Robust Patterns and Uncertainties of Tropical Rainfall and Circulation Projections

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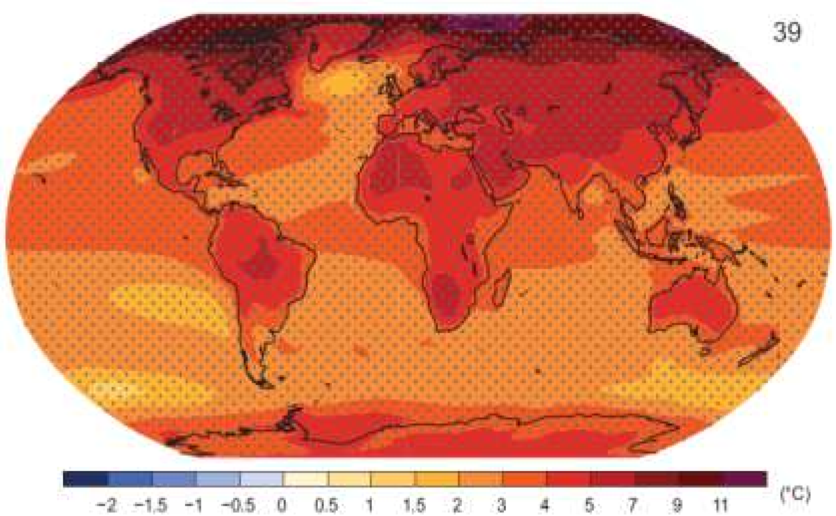
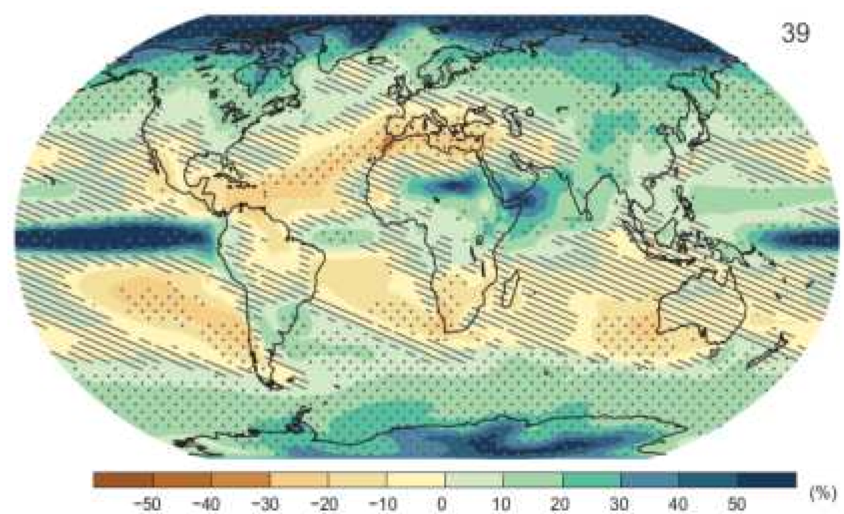
Precipitation change is to first order spatially variable.

- 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



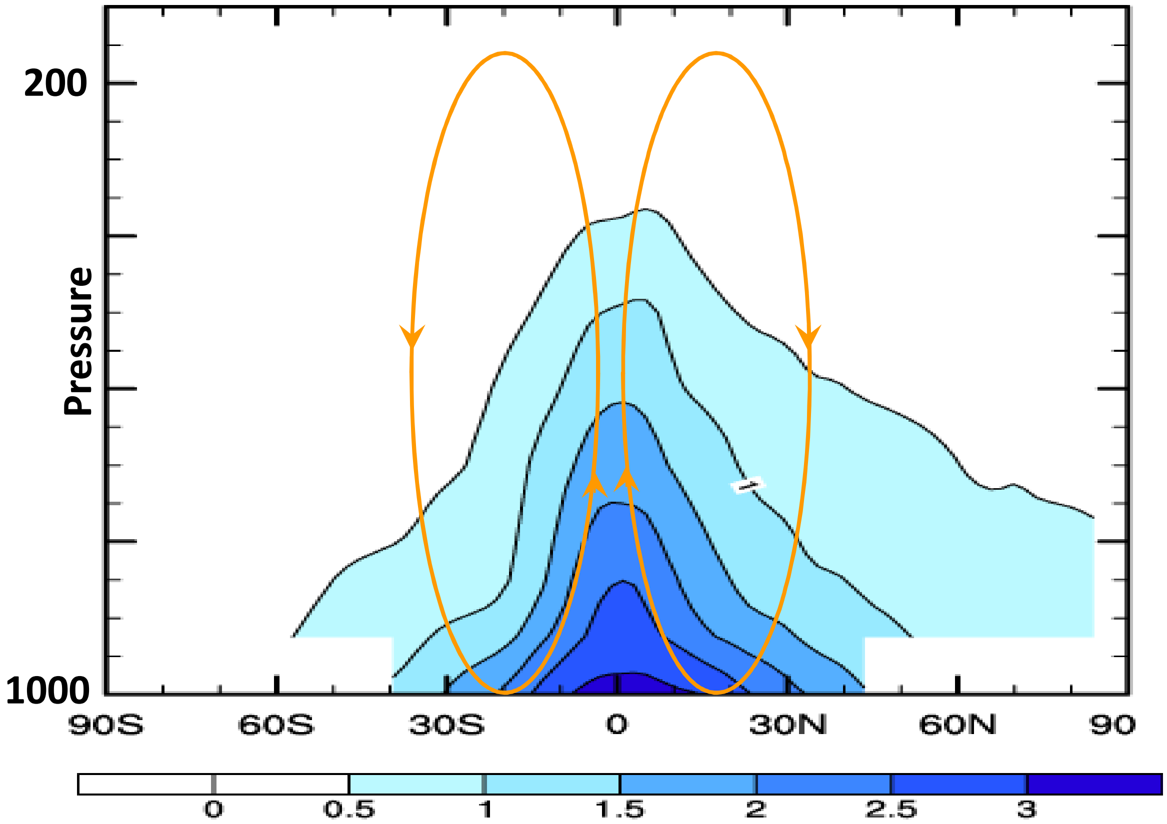
precipitation

What determines rainfall change?

The wet gets wetter

(e.g., Neelin et al. 2003; Held & Soden 2006)

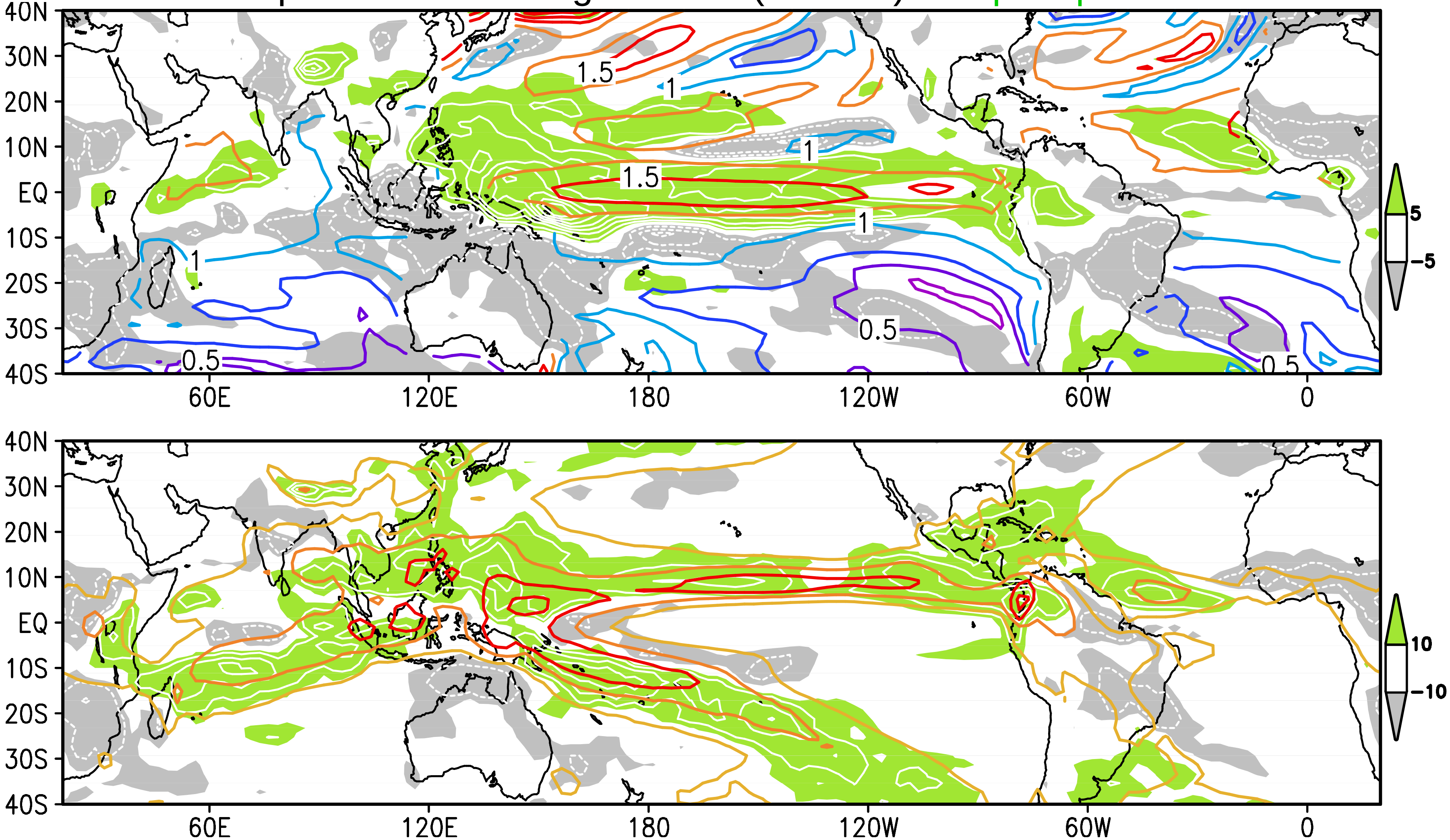
Precipitation increases in equatorial rain bands; decreases in subtropics; and increases in high-latitudes due to increase in moisture transport



Zonal-mean change in specific humidity **δq [g/kg]**

Warmer-get-wetter pattern

Coupled model: change in SST (contour) and precipitation

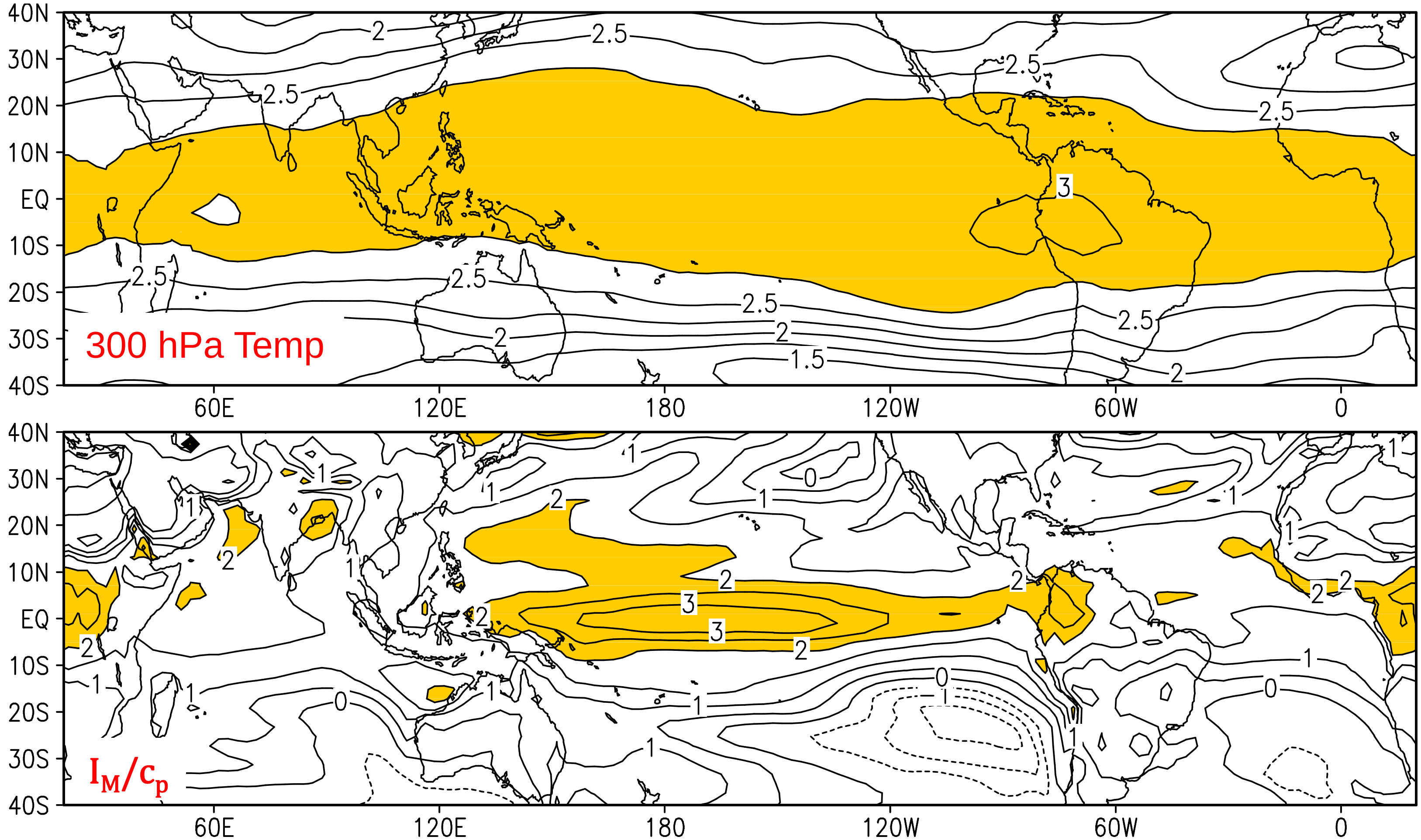


2K uniform SST warming: mean (contour) and change of precipitation

→ Wet-get-wetter pattern

- Flat warming in upper troposphere ← weak temp gradient (Sobel et al. 2001)
- Convective instability follows closely SST patterns

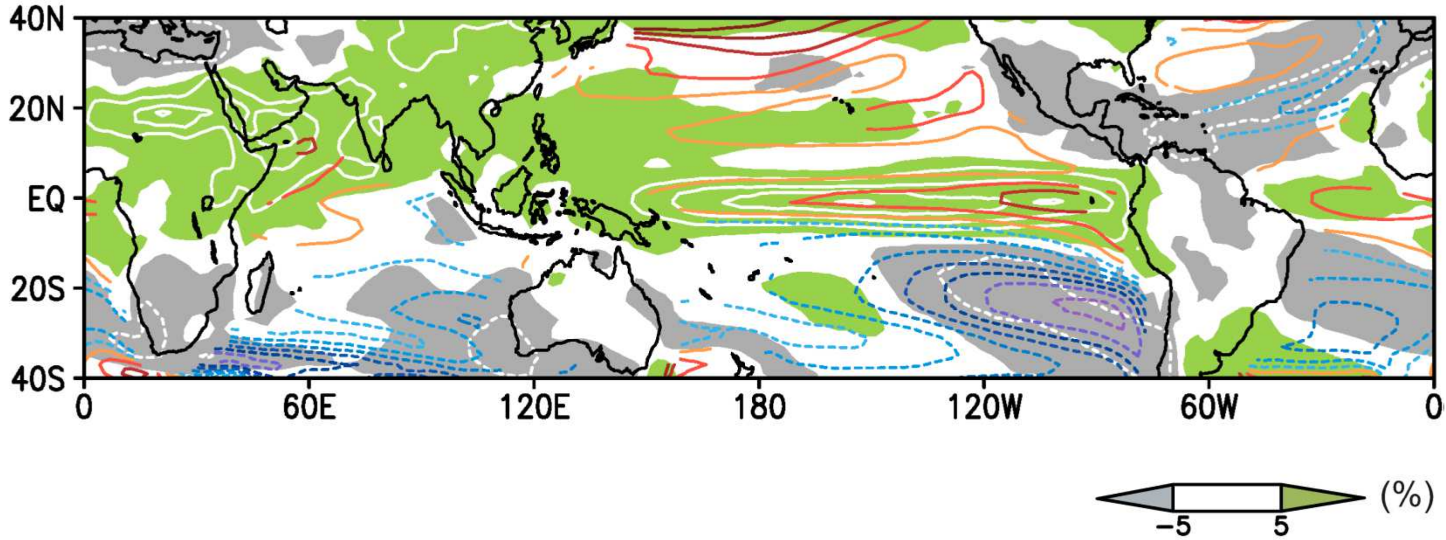
Convective Instability: $I_M = (c_p T + Lq)_{sfc} - (c_p T + Lq)_{300\ hPa}$



Xie, S.-P., C. Deser, G.A. Vecchi, J. Ma, H. Teng, and A.T. Wittenberg, 2010: Global warming pattern formation: Sea surface temperature and rainfall. *J. Climate*, 23, 966-986.

Ocean warming pattern effect: warmer get wetter

2081-2100 minus 1986-2005 difference



ΔT=2.8°C
(Tropical mean)

r(ΔT,δP/P)=0.63
(Tropical region)

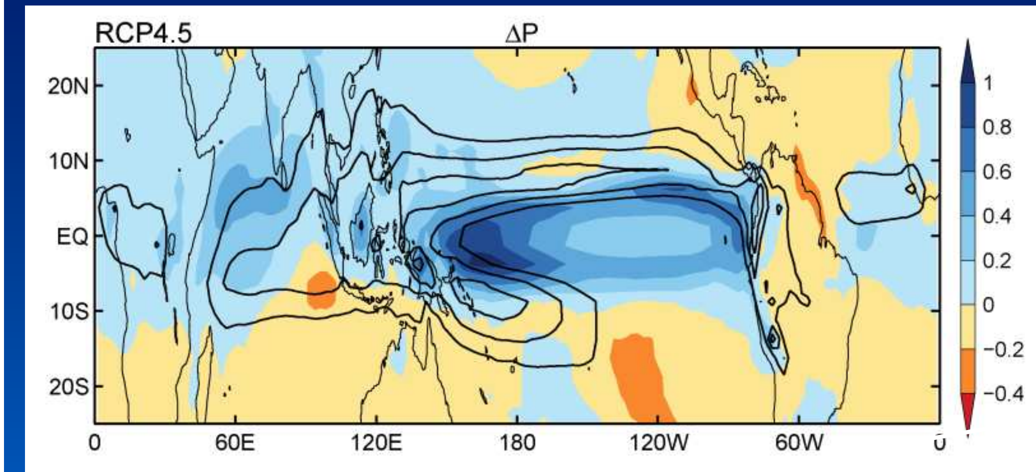
ΔP/P & ΔT*

Robust patterns:

- Equatorial peak in Pacific and Atlantic
- Warmer NH than SH

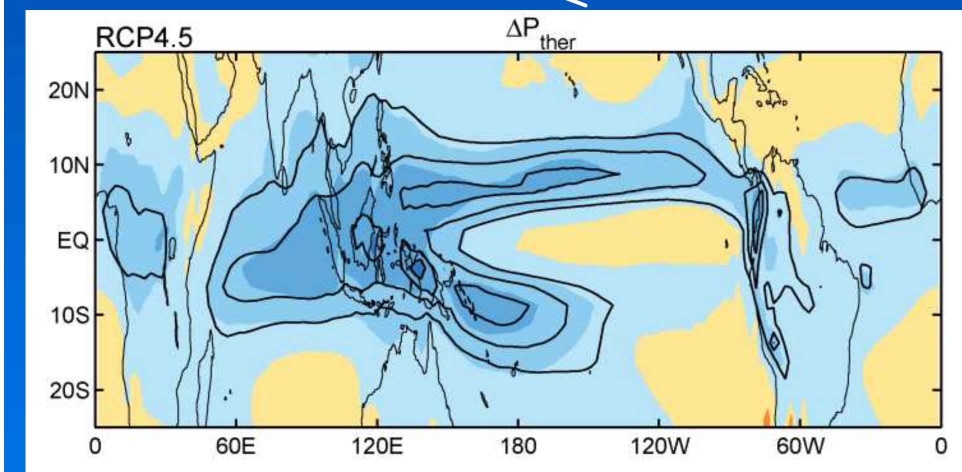
IPCC AR5
Figure 14.8

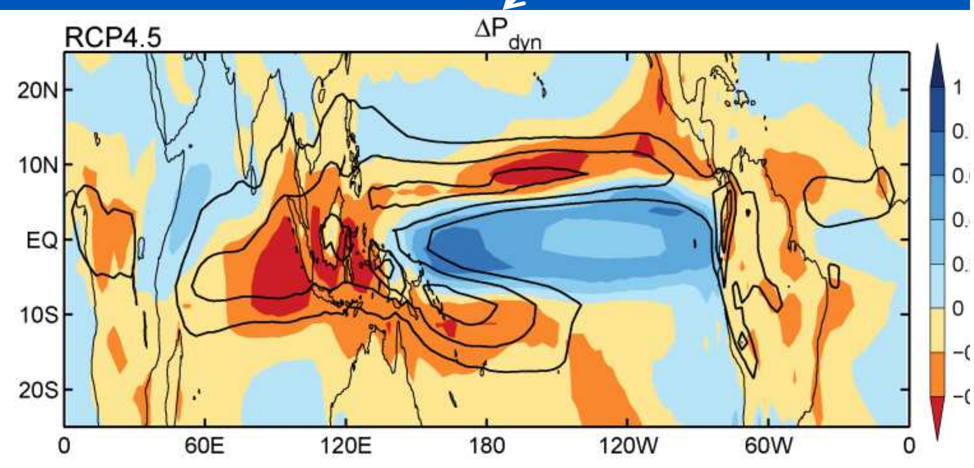
Decomposition of rainfall change



$$\Delta P \approx \Delta P_{ther} + \Delta P_{dyn}$$

$\omega \Delta q$ $\Delta \omega q$





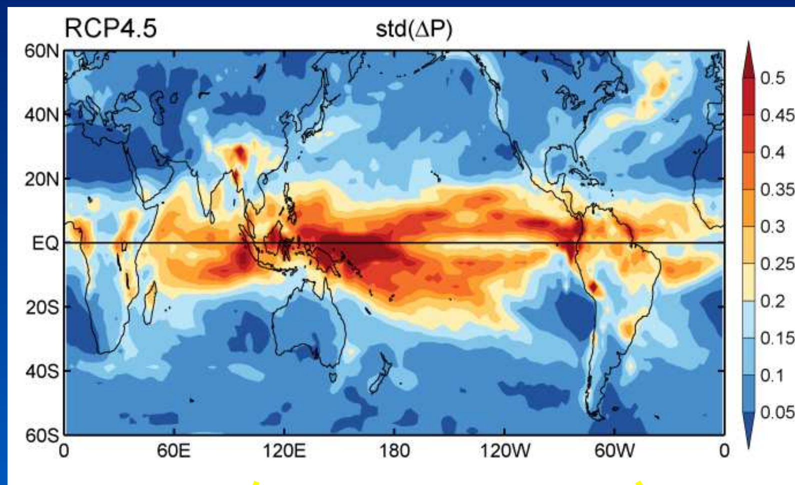
Wet get wetter

Circulation slowdown + SST pattern

Inter-model variability in 2050-99 minus 1950-99 difference

Dynamic component dominates inter-model spread

RCP4.5 Inter-model spread



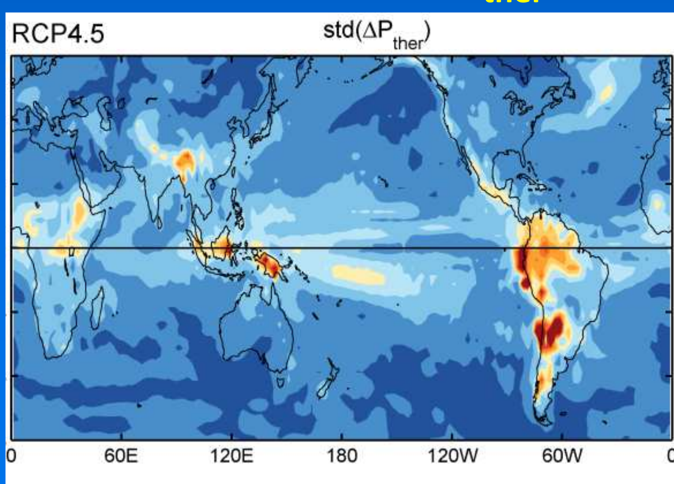
ΔP

Circulation uncertainty
(air-sea coupling)

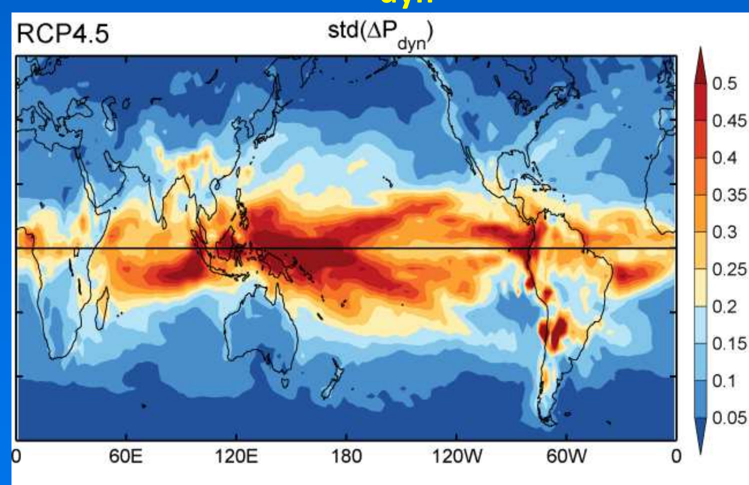
$$\Delta P \approx \Delta P_{ther} + \Delta P_{dyn}$$

$\omega \Delta q$ $\Delta \omega q$

ΔP_{ther}



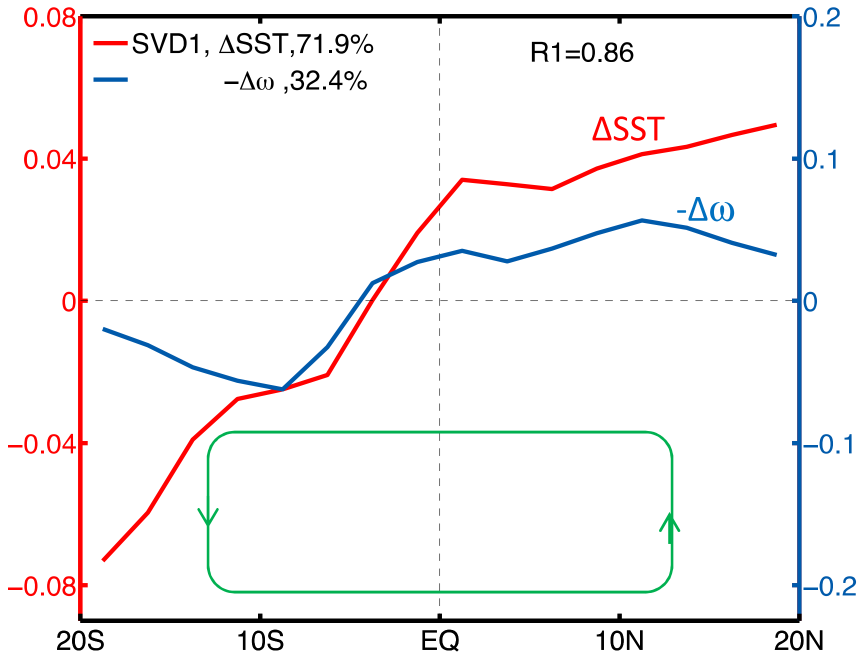
ΔP_{dyn}



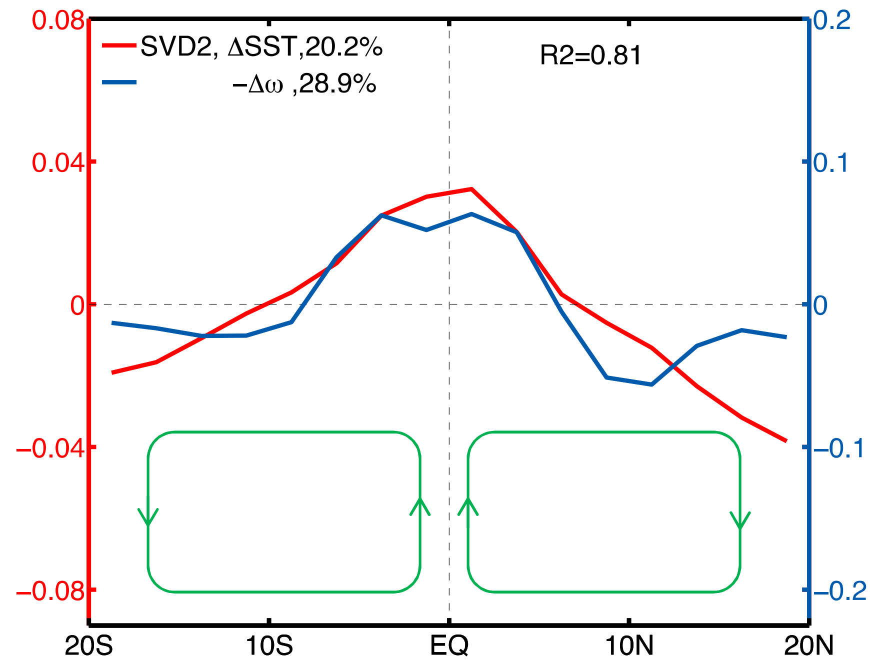
S.M. Long, in prep.

Atmospheric circulation uncertainty is tightly coupled with SST patterns

SVD analysis of inter-model spread of zonal mean ΔSST & Δω in CMIP5

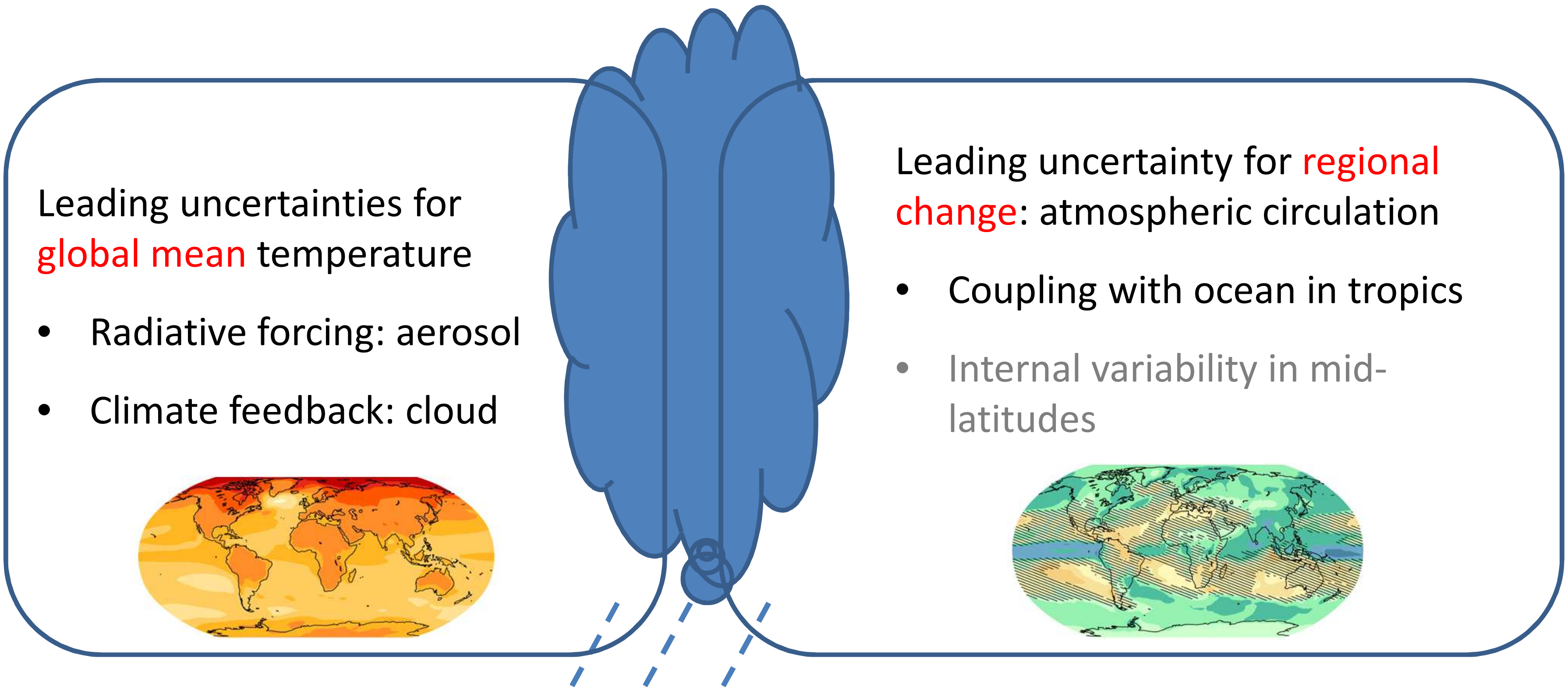


Uncertainty in cross-eq. gradient



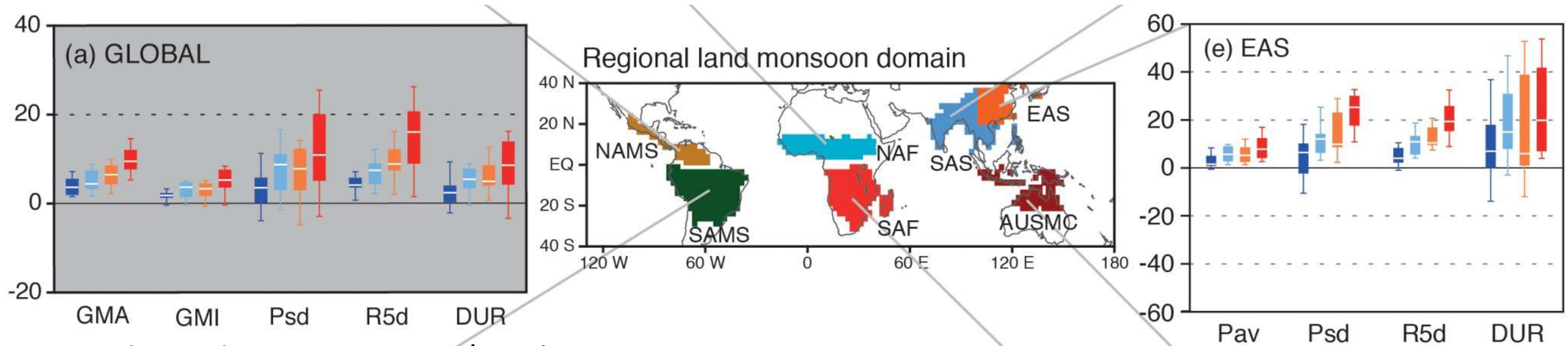
Uncertainty in eq. peak

See (Ma & Xie 2013, JC) for CMIP3 analysis



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

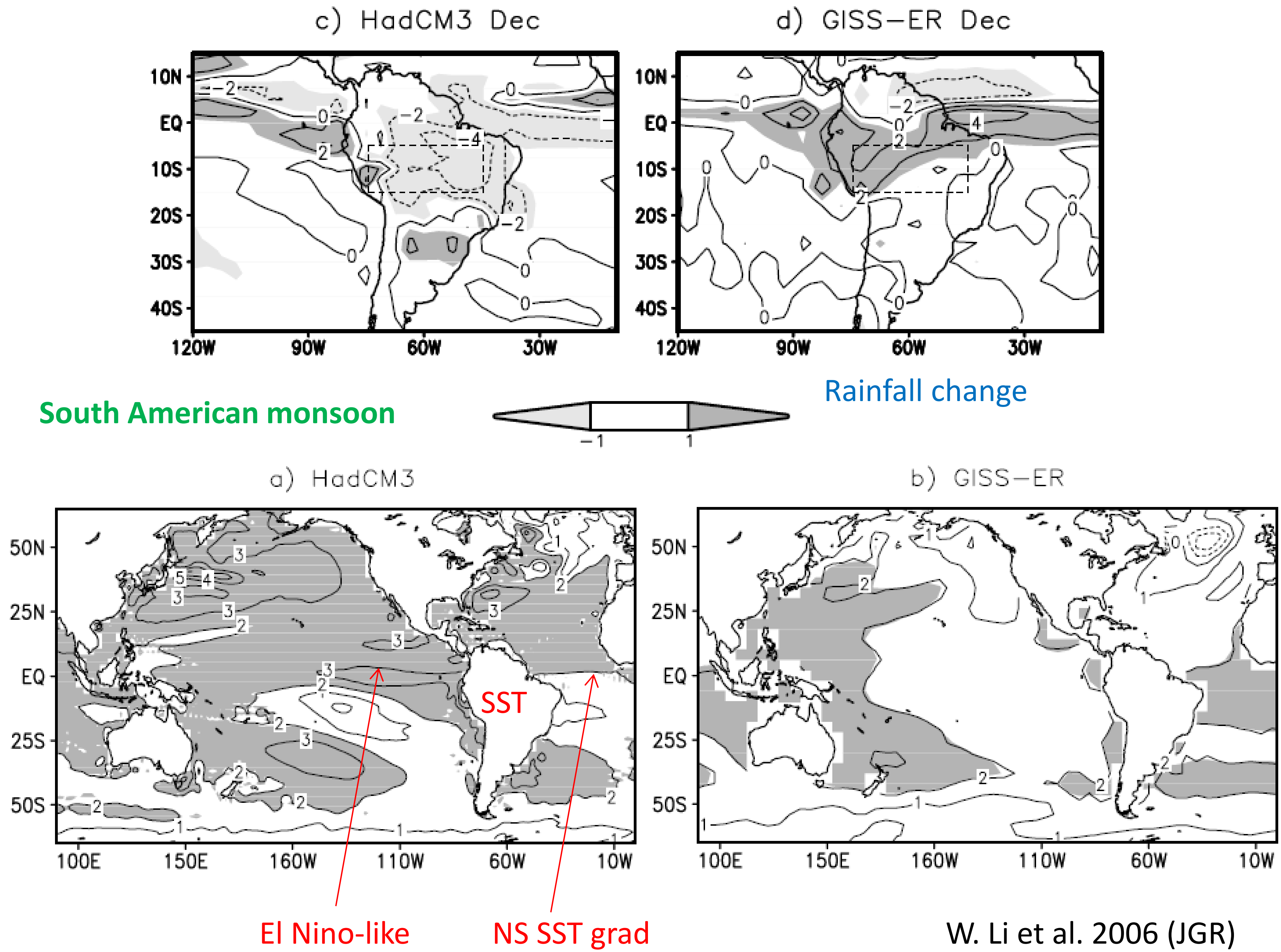
Monsoon change in AR5



area, intensity, σ, extreme, duration

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

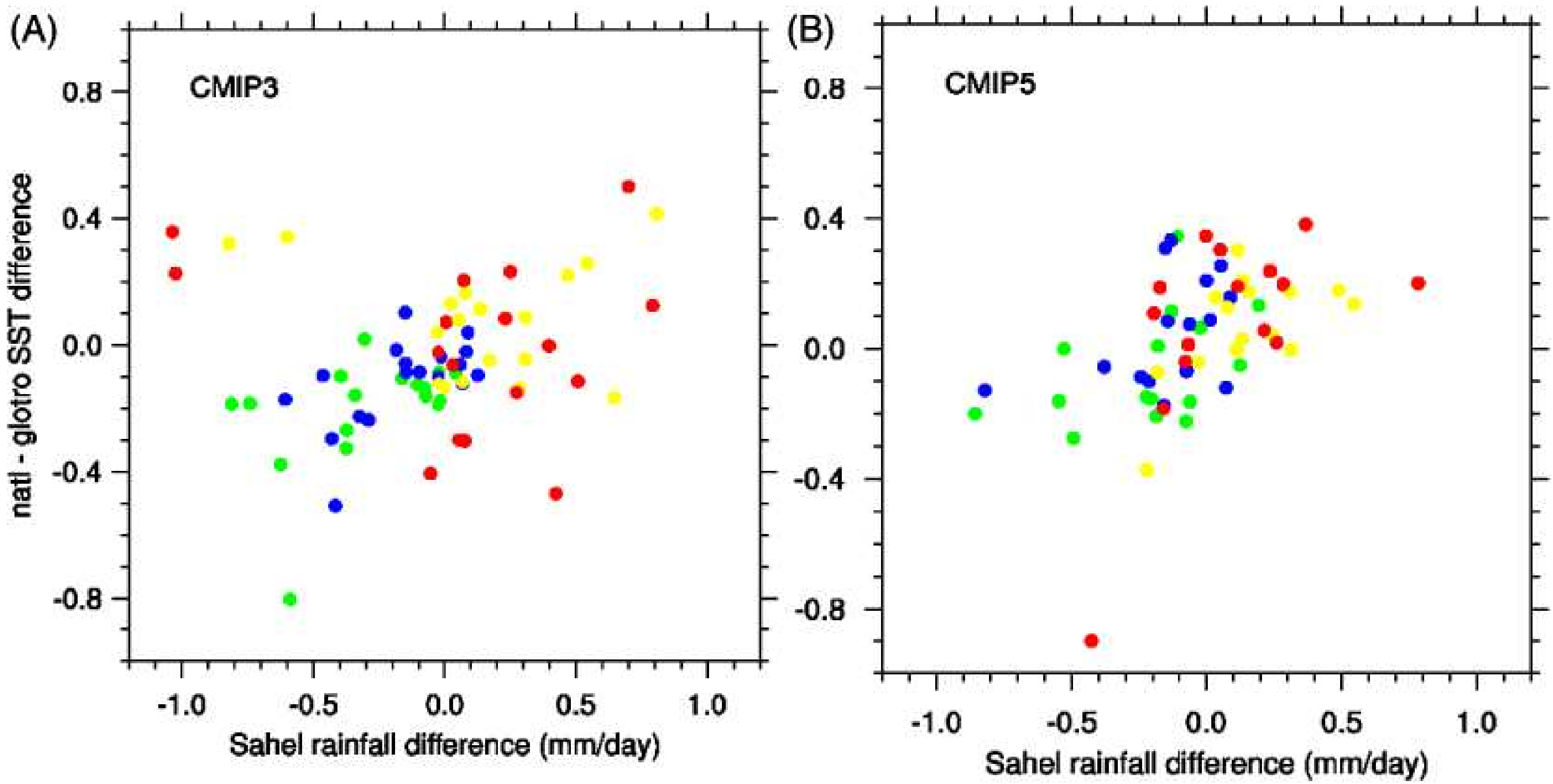
Fig. TS-24



W. Li et al. 2006 (JGR)

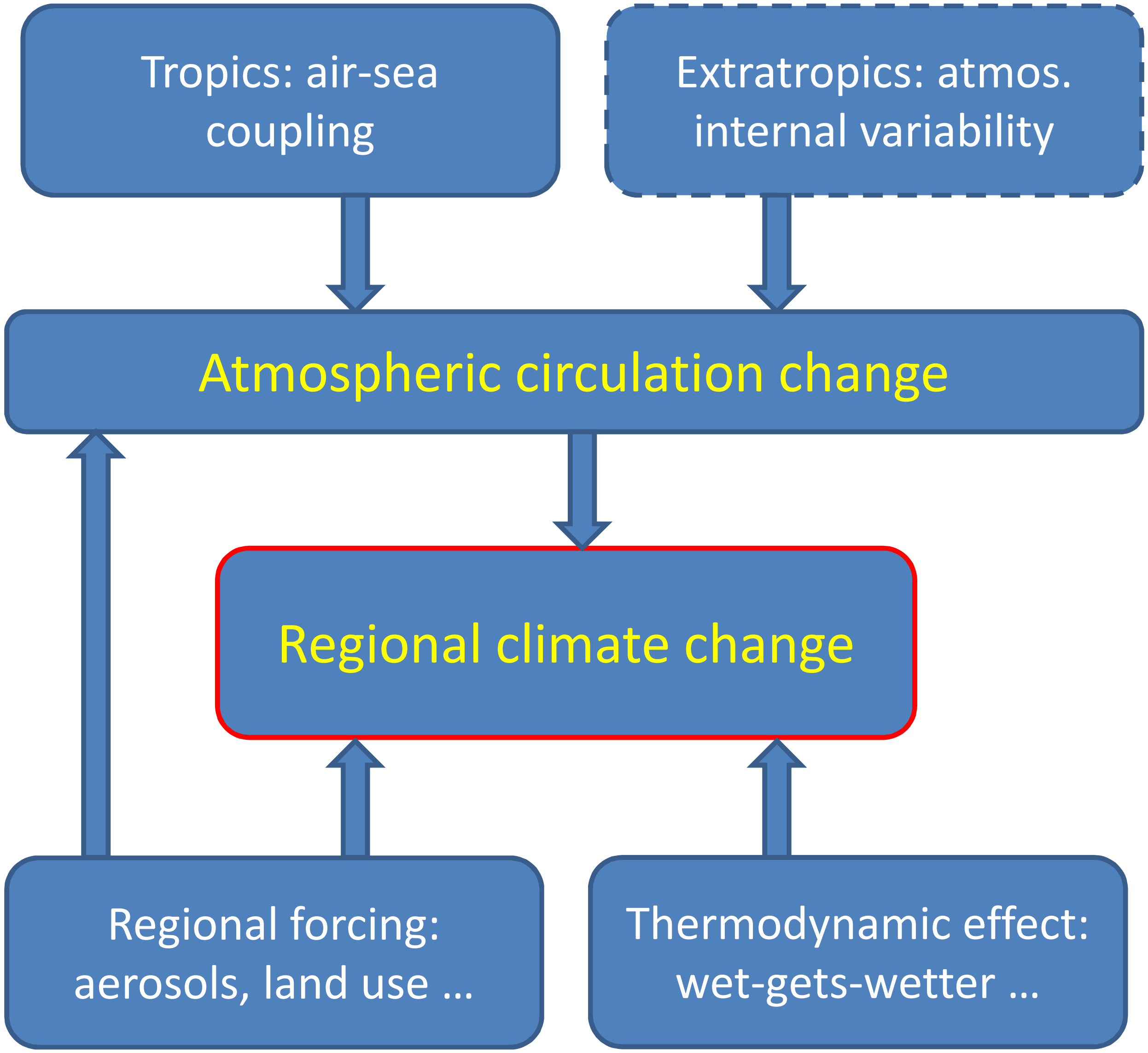
West African monsoon

Sahel rainfall change vs. N Atlantic relative SST



Giannini et al. (2013, ERL)

Physical origins of regional climate change.



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

JJA precip

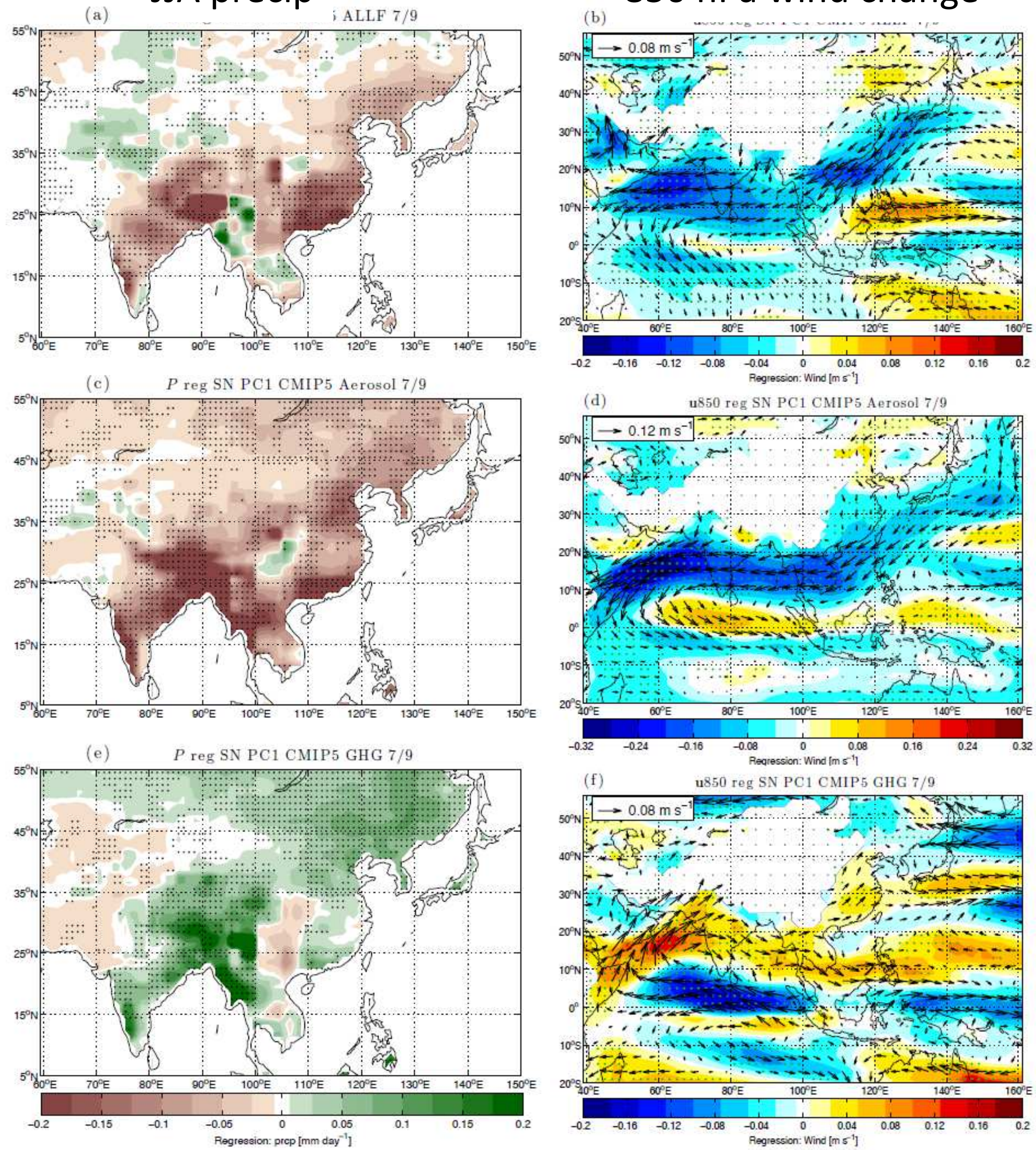
850 hPa wind change

All forcing

Asian summer monsoon

Aerosol

GHG



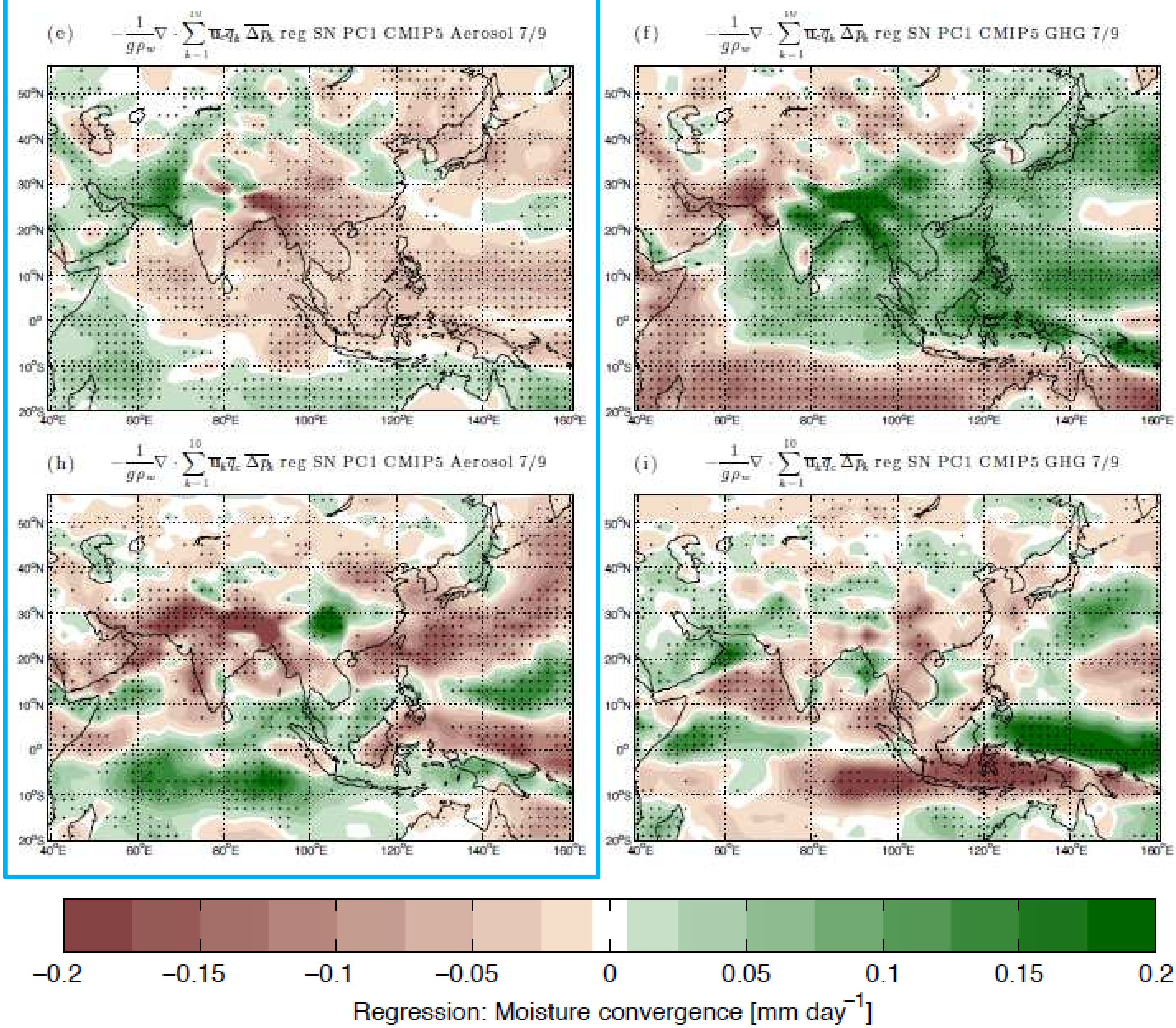
Aerosol run: Large dynamic component

GHG run: Large thermodynamic component

Water budget

thermodynamic component

dynamic component



Li, Ting et al. (2015, JC)

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?