Dynamics and the Hydrologic Cycle over Land: A GEWEX-CLIVAR Nexus

Tapio Schneider
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Climate change: \[ \delta P - \delta E \approx -\nabla \cdot \langle \overline{v_0 \delta q} \rangle - \nabla \cdot \langle \overline{\delta v q_0} \rangle \]
Precipitation - Evaporation (JJA)

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Rainfall in African Sahel

(Folland et al. 1986; Giannini et al. 2003; Held et al. 2005; Schneider et al. 2014)
Sahel Rainfall

- Correlates with extratropical NH-SH temperature difference
- Variations at least in part linked to continental ITCZ migrations
- ITCZ migrations driven by variations in NH-SH temperature contrasts (caused by AMOC variations, aerosols, etc.)
- Potential for rich interactions with land surface (soil moisture, vegetation)

To improve Sahel rainfall predictions, we need to improve understanding of dynamical links, e.g., to ocean variability, aerosol forcing etc.
ITCZ Coupling to Extratropics (Grand Challenge Question)

Eddy energy export into extratropics

Surface winds

Subtropical cells in oceans

(Schneider et al., Nature, in press)
Interannual Asian Monsoon Variability

Fig. 2. Interannual variability in the South Asian summer monsoon strength, based on the ERA-Interim atmospheric moisture budget, showing the dynamic component, thermodynamic component, and total variability.

(Walker et al., in prep.)
Monsoons Stronger When Energy Export Into SH Enhanced

Fig. 12. Climatology (a) and regression coefficient onto monsoon index (b) of JJAS ERA-Interim vertically integrated MSE transient eddy fluxes. Gray stippling shows the regions where the regression coefficient is significant at 95% confidence level. The green rectangle shows the averaging region for the monsoon strength index.

(Walker et al., in prep.)
• Well-known dynamical connections (MJO, ENSO etc.)
• Lesser known but important global connections (e.g., to SH)
• Involves rainfall re-distribution (similarities to ITCZ migrations)
• What is effect of global energy fluxes on monsoons and ITCZ?
• What is role of variations in overturning (Hadley, Walker) circulations and transients and how do they arise?
• How do land interactions modulate variability?

*Improving understanding of global-scale connections crucial for longer-term (interannual and beyond) monsoon predictions*
Asian Monsoon-Atlantic ITCZ Correlation (Holocene)

NH-SH Temperature Anomaly (K)

-0.5 -0.5 0.5 1.5

0 2 4 6 8 10 12

Age (kyr B.P.)

O (per mil)

-2.5 -0.5 0.5

0 2 4 6 8 10 12

Age (yr B.P.)

0 400 800

Ti (%)

0.05 0.25

0.1

ITCZ

NH Temperature Anomaly (K)

-1 -0.6 -0.2

0 0.6

Age (yr B.D.)

1900 1980 2012 1940

Sahel Rainfall (mm/day)

3

Atlantic ITCZ (Cariaco)

Today

stronger

weaker

Indian Monsoon Rainfall

δ\(^{18}\)O (per mil)

-2.5 -0.5 0.5

0 2 4 6 8 10 12

Age (kyr B.P.)

0.1

ITCZ

north (wetter)

south (drier)

0.05 0.25

0.1

3

(Stronger)

 weaker

drier

wetter

Thermal Max

Schneider et al., Nature, in press)
Asian Monsoon Variability (CLIVAR Research Focus)

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Marine ITCZ

[Map showing the distribution of precipitation over the Earth's surface, with a focus on the Intertropical Convergence Zone (ITCZ). The map includes color-coded areas indicating different precipitation rates, with a highlighted region in the central Pacific Ocean.]
Double ITCZ Bias

Hwang & Frierson (2013)

Tend to overprecipitate over all ocean basins in the Southern Hemisphere tropics. The Northern Hemisphere tropical ocean basins behave differently: a negative precipitation anomaly exists in the Atlantic, whereas the Indian and Pacific have positive anomalies that are smaller than the positive anomalies south of the equator. In the immediate vicinity of the equator in the Pacific Ocean, there is a large negative anomaly. Central America, the Amazon, and India all have large deficits of rainfall in the multimodel mean, whereas Indonesia has too much rainfall. Many of these features are similar to the CMIP3 biases shown in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (3) and are described in detail in SI Text.

As shown in Fig. 2, the biases in zonal mean precipitation in CMIP3 global climate models (2) still exist in CMIP5 global climate models. First of all, comparing with Global Precipitation Climatology Project (GPCP) observational data, most models simulate excessive precipitation in the entire tropics. However, precipitation anomalies are larger than in observations. In the northern Pacific, there is a large negative precipitation anomaly, whereas the Indian and Atlantic Oceans have positive anomalies. In the Southern Hemisphere, there is a large negative precipitation anomaly in the South Pacific and a large positive anomaly further north. The cold pool over western Africa is too cold, whereas the warm pool over the North Pacific is too warm. The warm pool over the western Pacific is too warm, whereas the cold pool over eastern Africa is too cold.

Linked to SH CRF bias

(Hwang & Frierson 2013)
• Appears to be linked globally, e.g., to Southern Ocean clouds
• Also important links to tropical cloud biases
• What is role of extratropical vs. tropical processes and their effect on energy balance?
• Do biases in ocean energy uptake near equator play a role?

*Marine ITCZ position not controlled locally, but through global dynamical processes*