Climate Change in the West African Monsoon: Consensus, Confusion, and the Way Forward.

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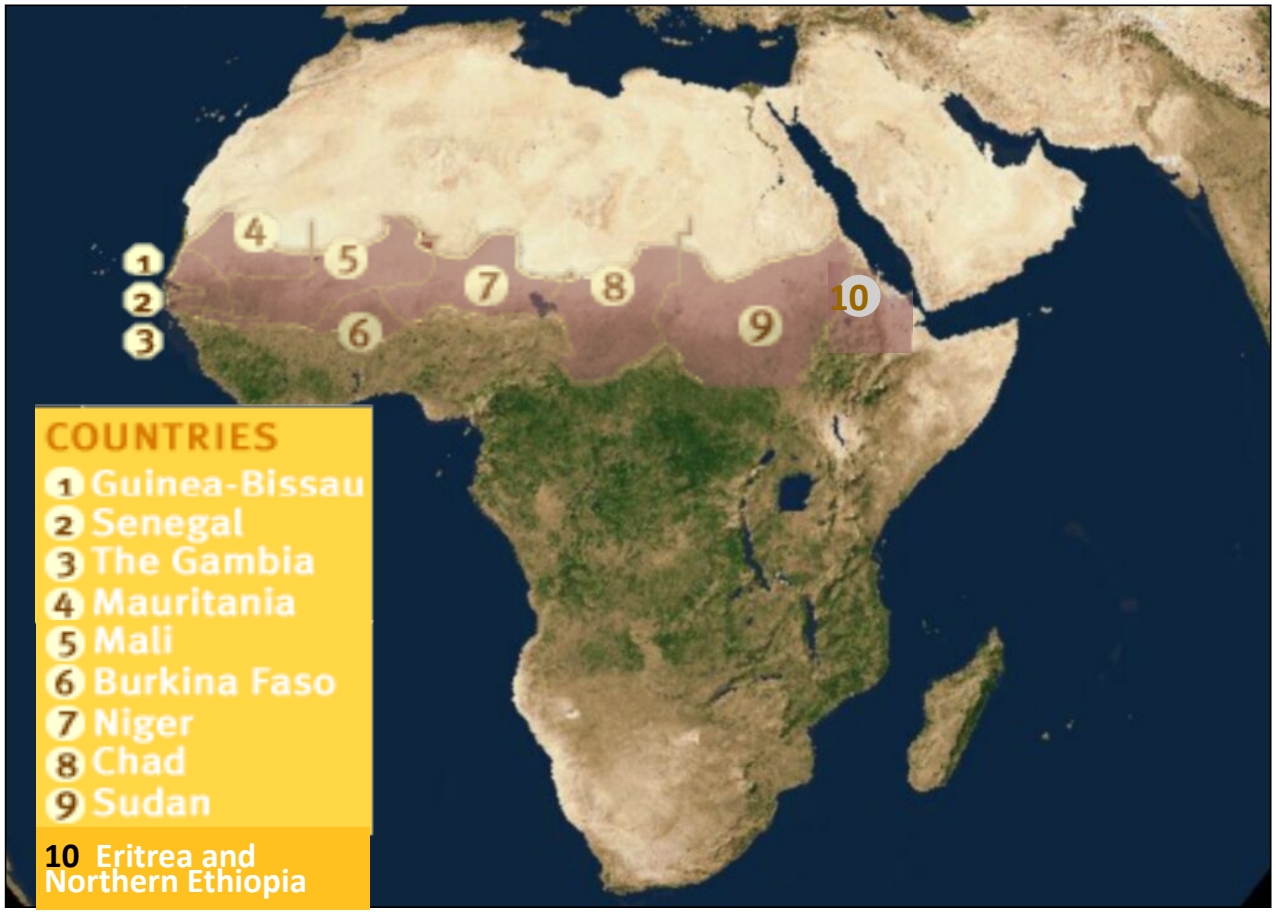
or…

Why we need aquaplanet simulations to help sorghum farmers in the Sahel

1. What climate information is needed for adaptation(s) in the Sahel?
2. How “good” are the models that provide it?
3. Is that “good enough” for reliable projections?
4. A hierarchy of models: *Understanding what we must get right.*

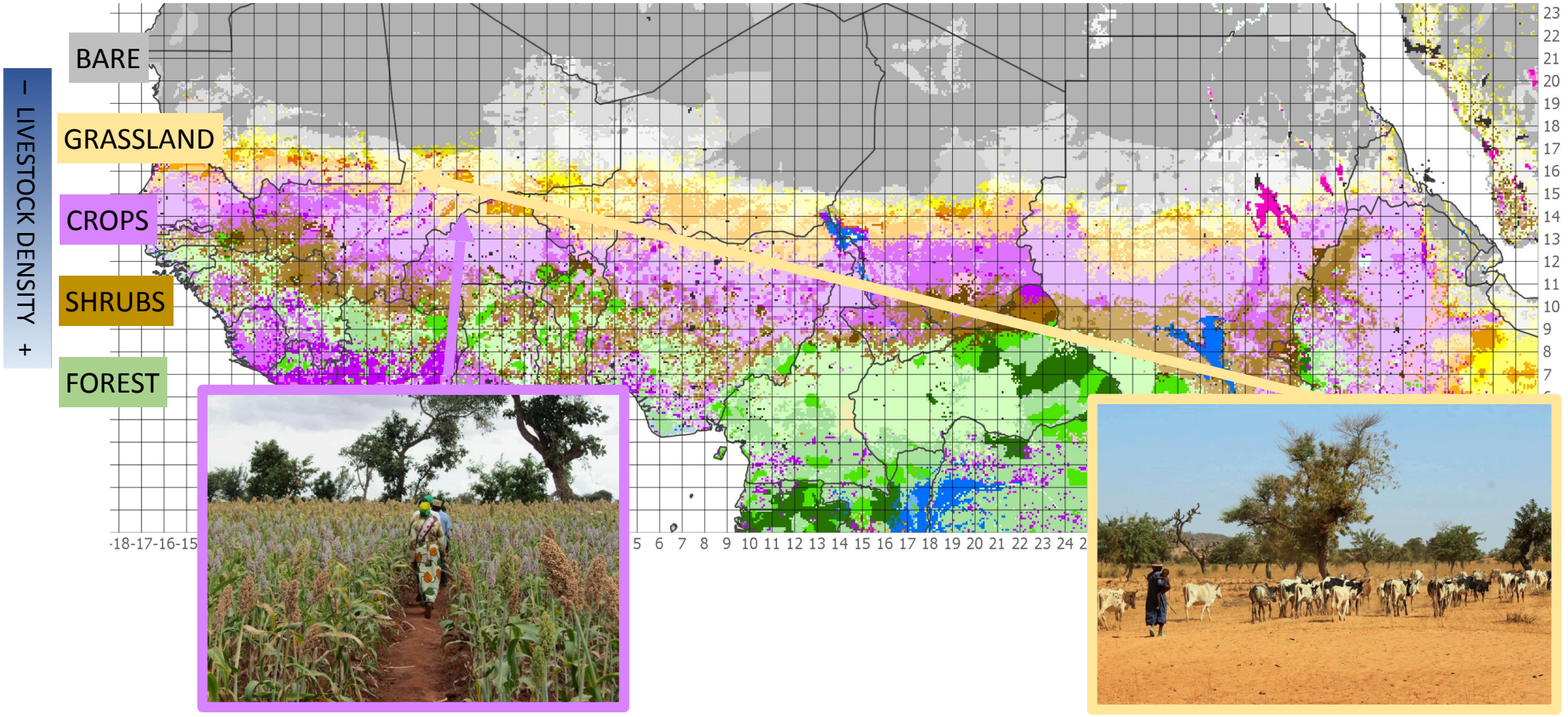
The Sahel: the shore of a sea of sand.



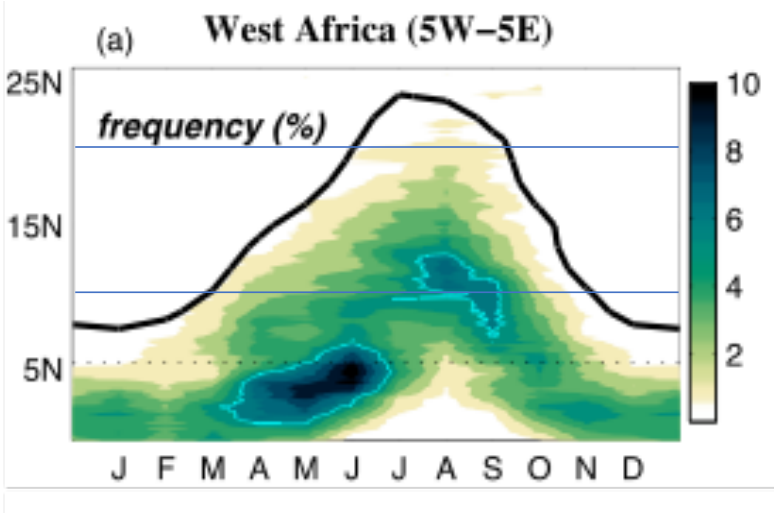
1 Chad = 3 California

http://mapfight.appspot.com/

Agriculture & Animal Husbandry are the main economic activities.

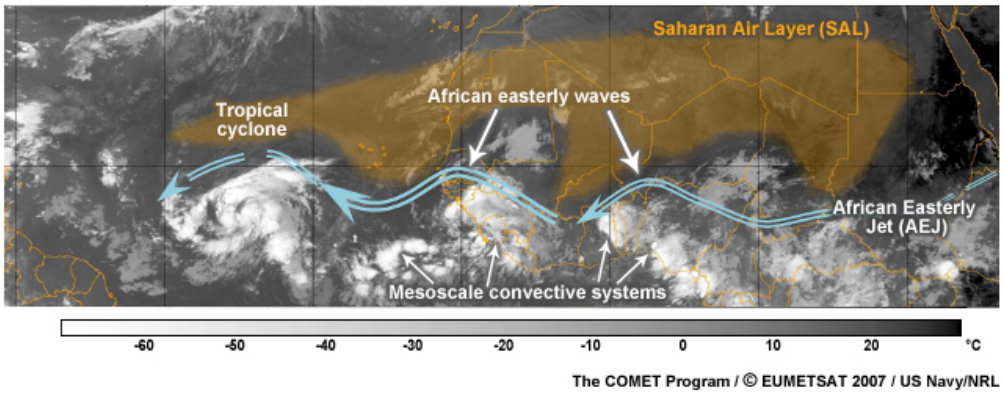


Sahel Rain is seasonal, scarce, and episodic



b

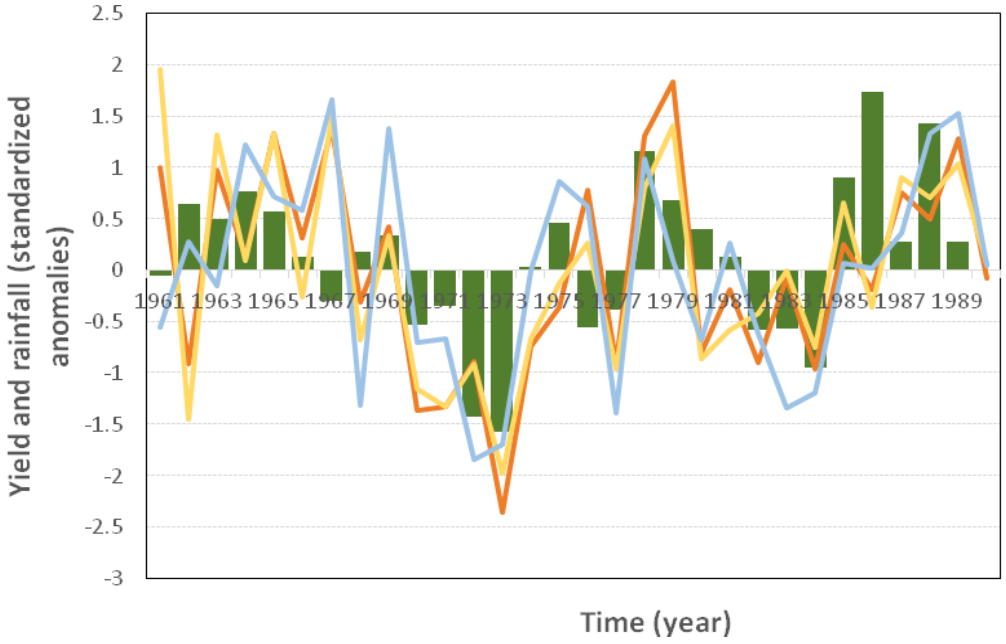
Major Synoptic and Mesoscale Systems of the West African Monsoon



The COMET Program / © EUMETSAT 2007 / US Navy/NRL

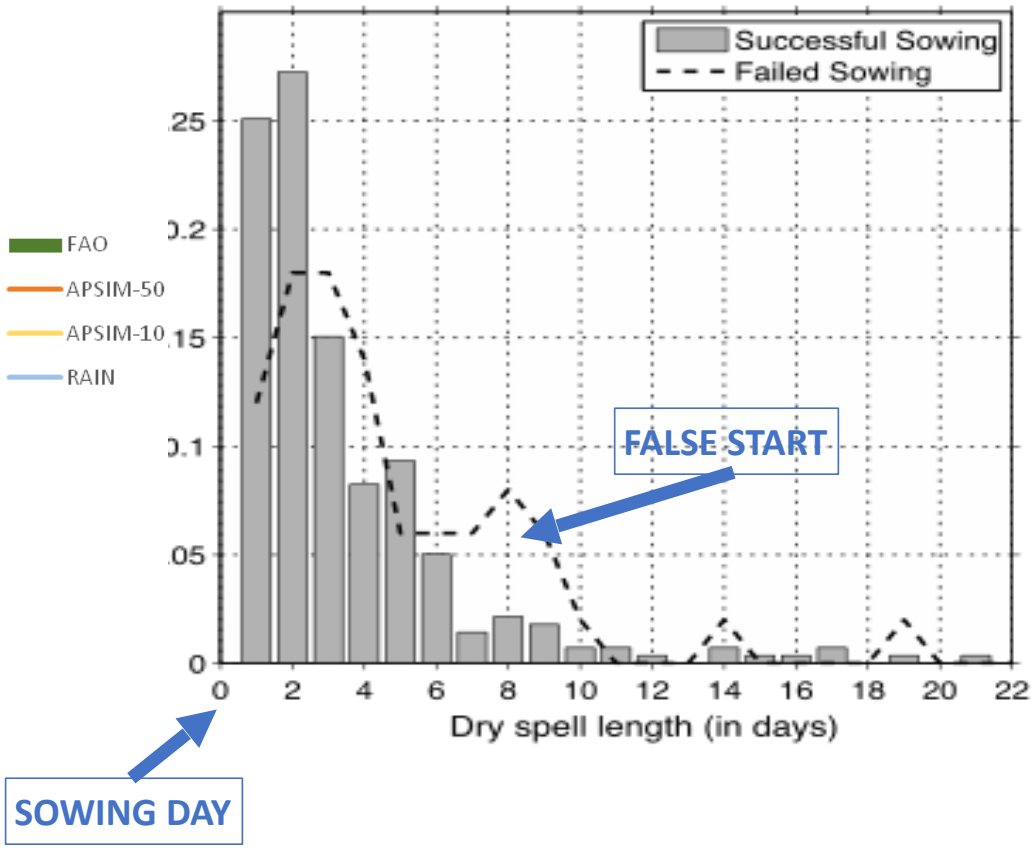
The African Sahel is a semi-arid region with a **monsoon climate**, with rainfall only during the summer months. 80% of the rainfall is brought by mesoscale convective systems (MCSs)

The Past & The Present: Rainfall scarcity determines agricultural impacts



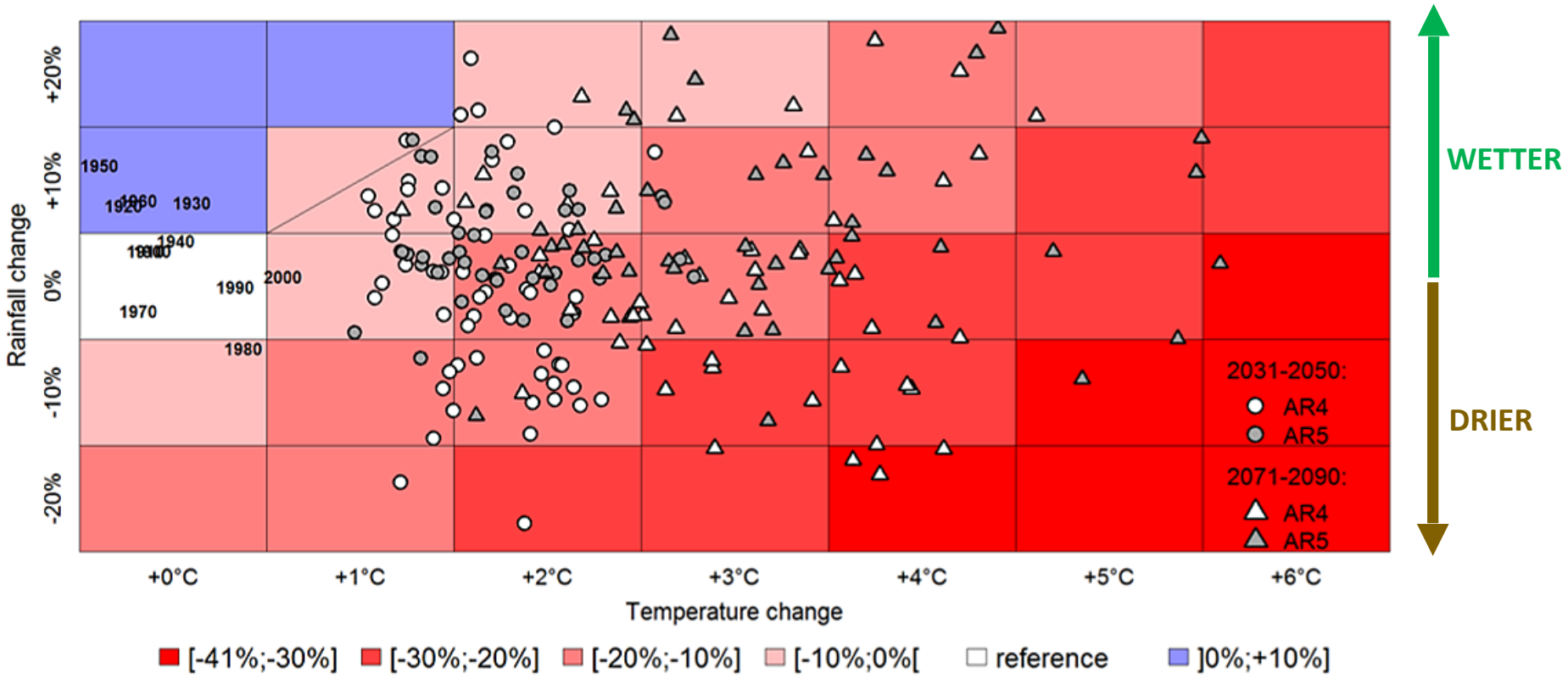
Sultan et al 2014

	Mean	Correlation with rainfall
FAO Observations	588 kg ha^{-1}	0.62
SARRA-H Simulations	1781 kg ha^{-1}	0.90
APSIM-10 Simulations	2248 kg ha^{-1}	0.57
APSIM-50 Simulations	2879 kg ha^{-1}	0.67



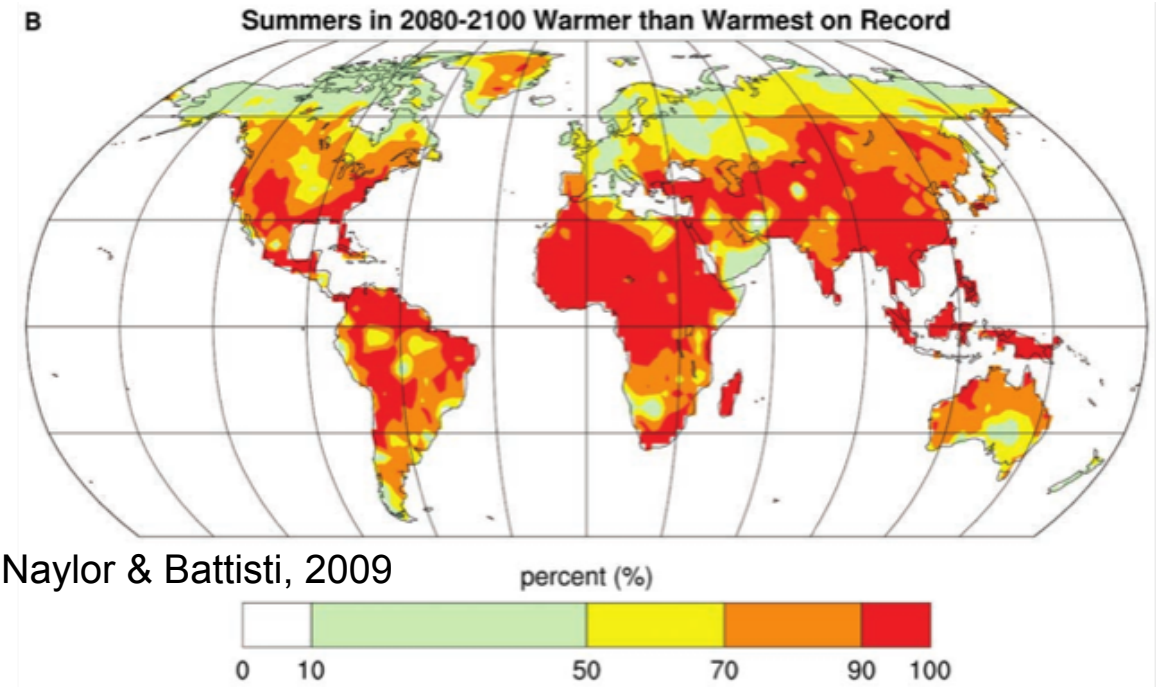
R. Marteau et al. / Agricultural and Forest Meteorology 151 (2011) 1356–1369

The Future: Heat emerges as the dominant hazard for yields

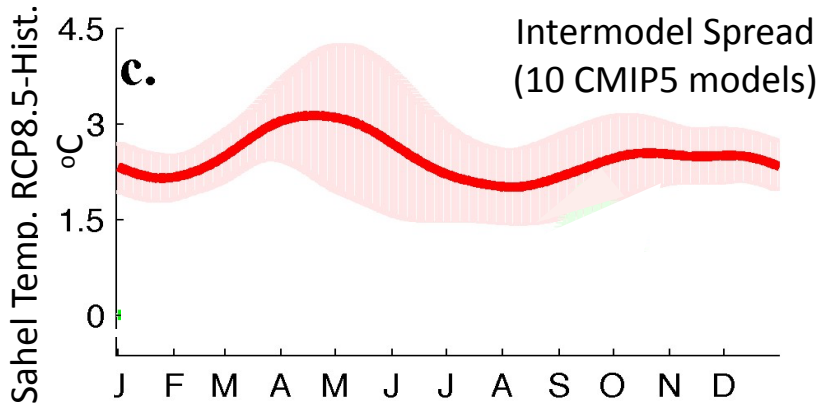


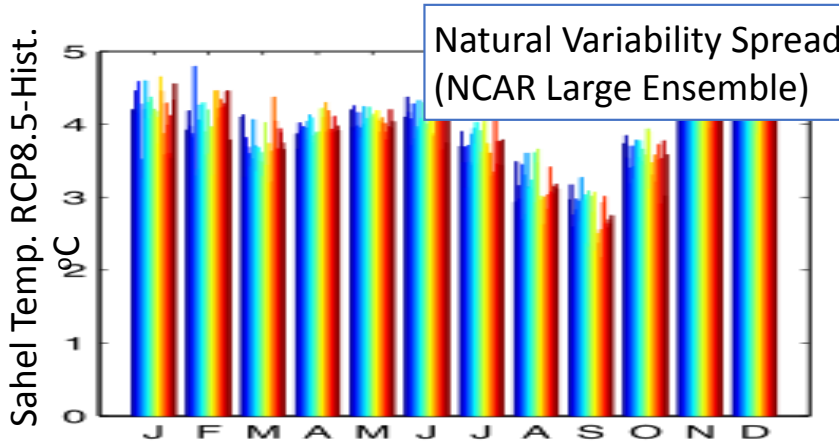
Sultan et al 2013

Growing Season Temperature Projections: Unprecedented Heat



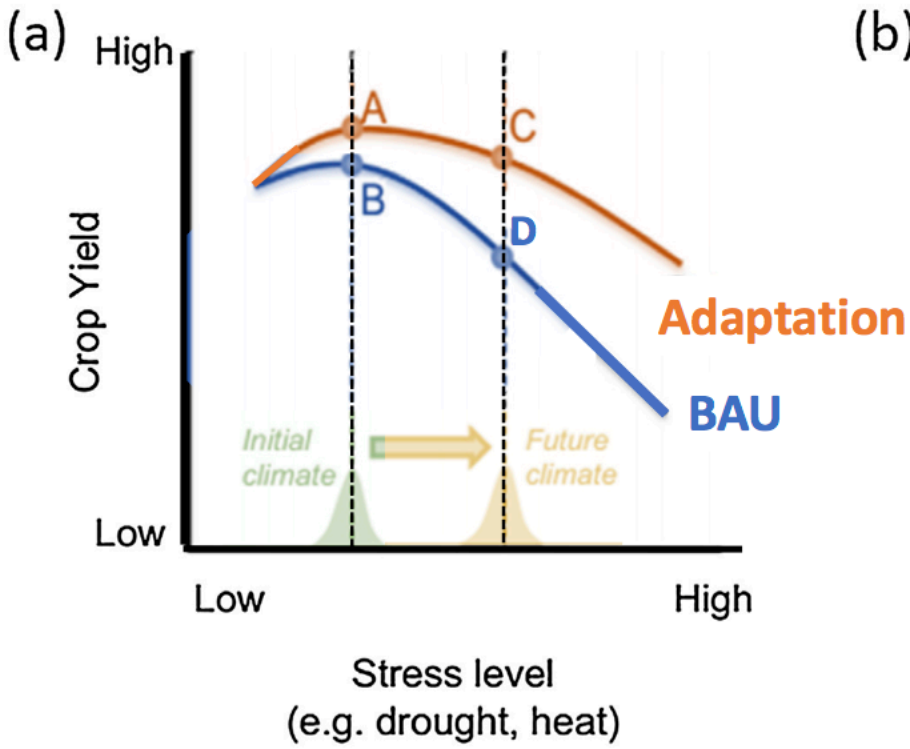
Naylor & Battisti, 2009

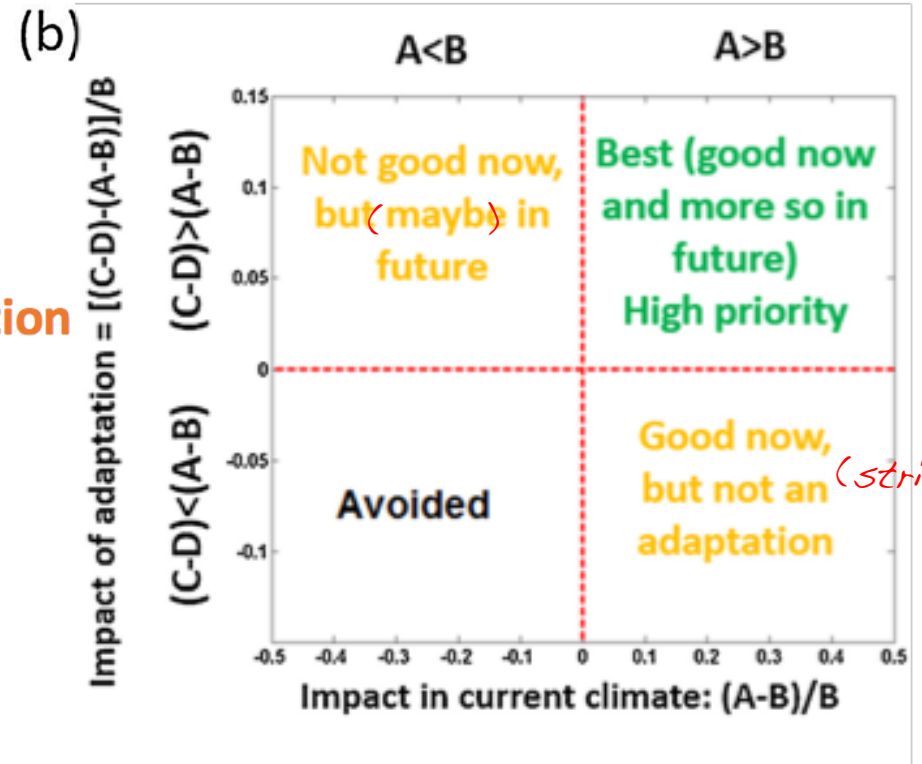




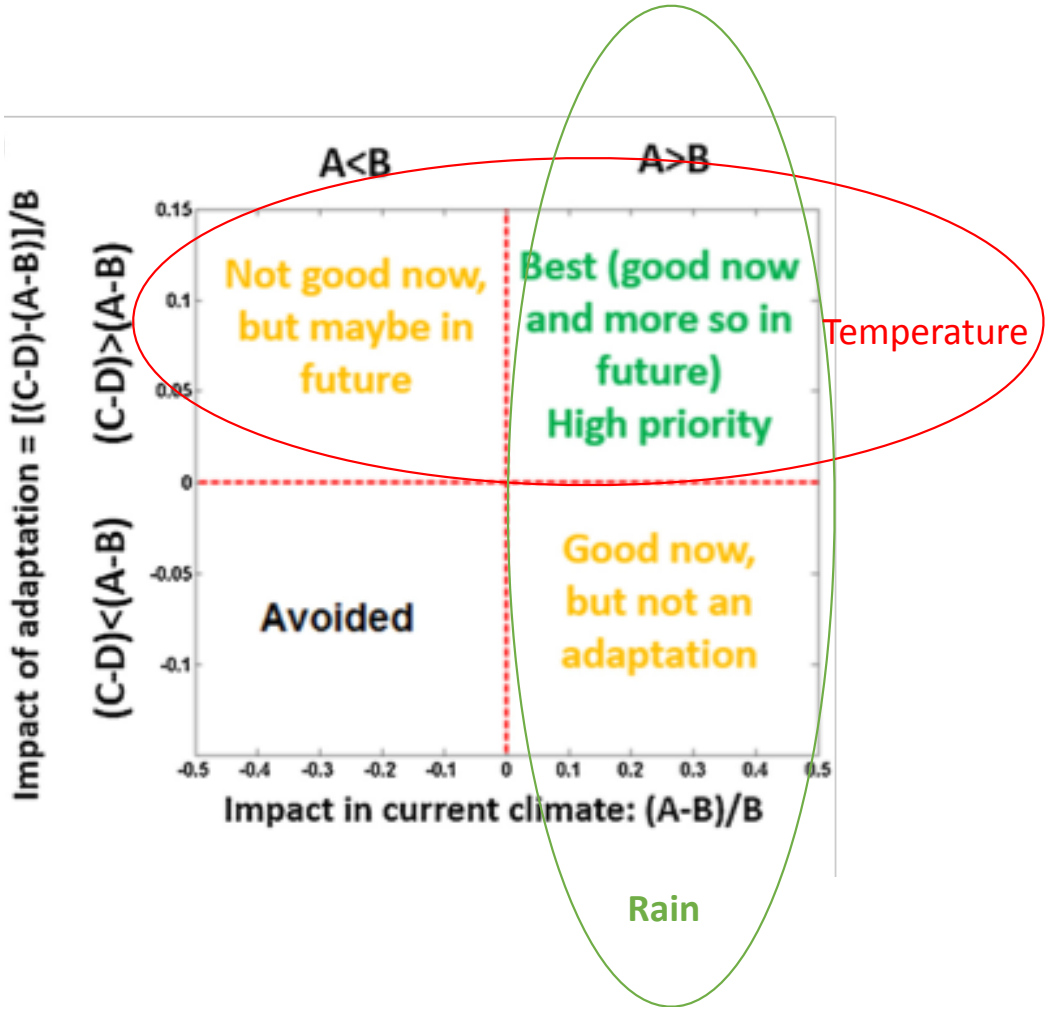
Adaptation Options

K. Guan et al. / Agricultural and Forest Meteorology 232 (2017) 291–305





Adaptation Options

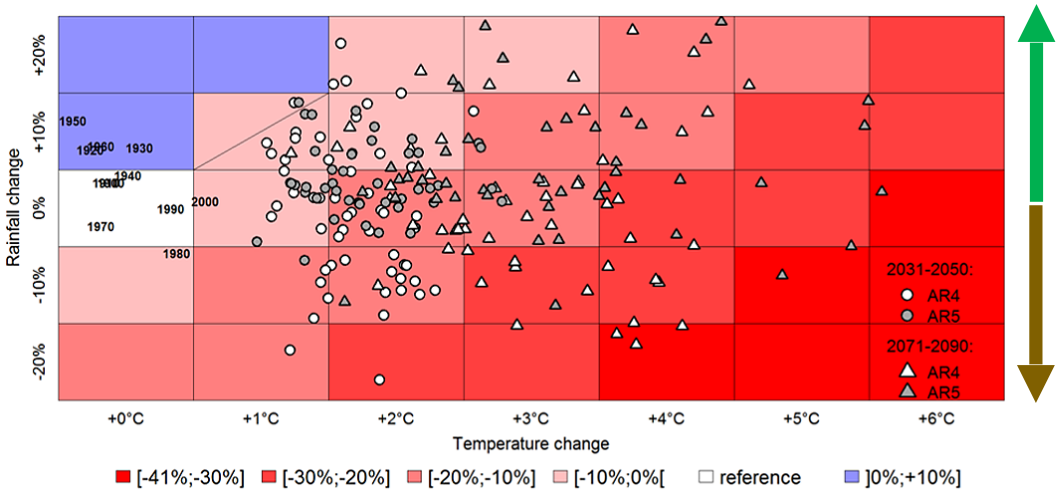


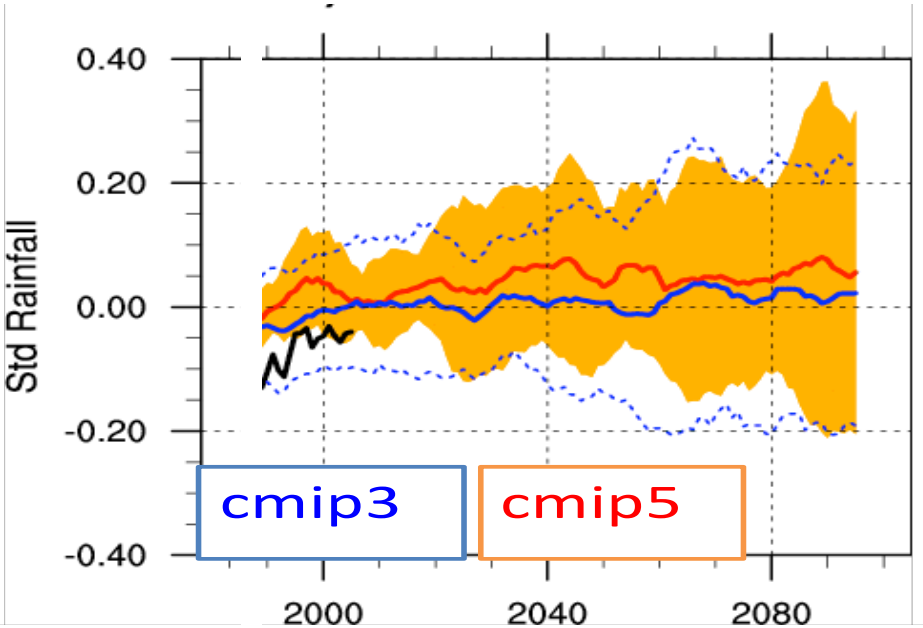
Temperature Hazard: Adaptation (e.g. new heat-resistant cultivars) is more likely to happen at the institution level (no buy-in from farmers who won't see immediate advantage).

Rainfall Hazards: "Adaptation" (to dry spells, drought, heavy rainfall) is the priority at the local level, because it constitutes "climate smart" development. Is it a true adaptation?

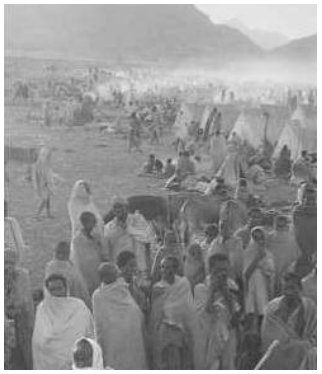
Is the hazard made worse by AGW?

The Future:
Rainfall still matters & Changes are uncertain!



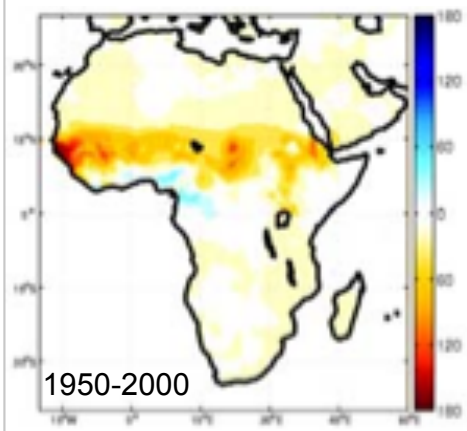


How come? Are the models any good?



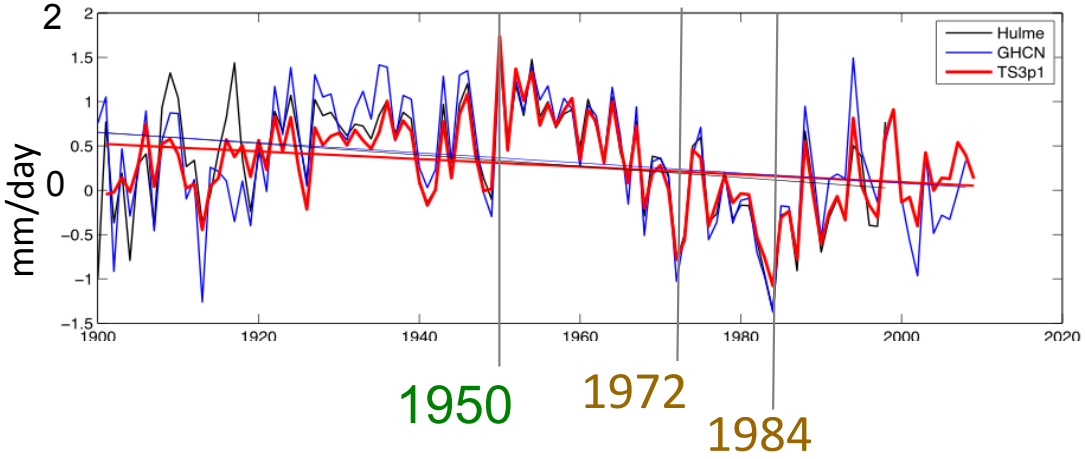
TEST: 20th Century Sahel Drought

Continental scale

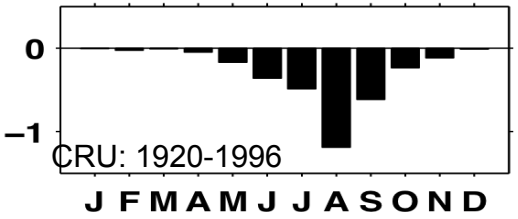


Lu and Delworth 2005

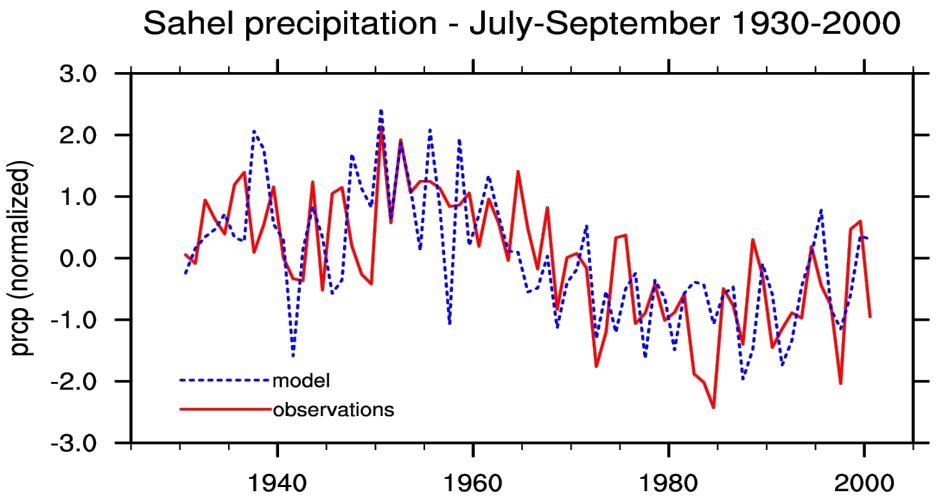
Multi-decadal duration



Year-round signal



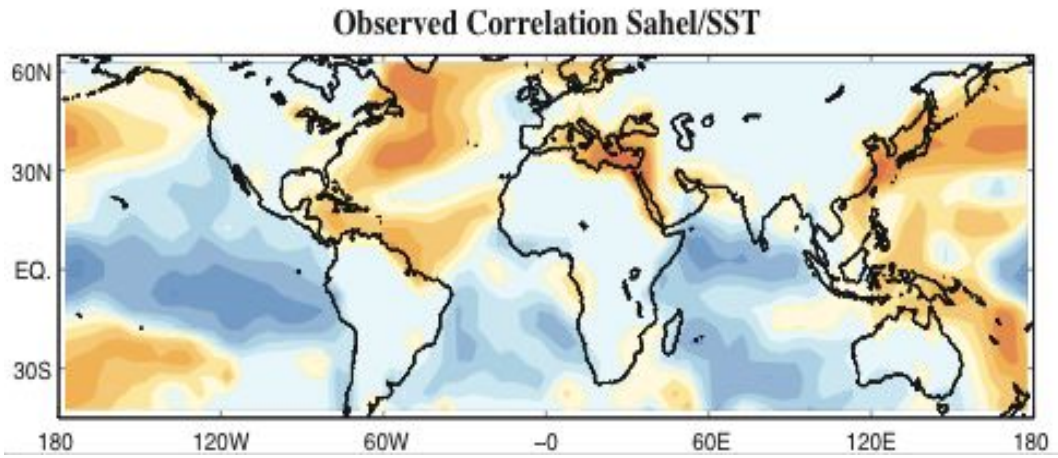
20th Century Sahel drought was paced by SST



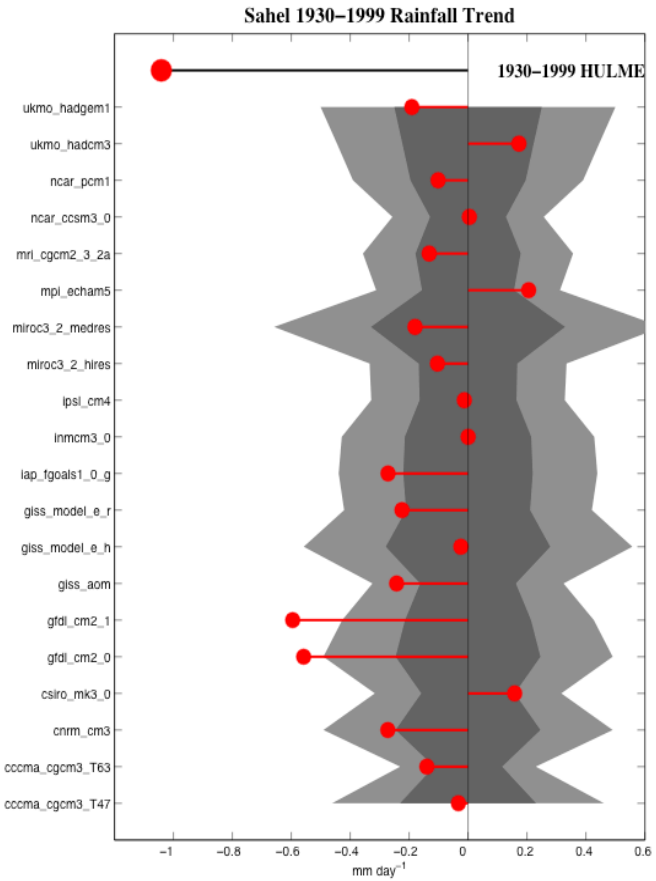
Giannini et al. 2003

AGCM driven by observed SST

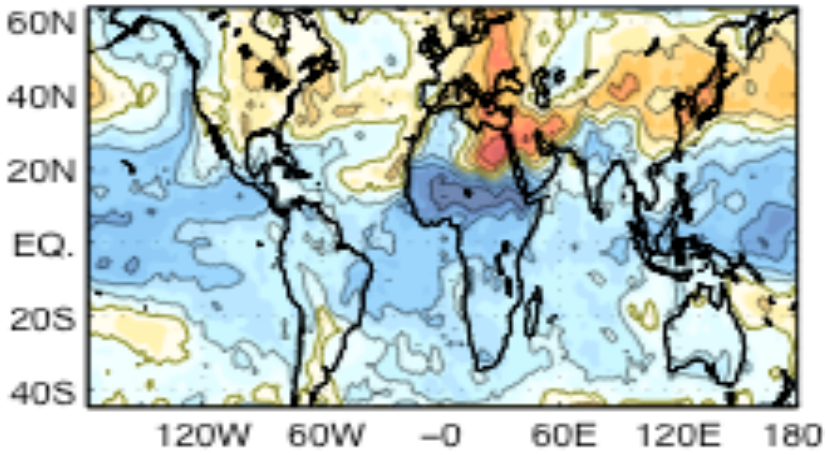
AGCM: "Good" hindcast of (low-frequency) variability.



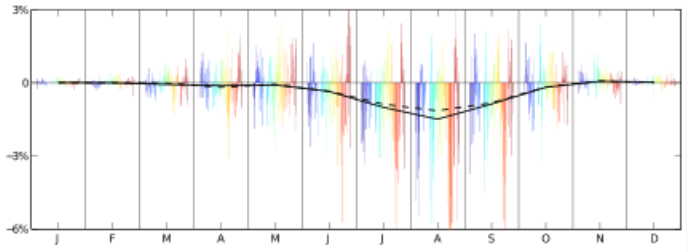
Are Coupled Models "Good"?



Variability is too small



The relationship with SST is captured



The seasonality is captured

Are Coupled Models "Good Enough" ?

Are observations (of the past) enough to constraint projections (of the future)?

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Is the quality of the hindcast of the 20th century variability an appropriate discriminant for the quality of projections?

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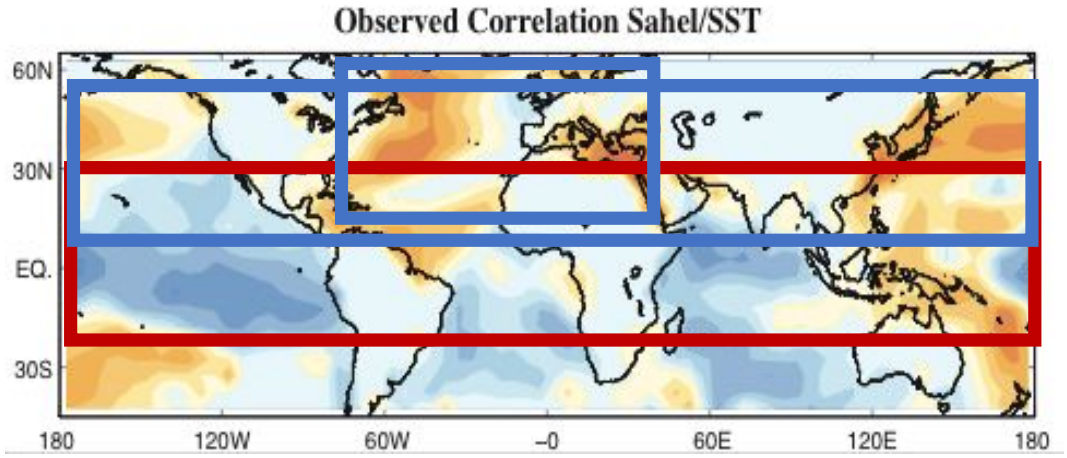
Are observations (of the past) enough to constraint projections (of the future)?

Is the quality of the hindcast of the 20th century variability an appropriate discriminant for the quality of projections?

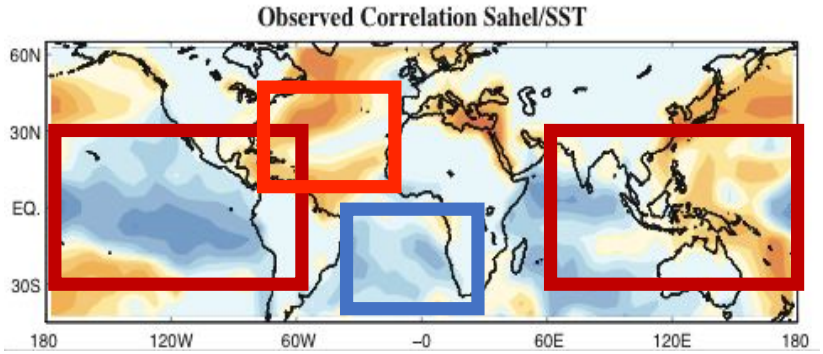
*Only if the **mechanism** behind future trends has been tested within the 20th century sample!*

Assume future Sahel trends will also be paced by SST

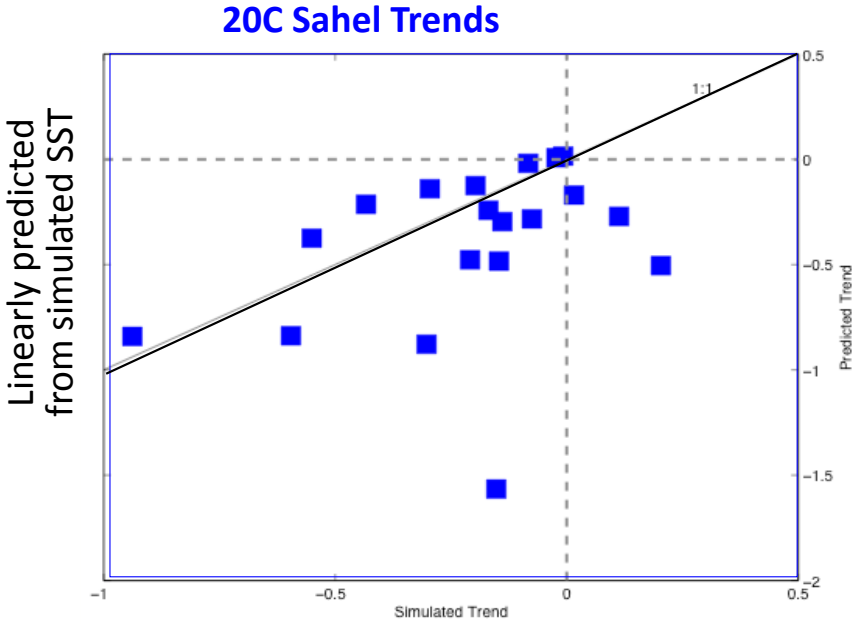
But future trends in SST will be different!
IDEA: encapsulate the mechanism of the 20th century variability in a linear link from SST to Sahel rainfall and apply it to the 21st century



The 20th century trend is created by a mechanism seen at interannual time scales



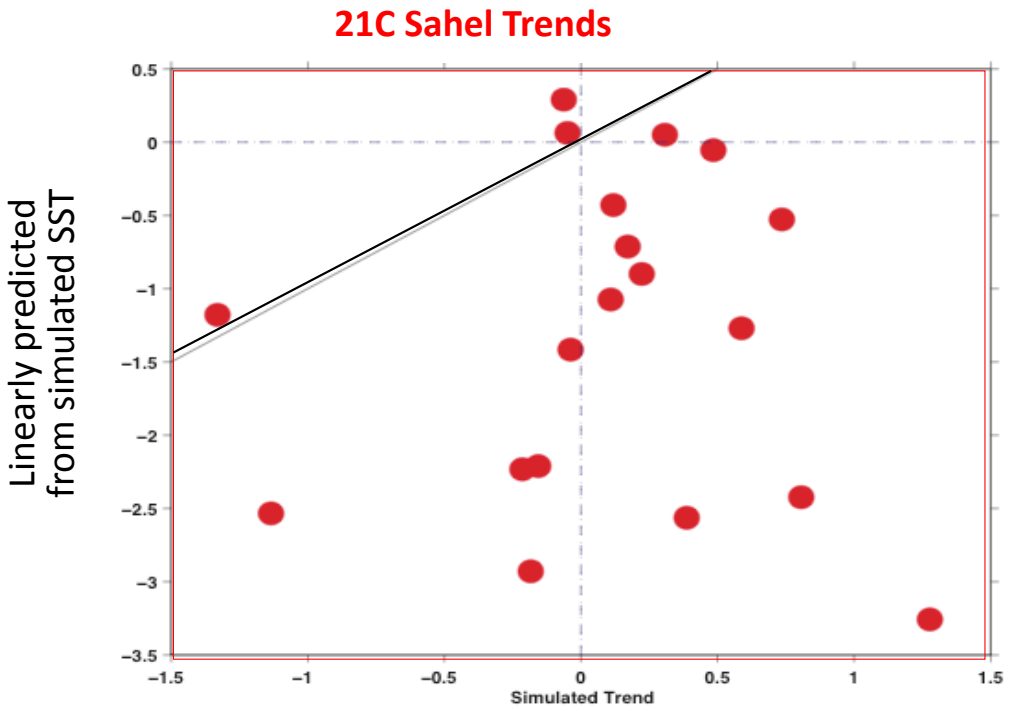
Atlantic gradient: NTA(7°N-30°N)-STA(20°S-7°N)
Indo-Pacific: 20°S–20°N, 50°E–90°W



Simulated by CGCMs

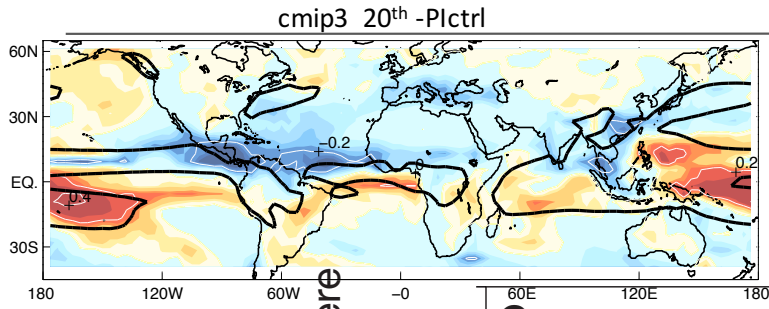
The 21st century trend is NOT created by the dominant mechanisms for variability during the 20th century

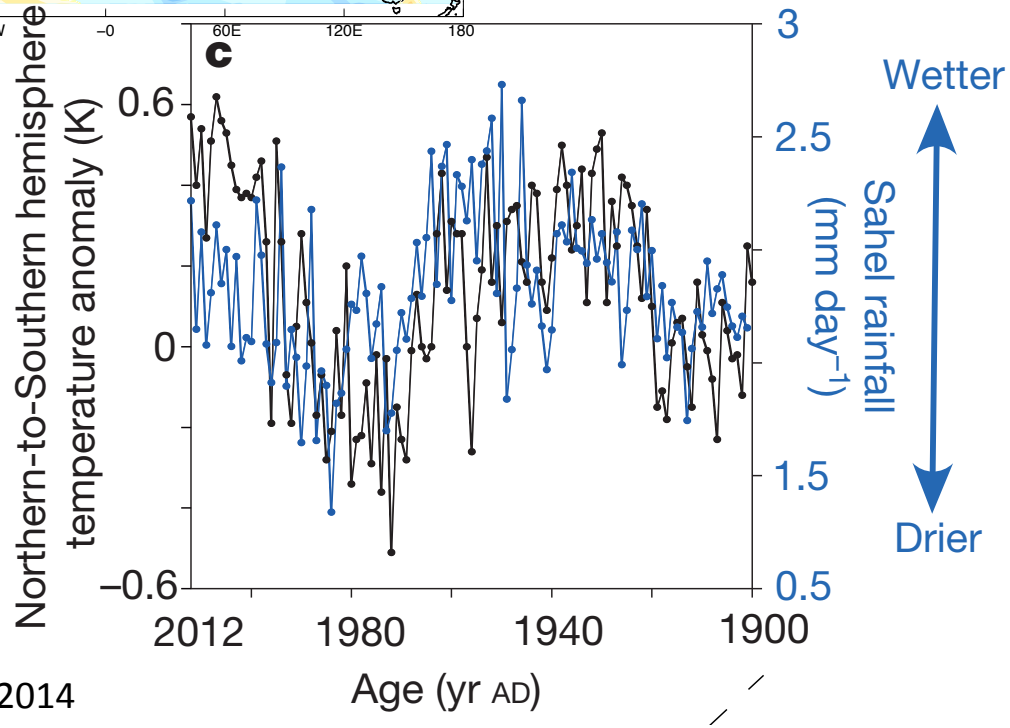
Projections for 21st century summer rainfall don't seem consistent with projections of SST changes *if we assume the same relationship of the past between precipitation, Atlantic gradient, and Indo-Pacific SST.*

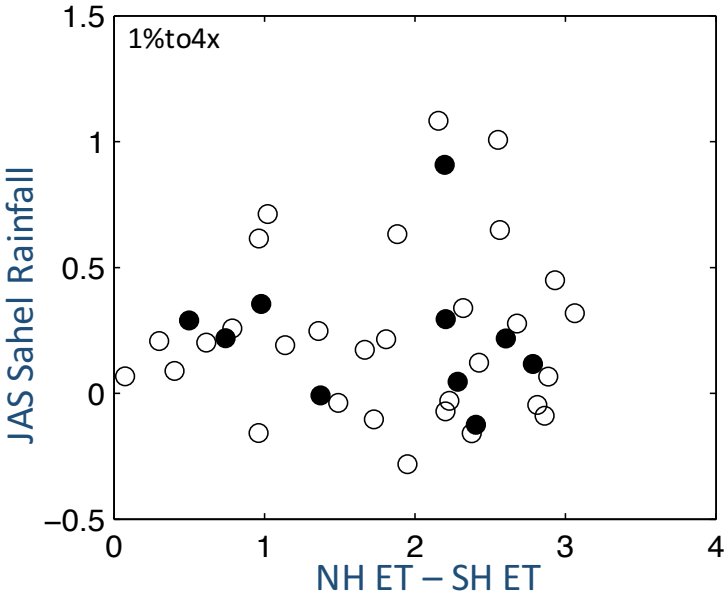


Simulated by CGCMs

Let's try those SST indices that explain past multi-decadal trends (shifts)



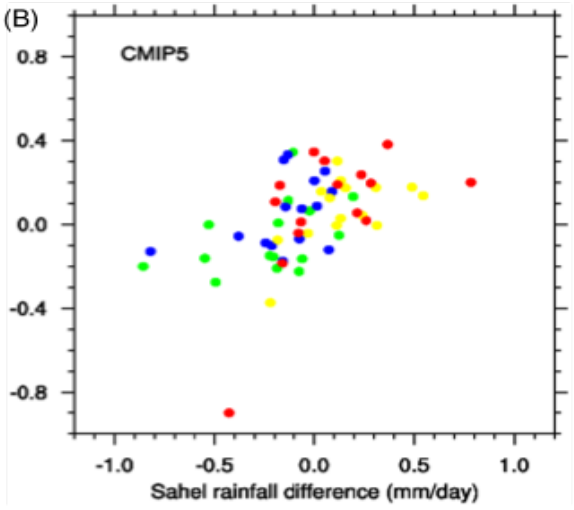




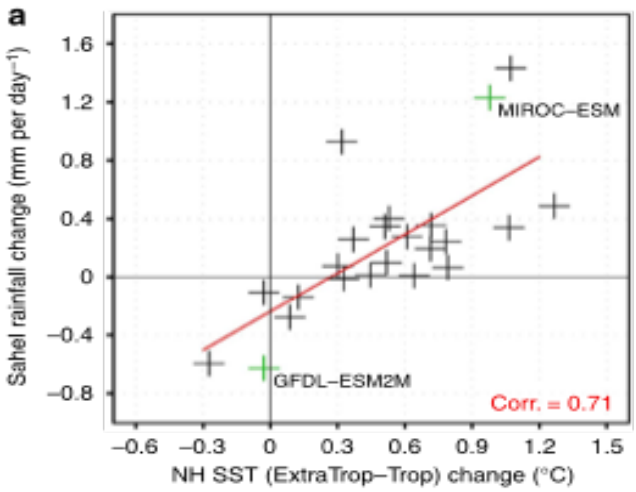
Schneider et al. 2014

The 21st century trend is still related to SST, but the relationship is not stationary

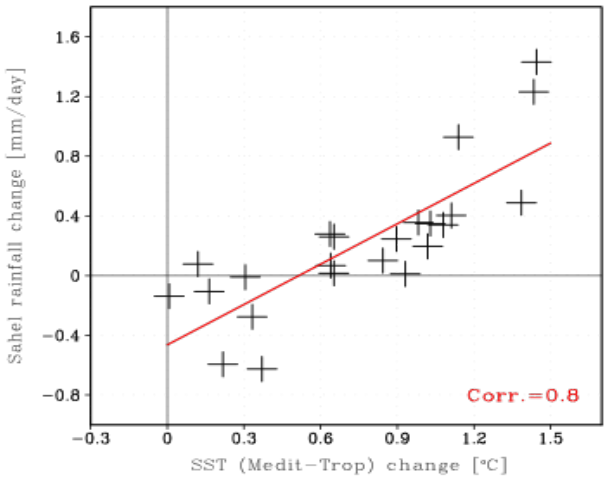
NorthAtlantic – GlobalTropics SST



Giannini et al



Park et al



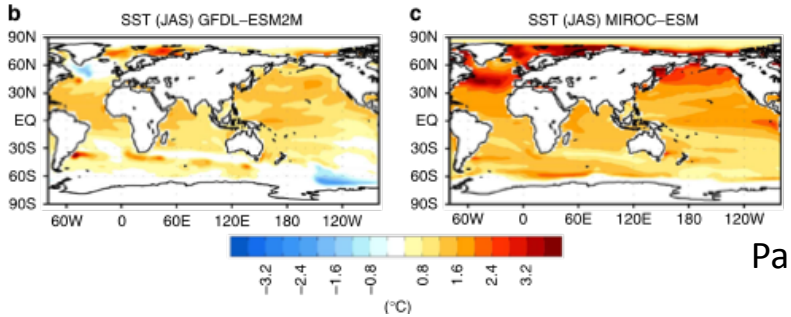
Park et al

🙂 *We gain insight in emerging processes*

🙁 *past SST-driven variability is not a good discriminant!*

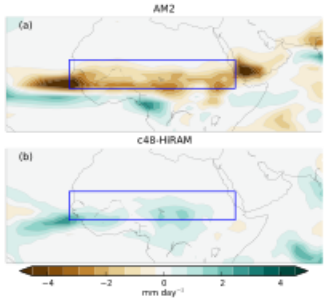
The 21st century spread in JAS rainfall trends remains unconstrained

1. We don't know future SSTs



Park et al

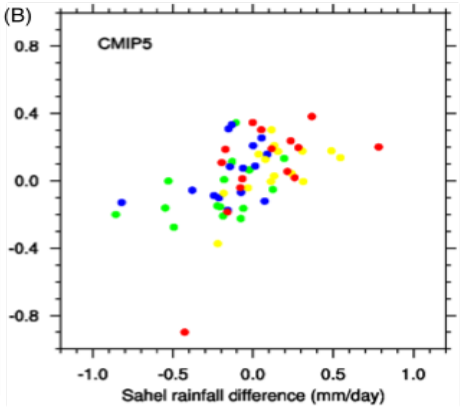
2. We do not know what the SST/rainfall relationship should be



July-August-September δP in +2 K simulations in two GFDL AGCMs

Hill et al.

3. We cannot use past variability to validate future SST/rainfall relationship



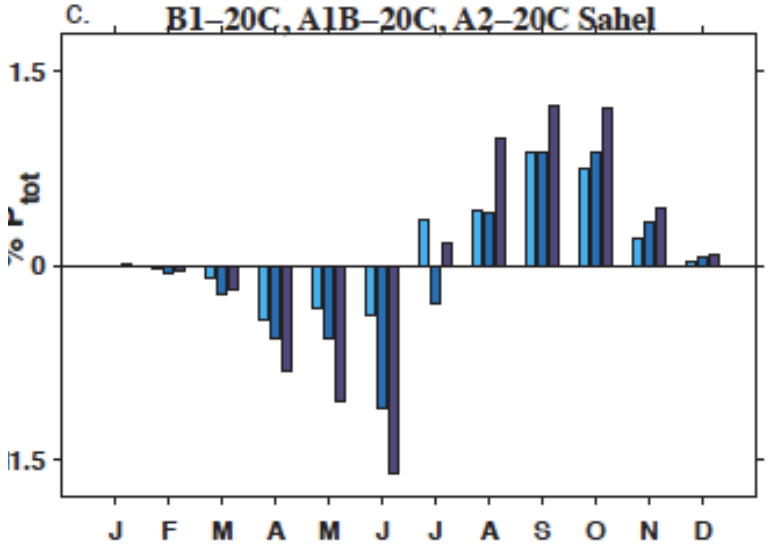
Giannini et al

Are Coupled Models "Good Enough" for rainfall projections in the Sahel?

20th century variability is not an appropriate discriminant for the quality of rainfall projections

What about the **annual cycle**?
(after all, it is the externally forced signal par excellence!)

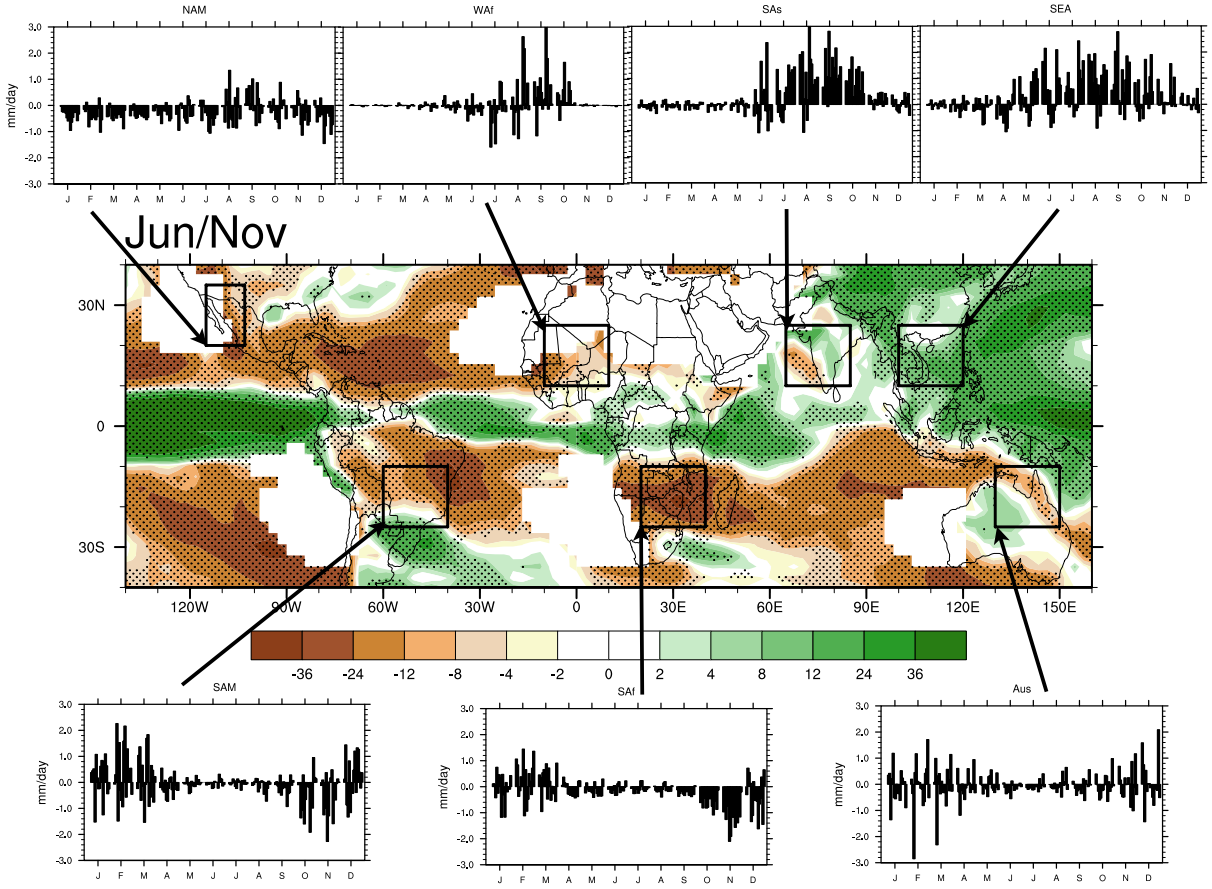
The annual cycle of Sahel rainfall changes in response to increased GHG



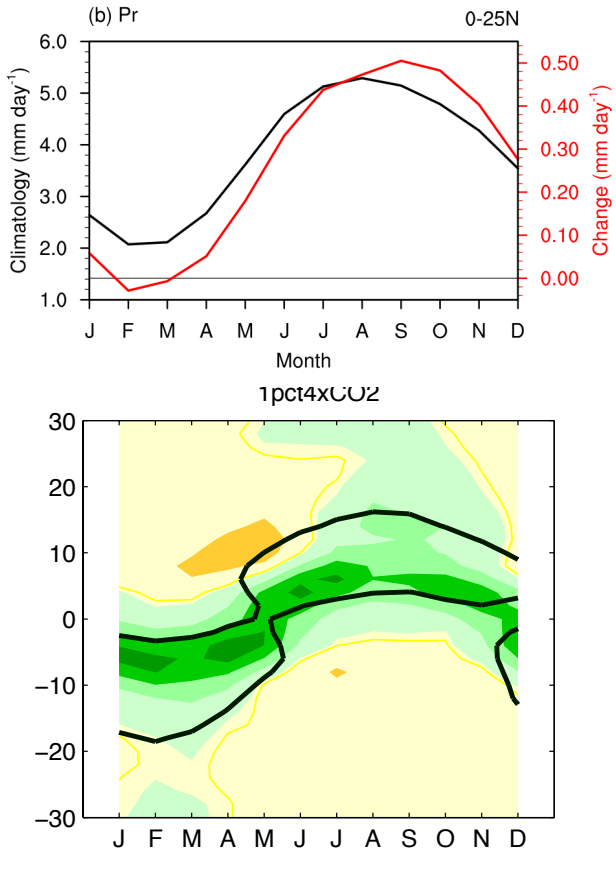
The projections for the Sahel tell us that the annual mean anomalies are not very meaningful.

But if we can describe the dynamics of the seasonal cycle we might also describe its changes in the future.

The precipitation delay is tropic-wide



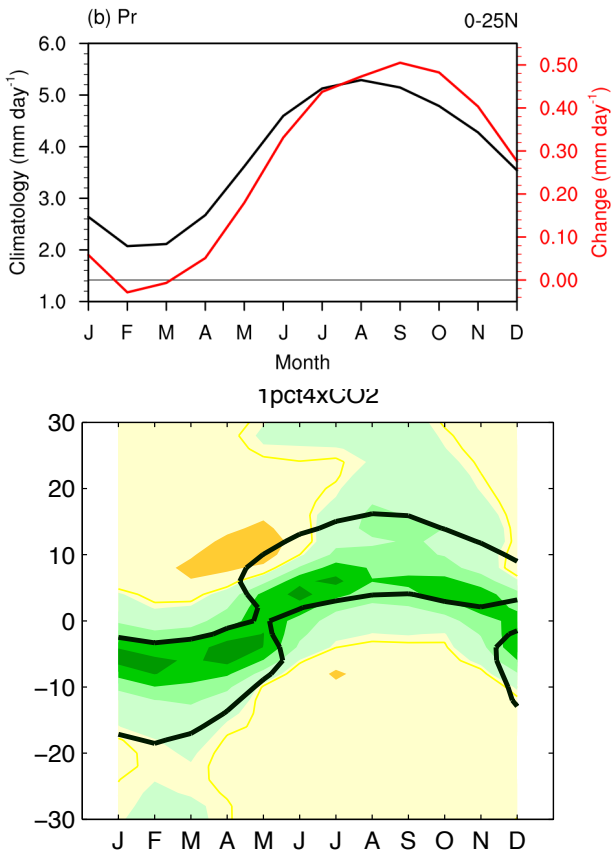
coupled response to CO2 quadrupling



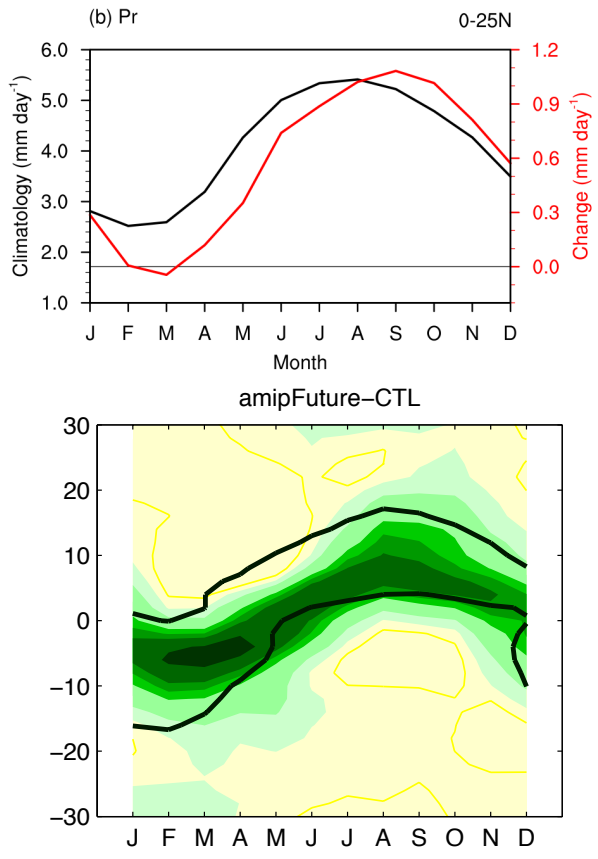
Yet, a distinction between the ITCZ and the monsoon is necessary to understand changes in Sahel rainfall

A delay in the ITCZ seasonal progression can be explained by SST warming

coupled response to CO2 quadrupling

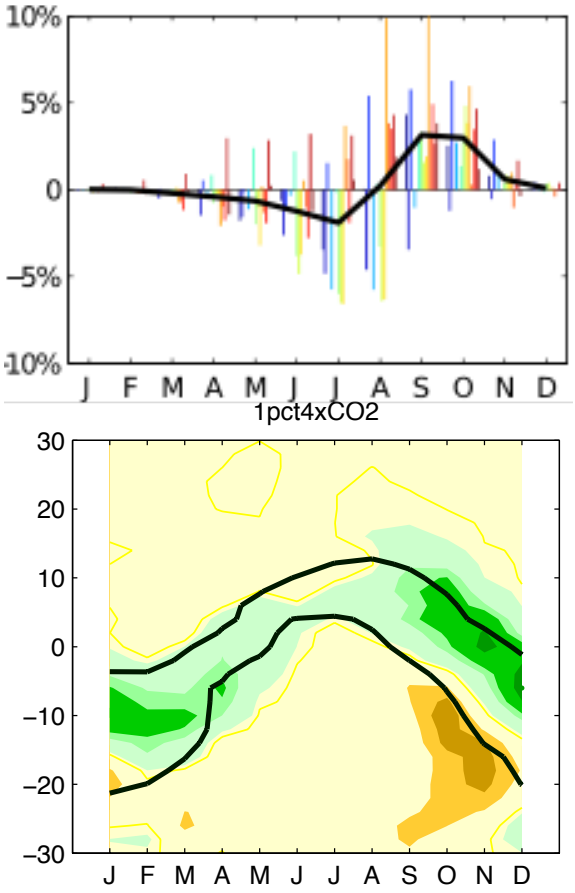


uncoupled response to warmer SST

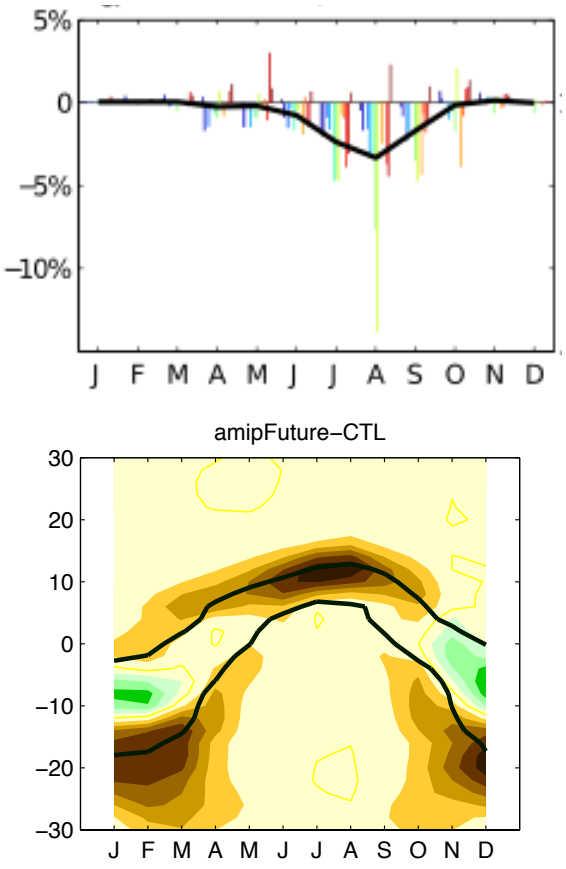


The delay in the Sahel rainy season CANNOT be explained by SST warming

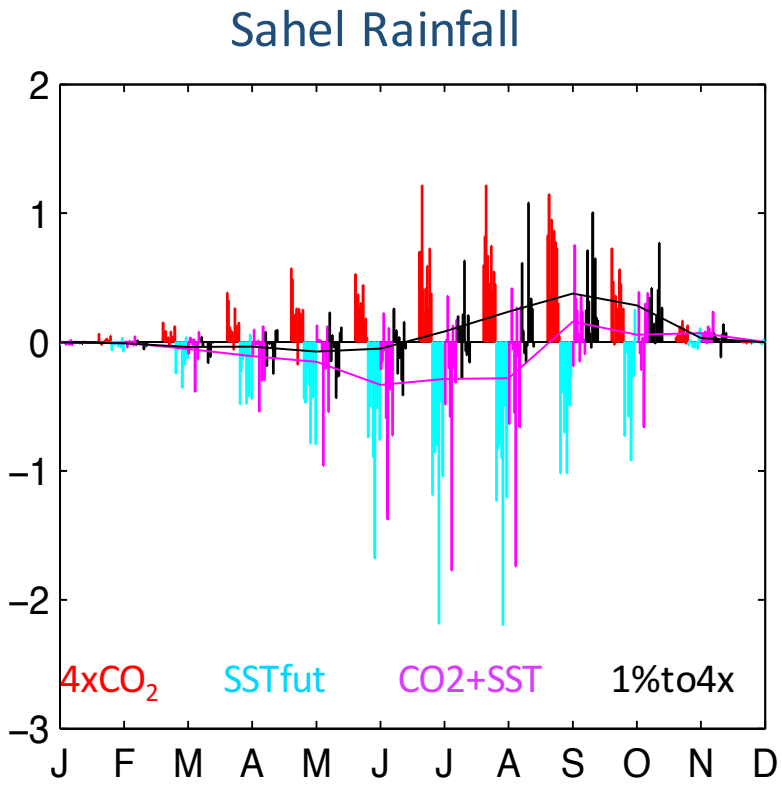
coupled response to CO2 quadrupling



uncoupled response to warmer SST



The direct effect of CO2 is to increase land rainfall and delay the peak



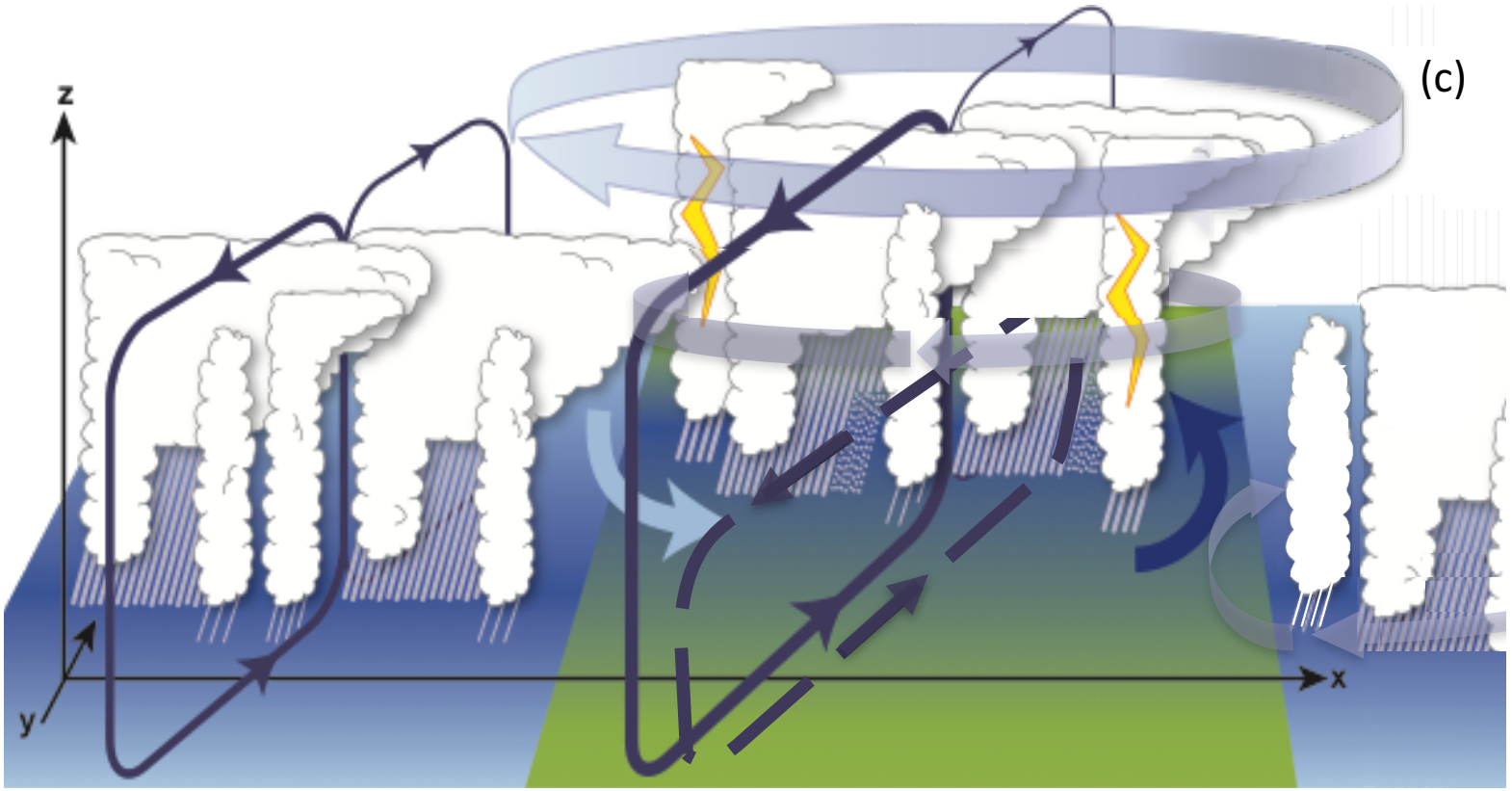
Effect of $4xCO_2$

Effect of SST +4K warming and pattern change

Linear Combination

Full coupled response

A distinction between the ITCZ and the monsoon is necessary to understand Sahel rainfall



or :

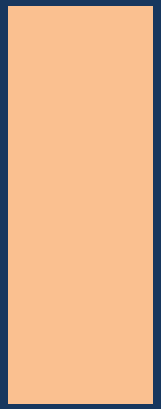
Why we need aquaplanet simulations to help sorghum farmers in the Sahel

We need a theory for the annual cycle of the monsoon & ITCZ

…enters TRACMIP

TRACMIP:
Tropical Rain belts with an Annual cycle and Continent Model Intercomparison Project

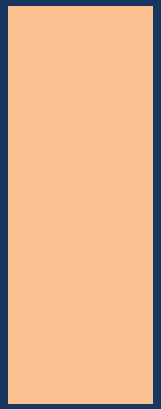
Michela Biasutti and Aiko Voigt (tracmip@gmail.com)



Simulations by: Jürgen Bader, Simona Bordoni, Francis Codron, Ross D. Dixon, Sarah Kang, Nicholas P. Klingaman, Ruby Leung, Jian Lu, Elizabeth A. Maroon, Sonali McDermid, Jong-yeon Park, Romain Roehrig, Brian E. J. Rose, Jeongbin Seo, Thomas Toniazzo, Masakazu Yoshimori, Aiko Voigt

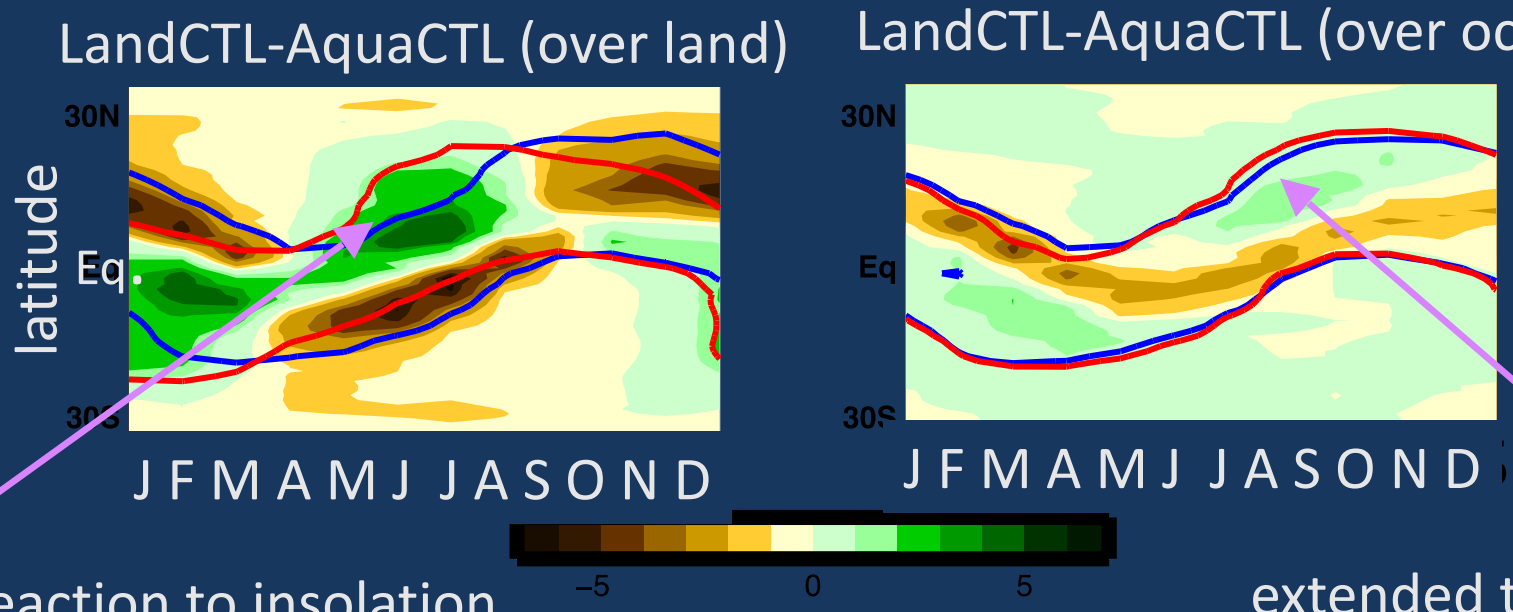
And help from: Jacob Scheff, Brian Mapes, and Lucas R. Vargas Zeppetello

Aquaplanet **OR** Aquaplanet + “jell-o” continent



1. Low heat capacity
2. Brighter than water
3. Resists evaporation
4. Does not transport heat

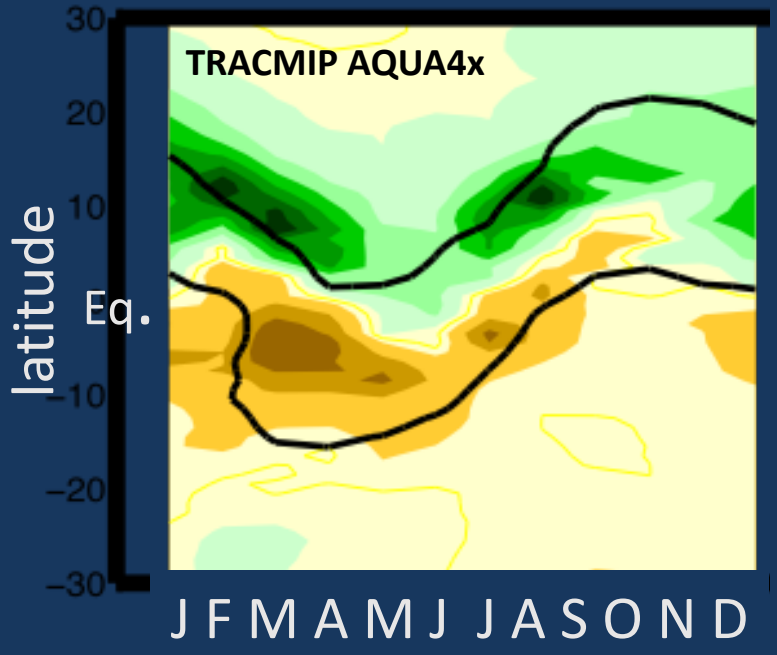
(unsurprisingly) Adding a continent changes the annual cycle of the rain bands



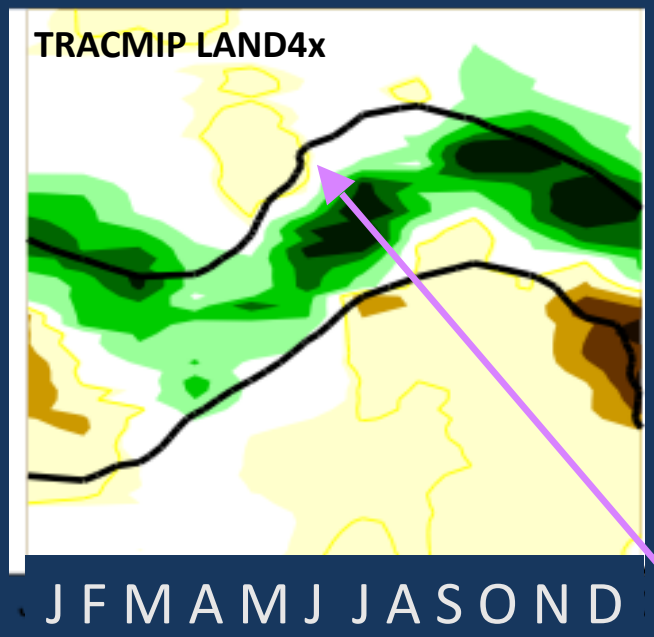
faster reaction to insolation over land

extended to the ocean

Adding a continent changes the annual cycle of the response to 4xCO2: the monsoon is delayed!



meridional shift of the ITCZ



meridional shift of the ITCZ
+ delay of the monsoon!

Conclusions

1. Validating a future projection with past observations requires understanding the relevant mechanisms and validating those. *Model consensus is not (would not be!) sufficient.*
2. Variability & trends in Sahel rainfall depend on SST in a non-stationary way.
3. The annual cycle of the monsoon might be a better analog than past variability for the 21st century trend.
4. We can get started with mitigation & global adaptation to warming (hugely important!), but we don't yet have *reliable* projections for prioritizing regional adaptation.
5. We still need theory!