The Annual Cycle of Precipitation over the Tropical Atlantic, South America, and Africa.

Mutual Influences of Land and Ocean.

Michela Biasutti

with David S. Battisti and Edward S. Sarachik

New York, October 3, 2003

OUTLINE

- Motivation
- Method
- Results
- Conclusions
- Implications

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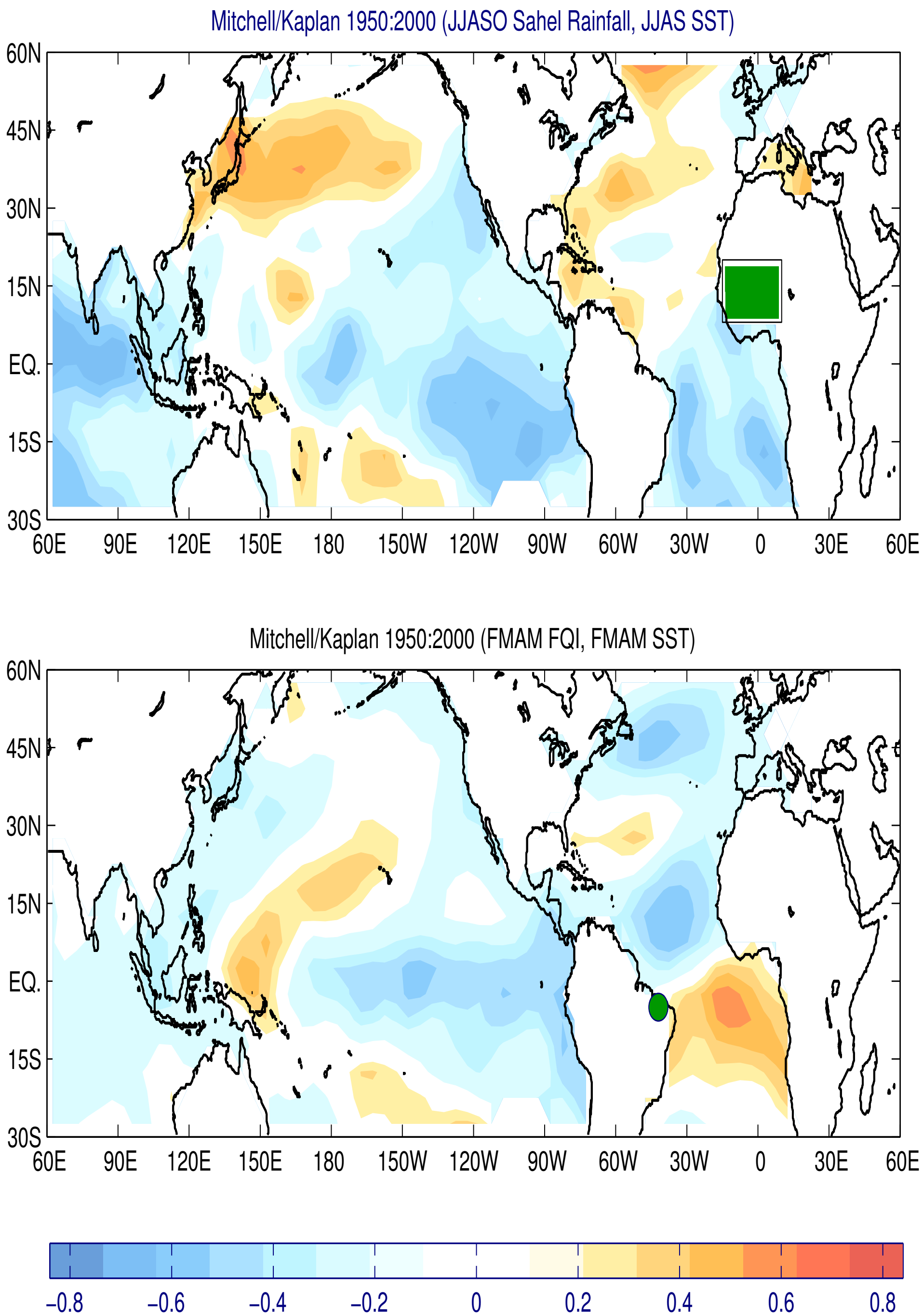

- Fact: Global SST is correlated with precipitation in Sahel and Northeast Brazil.
- Working Hypothesis: Tropical Atlantic SST influences land precipitation.
- Open Question: What are the mechanisms?
  - Is the SST influence direct?
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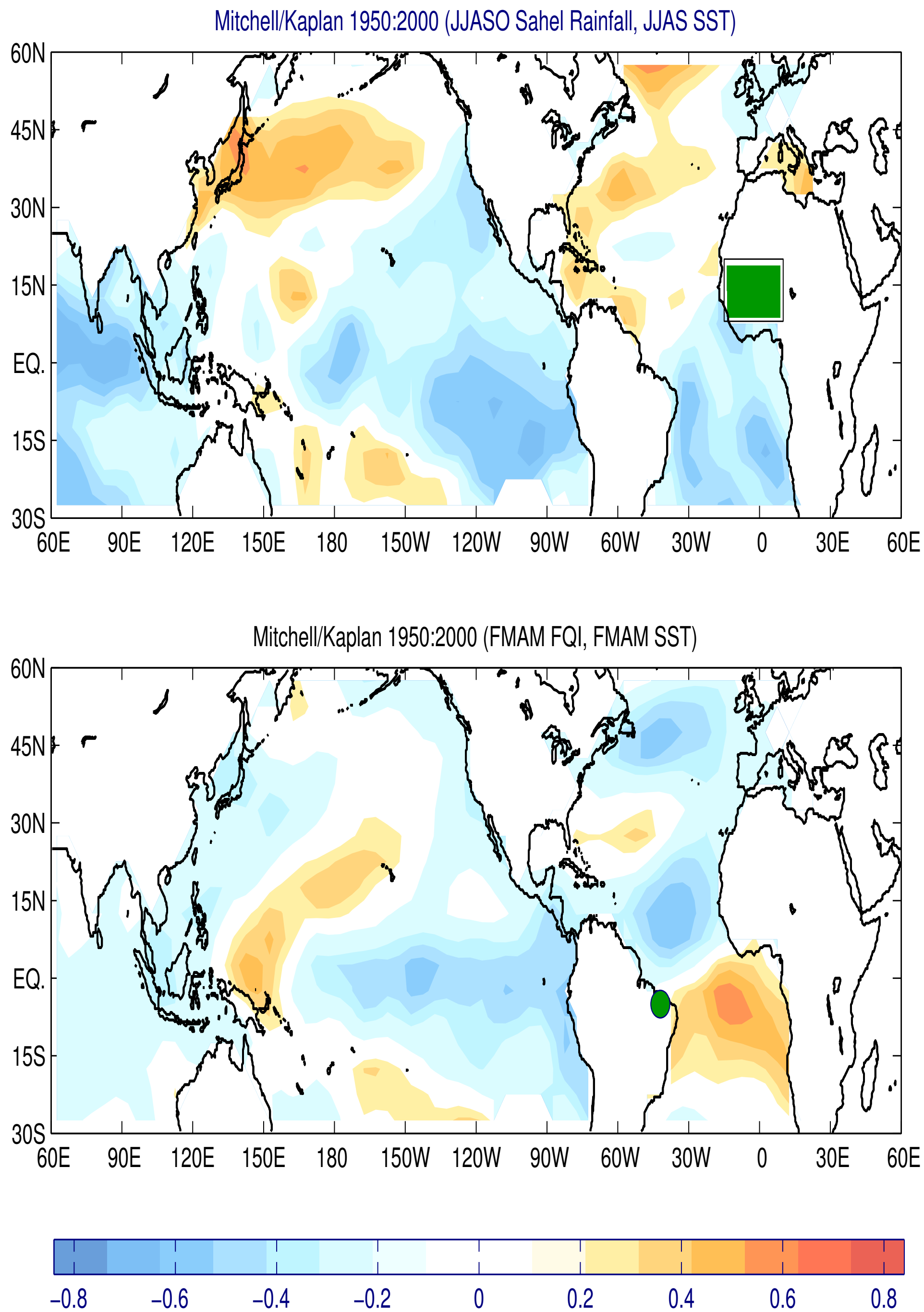

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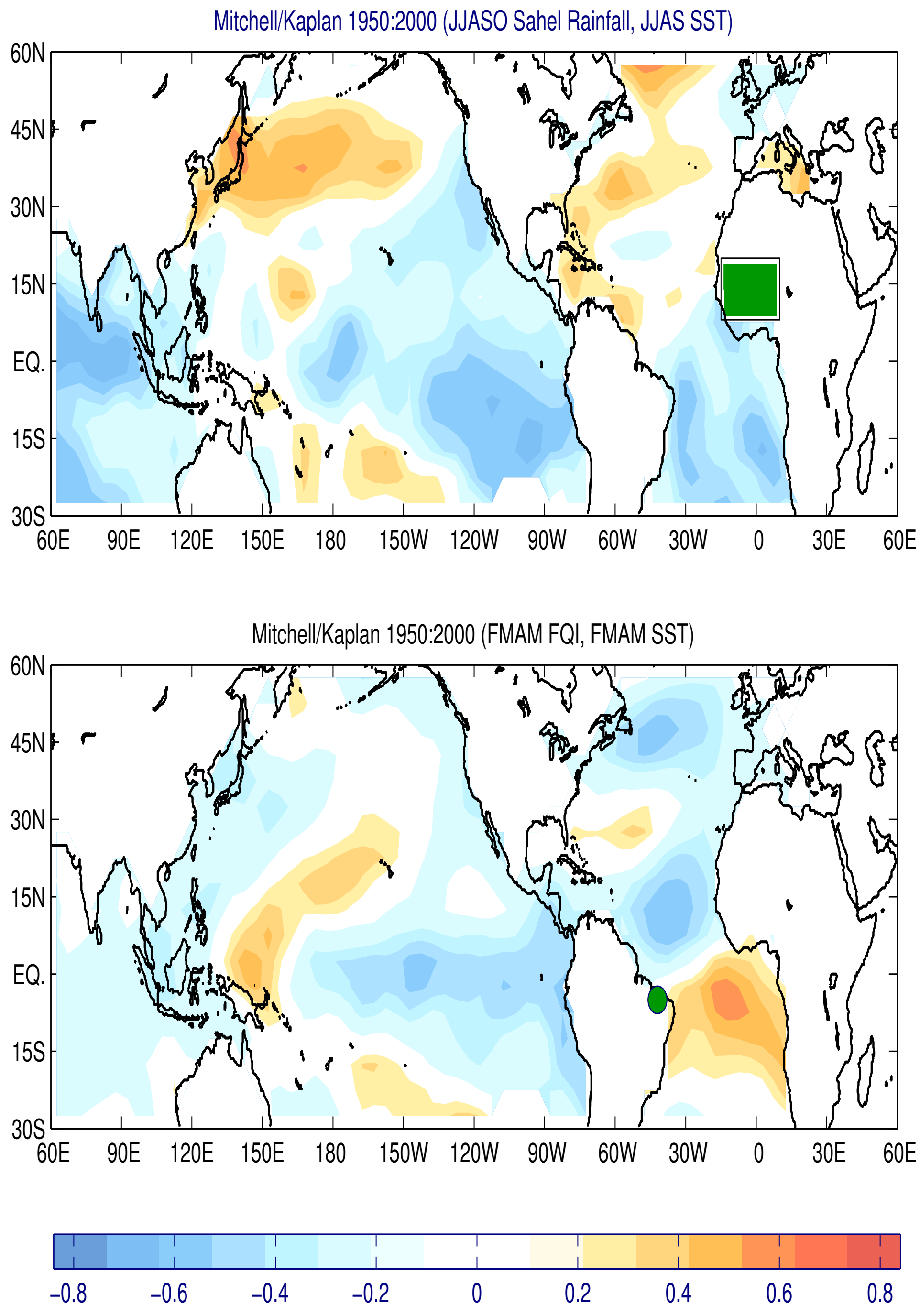

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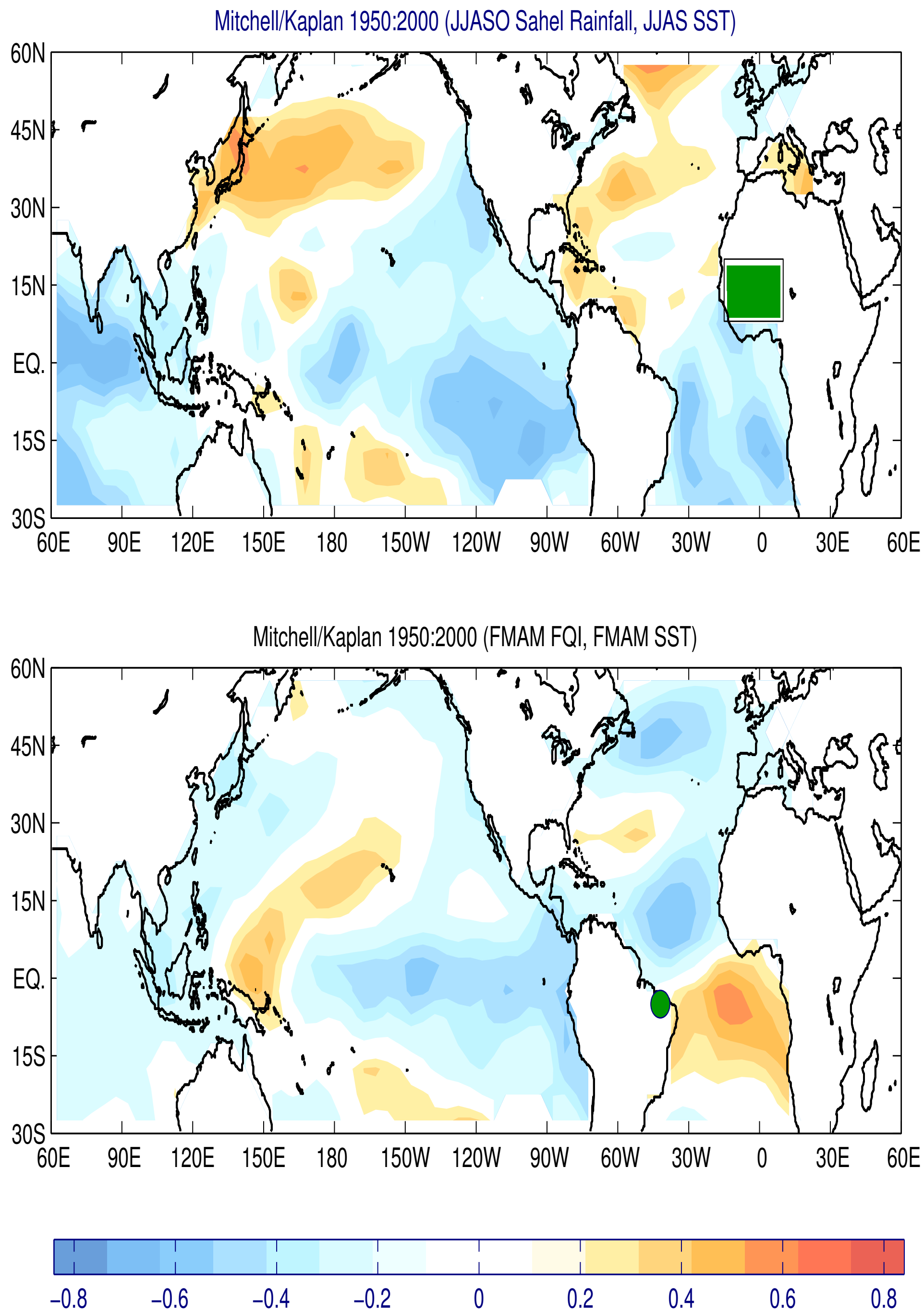

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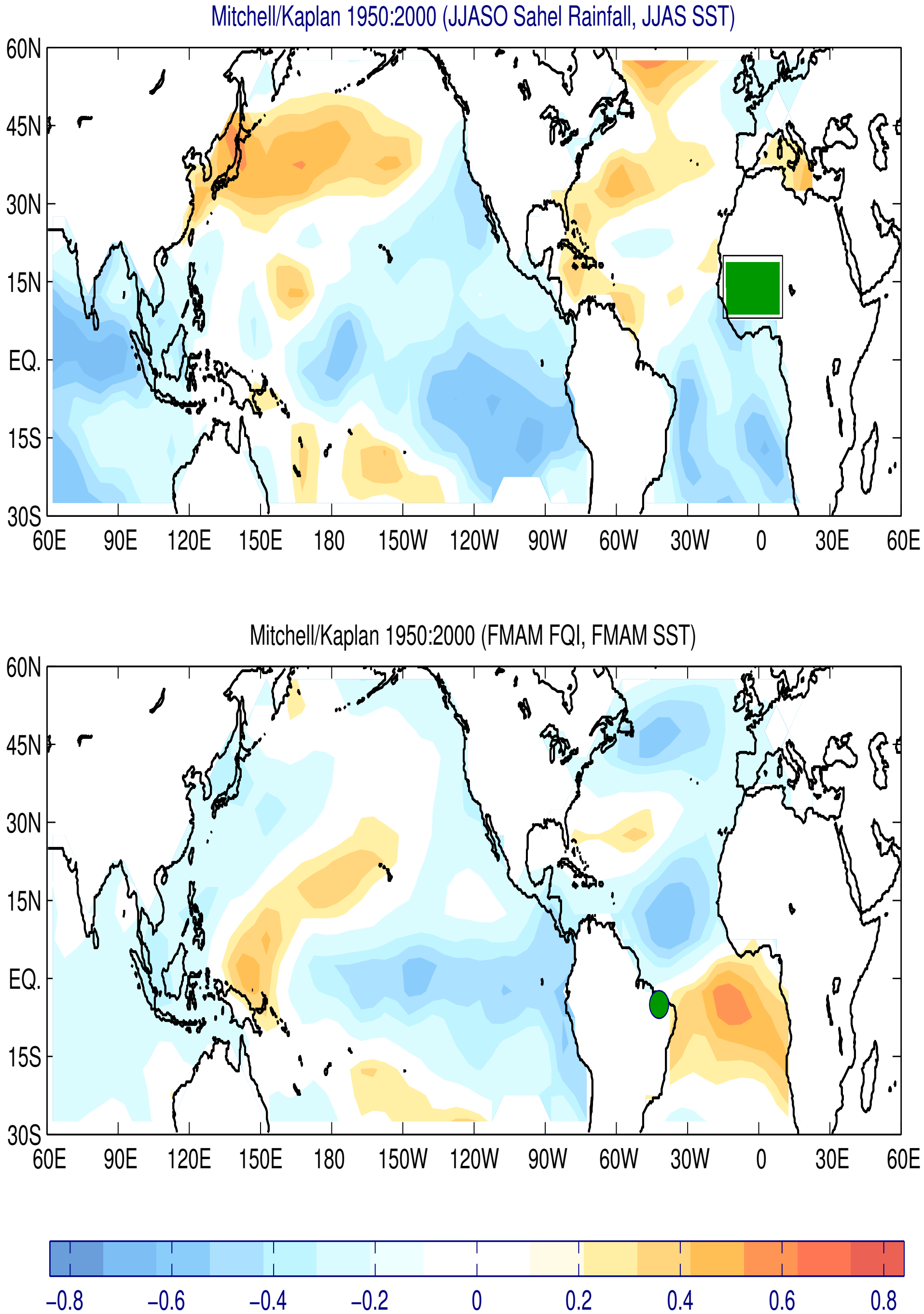

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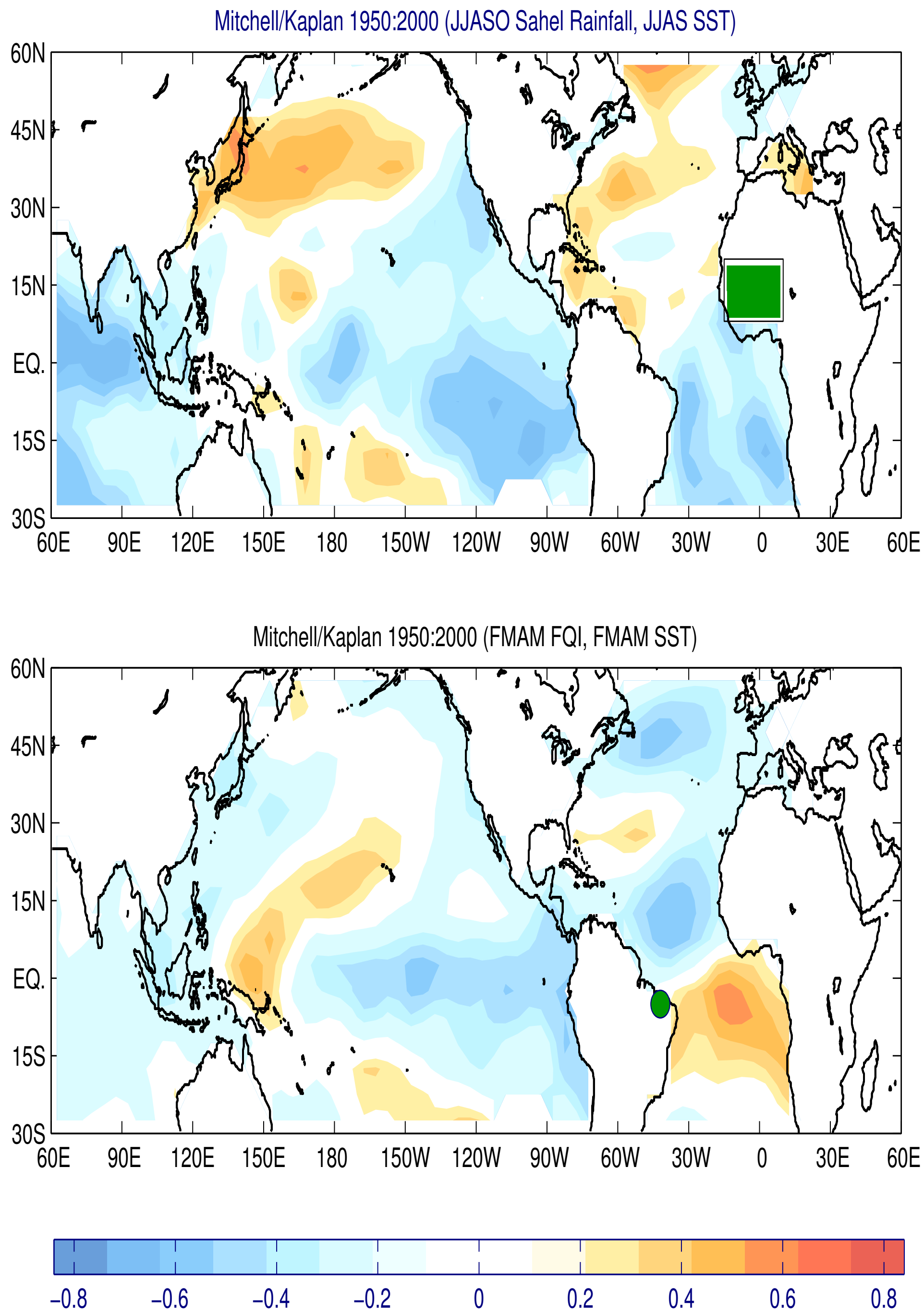

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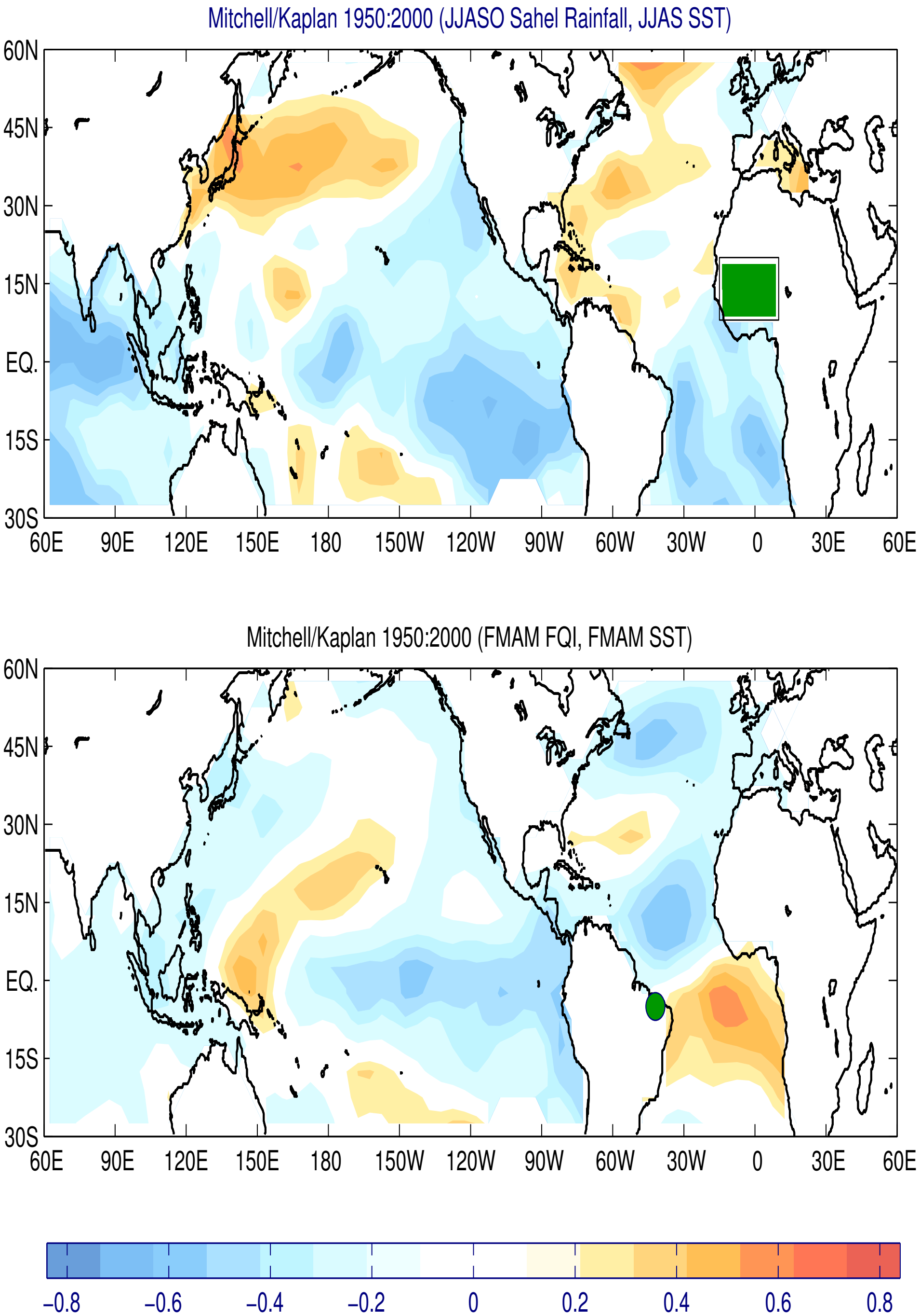

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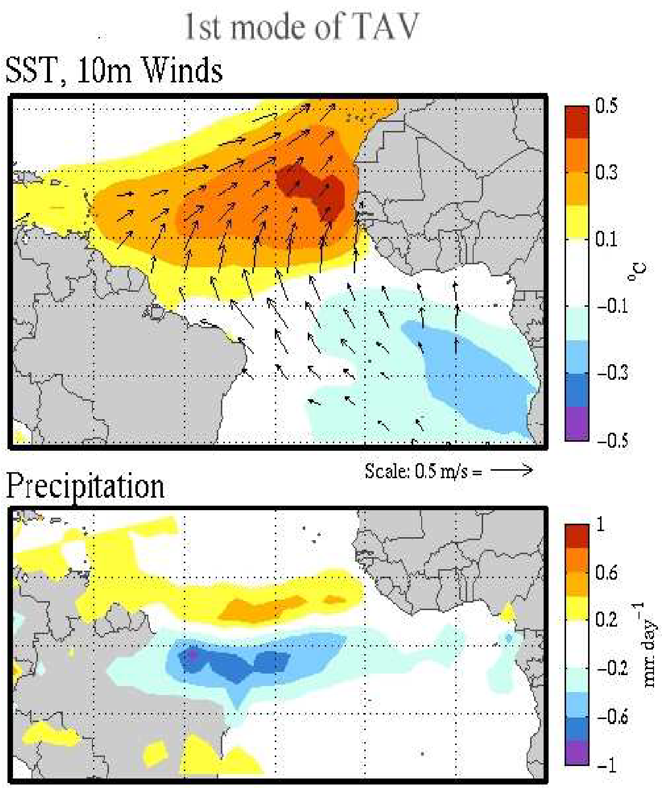
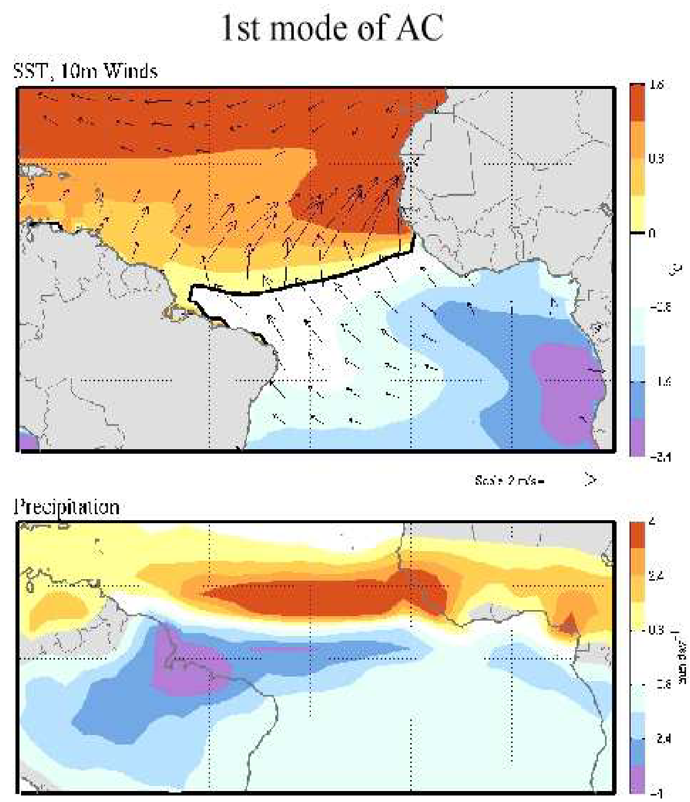
Motivation: AC & TAV ANALOGUE

- Atmospheric processes bring the SST signal inland $\Rightarrow$ the same fast atmospheric dynamics must be involved in both the AC and the TAV.
- The gross features of AC and TAV in the deep tropics look alike

Motivation: AC & TAV ANALOGUE





meridional mode

cross-equatorial SST gradient

cross-equatorial wind towards warm SST

meridional shift of ITCZ towards warm SST

Method: THE MODELS

- Uncoupled Community Climate Model Version 3 (CCM3) T42 resolution.

  ⇒ The precipitation over Africa and South America is overestimated.

  ⇒ Tropical land is too cold (especially the Sahara).

- Coupled CCM3 coupled to a Slab Ocean Model (SOM) in the tropical Atlantic only (prescribed SST elsewhere).

  ⇒ SST responds to radiative and turbulent heat fluxes.

  ⇒ No ocean dynamics (Ocean Heat Transport Convergence is parameterized with a flux adjustment, the Q-flux).

  ⇒ Climatology of CCM3+SOM is (by construction) nearly identical to the climatology of CCM3.

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Method:
THE IDEA BEHIND THE EXPERIMENTS

We want to identify:

- what features of the AC over land and ocean are locally forced?
- what features of the AC over land and ocean are remotely forced?
- the mechanisms of mutual influences between land and ocean regions

IDEA: we suppress the AC of forcings over land and ocean regions separately $\Rightarrow$ we can separate out local and remote responses.

Method: THE FORCINGS

- Insolation over land.
- Insolation over ocean.
- Q-flux.
- Elevated Condensational Heating (Q_{cond}) in selected areas

} or SST

Method: EXPERIMENTAL DESIGN

- Fixed insolation over land, AC of Ocean Forcings (Qflux+Insolation or SST)

- Fixed Ocean Forcings, AC of insolation over land

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  AC over LAND is a REMOTE response to AC over ocean

  AC over OCEAN is a LOCAL response

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  AC over LAND is a LOCAL response

  AC over OCEAN is a REMOTE response to AC over land

RESULTS

A. LOCAL LAND

- AC of insolation;
  March SST
  ⇒ AC of land precip

B. LOCAL OCEAN

- AC of SST;
  March Insolation
  ⇒ AC of ocean precip

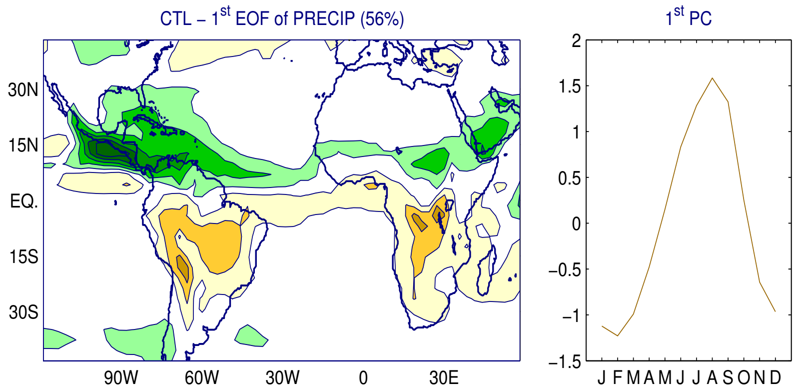
C. REMOTE LAND

- AC of SST;
  March Insolation
  ⇒ AC of land precip

D. REMOTE OCEAN

- AC of land insolation;
  March SST
  ⇒ AC of ocean

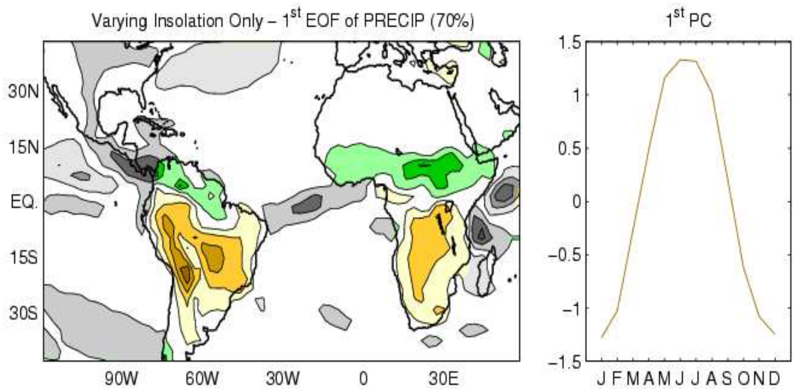
Results: **LOCAL LAND**



CTL:

North-South displacement over land and ocean

Extrema: February/August



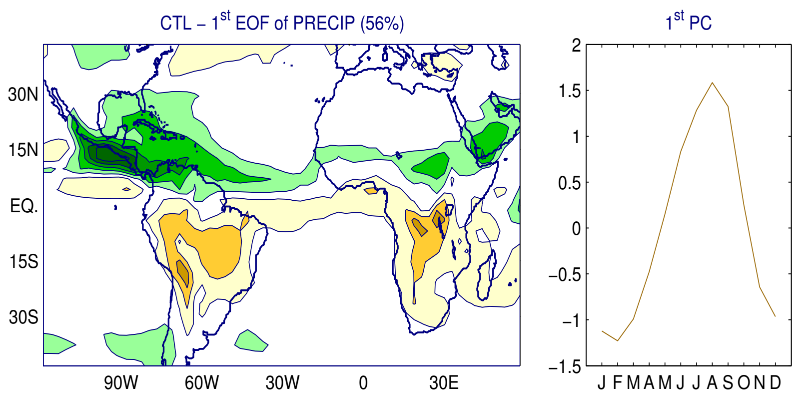
Local Land:

North-South displacement over land

Extrema: December/June

Gulf of Guinea is way off!

Results: **LOCAL LAND**



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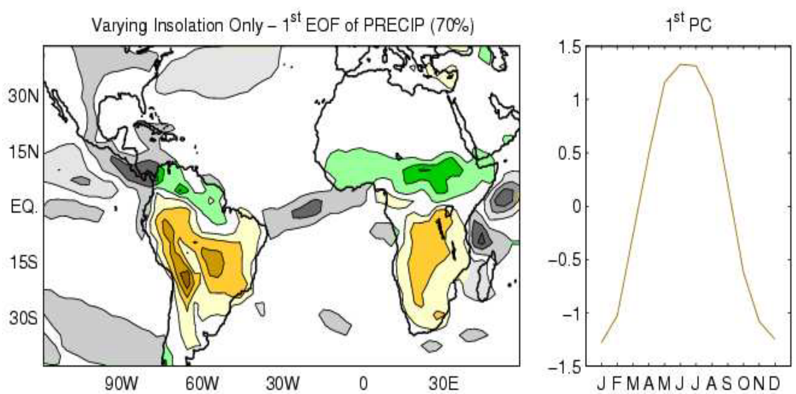

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D. REMOTE OCEAN

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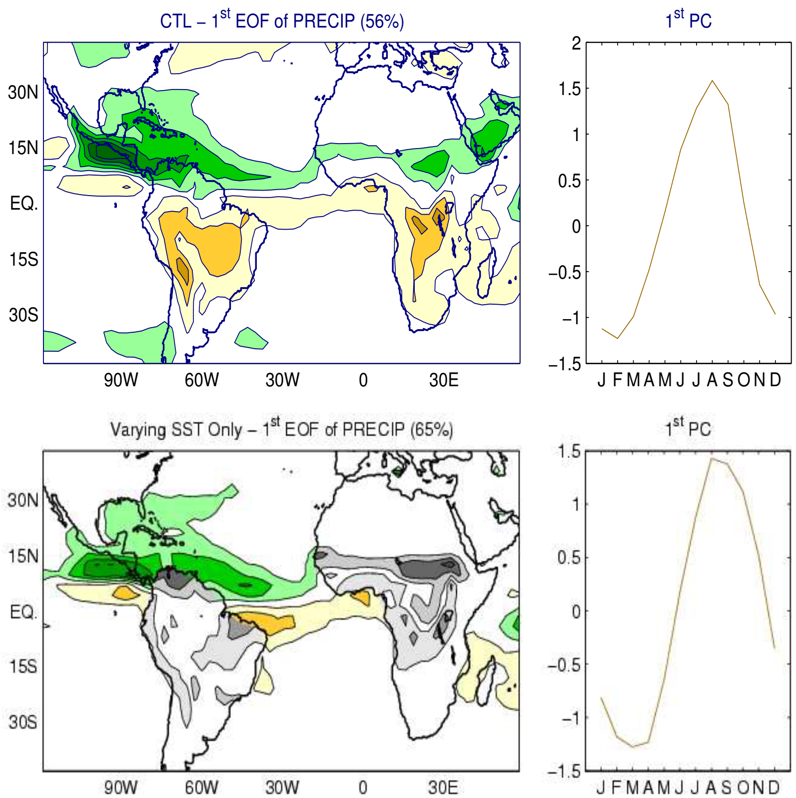
Results: **LOCAL OCEAN**



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North-South displacement over land and ocean

Extrema: February/August

Local Ocean:

North-South displacement over ocean

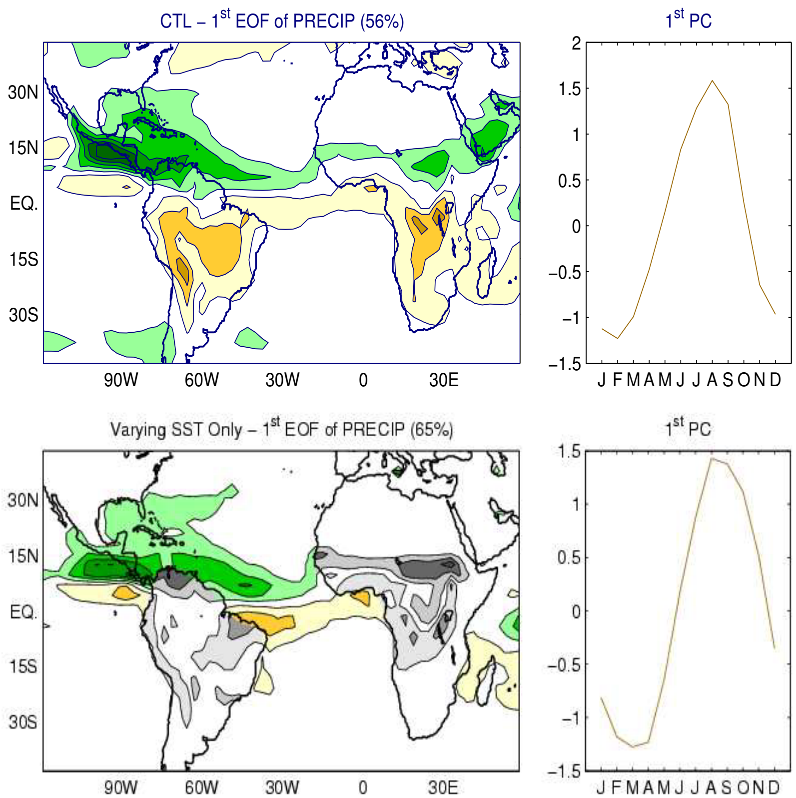
Extrema: March/August

Local control of ITCZ position

Non-local control of ITCZ intensity

What's the role of elevated condensational heating (Q_{cond}) in generating surface winds and convergence?

Results: **LOCAL OCEAN**



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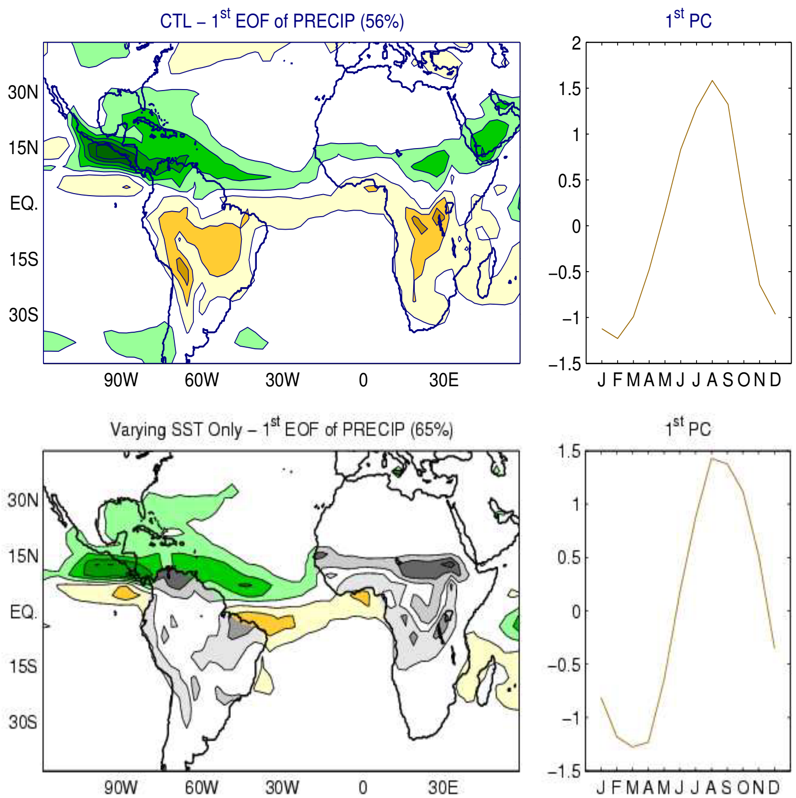

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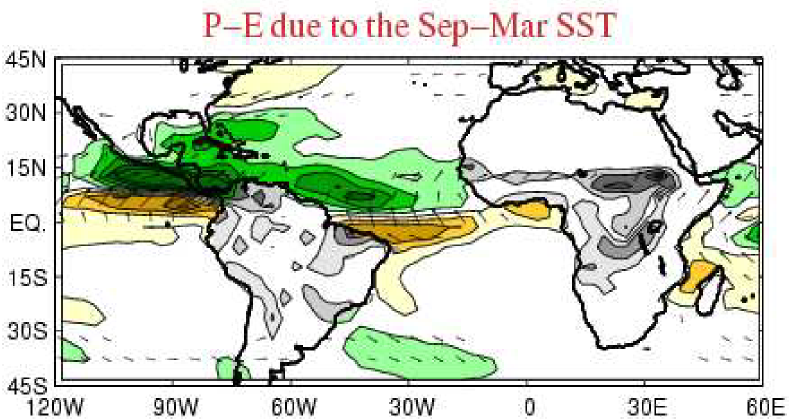
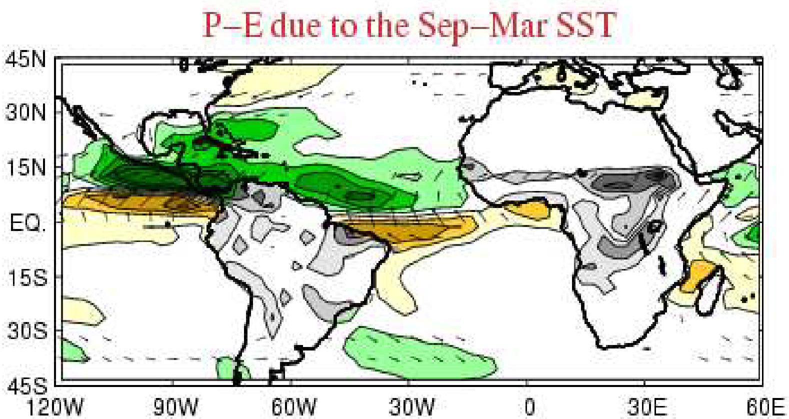
What's the role of elevated condensational heating (Q_{cond}) in generating surface winds and convergence?

Results: **LOCAL OCEAN**: the role of Q_{cond}.



Moisture Convergence (P-E) & Surface Wind Response to SST changes.

Results: **LOCAL OCEAN**: the role of Q_{cond}.



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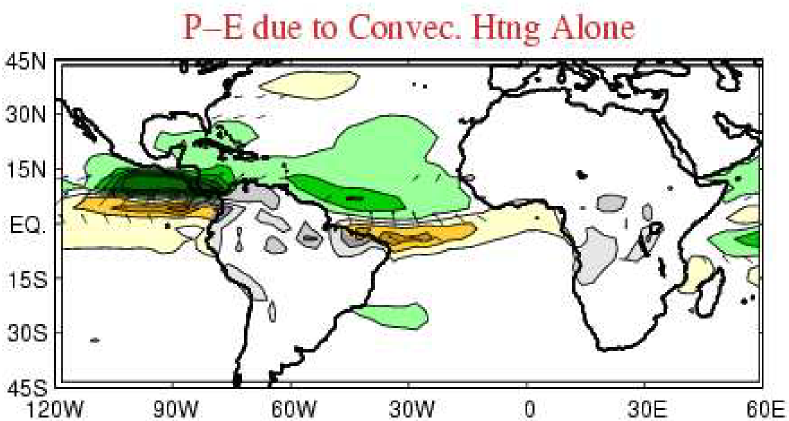

Moisture Convergence (P-E) & Surface Wind Response to Q_{cond} changes in the ITCZ. The ITCZ Q_{cond} drives a circulation that sustains the original SST-induced displacement of the ITCZ.

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B. LOCAL OCEAN

- AC of SST;
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C. REMOTE LAND

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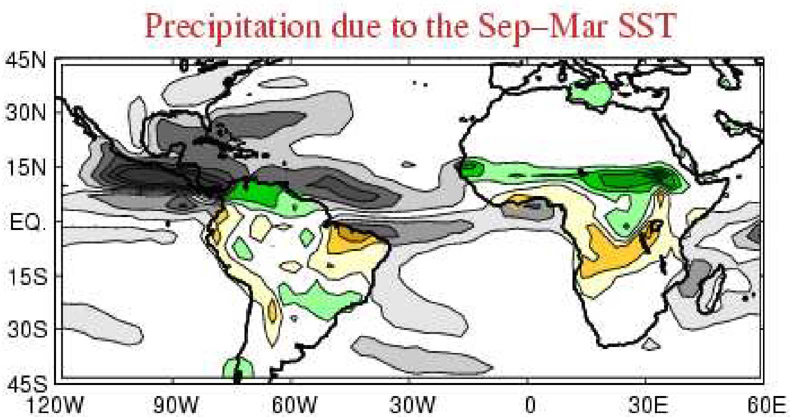
Results: **REMOTE LAND**.



Precipitation response to SST changes.

- Northeast Brazil /Guiana
- Equatorial Africa & Guinea /Sahel

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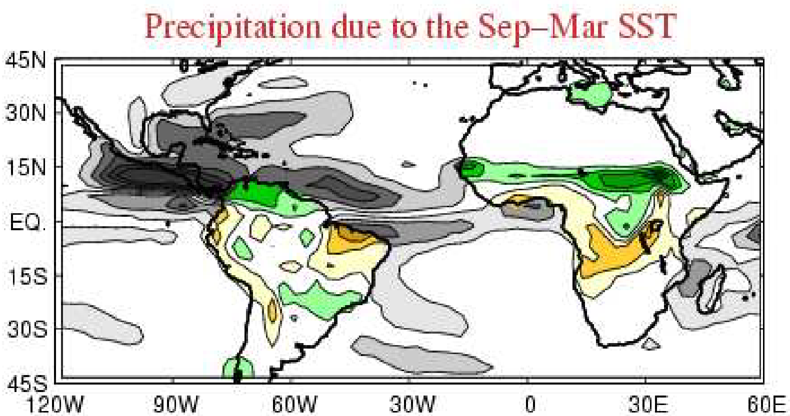

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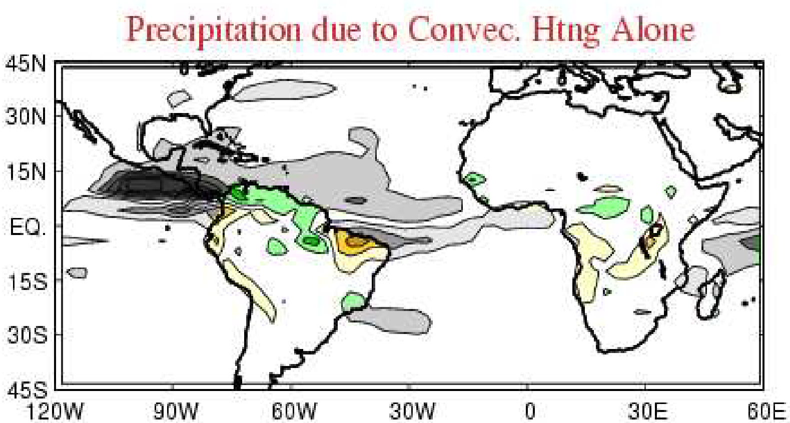
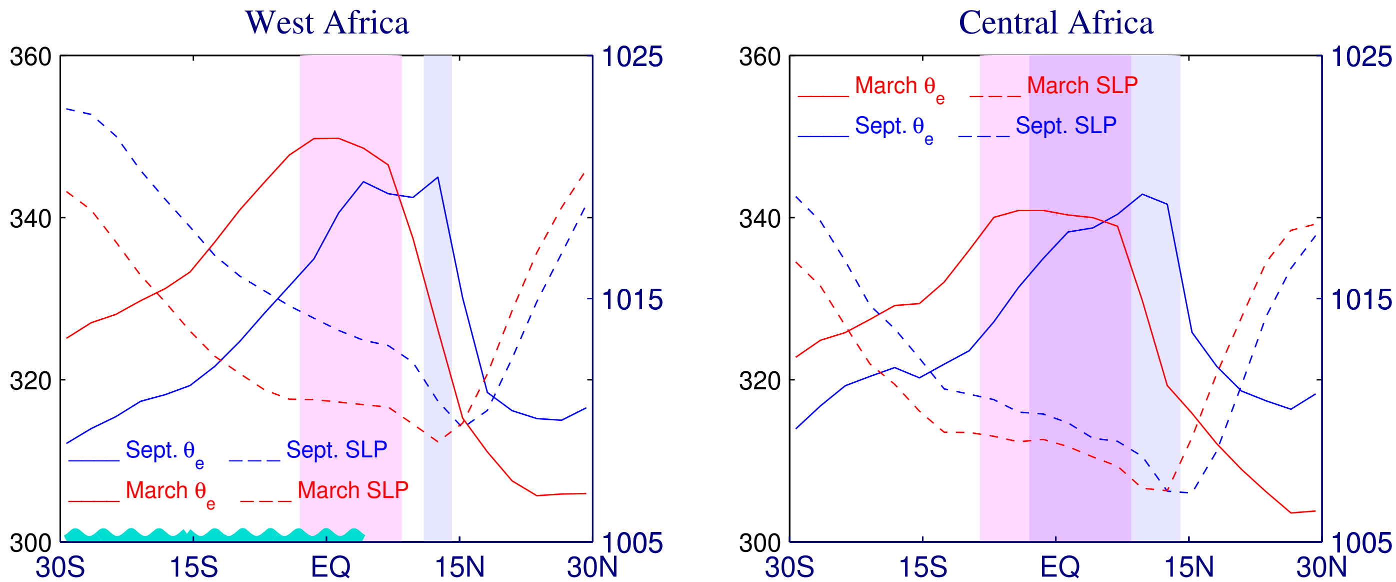


Precipitation response to Q_{cond} changes in the ITCZ.

- YES: South America
- NO: Africa

Results: **REMOTE LAND**: the role of T_{sfc}



SST

$\Downarrow$

Land T_{sfc}

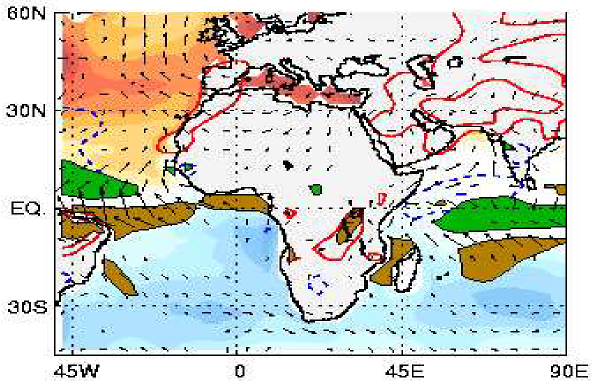
$\Downarrow$

θ_e and SLP

$\Downarrow$

P_{max} position.

Results: **REMOTE LAND**: Inland Advection of SST.



- SST ⇒ ITCZ
- ITCZ ⇒ wind in Africa + wind and SAT in Near East

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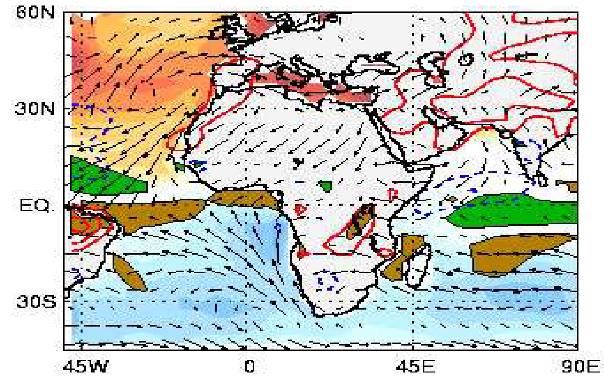
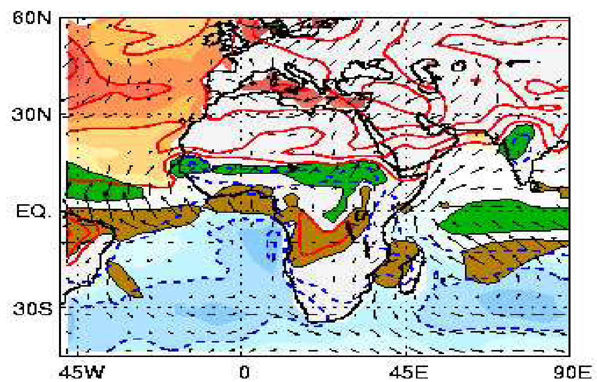


- mean westerlies ⇒ Arabian SAT
- mean easterlies + wind anomalies ⇒ Sahara SAT



- African SLP ⇒ southerly wind
- ⇒ moisture convergence into the Sahel

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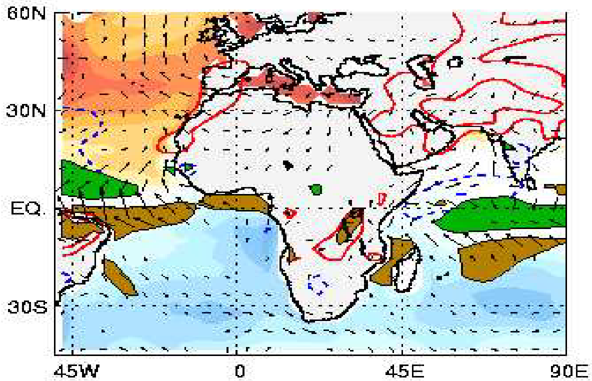

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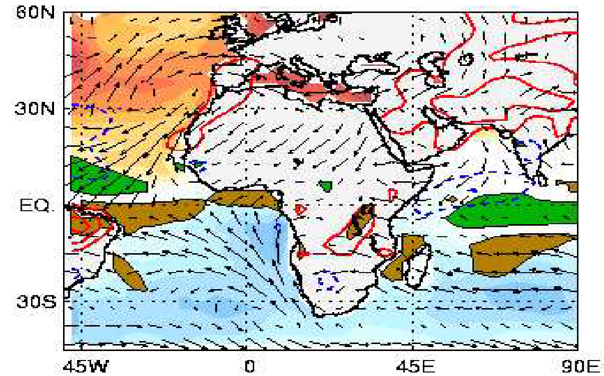

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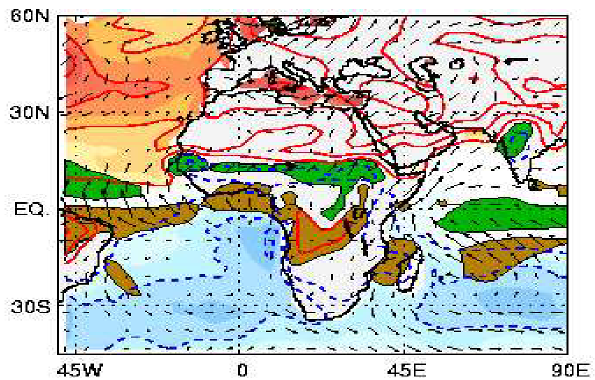

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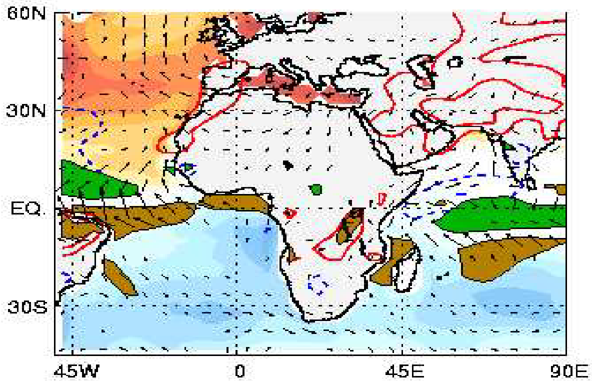

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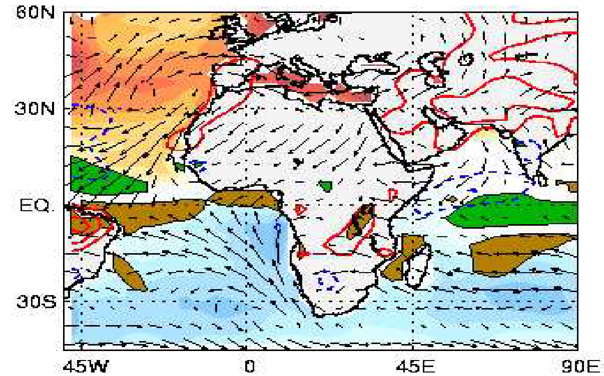

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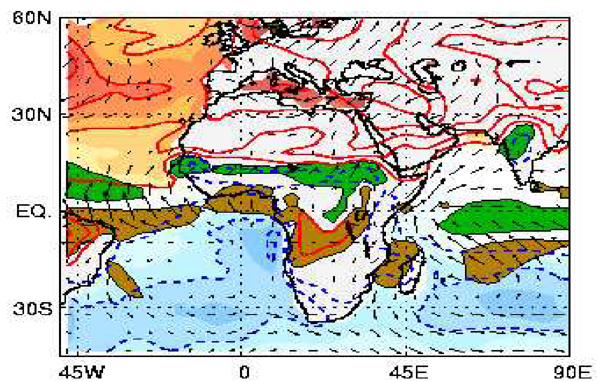

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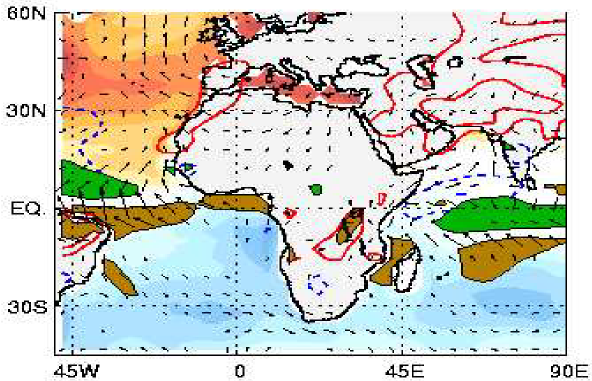
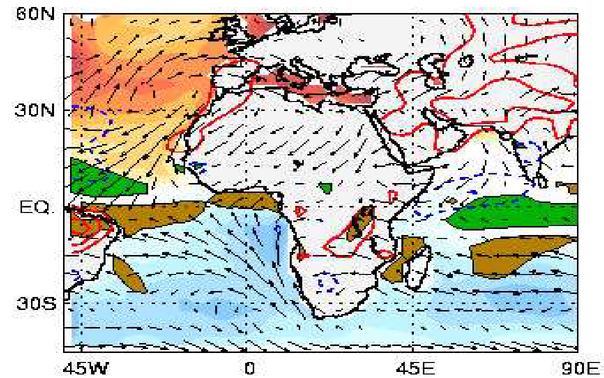
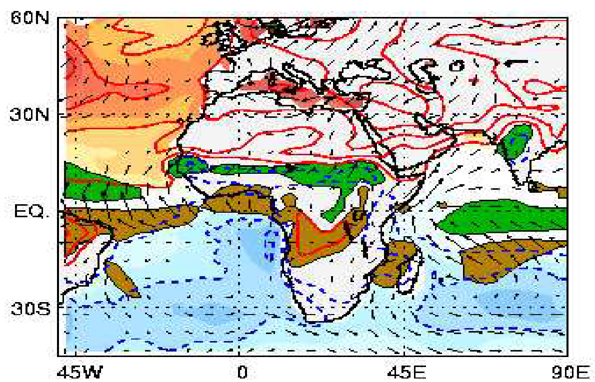


+



- SST ⇒ ITCZ
- ITCZ ⇒ wind in Africa + wind and SAT in Near East

- mean westerlies ⇒ Arabian SAT
- mean easterlies + wind anomalies ⇒ Sahara SAT



- African SLP ⇒ southerly wind
- ⇒ moisture convergence into the Sahel

RESULTS

A. LOCAL LAND

- AC of insolation;
  March SST
  $\Rightarrow$ AC of land precip

C. REMOTE LAND

- AC of SST;
  March Insolation
  $\Rightarrow$ AC of land precip

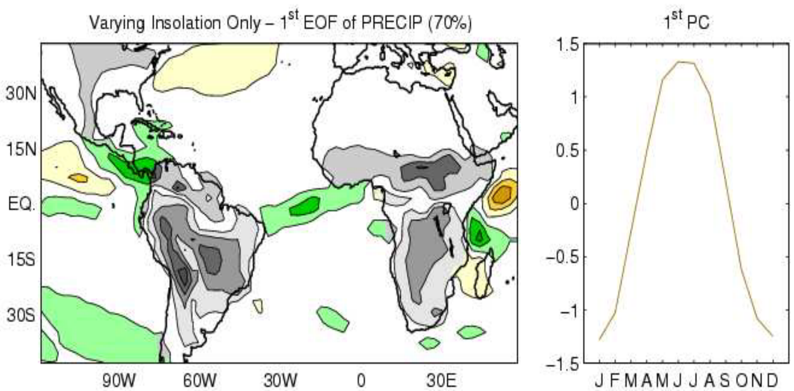
B. LOCAL OCEAN

- AC of SST;
  March Insolation
  $\Rightarrow$ AC of ocean precip

D. REMOTE OCEAN

- AC of land insolation;
  March SST
  $\Rightarrow$ AC of ocean

Results: **REMOTE OCEAN**: ITCZ Intensity Change



Uncoupled response: Land climate forces rainfall intensity anomalies in the Atlantic ITCZ.

- Does the ITCZ respond to changes in land surface temperature?
- Does it respond to changes in land precipitation (Q_{cond})?

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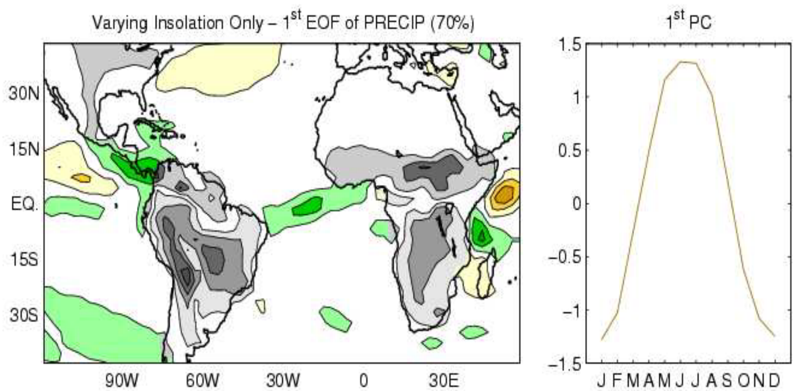

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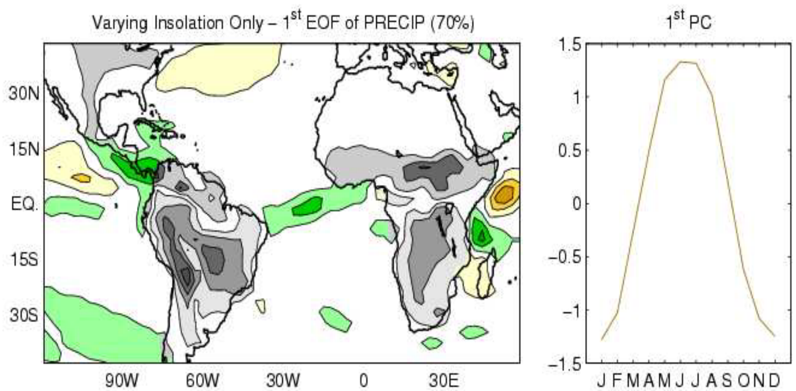

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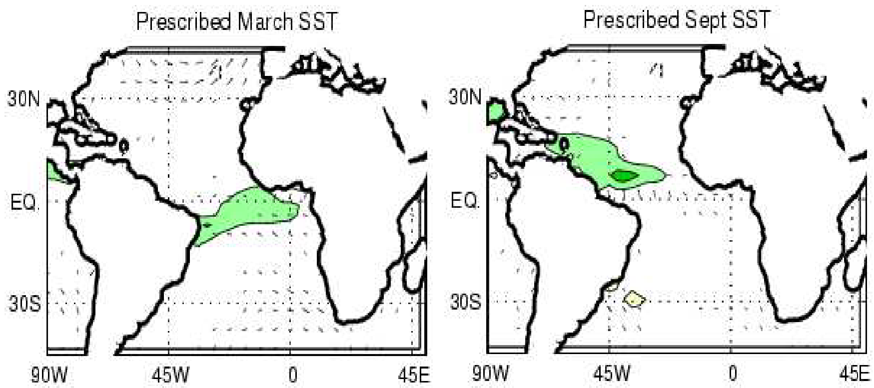
The response to imposed steady forcing in elevated condensational heating over Africa and South America.



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- Anomalies are co-located with the mean ITCZ.
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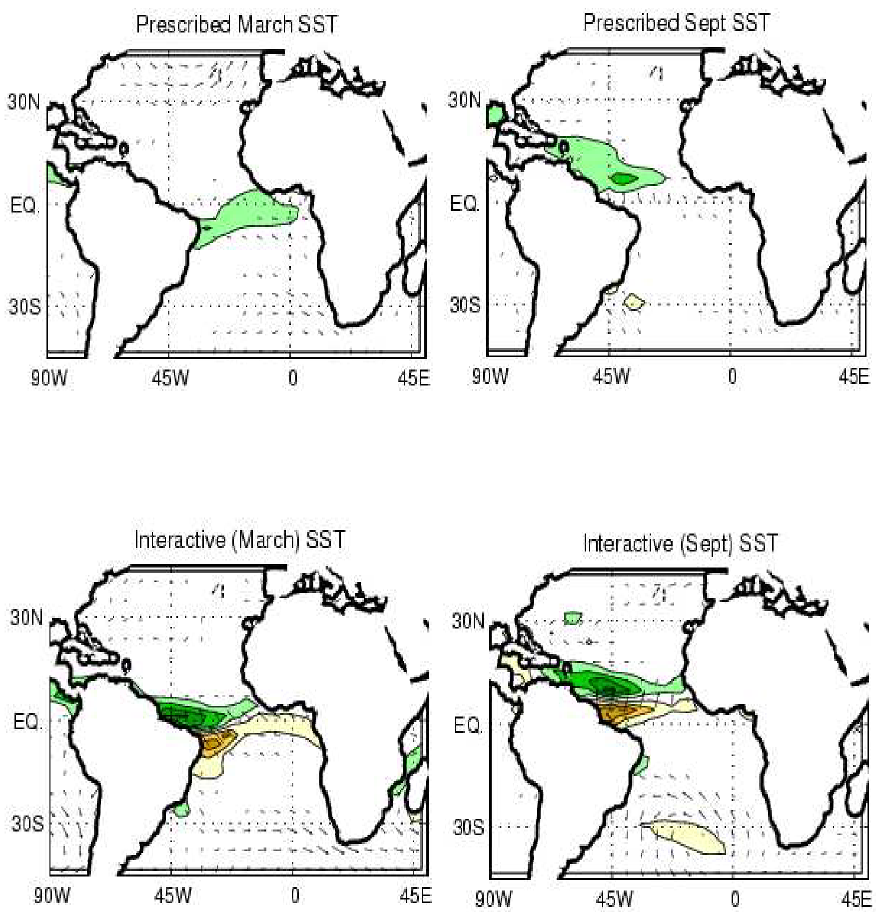

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Coupled response

- wind anomalies $\Rightarrow$ evaporation anomalies
- latent heat flux anomalies $\Rightarrow$ SST anomalies
- anomalous SST gradient $\Rightarrow$ the ITCZ shift
- wind/evaporation/SST/ITCZ feedback.

COUPLED RESULTS

D. REMOTE OCEAN (coupled!)

CTL

- AC of Insolation over Land.
- AC of Insolation over Ocean.
- AC of Q-flux.

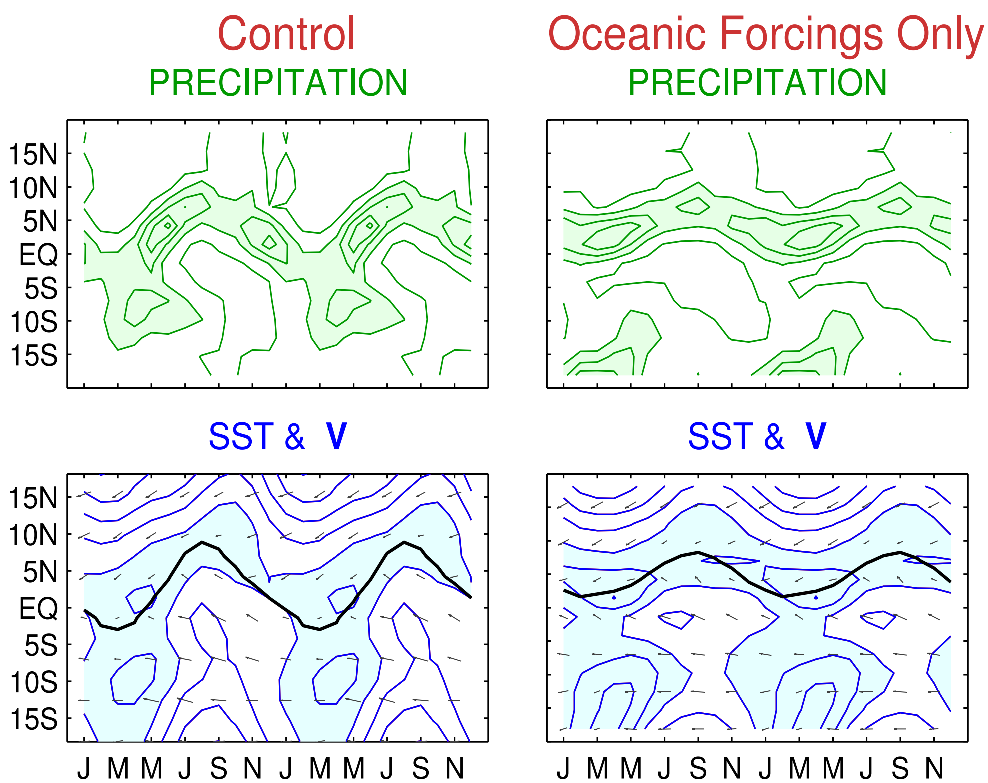
Fixed Insolation over Land

- March Insolation over Land.
- AC of Insolation over Ocean.
- AC of Q-flux.

$\Downarrow$

Effect of AC of Insolation over Land

Results: **REMOTE OCEAN**: Central Atlantic response to AC of Insolation over Land



suppressed AC over land ⇒ suppressed meridional annual march of ITCZ.

Concomitant changes in SST.

What forces the SST & ITCZ anomalies?

- Land surface temperature?
- Land precipitation?

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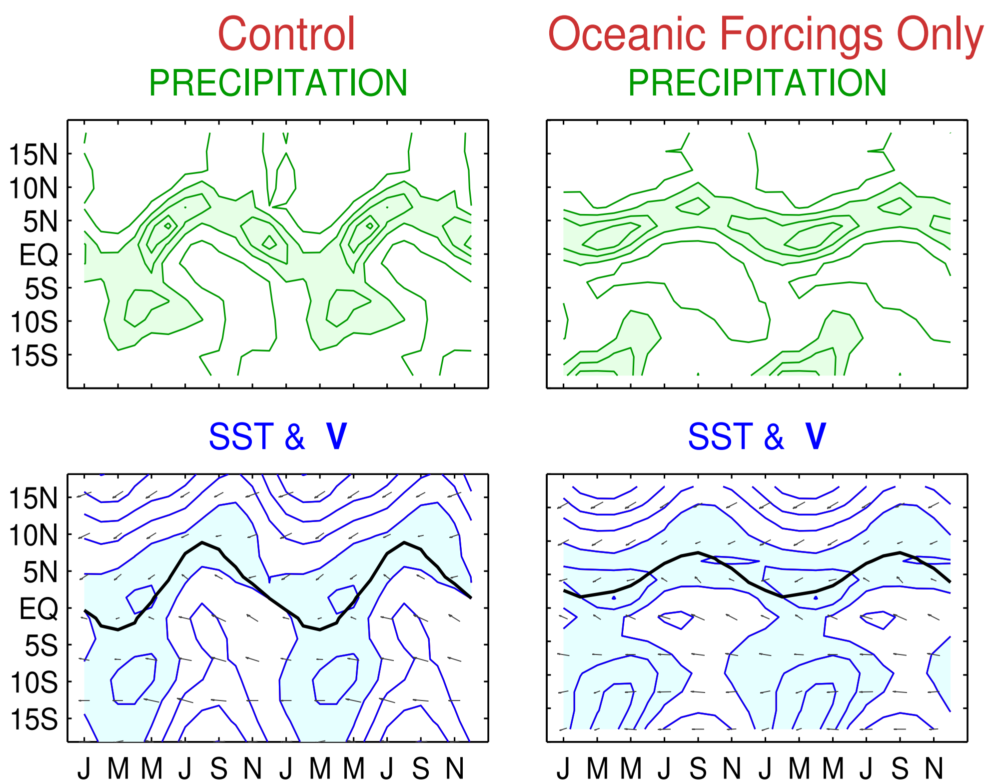

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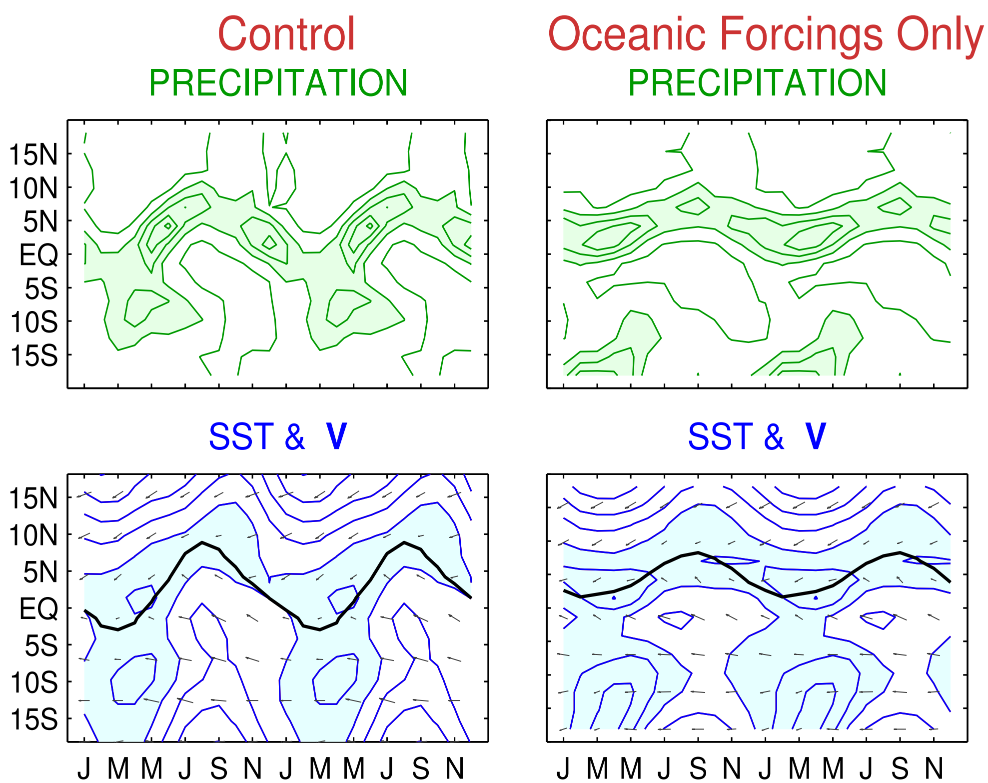

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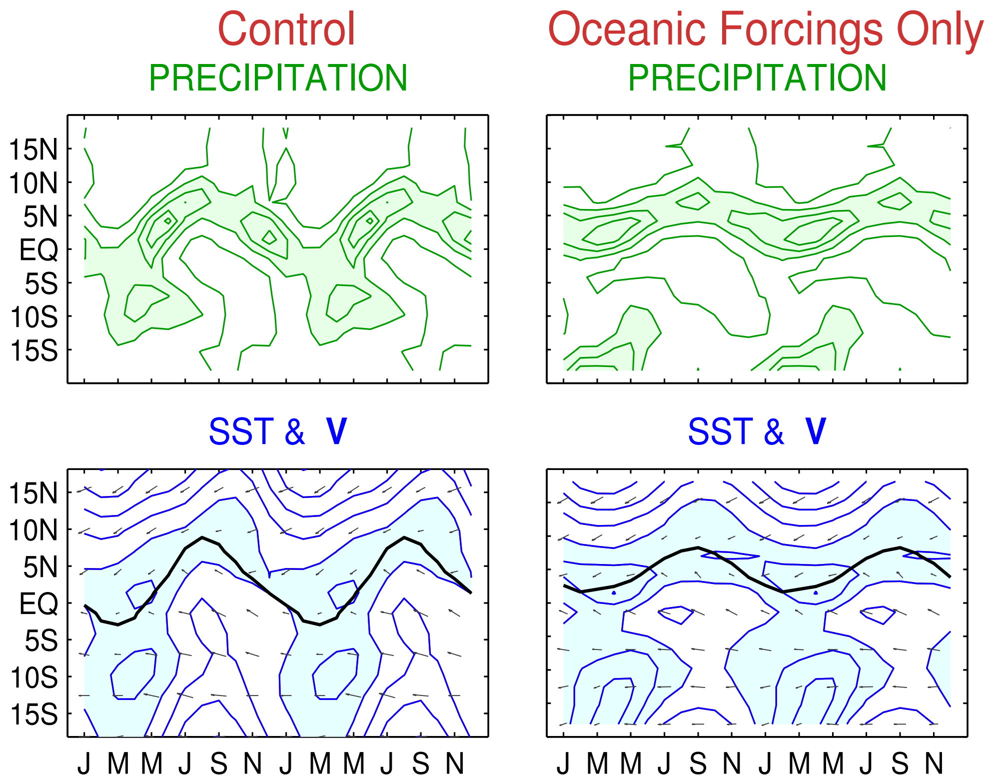

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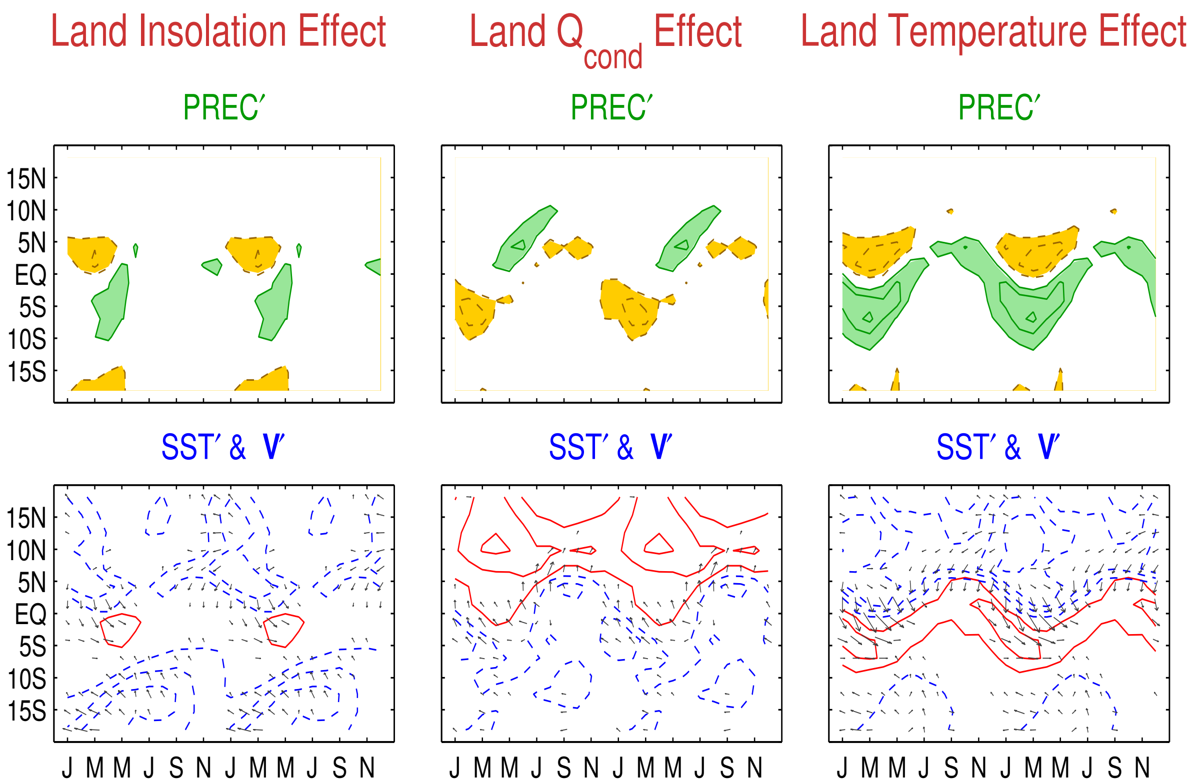
- Land precipitation?

Results: **REMOTE OCEAN**: Effect of Land Temperature and Precipitation

Compare the control simulation to the simulation with fixed insolation over land and the simulation with fixed elevated condensational heating over Africa and South America (Q_{cond})

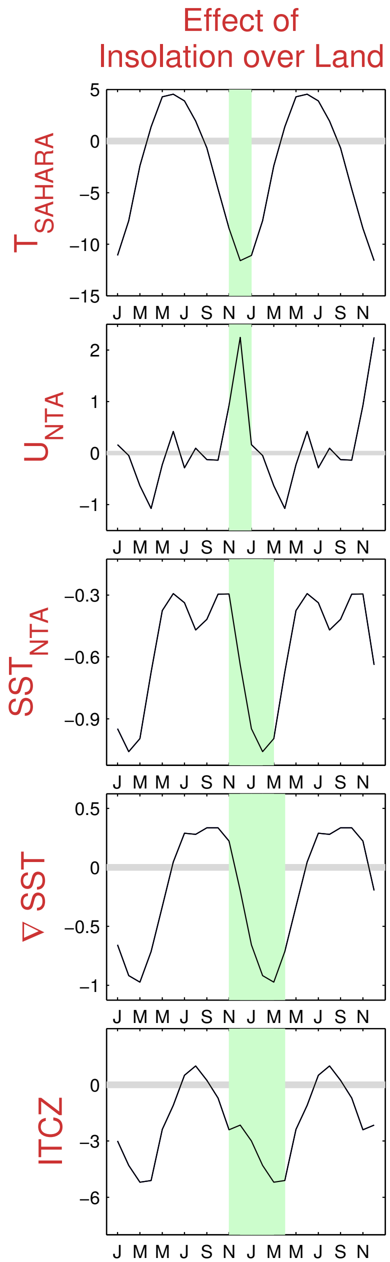


Land Q_{cond} and land T_{sfc} have large and opposite effects.

Land T_{sfc} dominant.

How?

Results: **REMOTE OCEAN**: Development of ITCZ Anomalies in Response to Land Forcing.



December cold "anomalies" in the Sahara $\Rightarrow$ thermal high

$\Downarrow$

stronger NTA Trades $\Rightarrow$ stronger evaporation

$\Downarrow$

colder NTA

$+$

feedbacks @ equator

$\Downarrow$

equatorial SST gradient

$\Downarrow$

ITCZ shift

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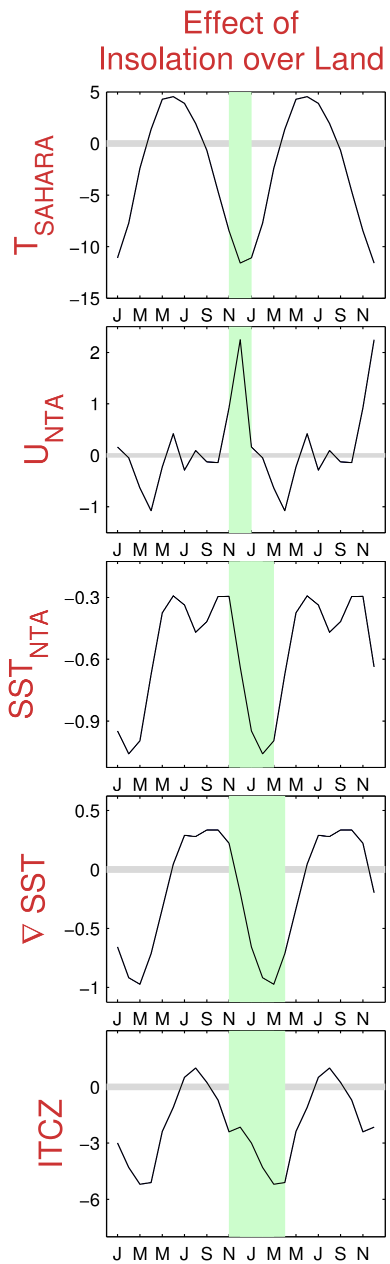

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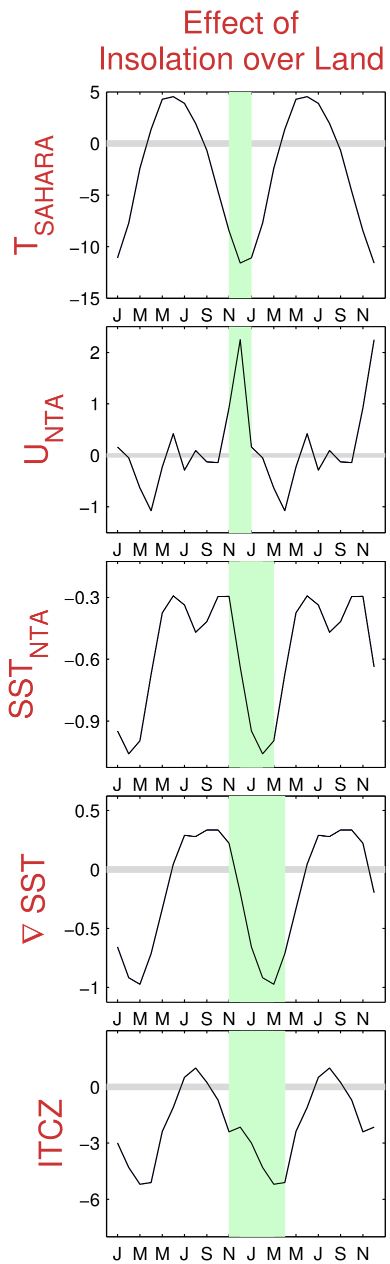

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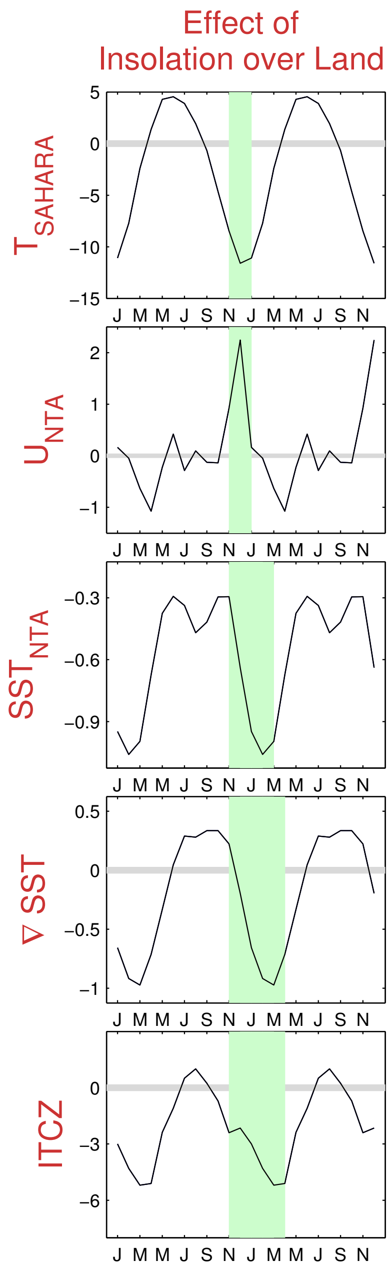

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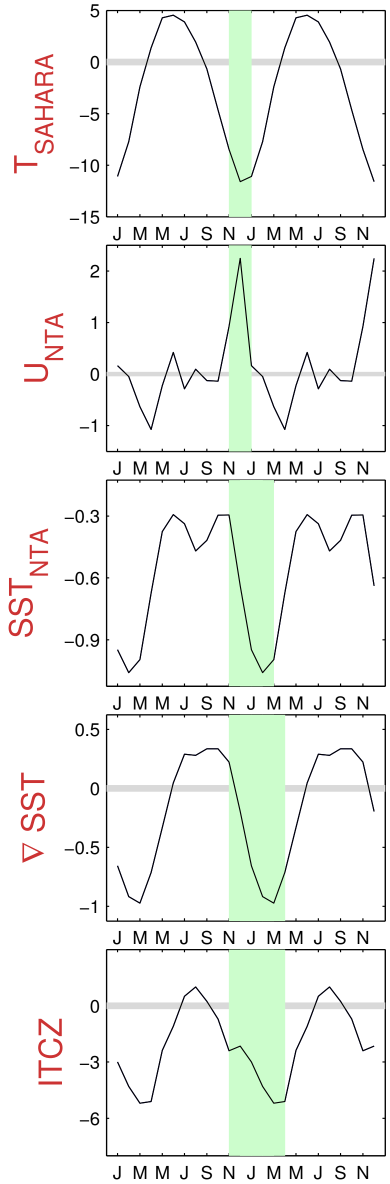
Effect of Insolation over Land



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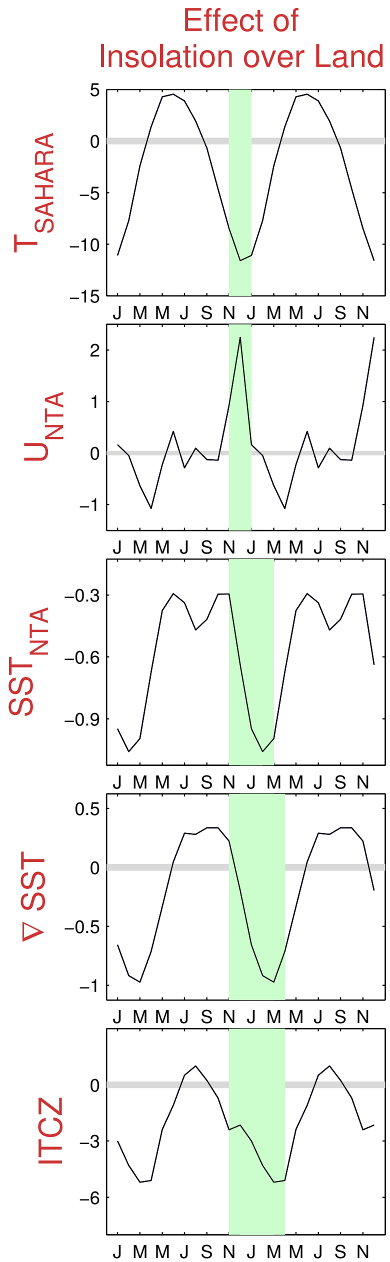

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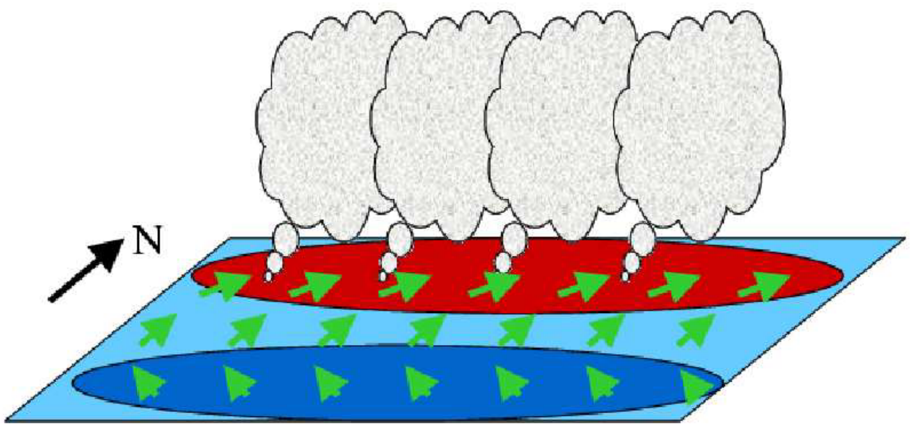
Equatorial Feedbacks

- SST gradient ===> cross-equatorial flow
  <==?



Feedback on SST gradient
- Cld-rad: -ve
- Winds : +ve

(• OHT : -ve?)

John Chiang

CONCLUSIONS:
Mutual Influences of Land and Ocean

Conclusions: **REMOTE** INFLUENCE OF SST ON **LAND**

The AC of SST influences the AC of land precipitation

in coastal areas: SST $\Rightarrow$ ITCZ $\Rightarrow$ Northeast Brazil and Guiana precipitation.

in the Sahel: SST $\Rightarrow$ Sahara T_{sfc} $\Rightarrow$ SLP gradient $\Rightarrow$ Sahel precipitation.

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Conclusions: **REMOTE** INFLUENCE OF LAND ON **OCEAN**

Land climate influences the ITCZ intensity and position.

intensity: Land Q_{cond} $\Rightarrow$ free tropospheric temperature $\Rightarrow$ stability over the ocean $\Rightarrow$ ITCZ intensity.

position: directly and indirectly forced wind $\Rightarrow$ latent heat loss $\Rightarrow$ SST $\Rightarrow$ ITCZ position.

- Sahara T_{sfc} $\Rightarrow$ north tropical Atlantic Trades.
- Land Q_{cond} $\Rightarrow$ equatorial wind.
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Changes in surface wind trigger coupled feedbacks among wind, SST, and ITCZ.

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IMPLICATIONS:
for models, TAV, and paleo

Implications: MODELING THE ANNUAL CYCLE

- CCM3 biases: reduce the overestimate of precipitation over land (by changing albedo?) $\stackrel{?}{\Rightarrow}$ solve the underestimation of precipitation in the ITCZ.
- CGCM biases: correct precipitation over equatorial coastal areas and Sahel $\Leftrightarrow$ correct SST.
- CGCM biases: correct march of Atlantic ITCZ $\Leftrightarrow$ correct AC of temperature in the Sahara and of precipitation in Africa and South America.

Implications: TROPICAL ATLANTIC VARIABILITY & CLIMATE CHANGE

- SST influences land precipitation at the annual timescale in the same way it does at the interannual timescale $\Rightarrow$ the AC is indeed a useful analogue for TAV.
- AC of land influences AC of ocean $\overset{?}{\Rightarrow}$ continental variability influences maritime variability.
- Change in African climate (e.g. due to deforestation) $\overset{?}{\Rightarrow}$ Northeast Brazil (via ITCZ).

Remaining question: How does the response time of the ocean modify the response to continental forcing at the interannual timescale?

Implications: PALEO CLIMATE STUDIES
e.g. the Green Sahara

- Simulation of precipitation at edge of Sahara $\Leftrightarrow$ correct basinwide Atlantic SST boundary conditions
- Simulation of precipitation in Sahara $\Leftrightarrow$ correct simulation of soil albedo (soil moisture and vegetation).
- The greening of the Sahara should be visible in paleo records of the ITCZ position (e.g. from the Cariaco basin). Is it?

Caveat: what's the role of ocean dynamics?