Future Changes in the Annual Cycle of Monsoons and the ITCZ

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TRMM climatology courtesy of NASA
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.

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

- 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.

Tan et al. (2008)
Amplification: precipitation increases in summer and decreases in winter.

The increase in seasonal range is especially clear over the ocean and the Asian monsoon regions.
A delay of tropical precipitation

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

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.
Mechanisms relevant for the (zonal mean) 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:

\[
\text{CMIP5 RCP8.5 SST changes} \equiv \text{Uniform warming} + \text{Seasonal SST changes}\]

(idealize)
ITCZ: lessons from the moisture budget

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

- precipitation
- evaporation
- horizontal moisture convergence
- vertical moisture tendency
- vertical moisture convergence

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 \( \omega = \omega_0 + \omega_1 e^{-i(\omega t + \varphi)} + \ldots \) 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.

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**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 $\omega$.

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$_2$)
The SST evolution after abrupt quadrupling of CO$_2$ reveals different timescales:

- **Annual mean** is slow
- **Land-Sea Temperature contrast** is intermediate
- **Amplitude** is abrupt
- **Annual phase** is nothing
- **Surface Temperature Phase** is nothing
Comparing ITCZ and monsoons in idealized CMIP5 simulations (Abrupt 4xCO₂)

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$_2$)

The 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

Intensive contributions to amplification, but not delay.  

Intensive contributions to amplification & delay.

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**Intensity**

![Graph showing intensity contributions to ocean and land](image-url)
Comparing ITCZ and monsoons by decomposing rainfall in intensity and frequency of rainy days

Frequency contributes to delay, but not amplification.

Frequency changes are not sinusoidal:
- mostly negative
- positive in NH fall.
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.
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

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