Simulated sensitivity of the tropical climate to extratropical thermal forcing

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Motivation

- Tropics driving extratropics:

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  Well known
  Example: El Niño Southern Oscillation

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  Evidence:

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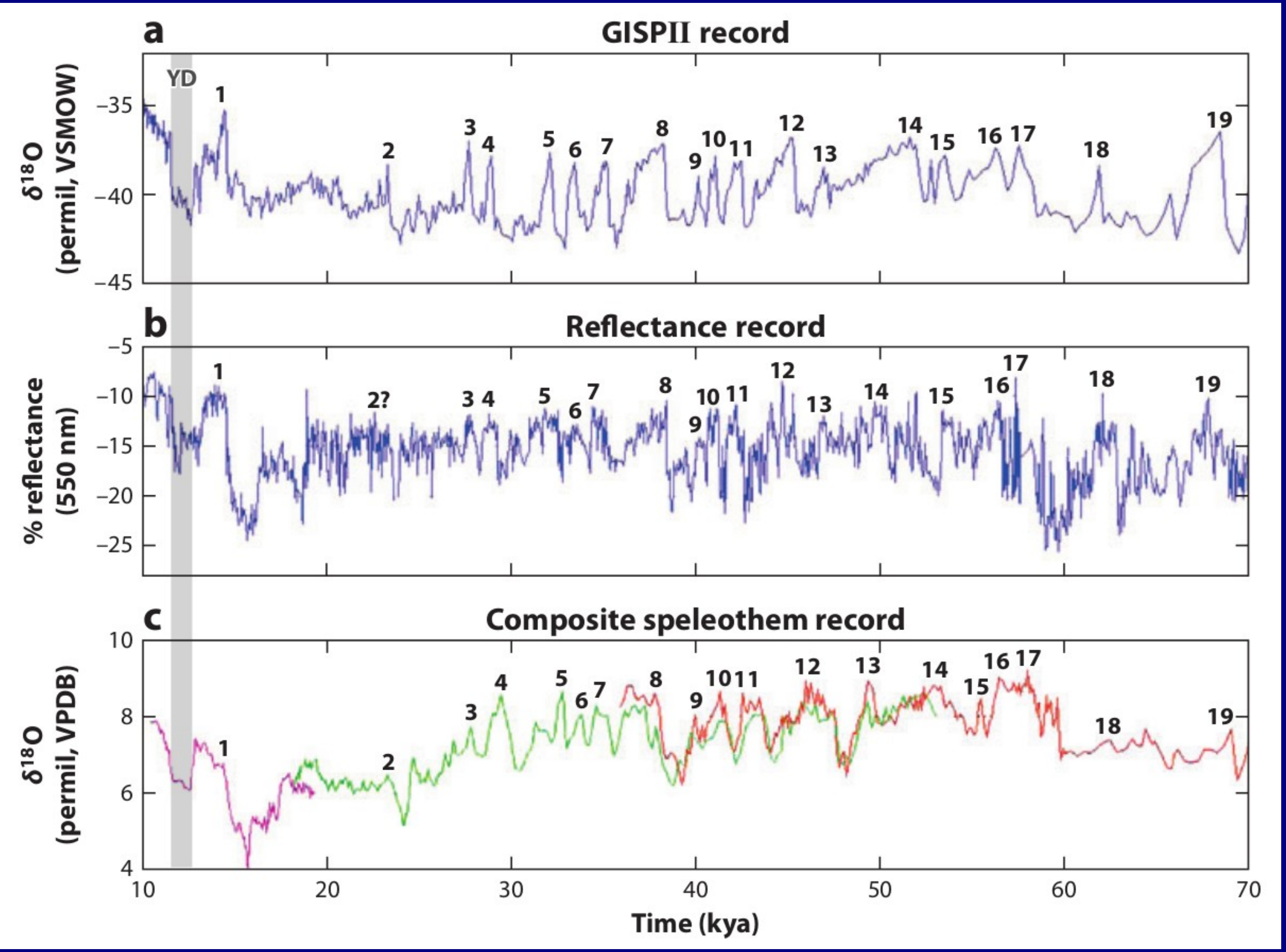
  Not so well understood
  Evidence:
  Paleoclimatic studies

Extra-tropical driving of the tropics: Paleoclimatic evidence

Close relationship between Greenland temperatures and rainfall in tropical Atlantic and China during the last glacial period.



Greenland temperature

Hydrological changes in Cariaco Basin (Venezuela)

Hydrological changes in China

Chiang and Friedman, 2012.

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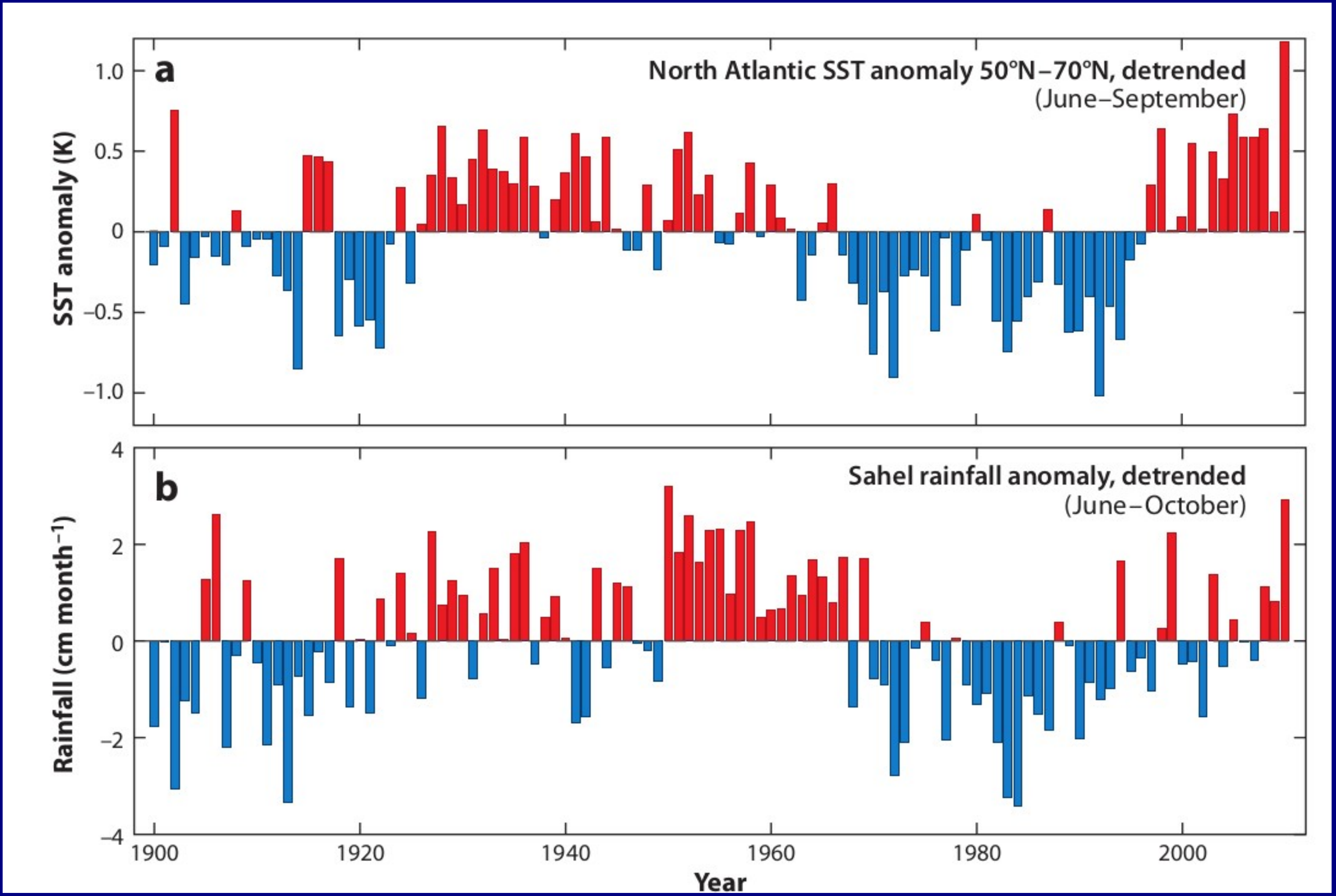
  Not so well understood
  Evidence:
  Paleoclimatic studies
  20th century observations

Extra-tropical driving of the tropics: 20th century observations

Influence of the high-latitude North Atlantic on Sahel rainfall: Decadal variability



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Motivation

- Tropics driving extratropics:

  Well known
  Example: El Niño Southern Oscillation

- Extratropics driving tropics:

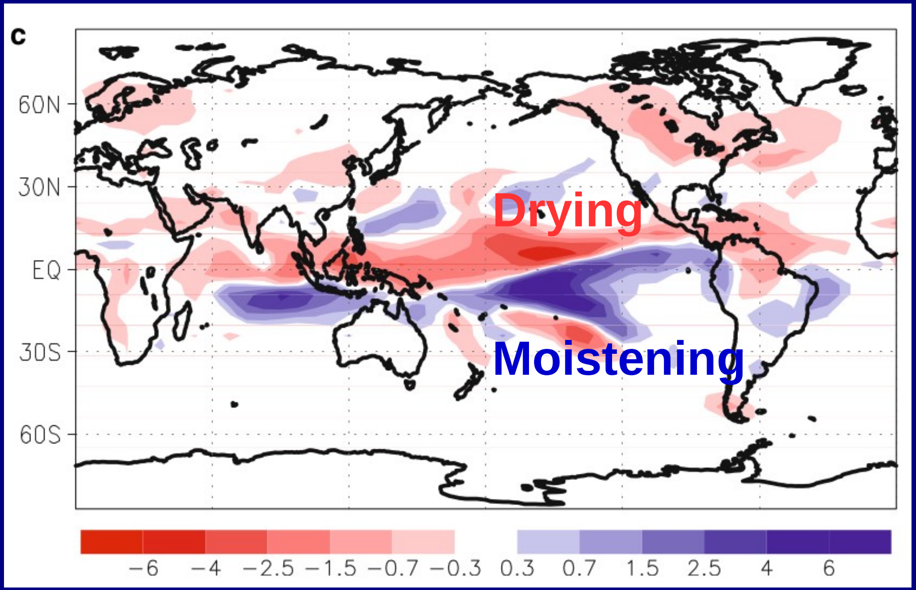
  Not so well understood
  Evidence:
  - Paleoclimatic studies
  - 20th century observations
  - Numerical Simulations

Extra-tropical driving of the tropics: Numerical Simulations

Increase in NH high-latitude ice →

Southward displacement of Intertropical convergence zone (ITCZ)

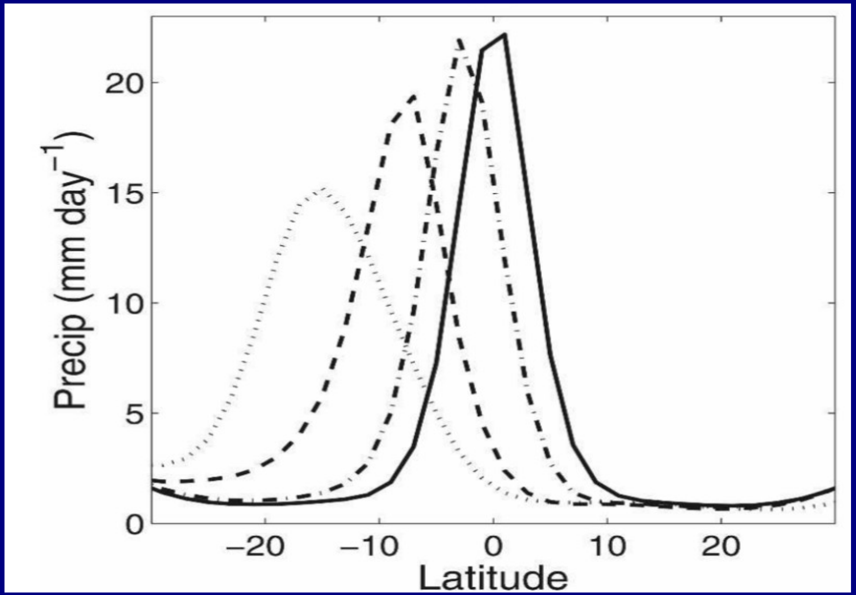
Precipitation anomalies



Chiang and Bitz, 2005.

Aquaplanet simulations,
AGCM + slab ocean

Imposed inter-hemispheric gradient → ITCZ shifts towards the wamer Hemisphere



Kang et al, 2008.

Objective

Investigate the ITCZ response to extratropical thermal forcing, using realistic boundary surface conditions.

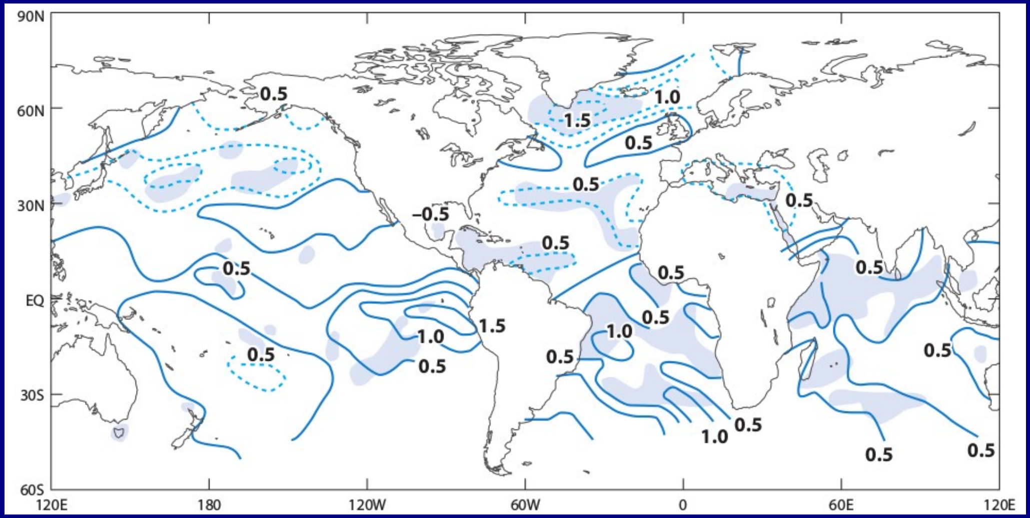
Determine the relative roles of the atmosphere, sea surface temperatures (SST) and land surface temperatures (LST).

Methodology

- Simulations:
  - AGCM (ICTP-SPEEDY) coupled to ocean and land slab models (just thermodynamic coupling).
  - Surface Boundary Conditions: Realistic
  - 40 years simulations
  - Different configurations:
    - Changing the region of application of the slab models

Extratropical forcing

Global boreal summer SST pattern associated with Sahel drought (starting in the late 1960s)



Inter-Hemispheric SST gradient

Folland et al., 1986.

Extratropical forcing

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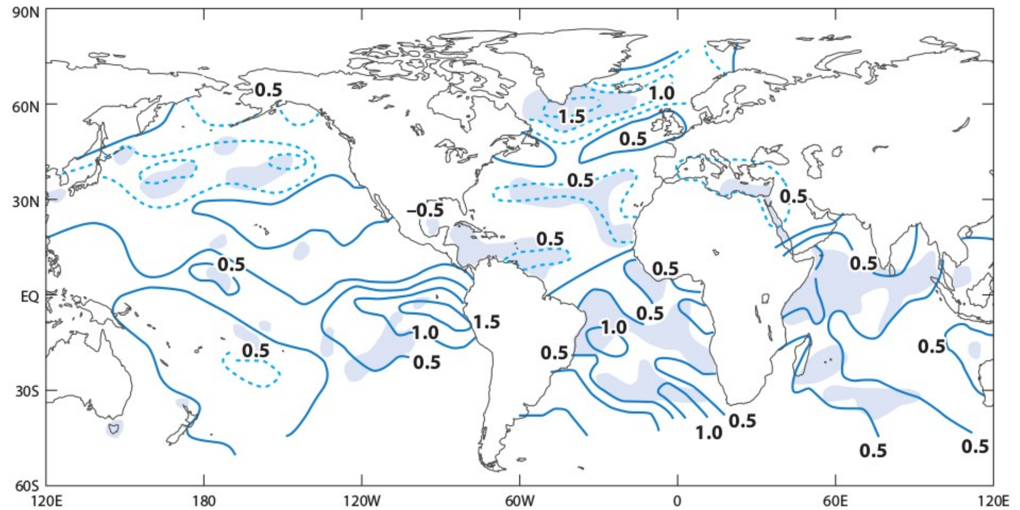
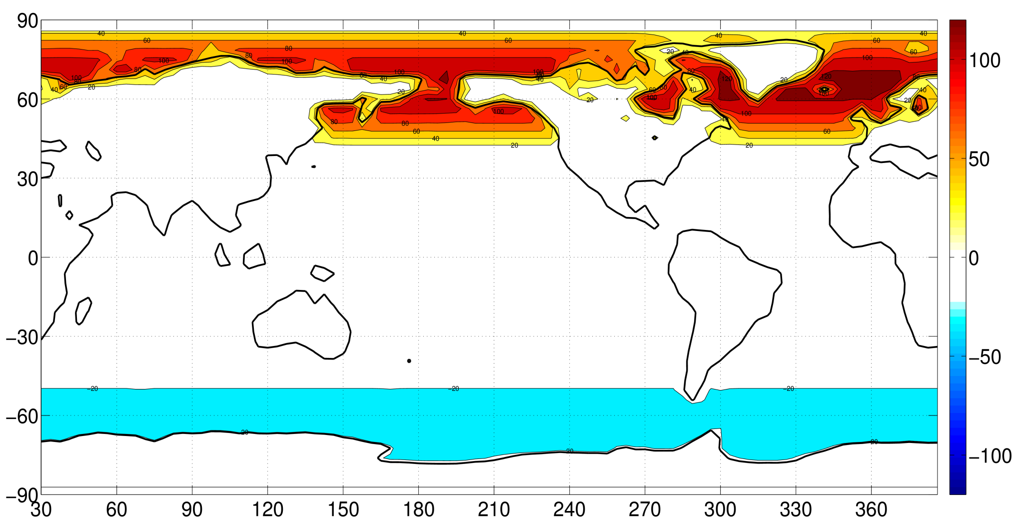




Forcing pattern: Heat Flux out of sea (W/m^2).

Inter-Hemispheric SST gradient

Folland et al., 1986.

Warming in NH / Cooling in SH

Poleward of 40º

Global mean: zero

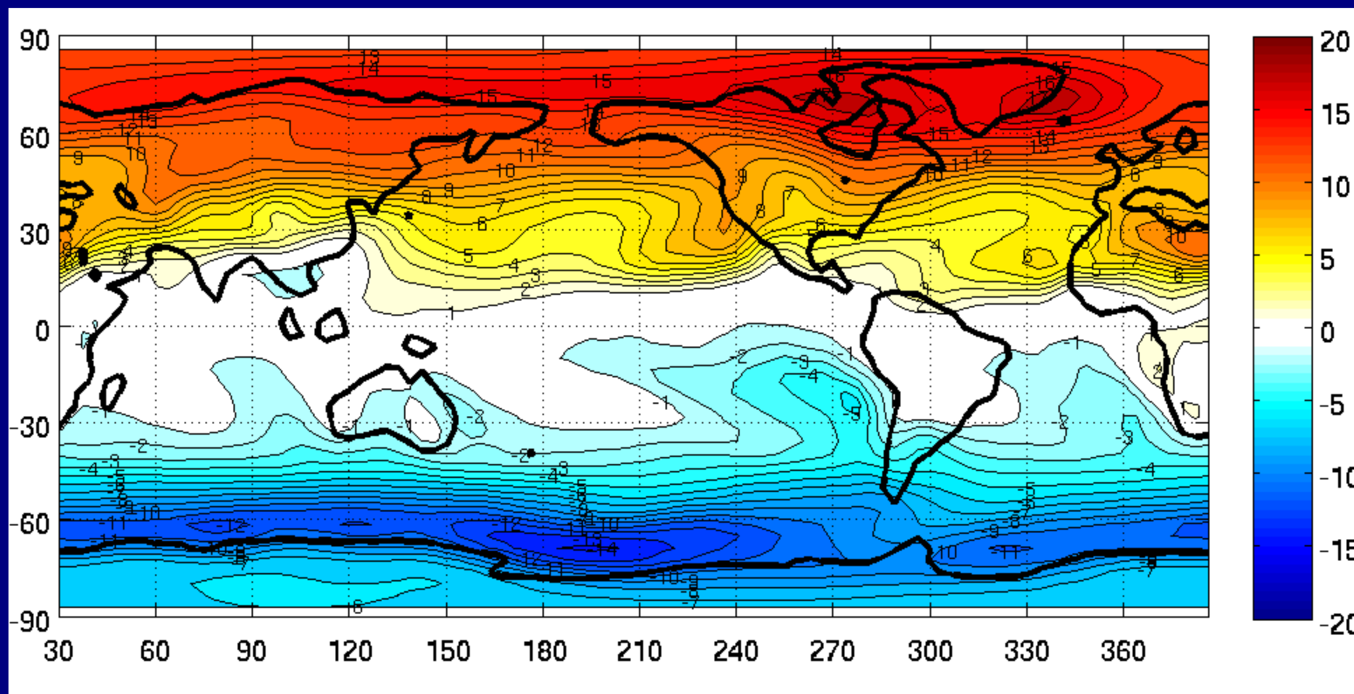
Results

Experiment with global slab models

Near-surface Air Temperature

Annual Mean

Anomalies with respect to Control

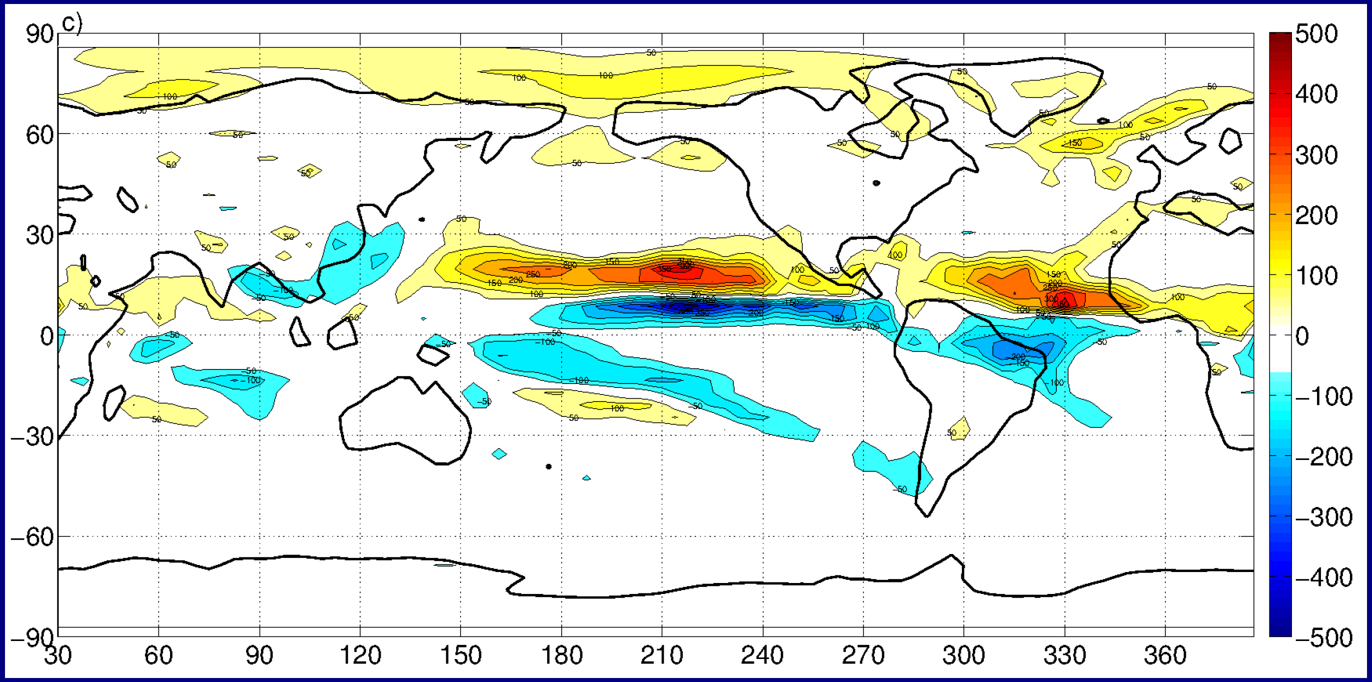


Interval: 1ºC

Warming in NH
Cooling in SH

Precipitation
Annual Mean

Anomalies with respect to Control



Interval: 50 mm/month.

ITCZ shifts towards the warmer Hemisphere

Are these ITCZ shifts possible without changes in the tropical SST?

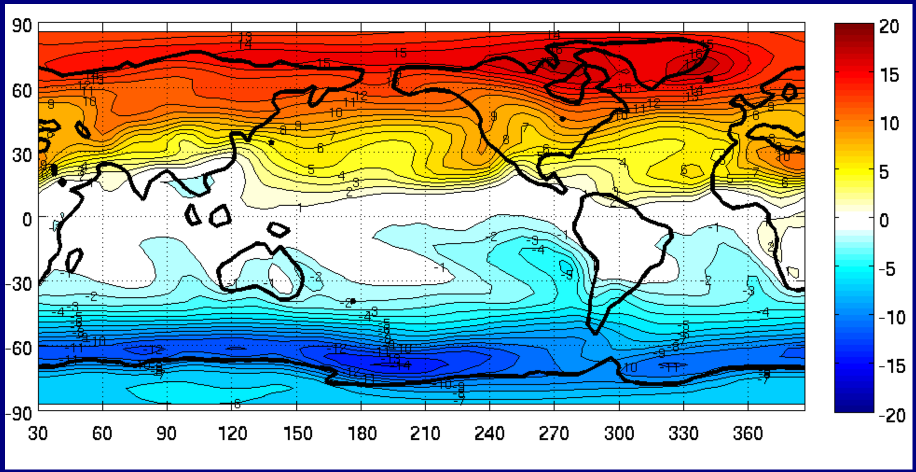
We repeat the experiments keeping the tropical (30ºS-30ºN) SST fixed

Results

Experiment with fixed tropical SST,
Global land slab model

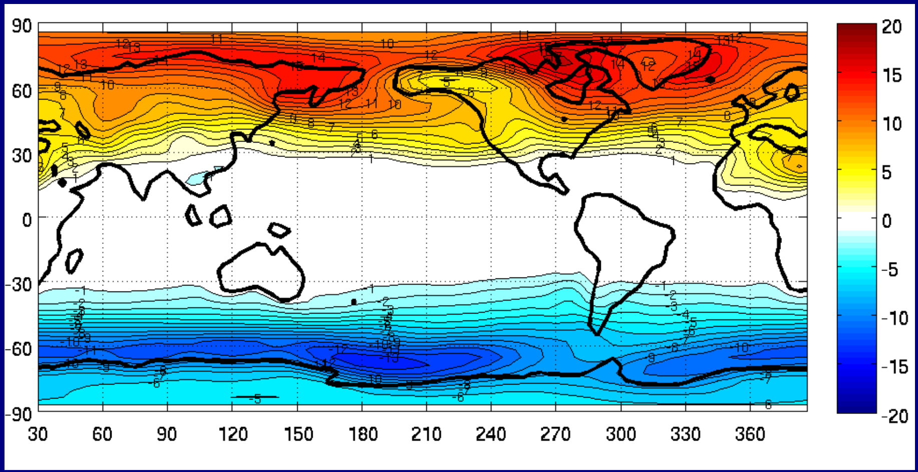
Near-surface Air Temperature
Annual Mean

Global slabs
Anomalies with respect to Control



Interval: 1°C.

Fixed tropical SST
Anomalies with respect to Control

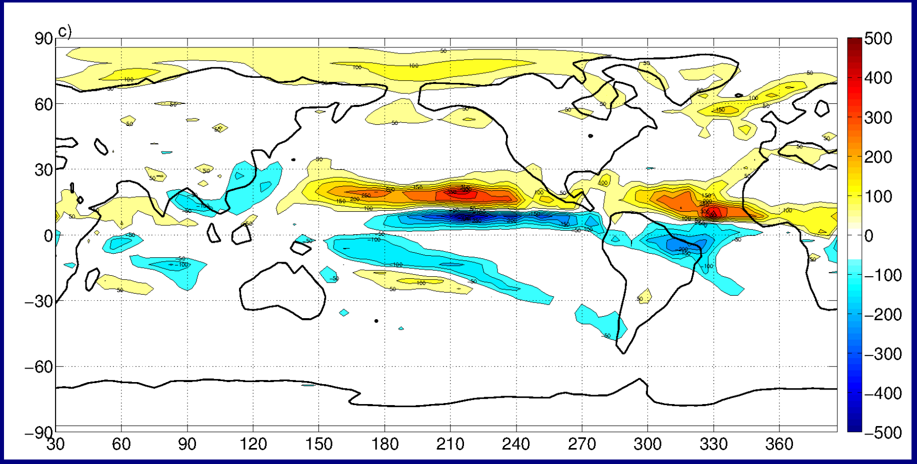


Interval: 1°C.

Ocean: No anomalies in the tropics
Land: Response in tropical Africa

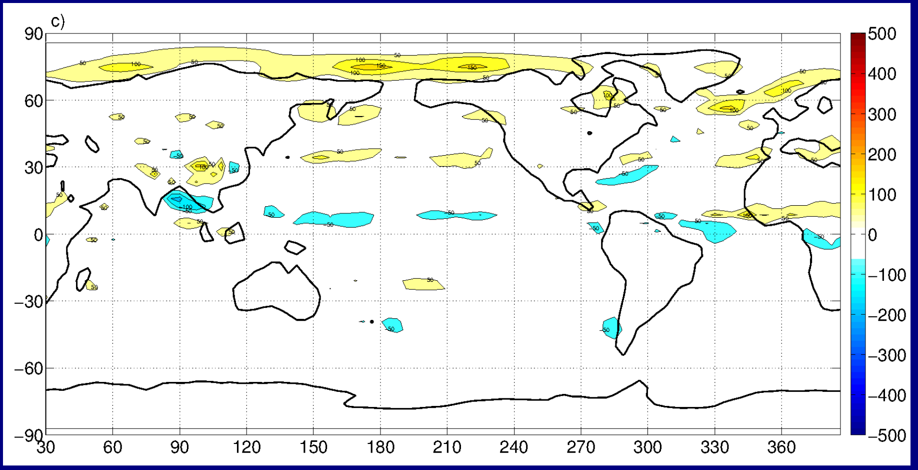
Precipitation
Annual Mean

Global slabs
Anomalies with respect to Control



Interval: 50 mm/month.

Fixed tropical SST
Anomalies with respect to Control



Interval: 50 mm/month.

Tropical response
Africa: 60% of magnitude
Atlantic: 20% of magnitude
(with respect to the previous experiment)

Are these ITCZ shifts possible without changes in the tropical SST nor in the LST over Africa?

We repeat the experiments now with

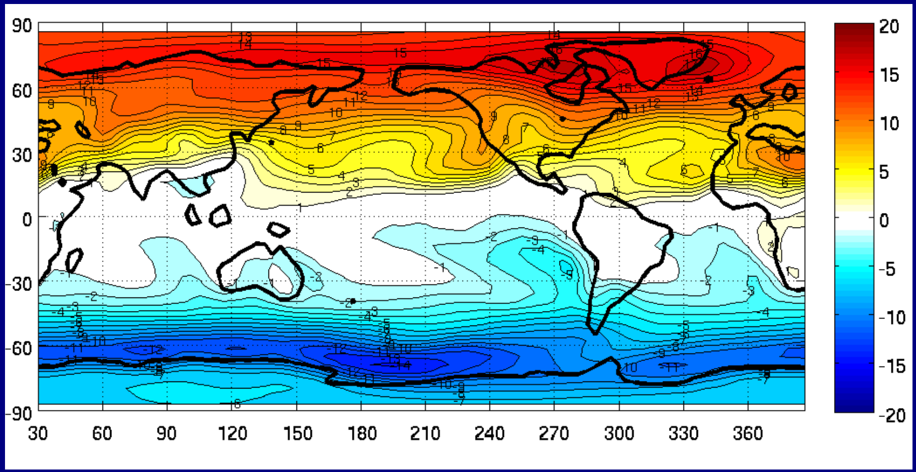
Fixed tropical SST
+
Fixed LST over Africa

Results

Experiment with fixed tropical SST, fixed LST over Africa

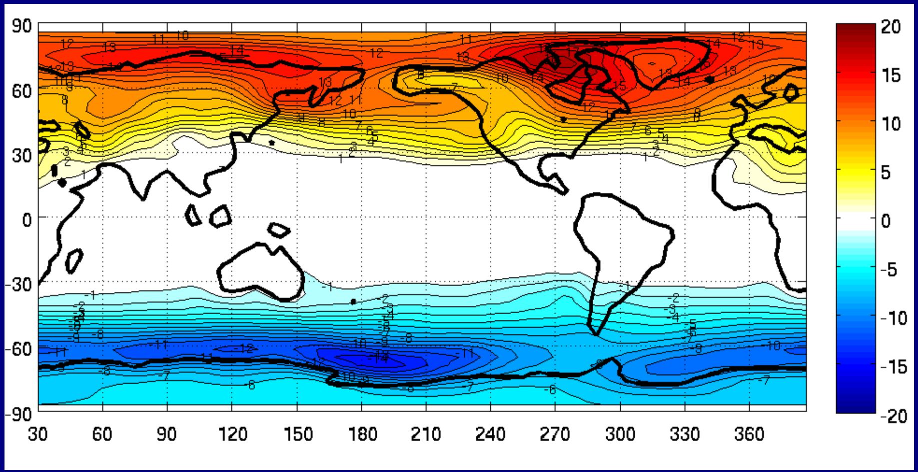
Near-surface Air Temperature
Annual Mean

Global slabs
Anomalies with respect to Control



Interval: 1°C.

Fixed tropical SST, fixed LST over Africa
Anomalies with respect to Control

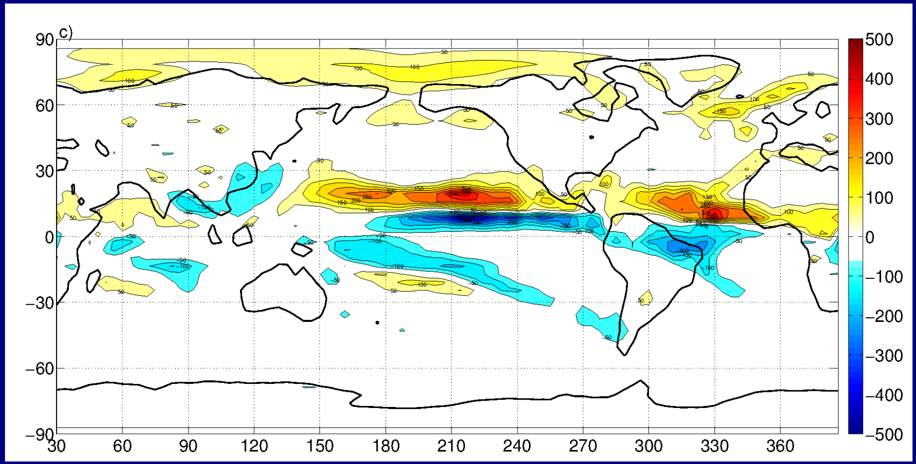


Interval: 1°C.

Over Africa: weaker anomalies

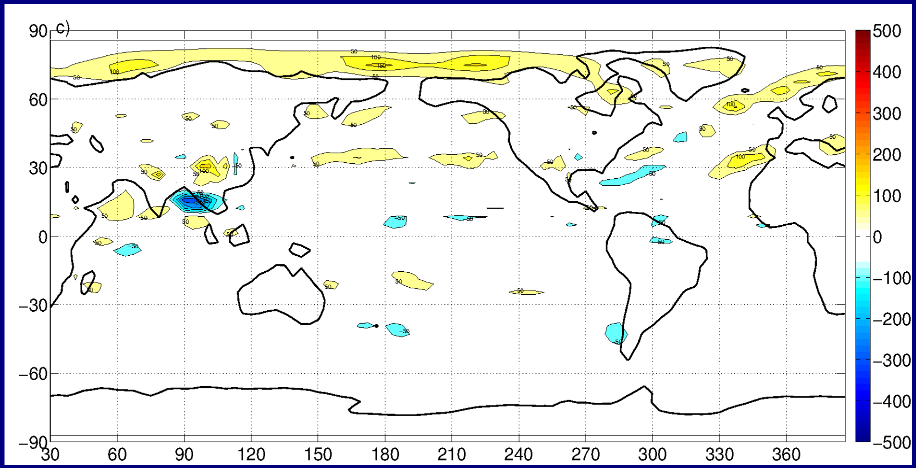
Precipitation
Annual Mean

Global slabs
Anomalies with respect to Control



Interval: 50 mm/month.

Fixed tropical SST, fixed LST over Africa
Anomalies with respect to Control



Interval: 50 mm/month.

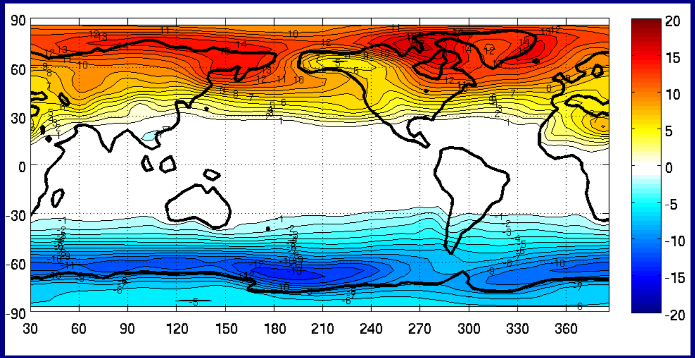
No shift of the ITCZ

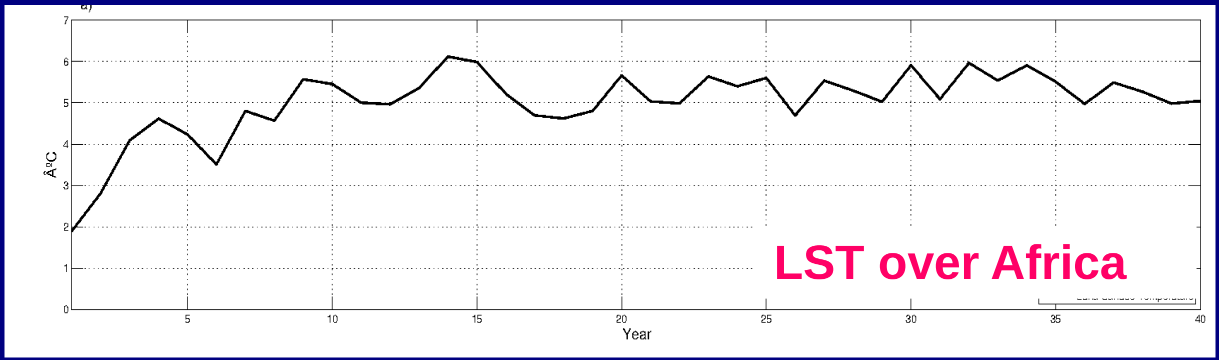
LST over Africa is essential to mantain a shift in the ITCZ when the tropical SST is not allowed to change

How is the teleconnection between high latitudes and Africa generated?

Experiment with fixed tropical SST

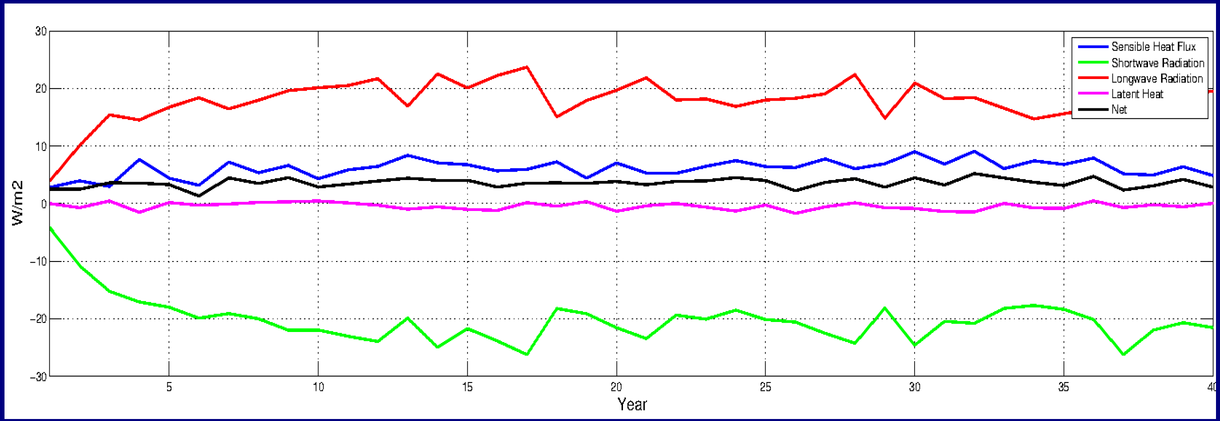
Annual Mean





Energy balance:

Long-wave radiation effect dominates



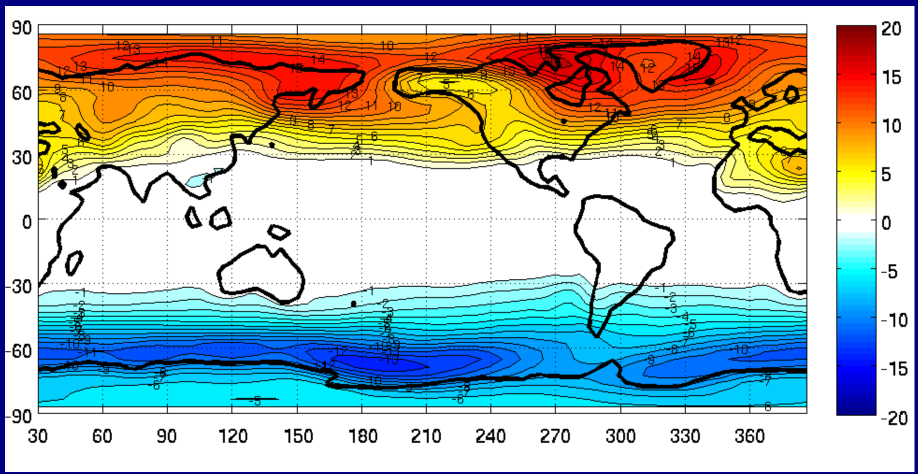
Long-wave: Clear-sky effect+ clouds effect

Small changes in clouds →
Hypothesis: Clear-sky effect is the dominant

Experiment: Fixed tropical SST + clear-sky long-wave effect turned off

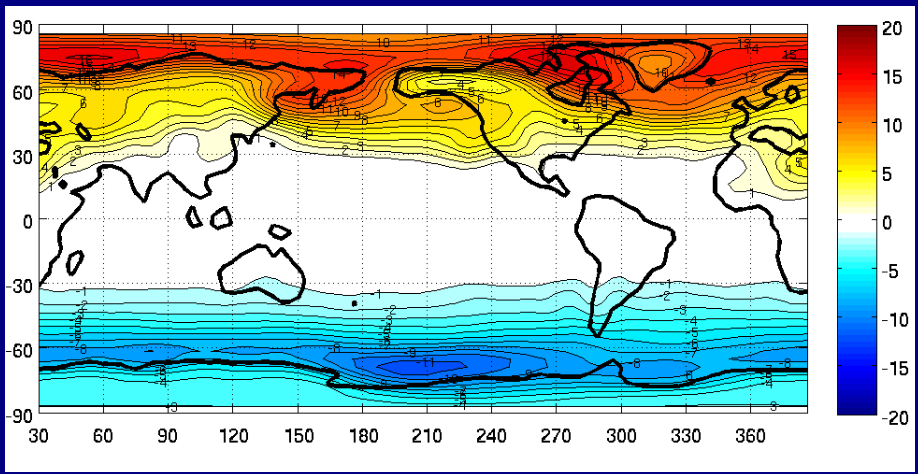
Near-surface Air Temperature
Annual Mean

Fixed tropical SST
Anomalies with respect to Control



Interval: 1°C.

Fixed tropical SST, clear-sky long-wave effect turned off
Anomalies with respect to Control



Intervalo: 1°C.

The warming over Africa is noticeably reduced

Teleconnection: High Latitudes – LST Africa

Physical mechanism:

- The forcing is imposed
- Warming in high latitudes of NH
- Specific humidity increases there
- Changes in atmospheric circulation advect humidity to Africa
- Clear-sky long-wave effect increases
- Warming of tropical Africa

What happens if we use a more complex ocean model in the tropics?
Does the ITCZ still shift?

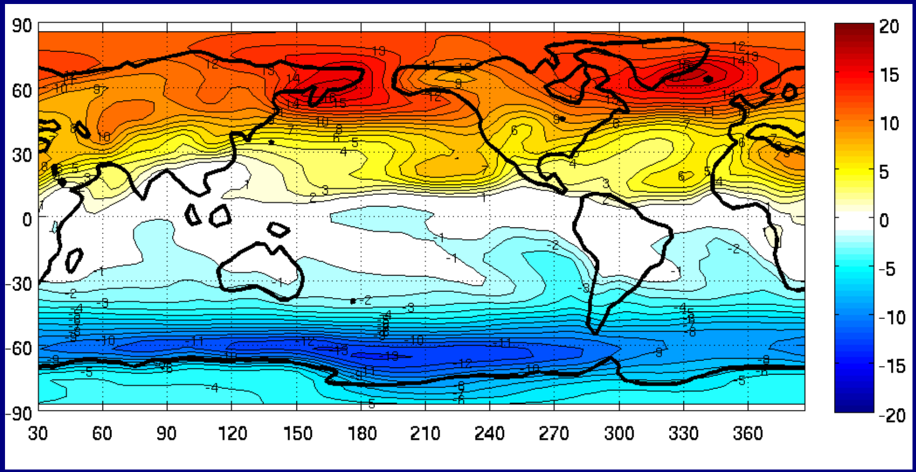
We repeat the original experiment including ocean dynamics in the tropics.

Results

Experiment with Reduced Gravity Ocean (RGO, Cane-Zebiak) model in the tropics

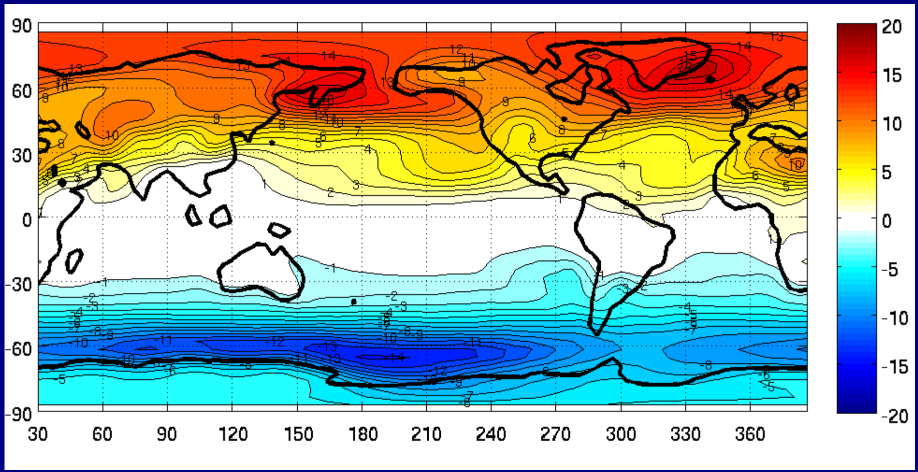
Near-surface Air Temperature
Annual Mean

Global slabs
Anomalies with respect to Control



Interval: 1°C.

+RGO in tropical oceans
Anomalies with respect to Control

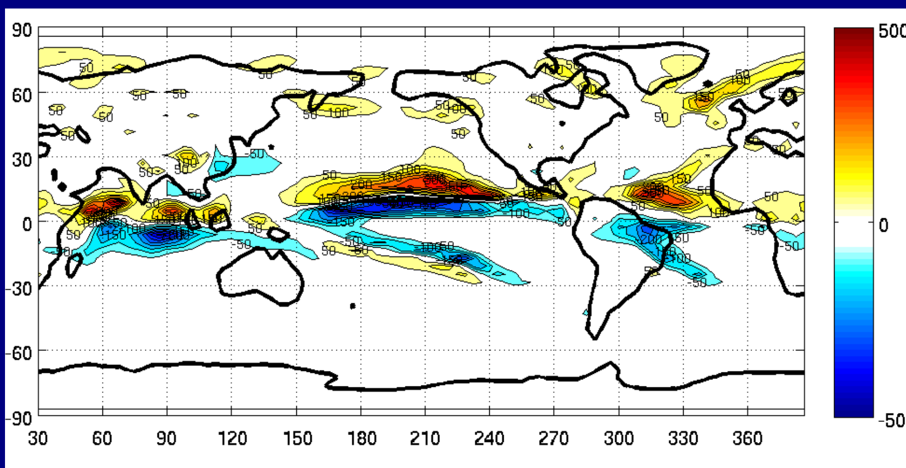


Interval: 1°C.

Extratropics: no changes
Tropics: Weaker signal over the Pacific Ocean

Near-surface Air Temperature
Annual Mean

Global slabs
Anomalies with respect to Control



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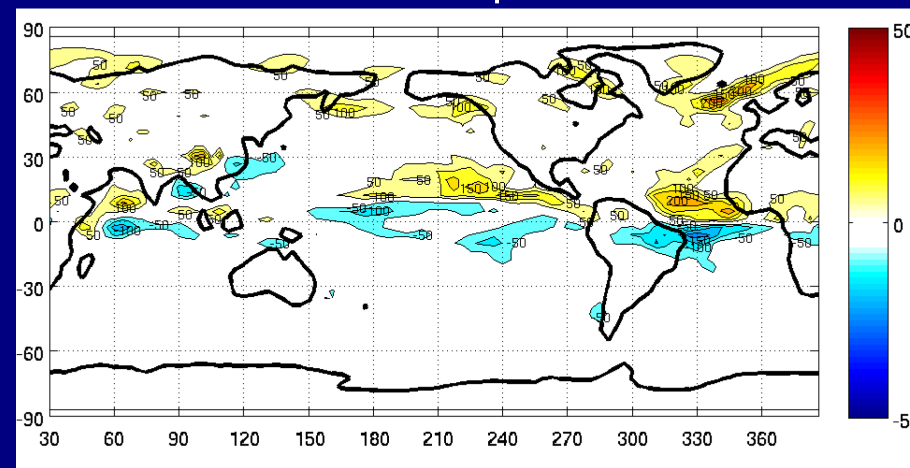

Interval: 1°C.

Weaker signal over the oceans
Similar signal over land and Atlantic Ocean

Conclusions

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- Medium-complexity ocean model:
    - Tropical ocean dynamics weakens the response over the Pacific
    - Africa/Atlantic: similar signal, indicating importance of LST.

Thanks.

Talento and Barreiro, Climate Dynamics, 2015, doi: 10.1007/s00382-015-2890-9