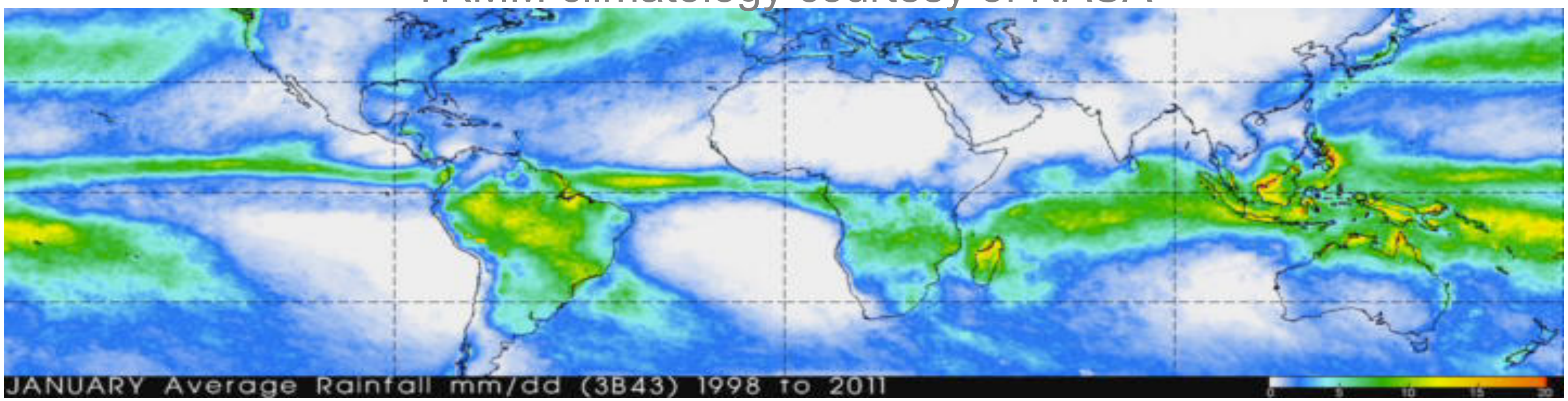
Future Changes in the Annual Cycle of Monsoons and the ITCZ

TRMM climatology courtesy of NASA

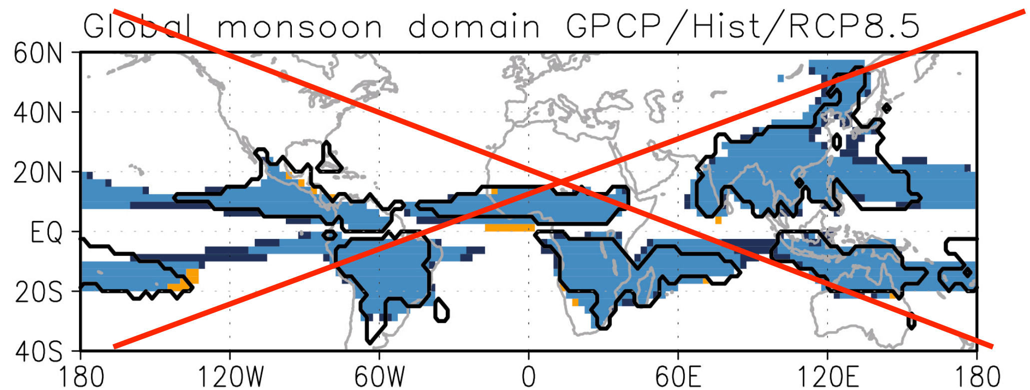


Michela Biasutti, **John Dwyer** (MIT), and Adam Sobel

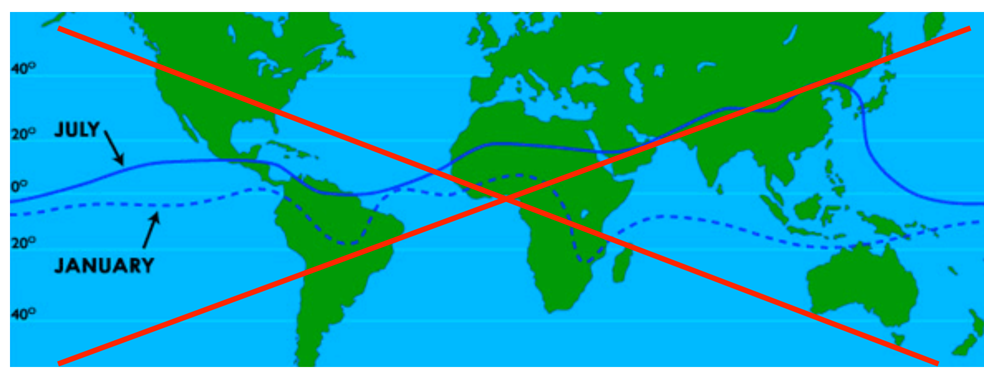
Lamont-Doherty Earth Observatory. The Earth Institute at Columbia University

(my) Nomenclature.

Monsoons are on land.



The *ITCZ* is the zonal-mean near-equatorial maximum of precipitation, or the oceanic rainfall that projects strongly on it.



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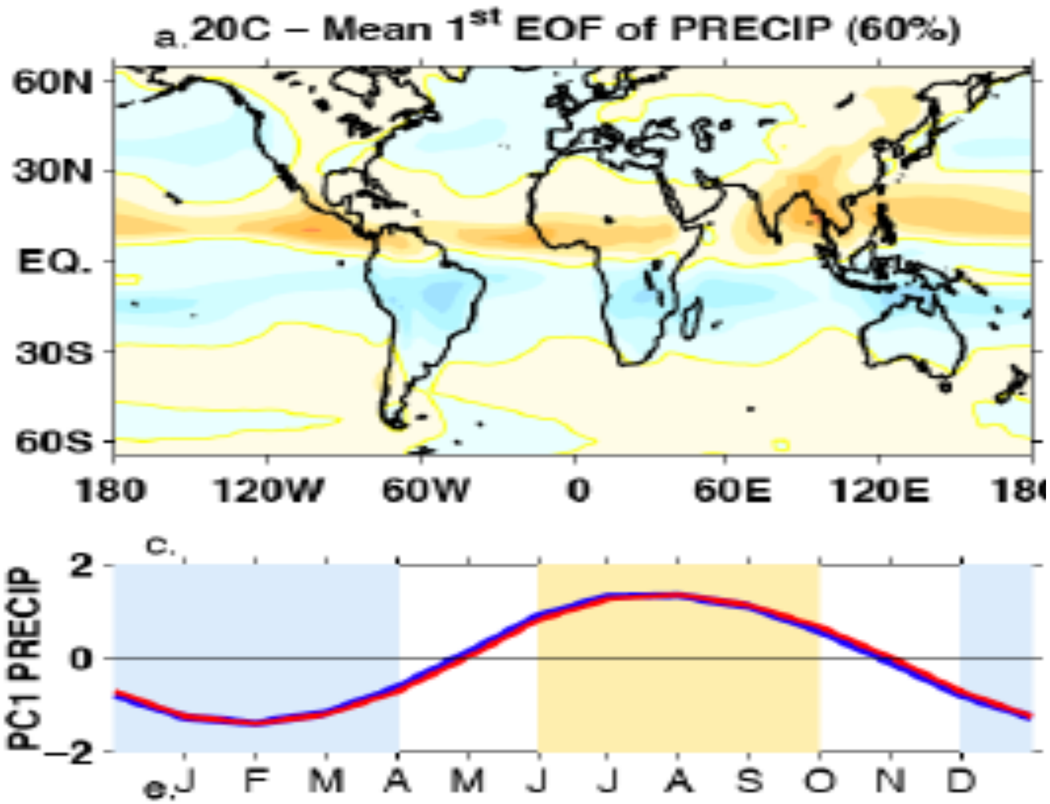
A regional measure of the annual cycle : The 1st EOF / PC pair.



✓ It selects locations where the annual cycle is dominant.

✓ It selects a near perfect sine wave.

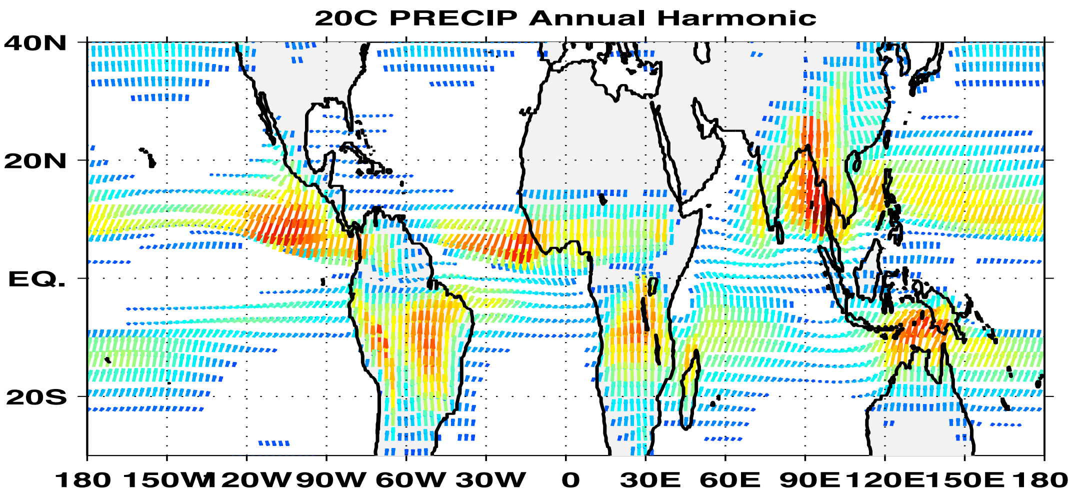
✗ It is sensitive to the choice of domain.

✗ It lumps together places that might behave differently in a different climate regime.

A local measure of the annual cycle : The local annual harmonic.

$$P = P_0 + P_1 e^{-i(\omega t+\varphi)} + \ldots\ldots\ldots\ldots$$

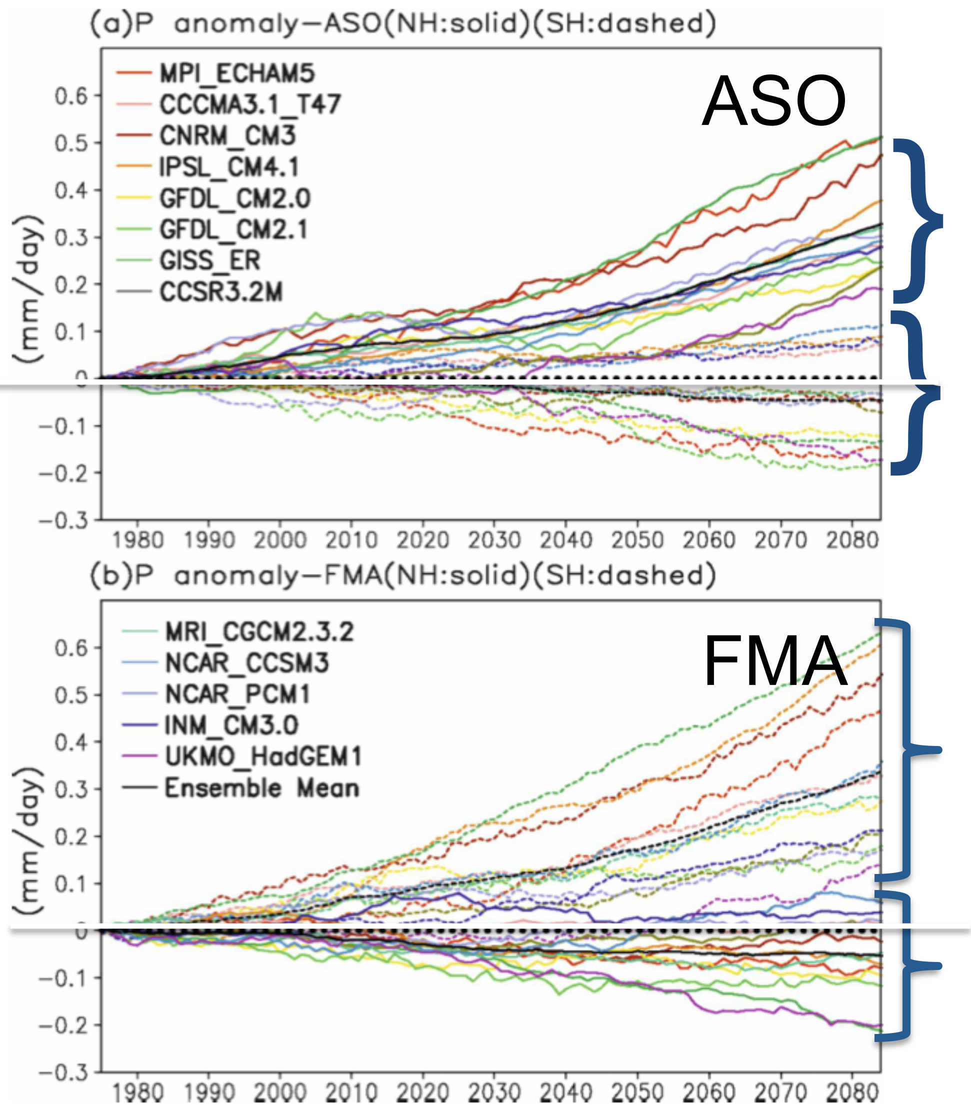
mean — annual harmonic — higher freq. harmonics



- ✗ It might explain a small fraction of the climatology.
- ✗ It can be noisy.
- ✓ It allows a less ambiguous interpretation of local changes.
- ✓ It can capture local changes that are not part of a global pattern.

The projected changes of the annual cycle : Amplification and Delay.

Amplification: precipitation increases in summer and decreases in winter.



Summer increases are large.
Winter decreases are modest.

Tan et al. (2008)

Amplification: *precipitation increases in summer and decreases in winter.*

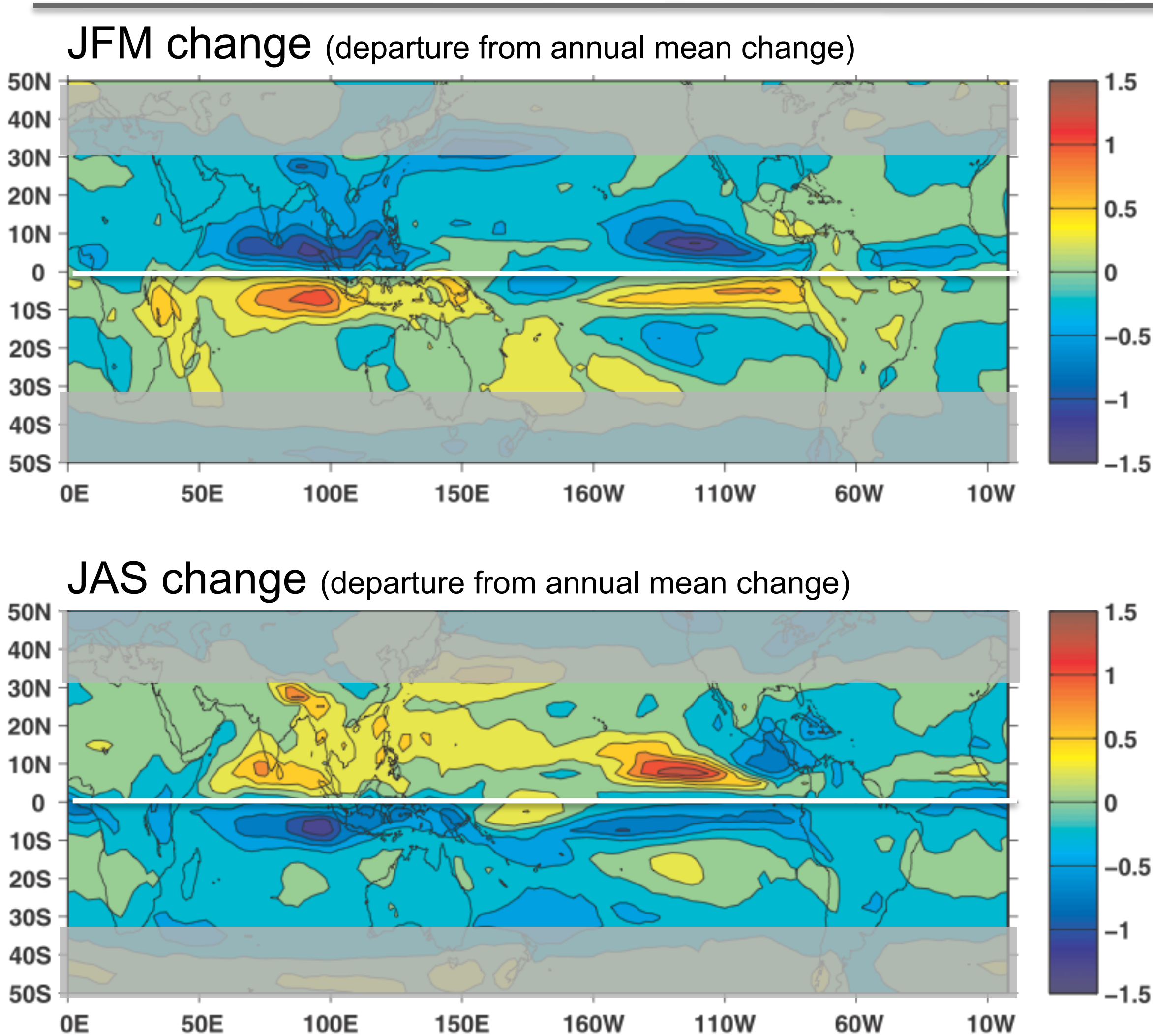


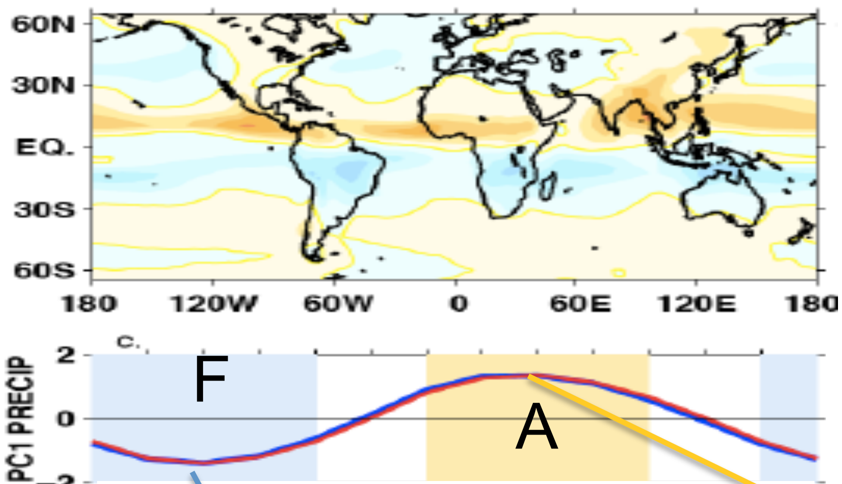
FIG. 9. Precipitation seasonal changes in (a) JFM [δPrec(JFM)] and (b) JAS [δPrec(JAS)] (contour interval = 0.25 mm day^{-1}).

The increase in seasonal range is especially clear over the ocean and the Asian monsoon regions.

Sobel and Camargo (2011)

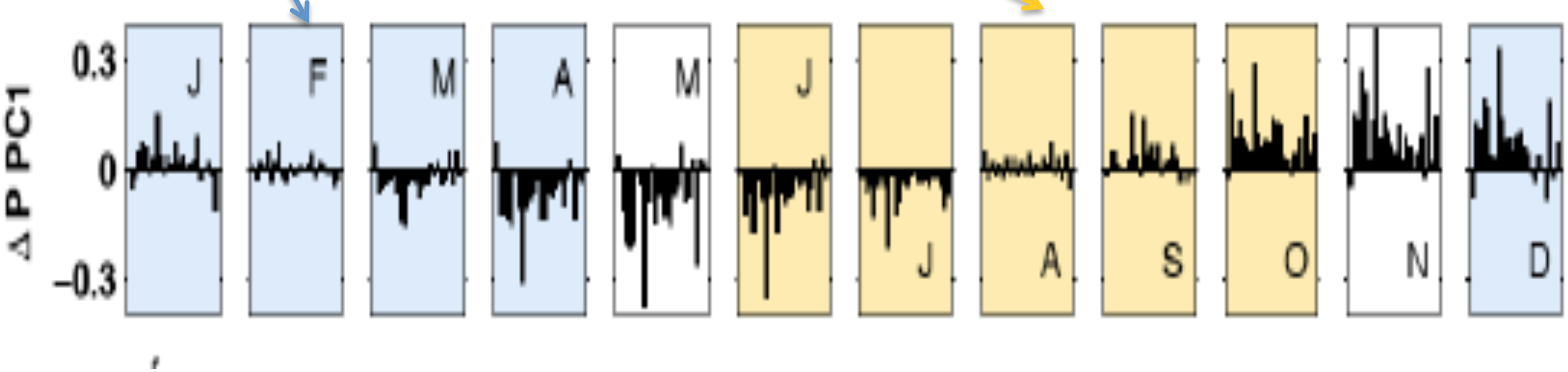
A *delay* of tropical precipitation

The annual mode of precipitation



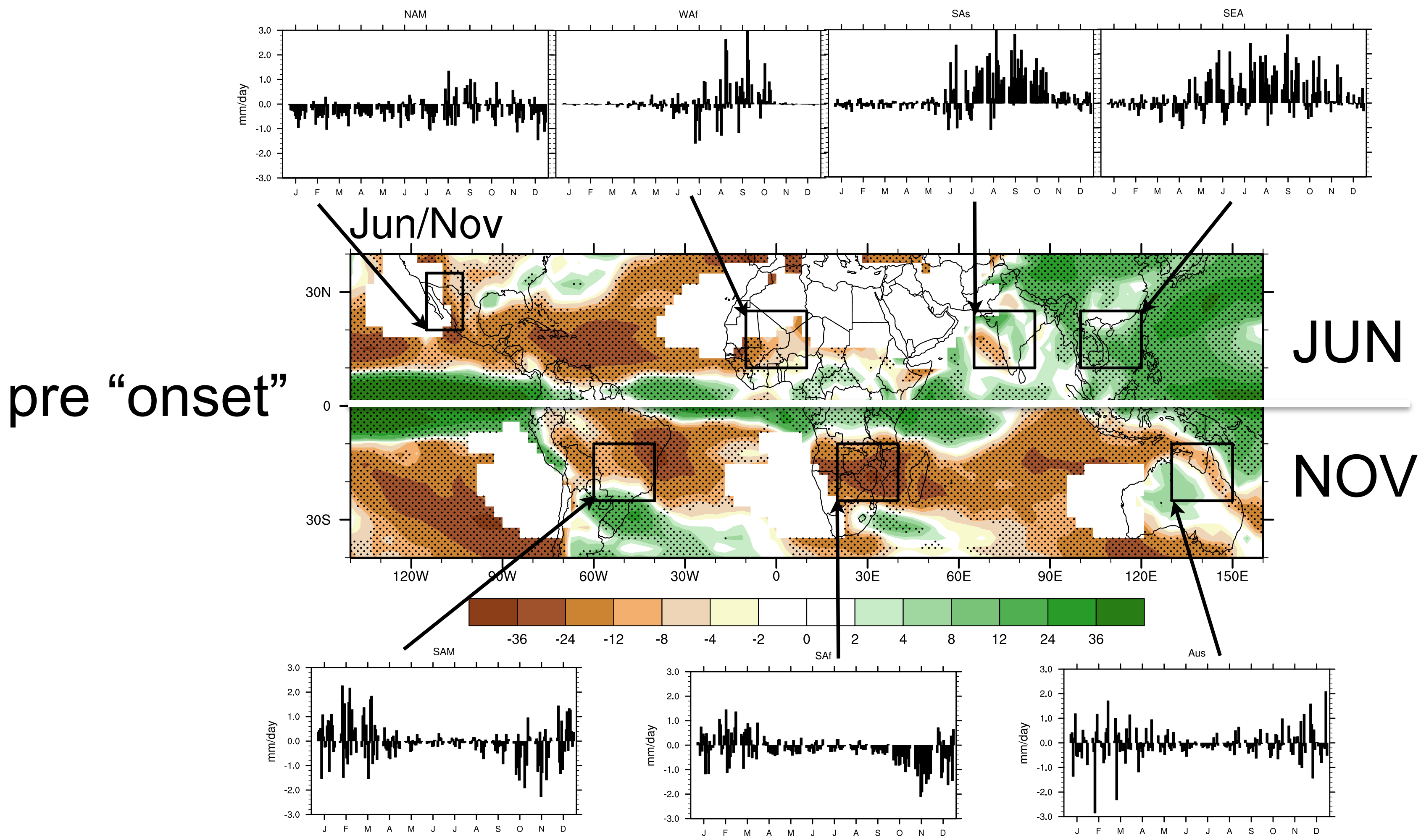
21C-20C anomalies are in quadrature: a delay! (~5days)

Change in the seasonal evolution



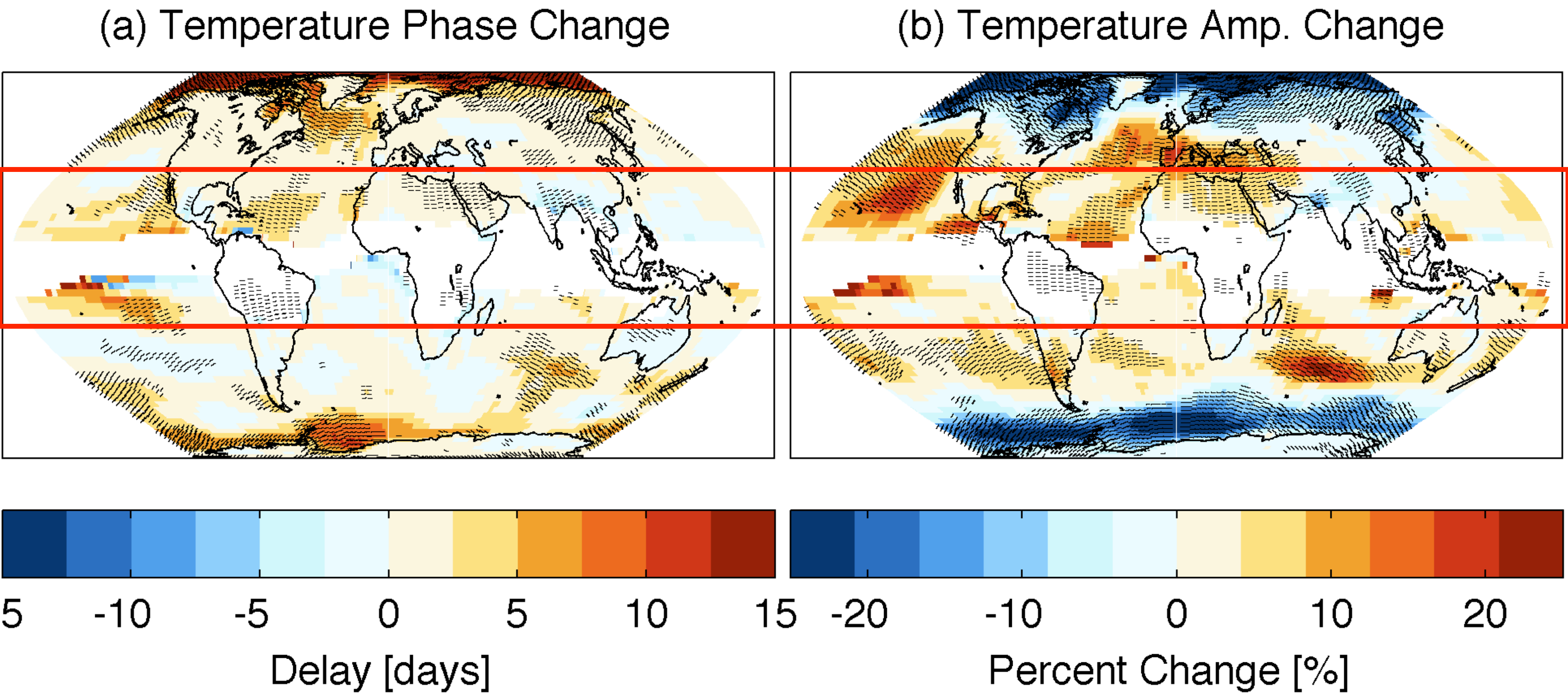
Biasutti and Sobel (2009)

Extended dry season in most monsoon regions (less robust than global pattern)



Seth et al. (2013)

There are amplification and delay in the annual cycle of tropical SST as well



Dwyer et al. 2012.

Mechanisms relevant for the (zonal mean) ITCZ:

ITCZ:

An AGCM forced by RCP8.5 SST produces amplification and delay in the zonal mean ITCZ

We decompose the SST changes in mean+annual cycle.

To get to the cause of precipitation changes we impose each component separately:

CMIP5 RCP8.5 SST changes ≅ Uniform warming + Seasonal SST changes

(idealize)

ITCZ:
lessons from the moisture budget

$$P = E + \left\langle -\vec{u} \cdot \vec{\nabla} q \right\rangle + \left\langle -\omega \frac{\partial q}{\partial p} \right\rangle - \left\langle \frac{\partial q}{\partial t} \right\rangle$$

precipitation

evaporation

horizontal moisture convergence

vertical moisture convergence

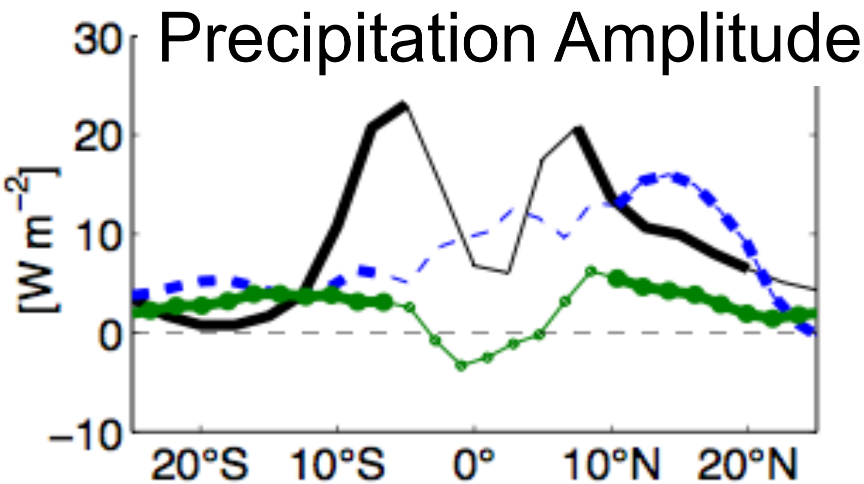
tendency

Write all terms as $P = P_0 + P_1 e^{-i(\omega t+\varphi)} + \ldots$ etc,
take the 21C-20C difference, linearize, rearrange…

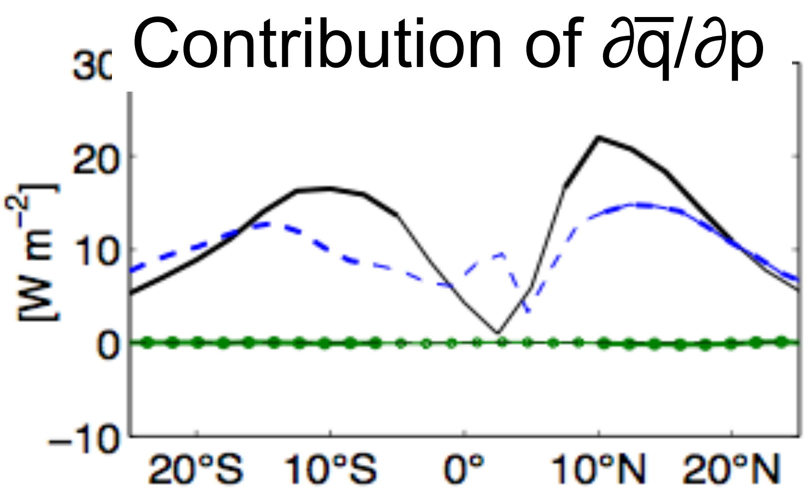
The dominant term is vertical moisture advection: $\left\langle -\omega \frac{\partial q}{\partial p} \right\rangle$

Write all terms as $\boldsymbol{\omega} = \boldsymbol{\omega_0} + \boldsymbol{\omega_1} e^{-i(\omega t+\varphi)} + \ldots$ etc

Amplitude changes are the seasonal expression of "*x-get-xer*"



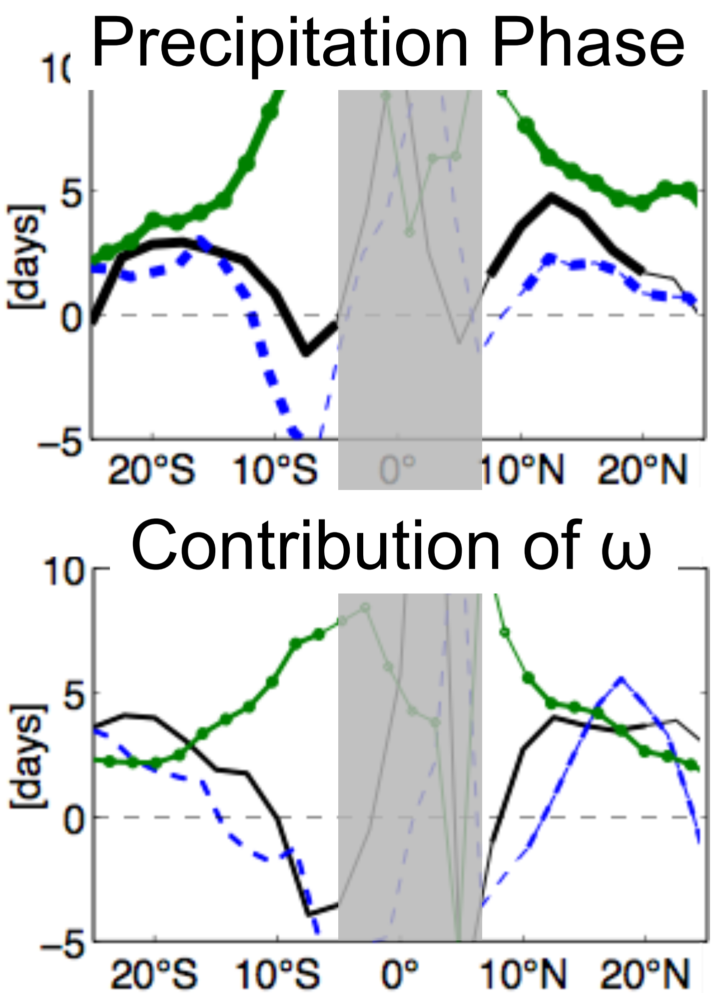
← Precipitation amplitude increases in all simulations



← But the mechanism is different: only in RCP8.5 and UW, the amplitude increases due to a rise in annual mean humidity

CMIP5 changes | Uniform warming | Seasonal SST changes

Phase changes come from circulation changes – but are still unexplained



← Precipitation phase delays in all simulations

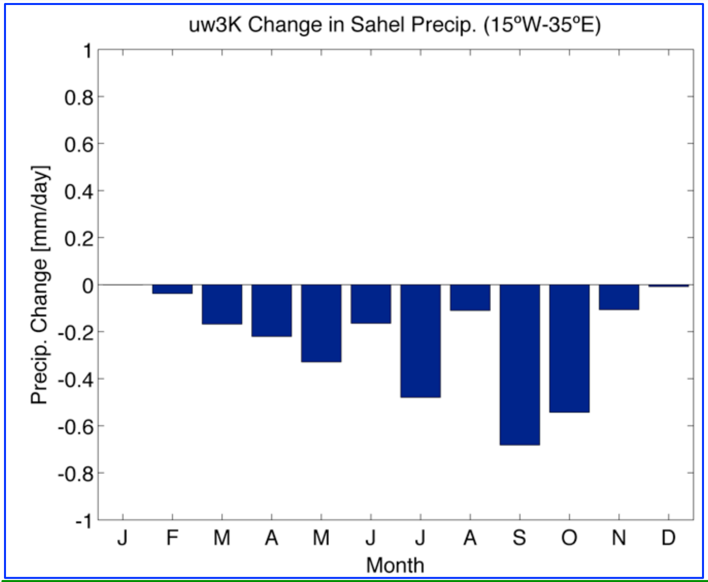
← Mechanism is the same: phase delay in ω

? The mismatch in the seasonal SST run might stem from the large uniform delay of SST (bad match for CMIP5)

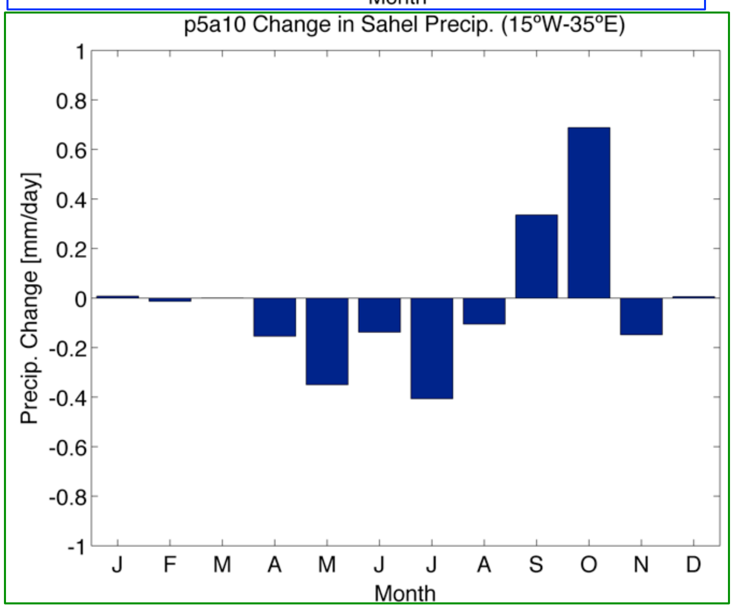
? What is the origin in the +3K run?

CMIP5 changes | Uniform warming | Seasonal SST changes

Do the same mechanisms explain rainfall anomalies in the monsoon regions? No



← Example: the uniform warming dries the Sahel



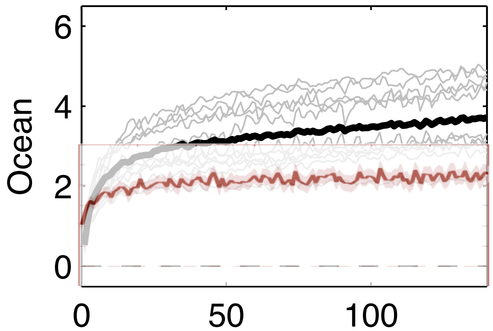
← the seasonal changes in SST induce a delay, similar to the RCP8.5.

Difference between ITCZ and all monsoons is apparent in idealized CMIP5 simulations (Abrupt 4xCO_2)

Abrupt 4xCO_2

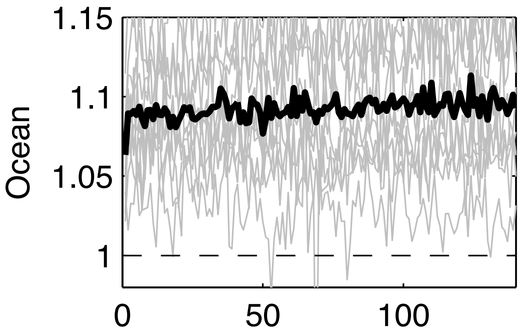
The SST evolution after abrupt quadrupling of CO_2 reveals different timescales:

SST



annual mean is slow

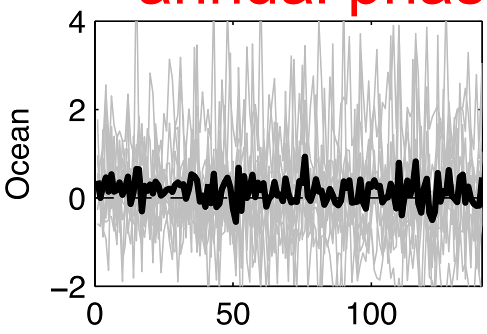
Land-Sea ~~Temperature~~ contrast is intermediate



~10%

amplitude is abrupt

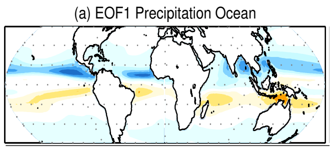
annual phase

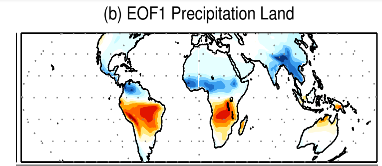


< 0.5 days

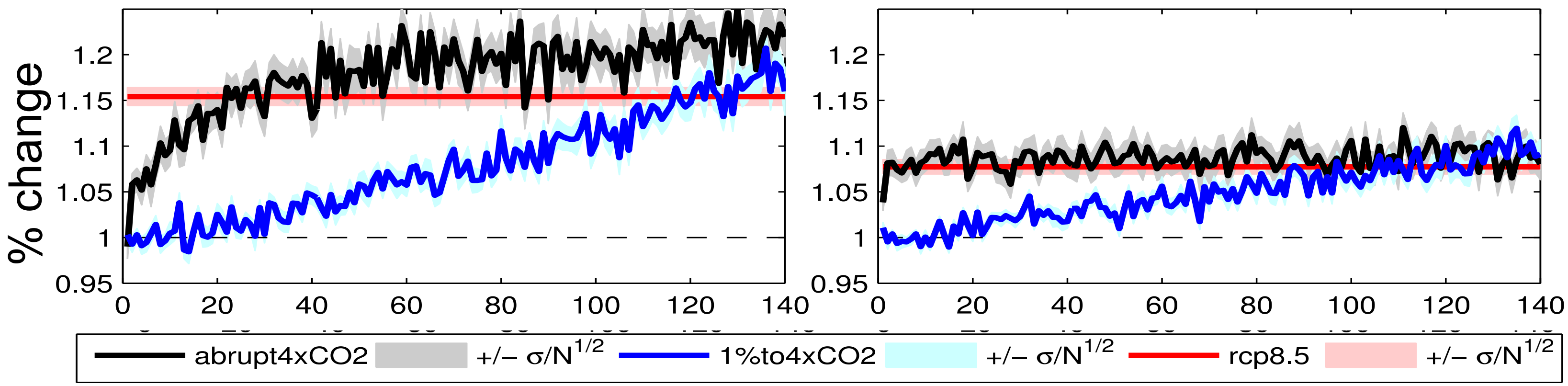
phase is nothing

Comparing ITCZ and monsoons in idealized CMIP5 simulations (Abrupt 4xCO_2)





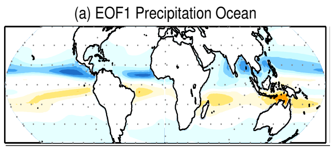
amplitude is slow for ITCZ, abrupt for monsoons

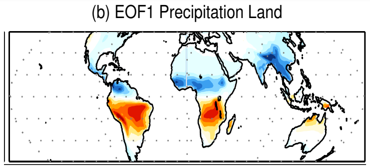


Confirms rich-get-richer thermodynamic argument.

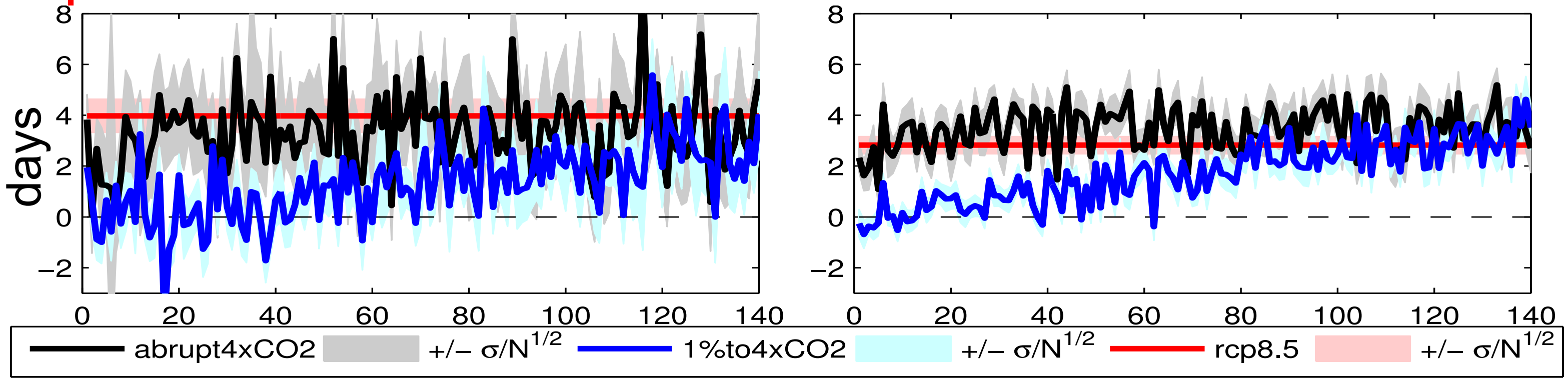
Confirms dynamic argument– possibly due to Amplitude of SST.

Comparing *ITCZ* and *monsoons* in idealized CMIP5 simulations (*Abrupt 4xCO_2*)



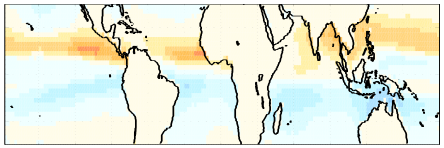


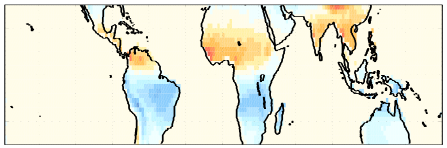
phase is "intermediate" for both ITCZ and monsoons



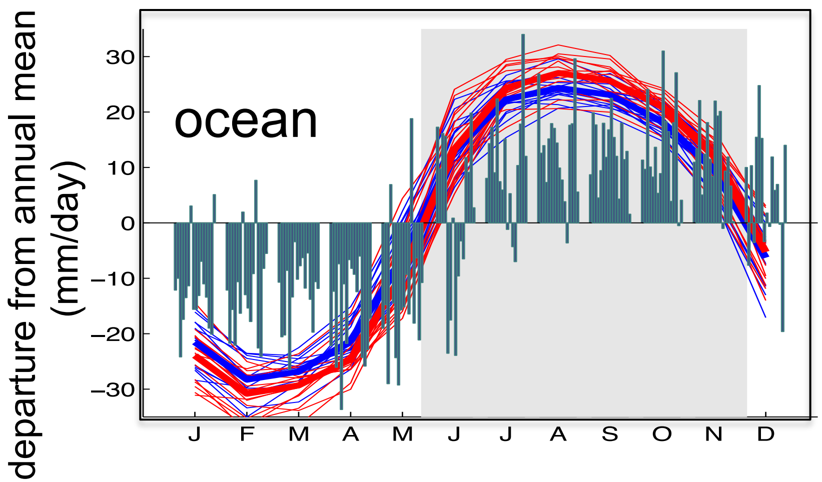
Confirms a complex interaction of thermodynamics and dynamics.
Possibly due to land-sea contrast.

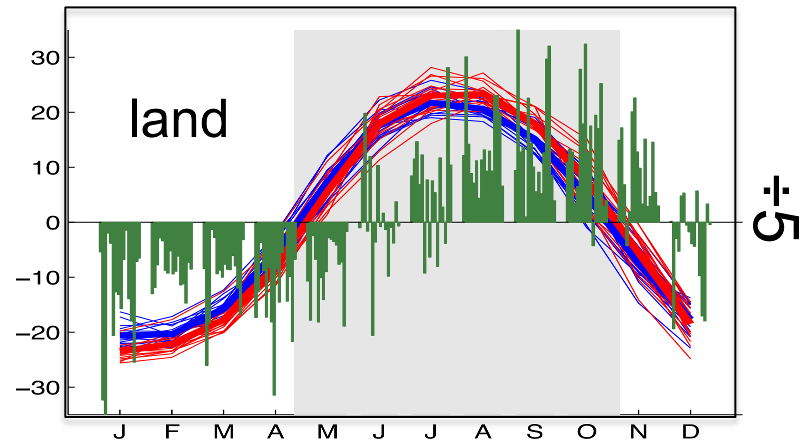
Comparing ITCZ and monsoons by decomposing rainfall in intensity and frequency of rainy days





intensity

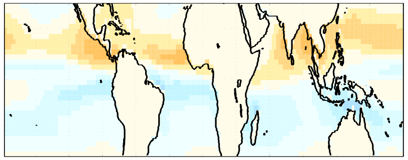


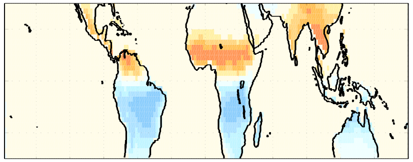


Intensity contributes to amplification, but not delay.

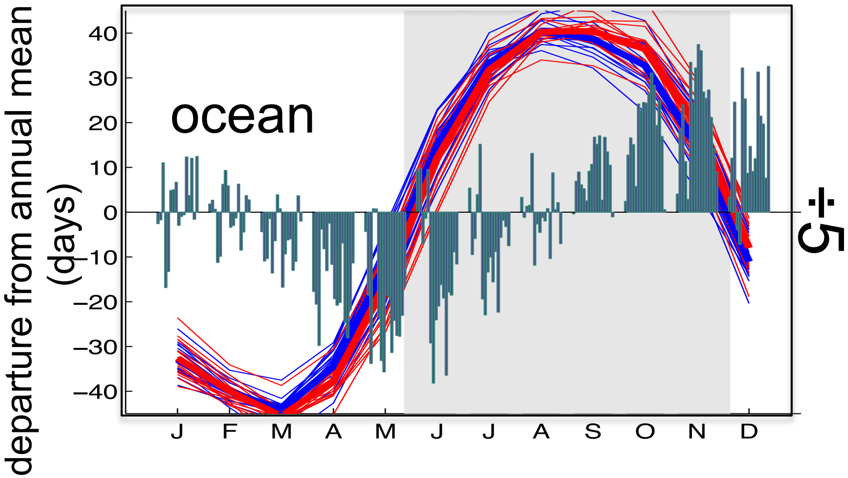
Intensity contributes to amplification & delay.

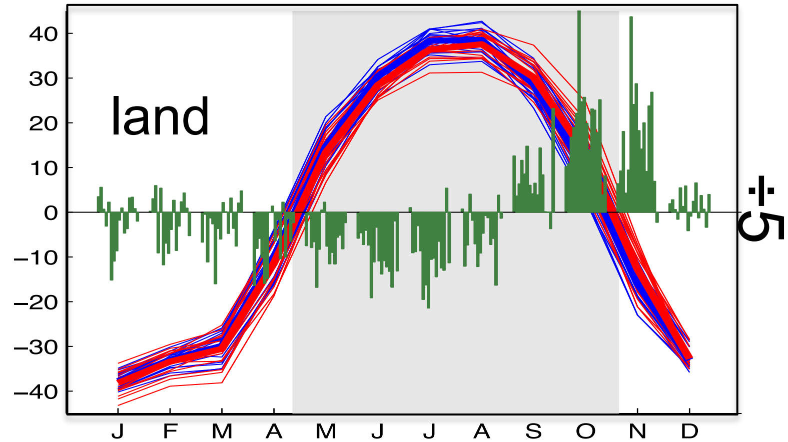
Comparing ITCZ and monsoons by decomposing rainfall in intensity and frequency of rainy days





frequency





Frequency contributes to delay, but not amplification.

Frequency changes are not sinusoidal:

- mostly negative
- positive in NH fall.

Summary (1)

The annual cycle of both ITCZ and monsoons is amplified and delayed when CO_2 increases.

For the annual cycle of the zonal mean ITCZ, uniform warming is the dominant forcing:

1. increased mean q leads to amplification (via rainfall intensity)–x-get-xer.
2. delay of the circulation leads to rainfall delay (via rain frequency)–unexplained. (but maybe a different story when land is included)

Anomalies in the amplitude and phase of the monsoons are initiated by circulation changes, but local moisture recycling might matter as well.

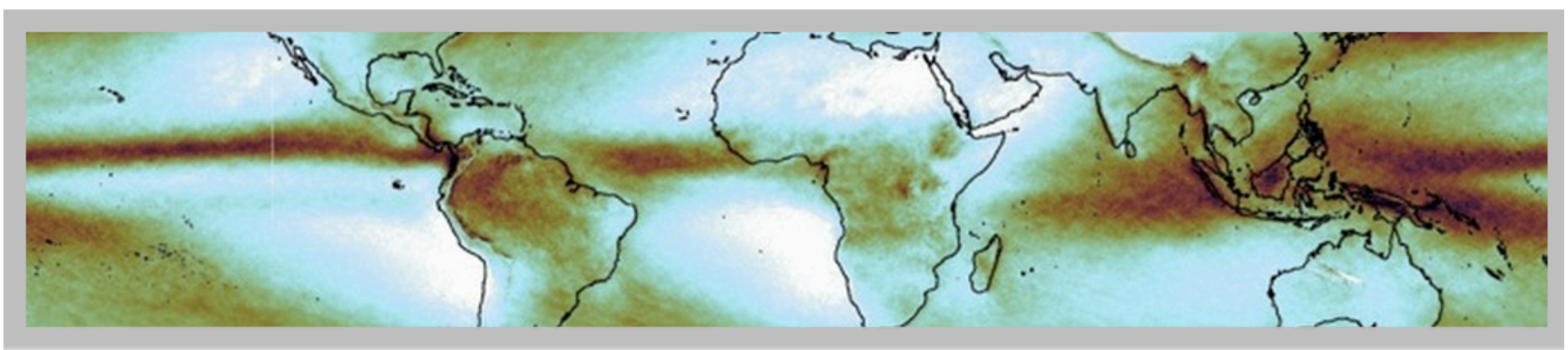
Summary (2)

You don't have to agree with my ITCZ/monsoon nomenclature, but please
treat land separate from ocean!

Join us in NYC in September (and join the MIP)

Monsoons & ITCZ:
the annual cycle in the Holocene
and the future.

September
15-18(19),
2015



An open conference and workshop at Columbia University, New York

http://www.ldeo.columbia.edu/~biasutti/MonsoonITCZsWorkshop/