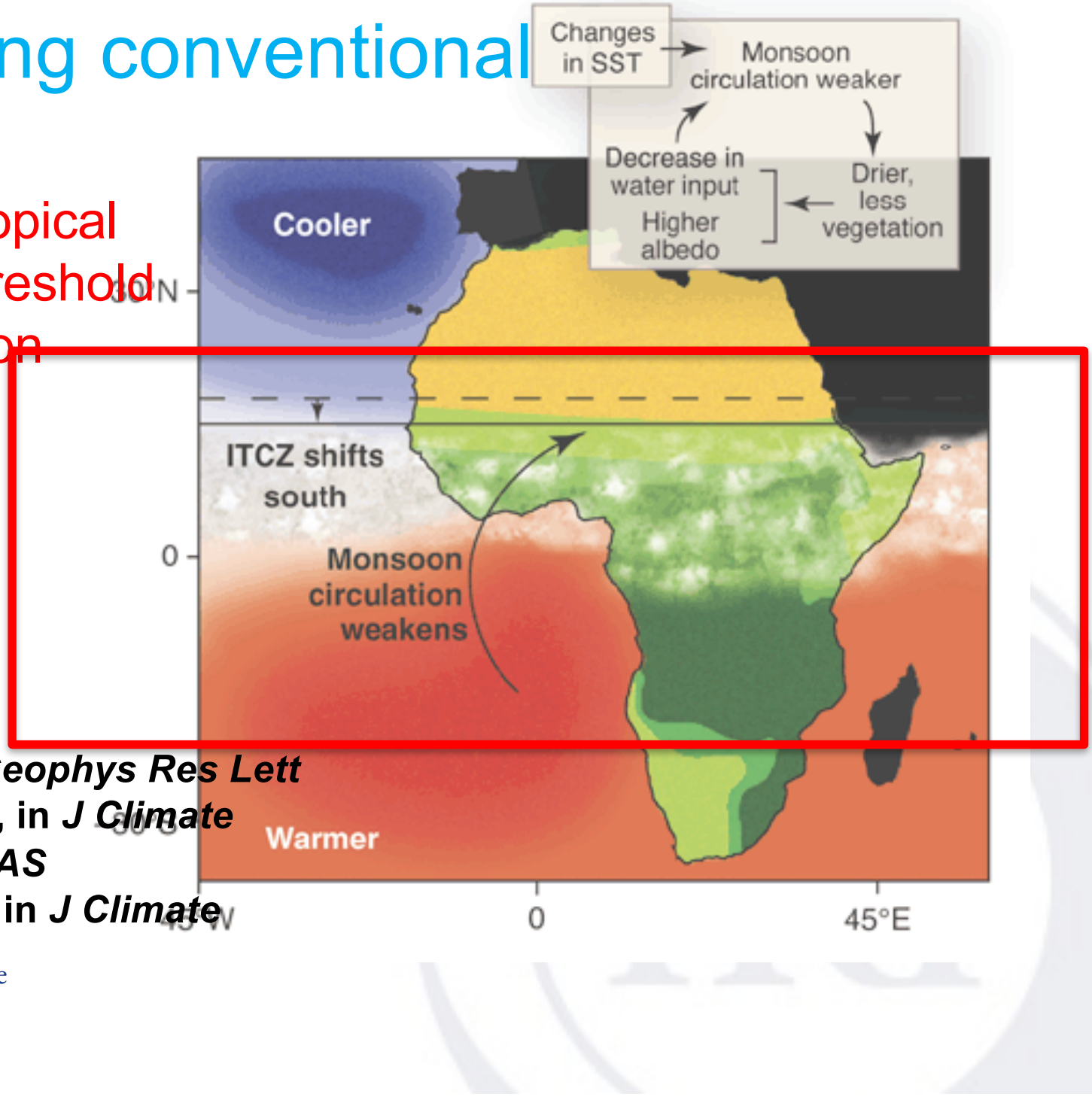
# Conventional wisdom

**[cartoon is from Zeng 2003, in *Science*]**



# Reinterpreting conventional wisdom…

(1/2) the global tropical oceans set the threshold for deep convection e.g., “upped ante” in warming




**Neelin *et al.* 2003, in *Geophys Res Lett***
**Chou and Neelin 2004, in *J Climate***
**Held *et al.* 2005, in *PNAS***
**Held and Soden 2006, in *J Climate***

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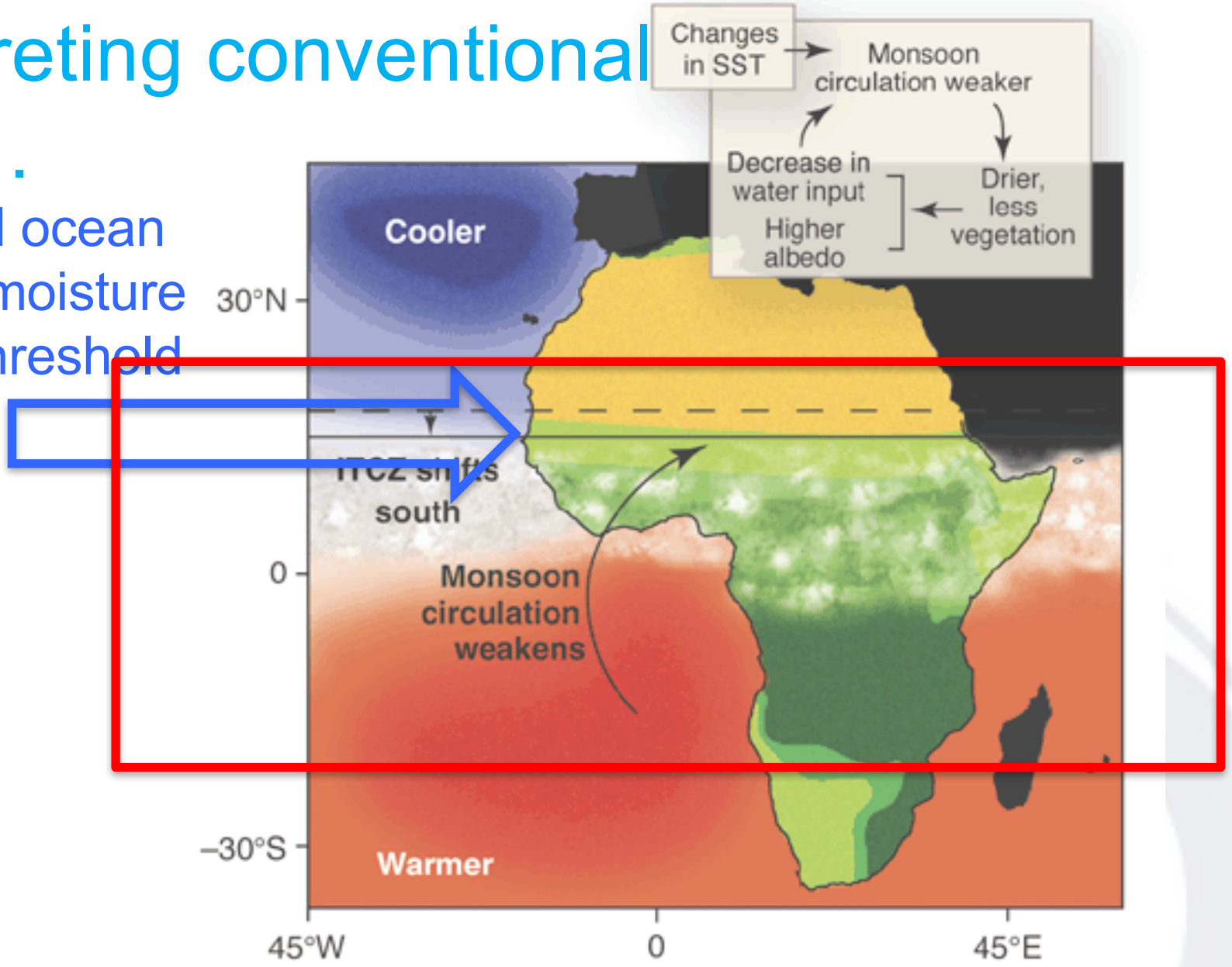
# Reinterpreting conventional wisdom…

(2/2) the local ocean supplies the moisture to meet the threshold

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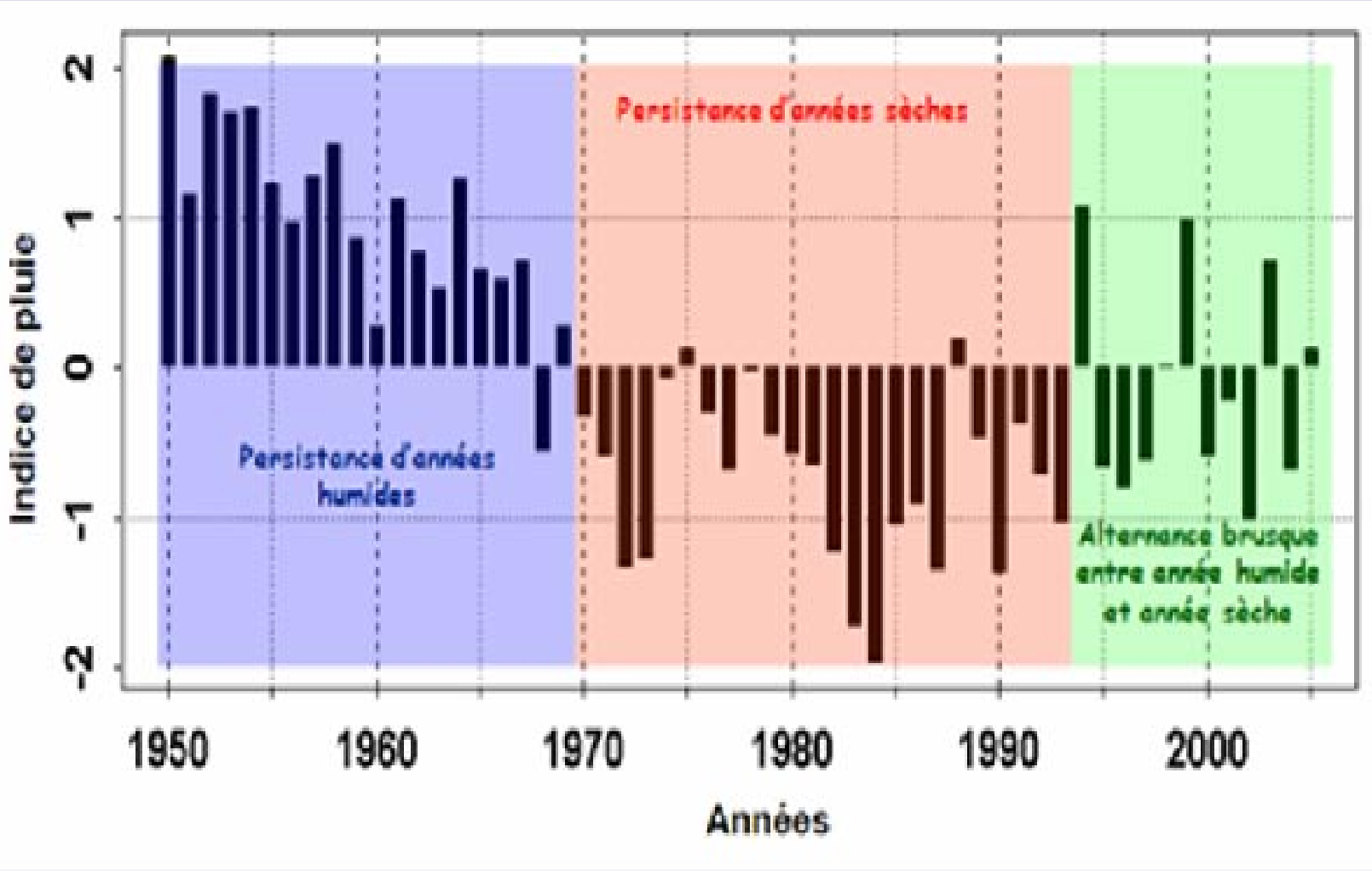
# Evolution of 20th century Sahel climate:
## anomalously wet, persistent drought, increased variability?
Agrhymet (2010)

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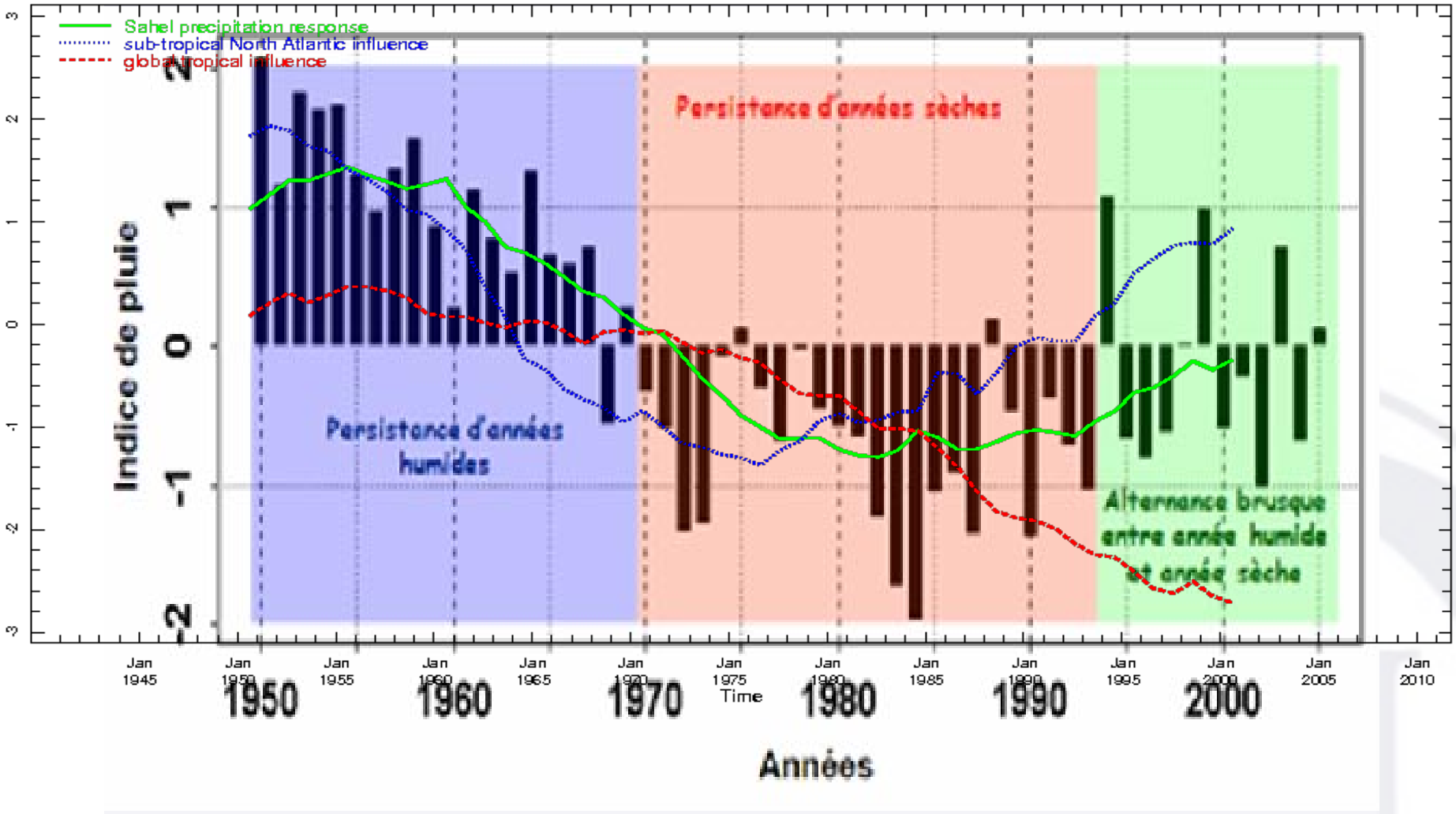


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**North Atlantic – global mean global tropical mean Sahel rainfall**

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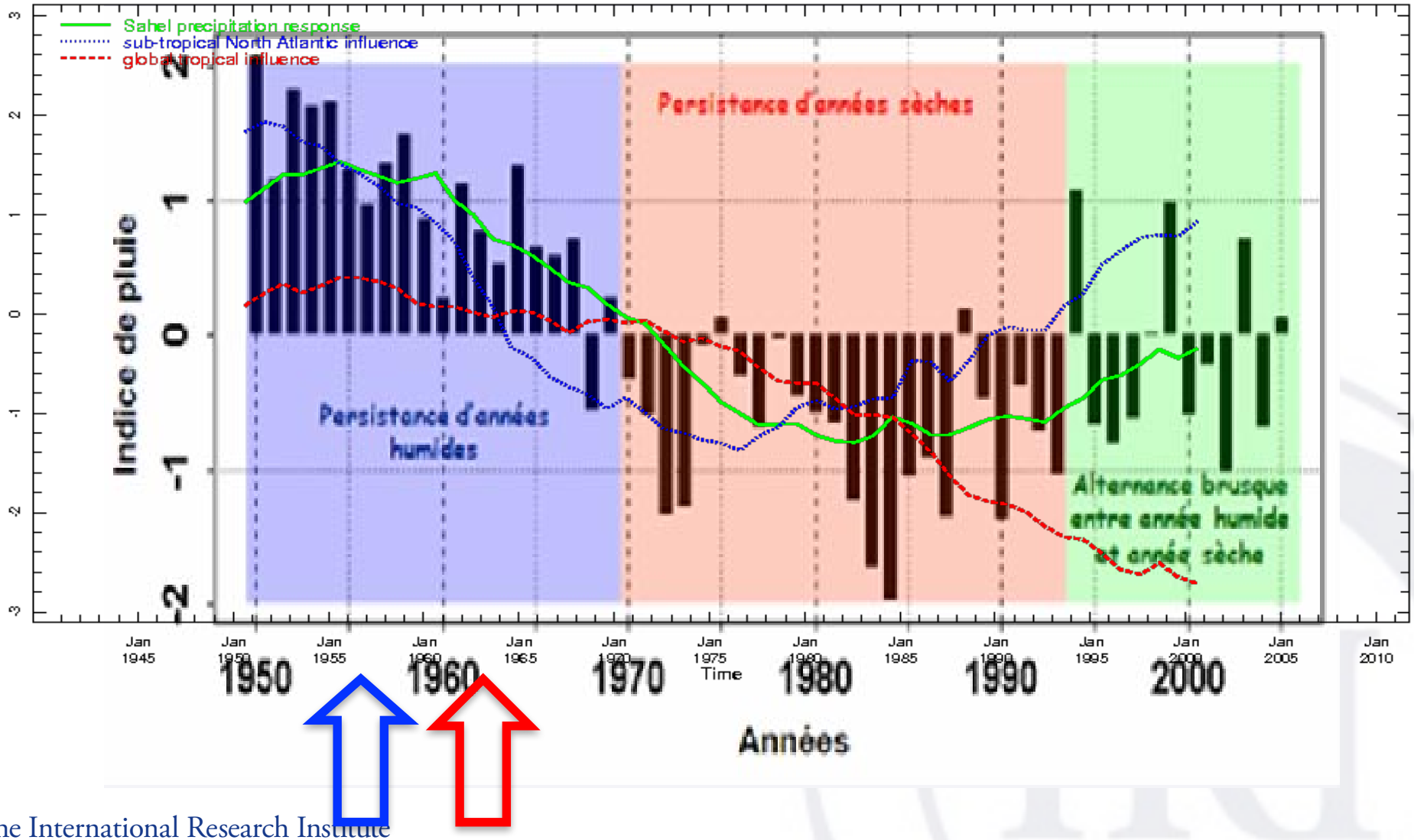


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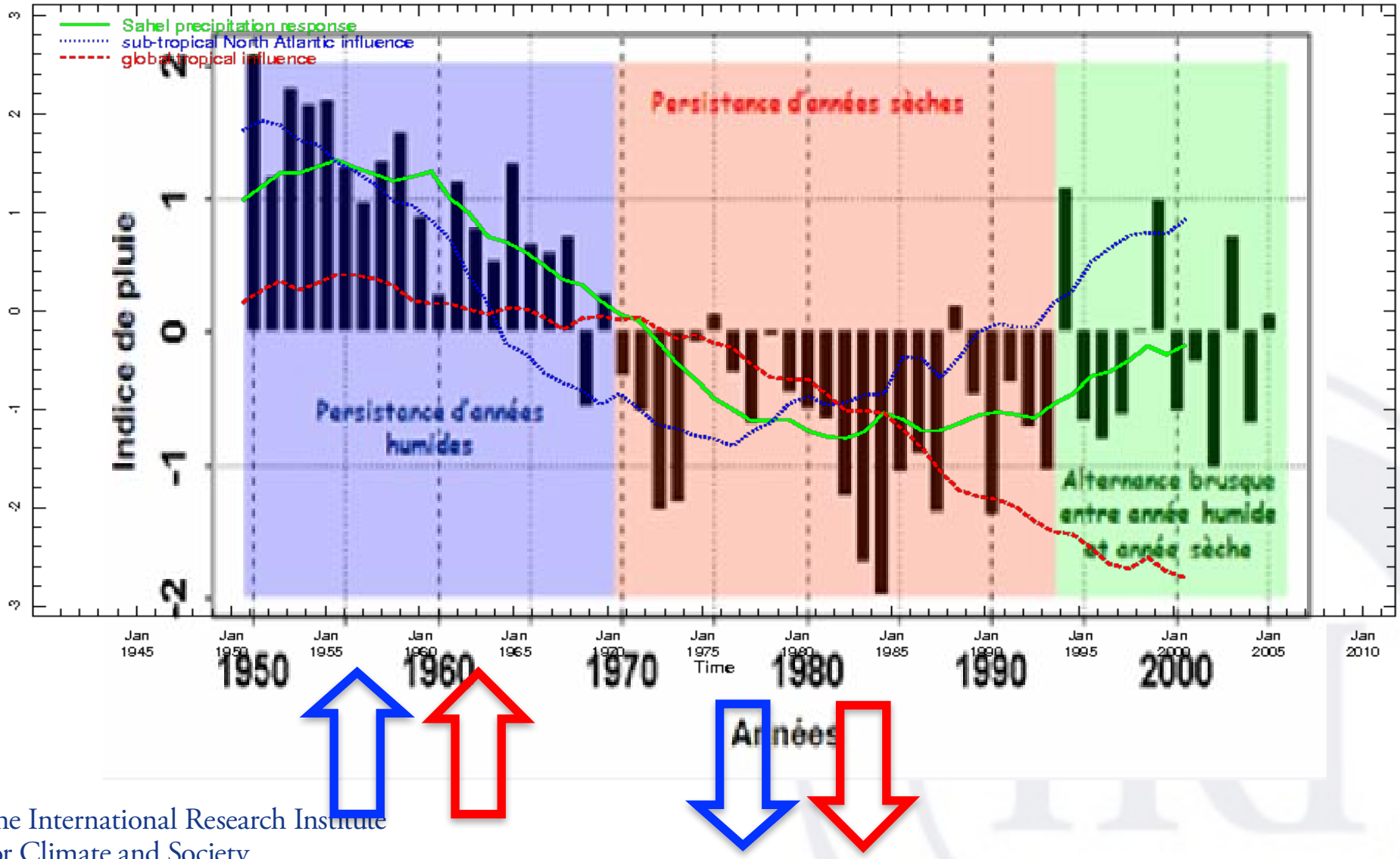


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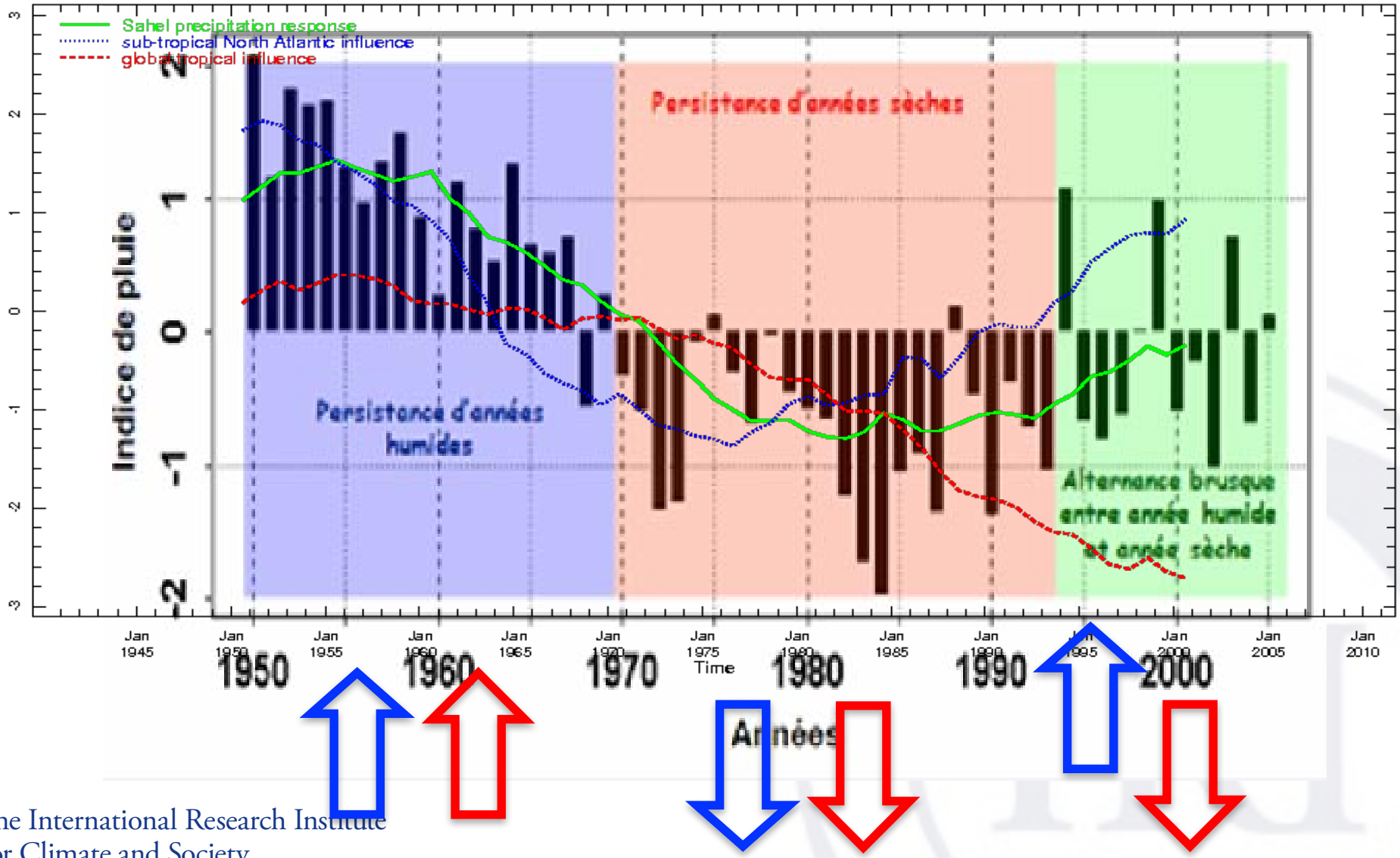


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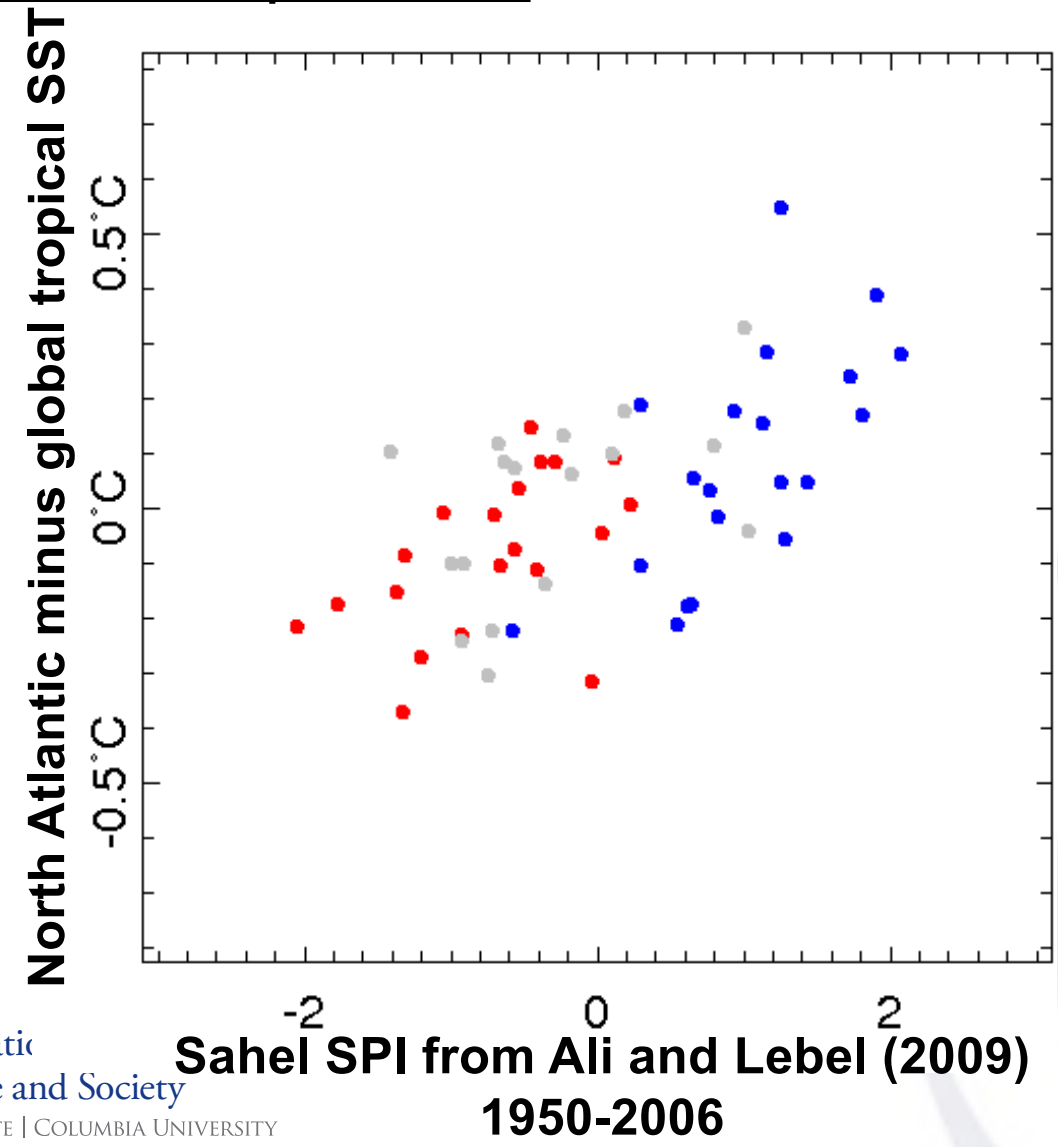
**North Atlantic – global mean global tropical mean Sahel rainfall**

# 20th century *observations* of Sahel climate

Subtropical North Atlantic minus global tropical mean SST is a potential predictor of Sahel rainfall




1950-1969 – wet
1970-1989 – dry
1990-2006 – variable

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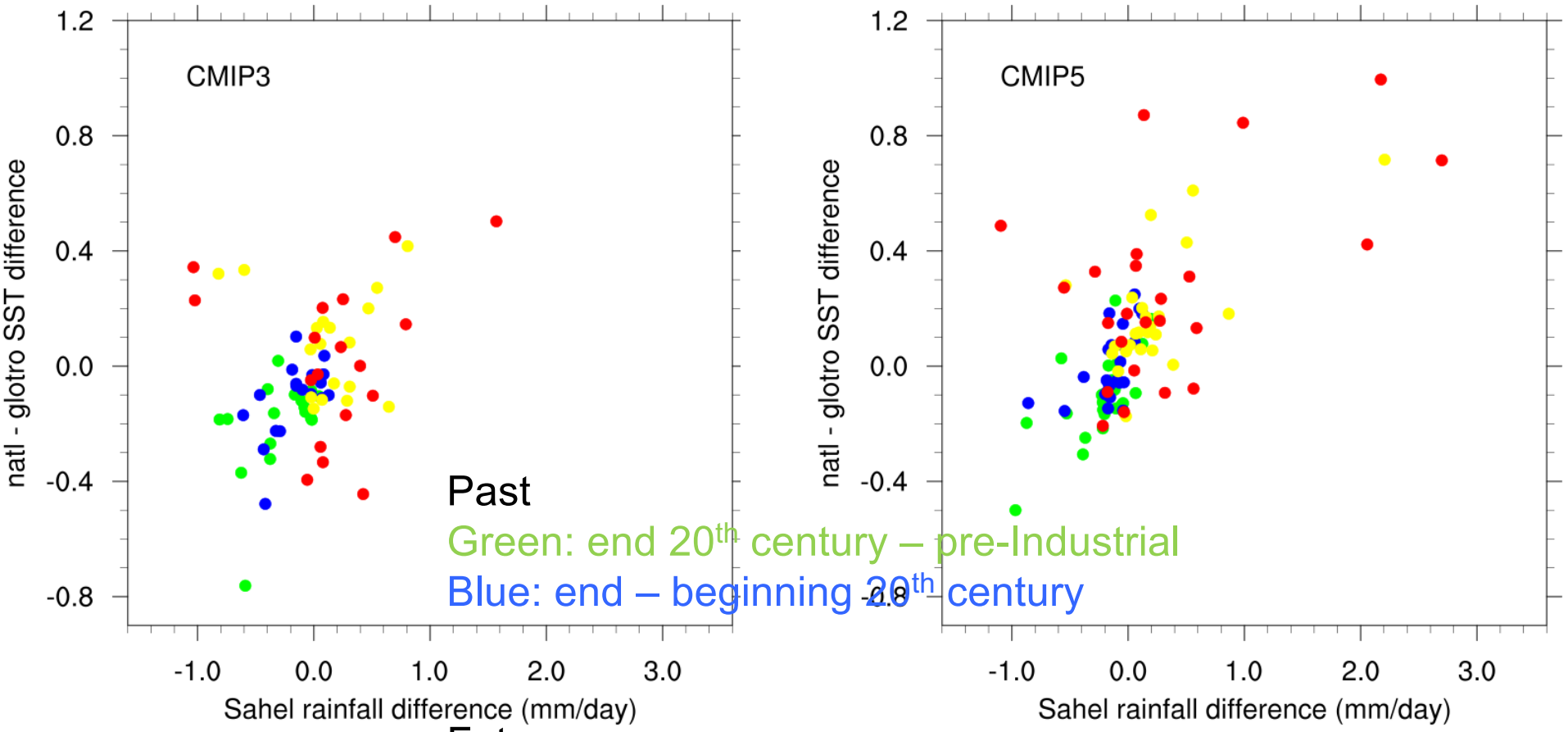
# 21st century *projections* of Sahel climate

Subtropical North Atlantic minus global tropical mean SST explains the uncertainty in projections of long-term change [Giannini, Salack, Lodoun *et al.*, 2013 in *Env. Res. Lett.*]




Past

Green: end 20th century – pre-Industrial

Blue: end – beginning 20th century

Future

Yellow: mid-21st – end 20th

Red: end 21st – end 20th

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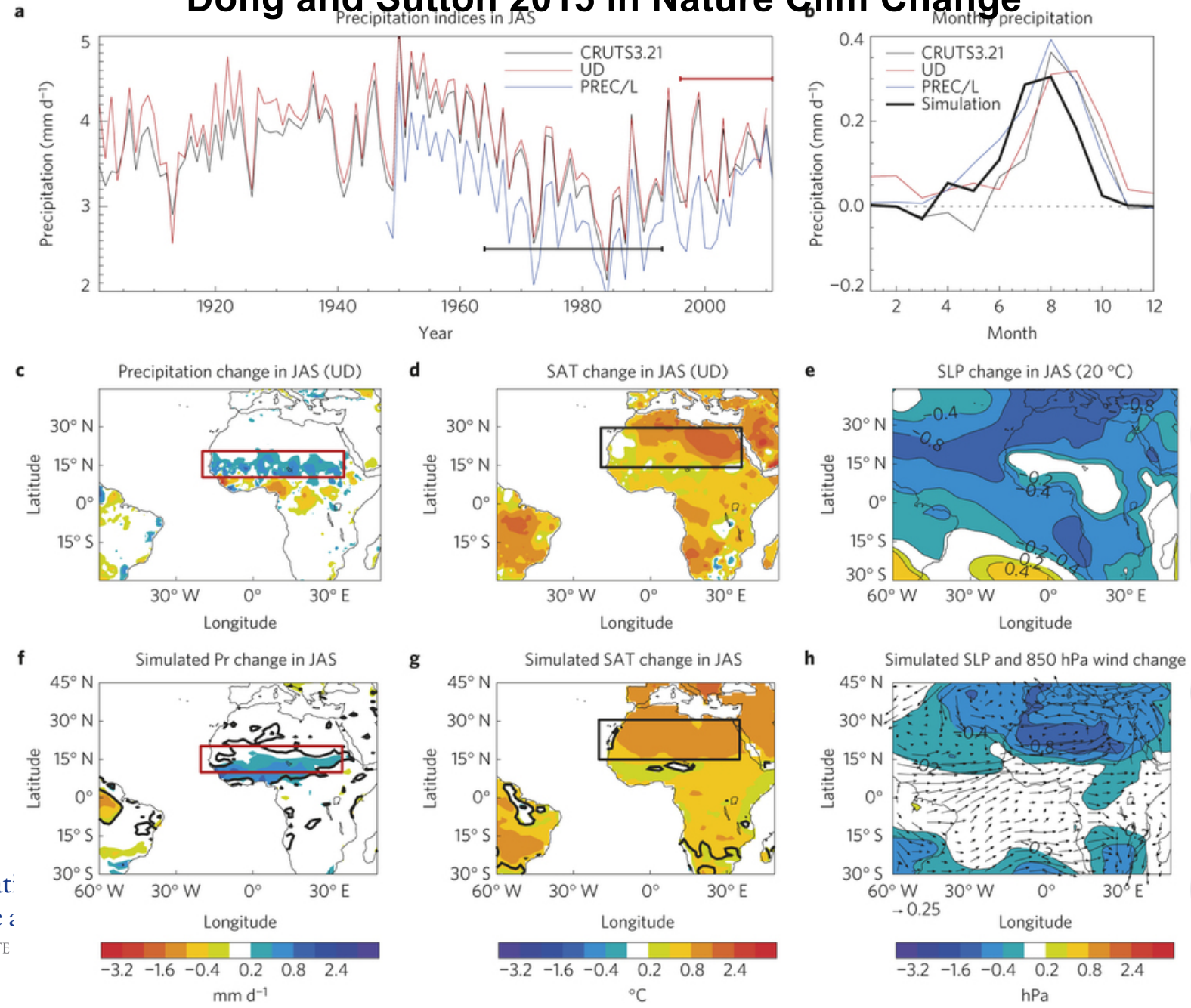
# The recent recovery in Sahel rainfall: observed changes and model-simulated responses

## Dong and Sutton 2015 in Nature Clim Change

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# Summary on the role of the oceans in Sahel rainfall variability/change

Oceans drive variations in West African rainfall on interannual [e.g., El Niño] and interdecadal [e.g., decadal variability in the Atlantic Ocean, whether internal or externally forced] time scales. *[Land surface-atmosphere interaction provides an amplifying [positive] feedback.]*

The simplest balance for the Sahel is one where the global tropical oceans set the threshold for convection, with warming of the oceans associated with a more stable vertical column, and the local ocean meets the threshold if it can supply sufficient moisture – *stabilization v. moisture supply*

*This framework is partly successful in explaining projections of change.*

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# questions

- How do stabilization v. moisture supply work during transitions into and out of the rainy season?
- Is onset predictable? [On what time scale?]
- What do decadal predictions say about sea surface temperatures in the North Atlantic?
- ...

## *Application #1 – attribution*

Oceans' influence explains attribution of drought to emissions of greenhouse gases and sulfate aerosols from industrialization

***How?***

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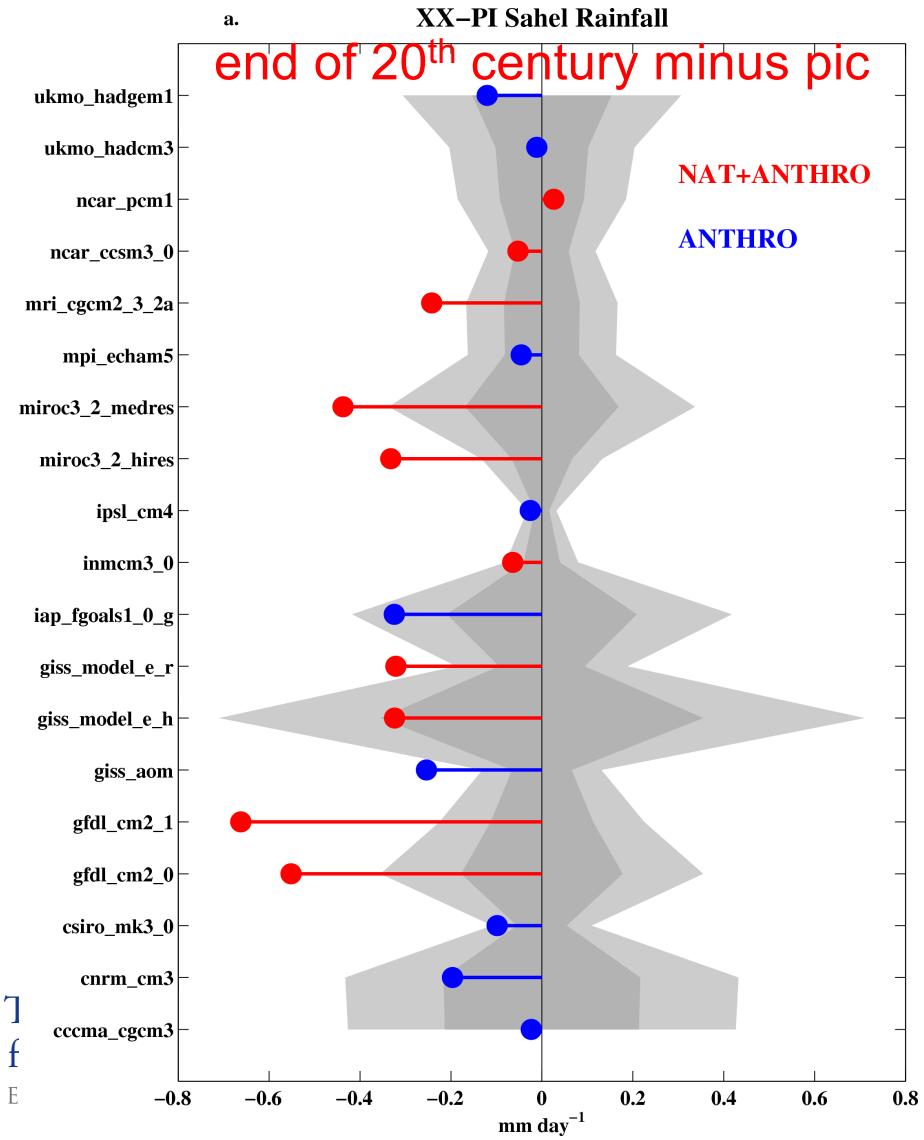
# *"Robust Sahel drying in response to late 20th century forcings"*

## Biasutti and Giannini, 2006 in *Geophys Res Lett*




No CMIP3 model simulates a wetter Sahel at the end of the 20th century compared to the pre-Industrial control.

Sulfate aerosols drive the coherence in this response.

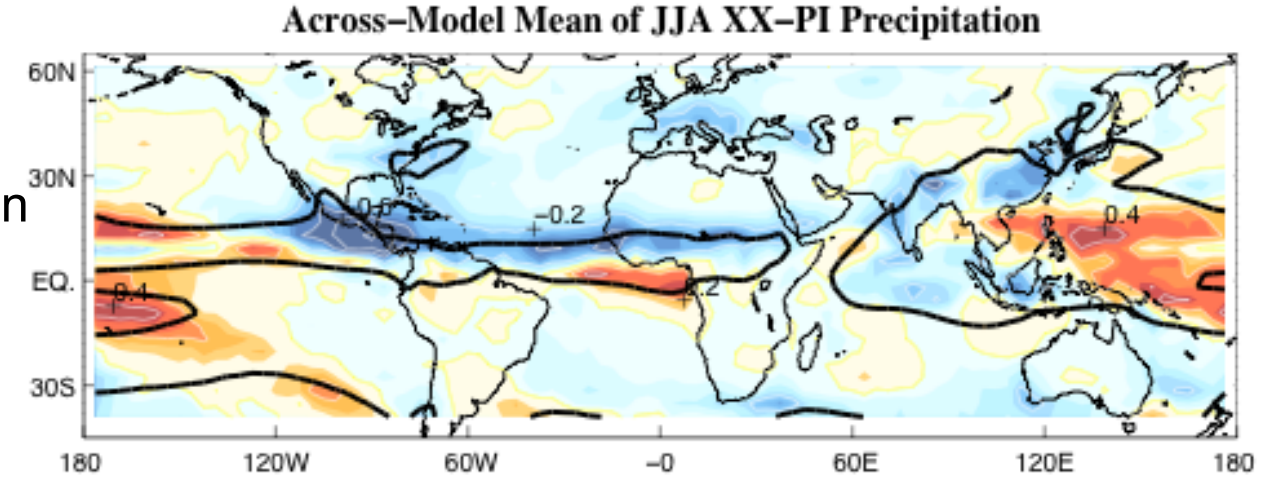
Also see:
**Chang, Chiang *et al.* 2011, in J Climate**
**Booth *et al.* 2012, in Nature**
**[Ting *et al.* 2009, in J Climate]**

# *"Robust Sahel drying in response to late 20th century forcings"*

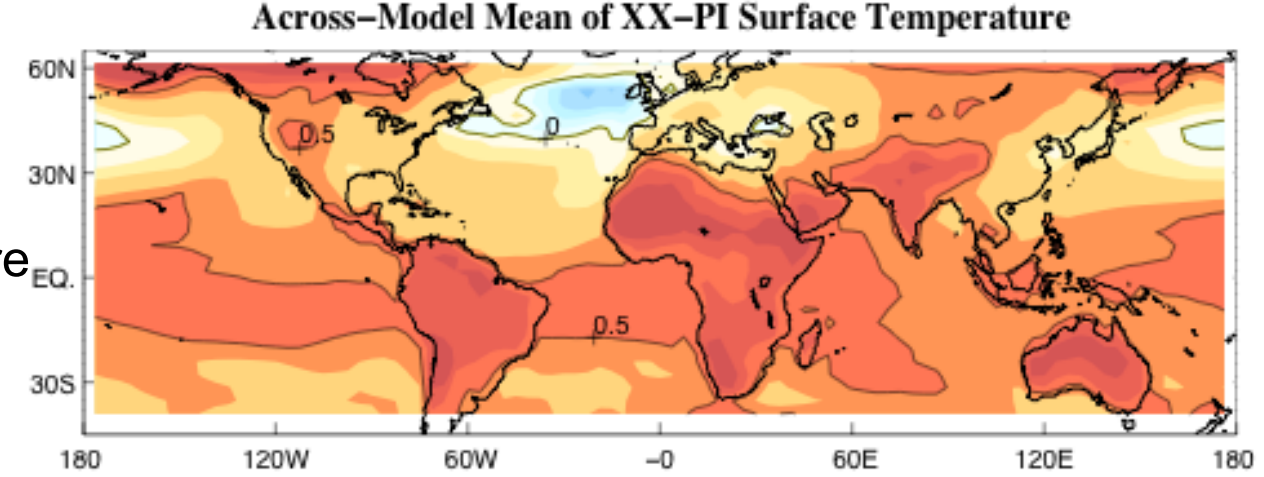
## Biasutti and Giannini, 2006 in *Geophys Res Lett*

**change between end of 20th century and pre-Industrial**
in 19 [CMIP3] coupled models

precipitation change




surface temperature change

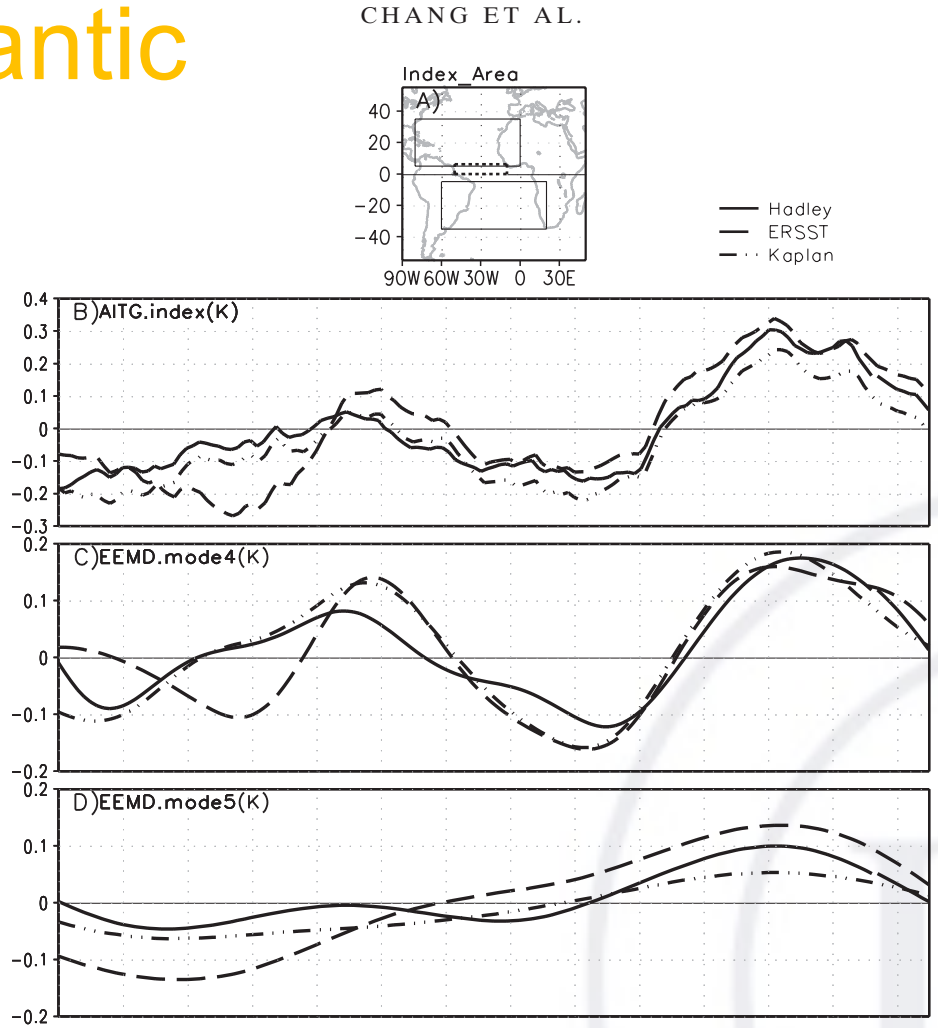


# Sulfate aerosols reduced 20th century warming of the North compared to the South Atlantic

Observations

Multi-decadal Oscillation

"Trend"

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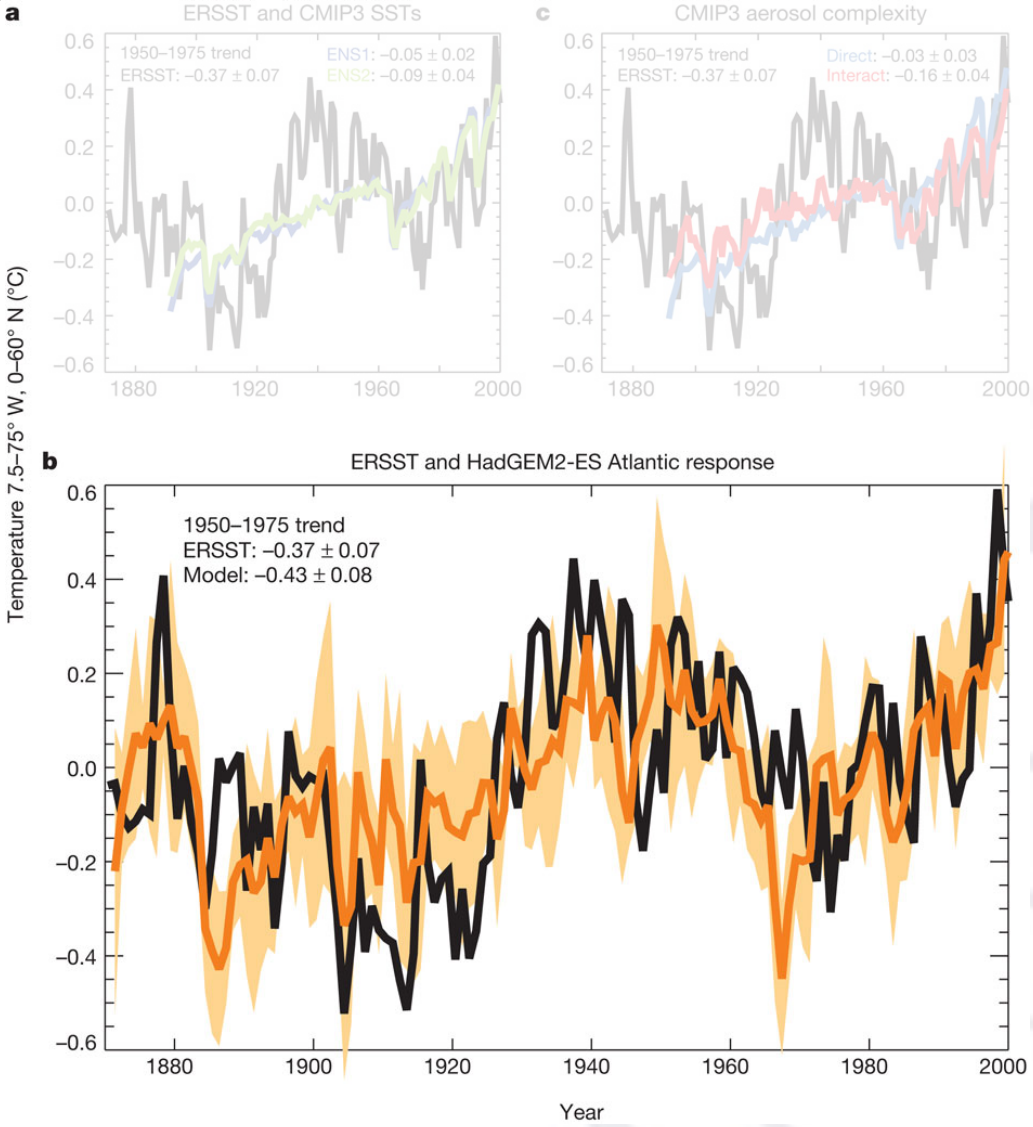
**Chang, Chiang et al 2010, in J Climate**

Hidden slide

# *Aerosols implicated as a prime driver of twentieth-century North Atlantic climate variability*

**Booth *et al.* 2012, in *Nature***





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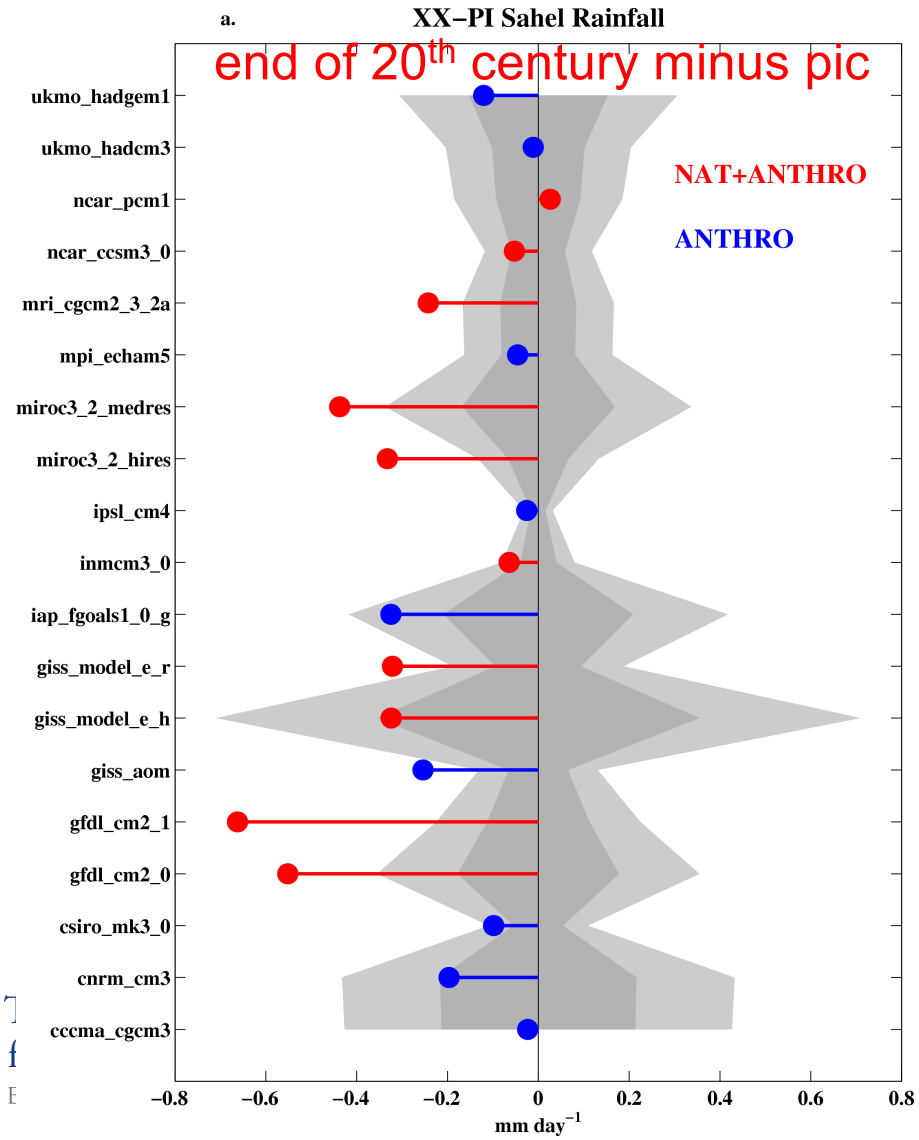
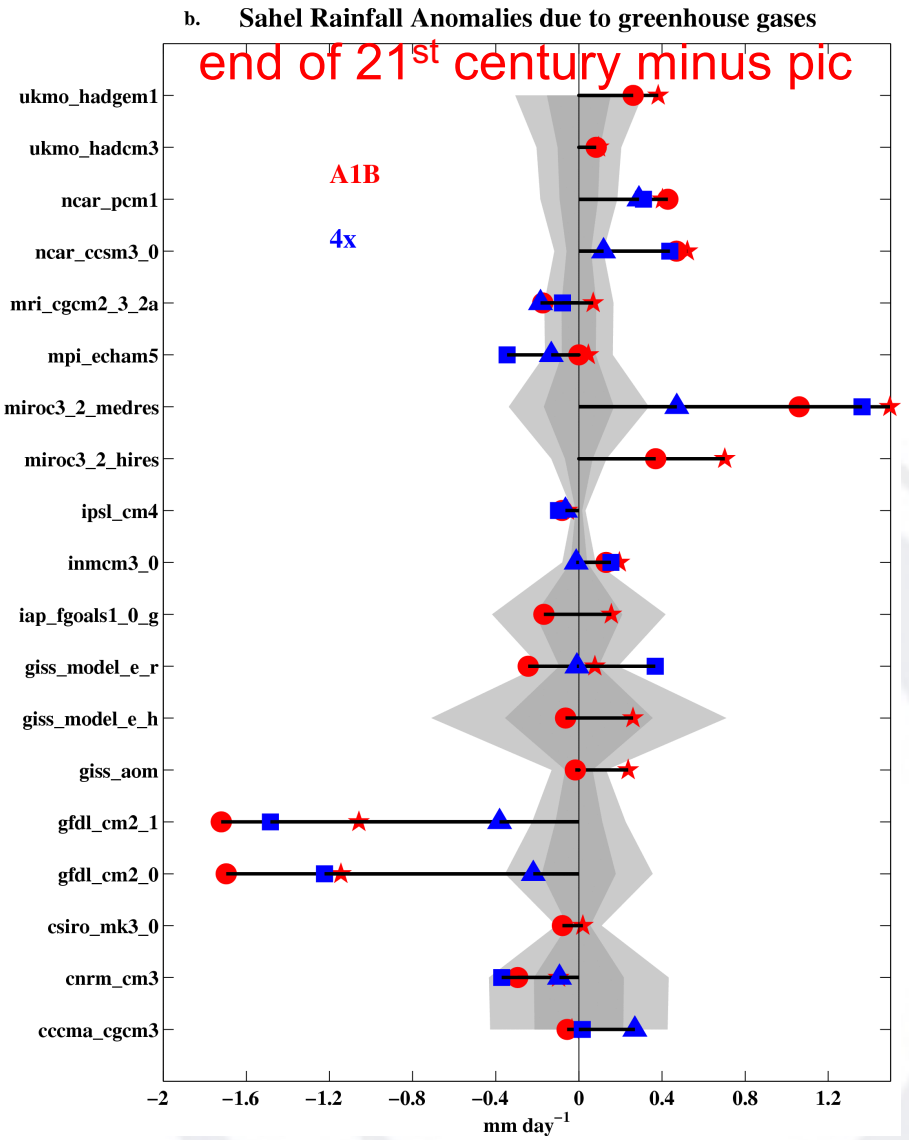
# *"Robust Sahel drying in response to late 20th century forcings"*

## Biasutti and Giannini, 2006 in *Geophys Res Lett*

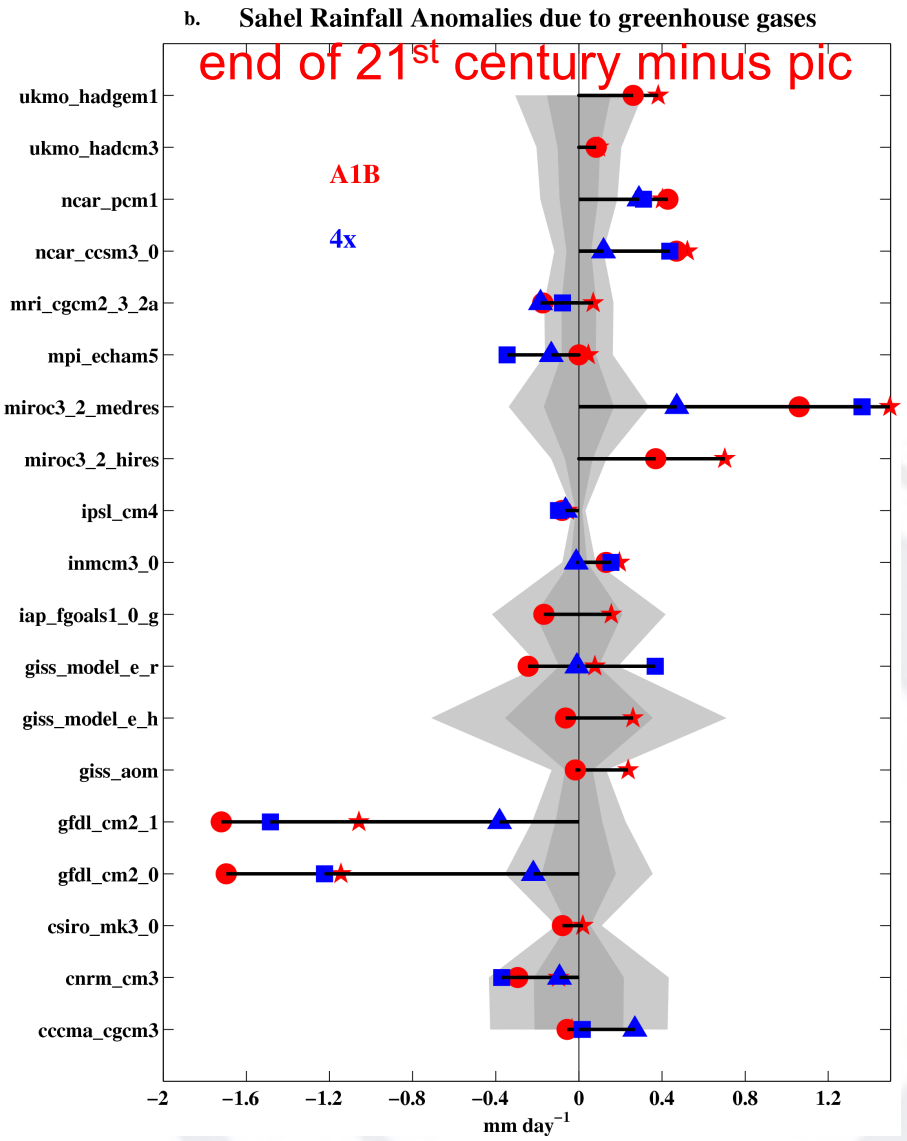


# *"Robust Sahel drying in response to late 20th century forcings"*

## Biasutti and Giannini, 2006 in *Geophys Res Lett*

The lack of coherence in projections is the manifestation of a fundamental, dynamical uncertainty in the response of precipitation to greenhouse gases...

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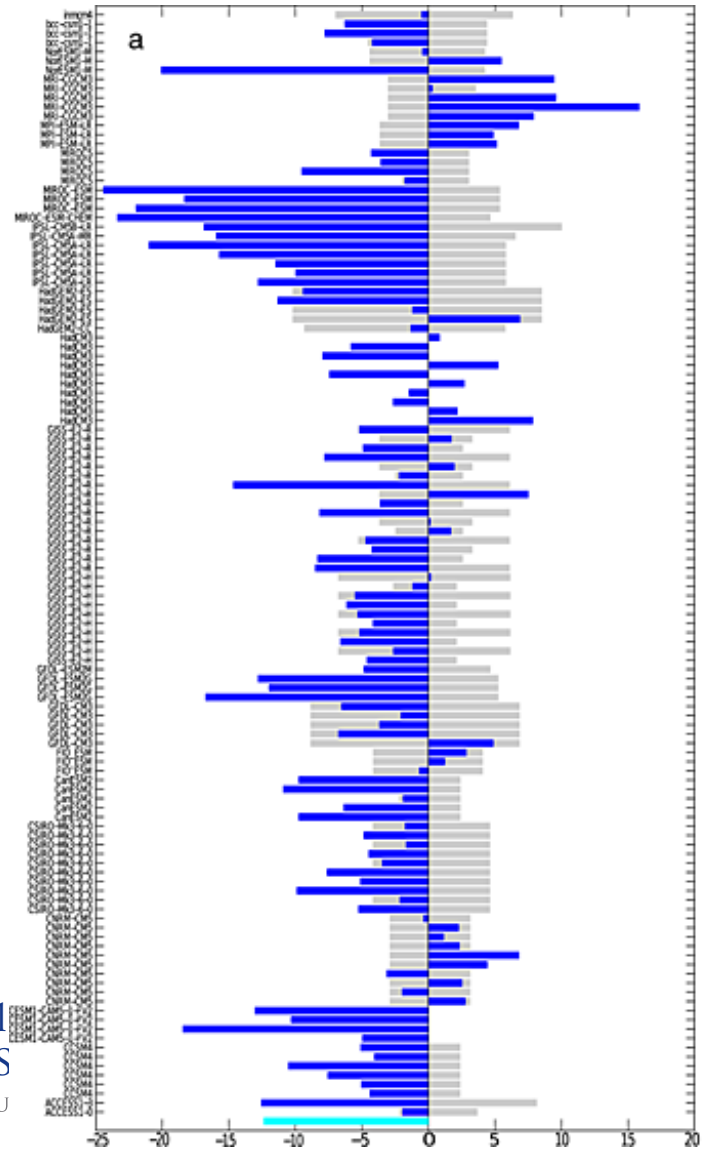
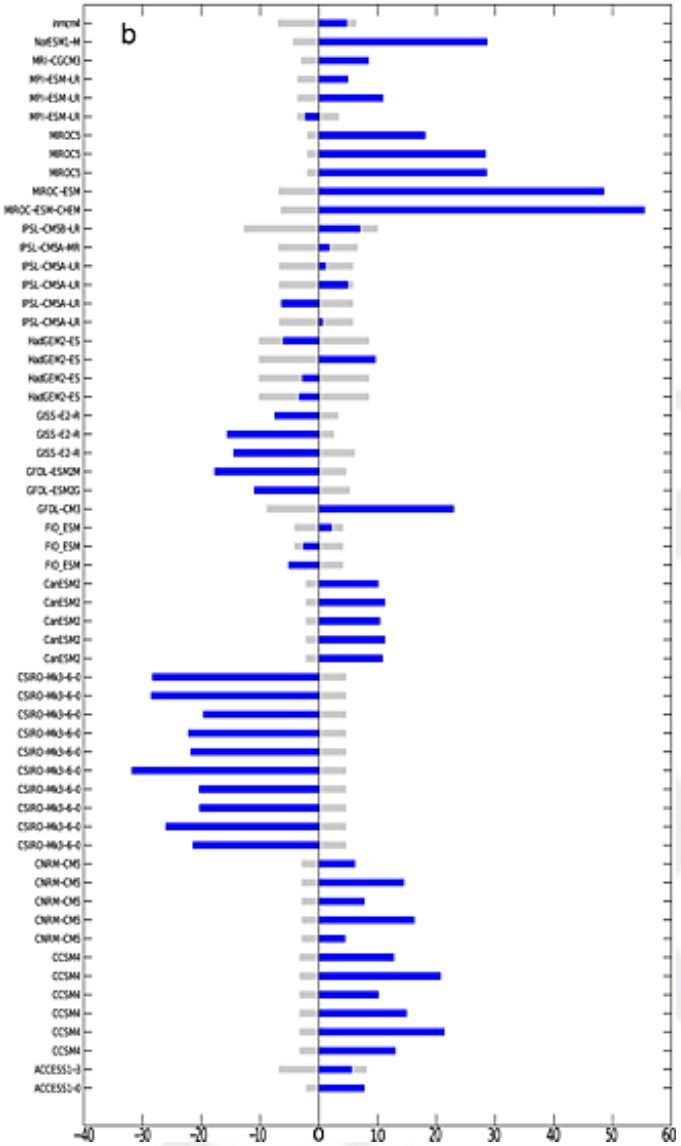
# *Update: "Forced Sahel rainfall trends in the CMIP5 archive"*

**Biasutti 2013, in J. *Geophys. Res.***

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# *Application #1 – attribution*

Oceans' influence explains attribution of drought to emissions of greenhouse gases and sulfate aerosols from industrialization:

Indian Ocean warming and greenhouse gases
**[Levitus *et al* 2000; Barnett *et al* 2005; Du and Xie 2009]**

North Atlantic not warming and sulfate aerosols
**[Rotstayn and Lohmann 2002; Chang *et al* 2011; Ackerley *et al* 2011; Booth *et al* 2012]**

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## *Application #2 – characterization of precipitation at sub-seasonal time scale*

How do we understand frequency and intensity of daily precipitation?

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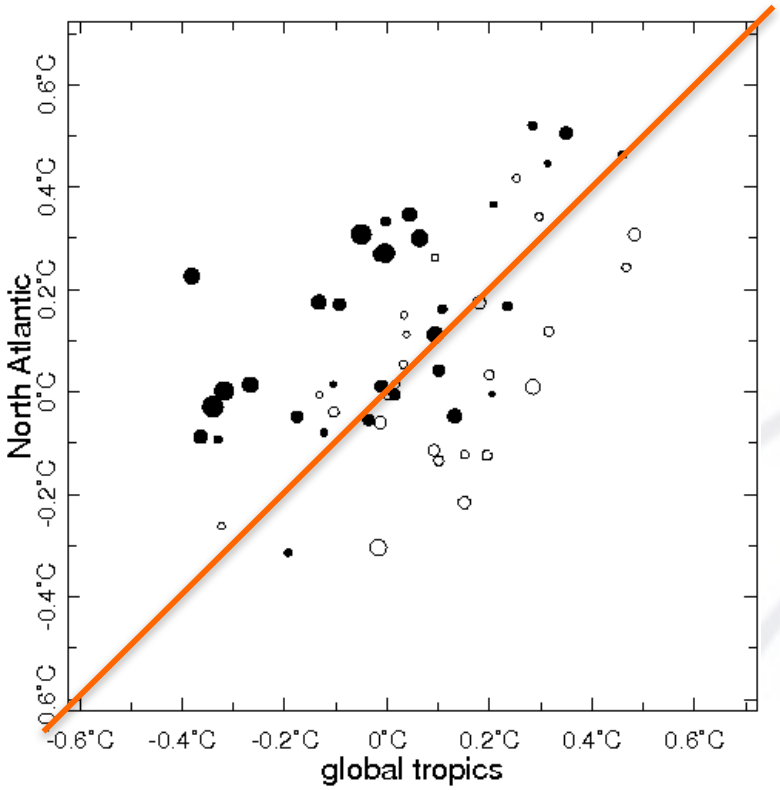
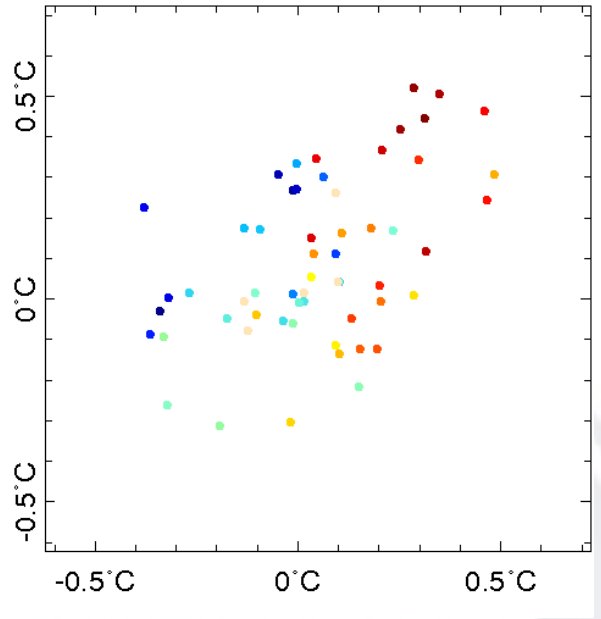
# North Atlantic and global tropics in the interannual variability of Sahel rainfall –

**rainfall index is from Ali and Lebel (2009)**

open circles are negative anomalies,
full dots are positive anomalies




years since 1950
blue is early
red is late

**Giannini, Salack, Lodoun *et al.* 2013, in Environ Res Lett**

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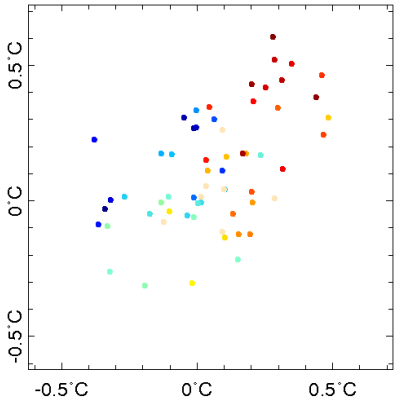
Mechanisms to connect dynamics of variability and change:

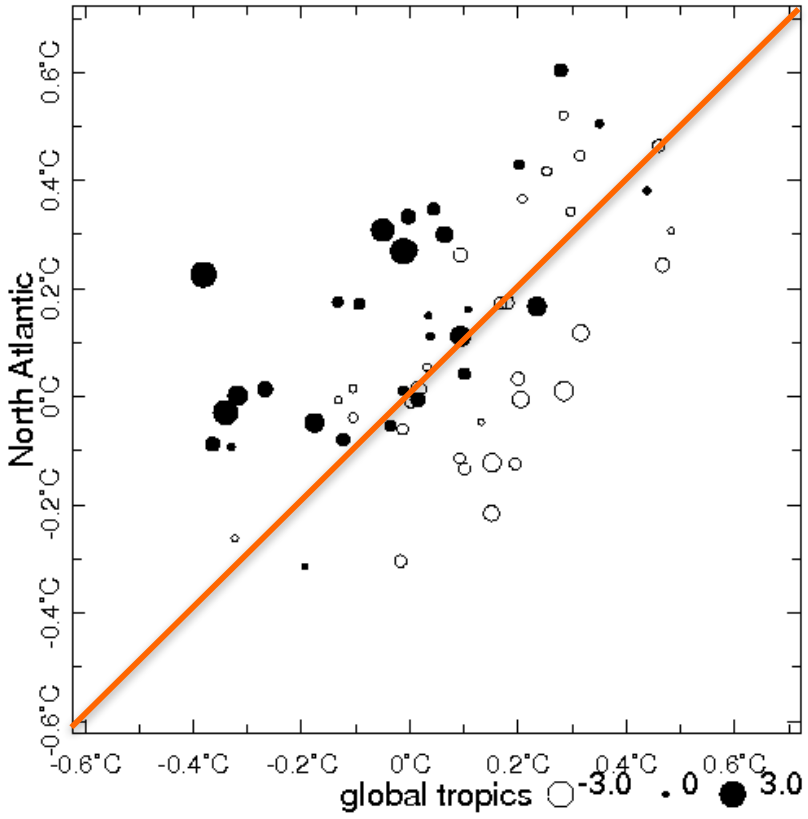
- tropical oceans
  - ⟷ controls vertical stability
  - ⟷ related to frequency of daily rainfall?

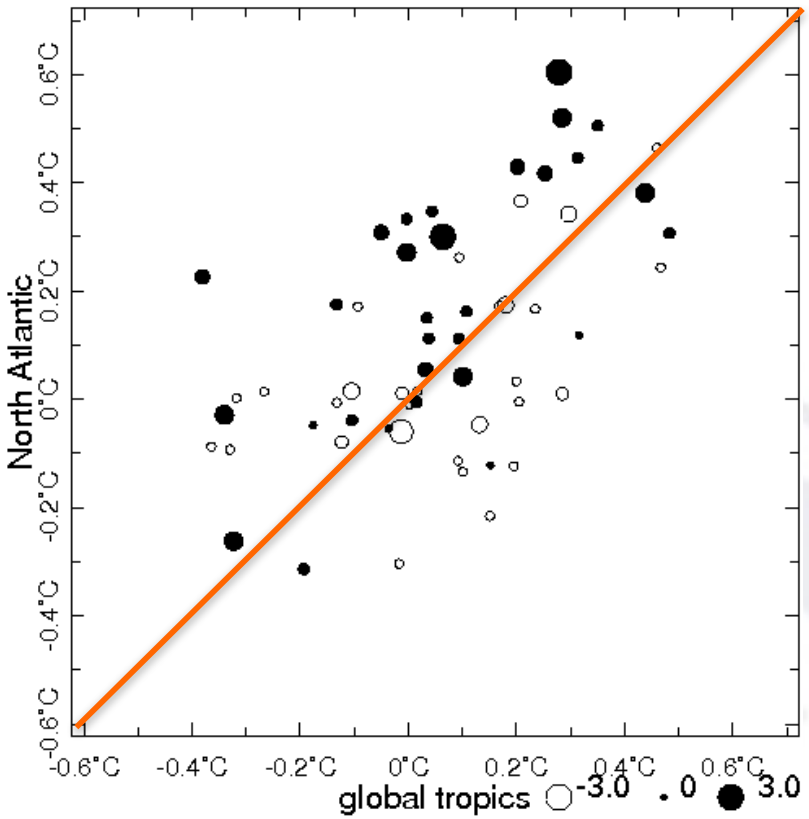
- Atlantic Ocean
  - ⟷ controls moisture supply
  - ⟷ related to intensity of daily rainfall?

# North Atlantic and global tropics in frequency (left) and intensity (right) of daily rainfall in Senegal (1950-2010)

open circles are negative anomalies,
full dots are positive anomalies




**Giannini, Salack, Lodoun *et al*. 2013, in Environ Res Lett**

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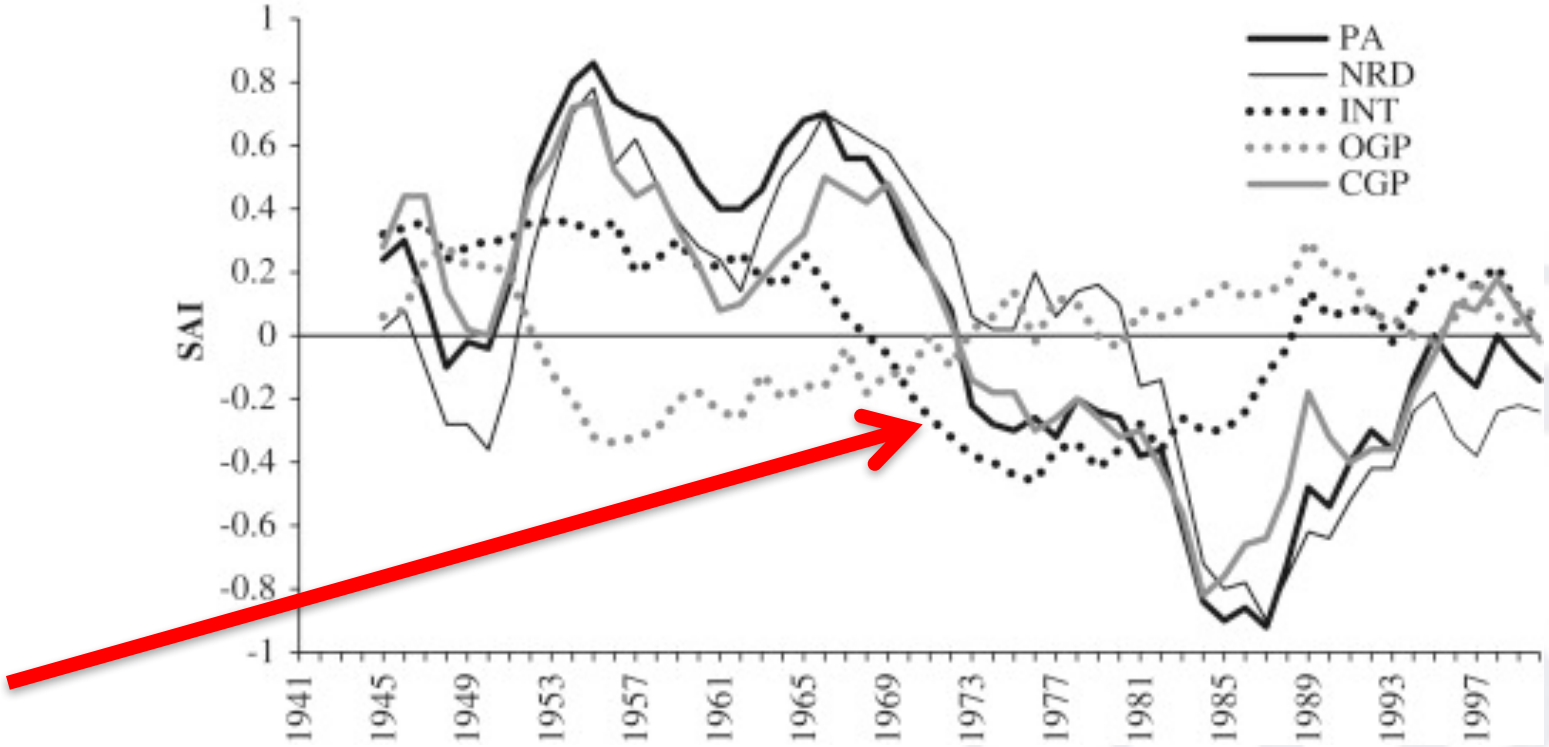
*"Changes in seasonal descriptors of precipitation in Burkina Faso associated with the late 20th century drought and recovery in West Africa"*

**Lodoun *et al*. 2013, in Environ Develop**

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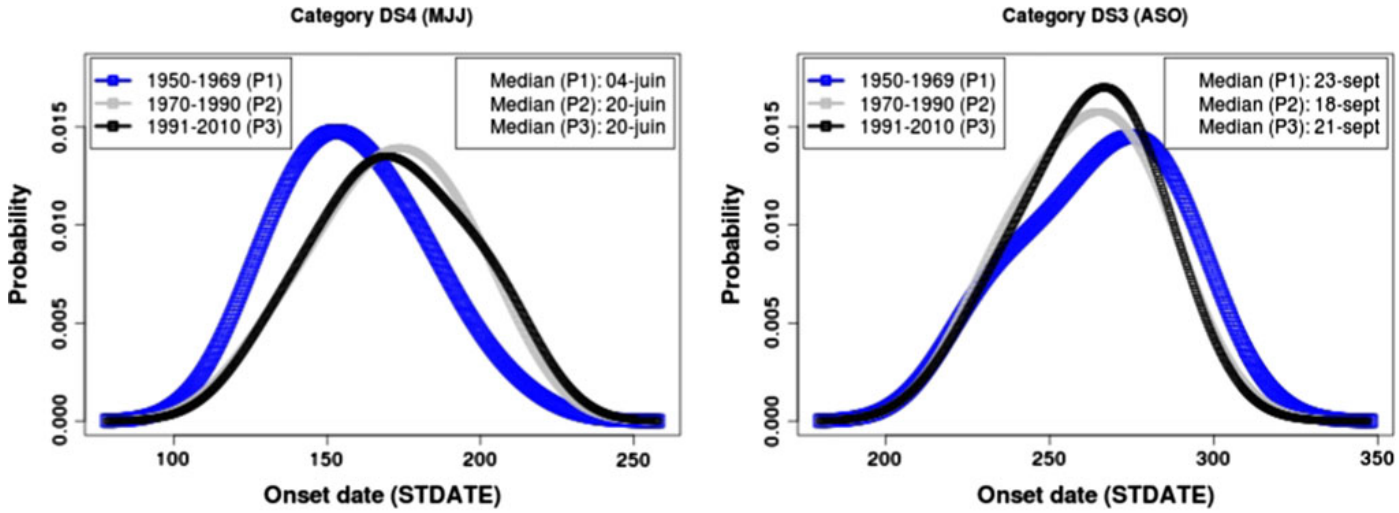
*"Oceanic influence on the sub-seasonal to interannual timing and frequency of extreme dry spells over the West African Sahel"*

**Salack *et al*. 2013, in Climate Dynamics**

[stations in Niger and Senegal]




These are the dry spells related to false start (DS4) and early cessation (DS3)

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# questions

- What is the influence of greenhouse gases [GHG] on Sahel rainfall?
- Are frequency and intensity of precipitation predictable? [in the S2S or SI sense?]
- ...

# In sum, oceanic influence

explains persistence of drought in the Sahel in the 1970s and 1980s, and partial recovery since

can be used to make sense of model projections of future precipitation change

implicates the influence of emissions of greenhouse gases and sulfate aerosols on late 20$^{th}$ century climate of the Sahel,
including persistent drought

provides a theoretical framework to interpret changes in the [sub-seasonal] “character of precipitation”

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# Merci!

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