Robust Patterns and Uncertainties of Tropical Rainfall and Circulation Projections

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Precipitation change is to first order spatially variable.

- What determines patterns of rainfall change?
- Can we predict the pattern?

Climate change (1986–2005 to 2081–2100), Business as usual (RCP8.5); IPCC AR5

Temperature

precipitation
What determines rainfall change?

**The wet gets wetter**
(e.g., Neelin et al. 2003; Held & Soden 2006)
Precipitation increases in equatorial rain bands; decreases in subtropics; and increases in high-latitudes due to increase in moisture transport.

![Graph showing zonal-mean change in specific humidity](image)
2K uniform SST warming: mean (contour) and change of precipitation
→ Wet-get-wetter pattern
• Flat warming in upper troposphere $\leftrightarrow$ weak temp gradient (Sobel et al. 2001)
• Convective instability follows closely SST patterns

Convective Instability: $I_M = (c_p T + Lq)_{sfc} - (c_p T + Lq)_{300 \text{ hPa}}$

Ocean warming pattern effect: warmer get wetter

Robust patterns:
- Equatorial peak in Pacific and Atlantic
- Warmer NH than SH

ΔT=2.8°C (Tropical mean)
r(ΔT,δP/P)=0.63 (Tropical region)

IPCC AR5
Figure 14.8
Decomposition of rainfall change

\[ \Delta P \approx \Delta P_{\text{ther}} + \Delta P_{\text{dyn}} \]

\( \omega \Delta q \quad \Delta \omega q \)

Inter-model variability in 2050-99 minus 1950-99 difference
Dynamic component dominates inter-model spread

RCP4.5

Inter-model spread

Circulation uncertainty (air-sea coupling)

\[ \Delta P \approx \Delta P_{\text{ther}} + \Delta P_{\text{dyn}} \]

\[ \omega \Delta q \quad \Delta \omega q \]

S.M. Long, in prep.
Atmospheric circulation uncertainty is tightly coupled with SST patterns.

SVD analysis of inter-model spread of zonal mean $\Delta$SST & $\Delta$ω in CMIP5.

Uncertainty in cross-eq. gradient

Uncertainty in eq. peak

See (Ma & Xie 2013, JC) for CMIP3 analysis.
Leading uncertainties for global mean temperature
- Radiative forcing: aerosol
- Climate feedback: cloud

Leading uncertainty for regional change: atmospheric circulation
- Coupling with ocean in tropics
- Internal variability in mid-latitudes

Leading sources of global and regional climate projections. Insets are multi-model projections for surface temperature (left) and precipitation (right) from IPCC AR5.
Monsoon change in AR5

Globally, it is likely that the area encompassed by monsoon systems will increase over the 21st century. While monsoon winds are likely to weaken, monsoon precipitation is likely to intensify due to the increase in atmospheric moisture. ... resulting in lengthening of the monsoon season in many regions. AR5 SPM
West African monsoon

Sahel rainfall change vs. N Atlantic relative SST

Giannini et al. (2013, ERL)
Physical origins of regional climate change.

- **Regional forcing:** aerosols, land use...
- **Thermodynamic effect:** wet-get-wetter...
- **Extratropics:** atmospheric internal variability
- **Tropics:** air-sea coupling

Atmospheric circulation change

Regional climate change
Near emission source, aerosol forcing dominates circulation and rainfall response.

**All forcing**

**Asian summer monsoon**

**Aerosol**

**GHG**
Challenges

• Over ocean, SST pattern, circulation and rainfall are coupled (diagnostic), but are there overarching principals (predictive)?

• What determines rainfall/monsoon change over continents?

• Interannual variability and extremes?