Regional patterns of rainfall change in a warming climate: Role of ocean-atmosphere interaction

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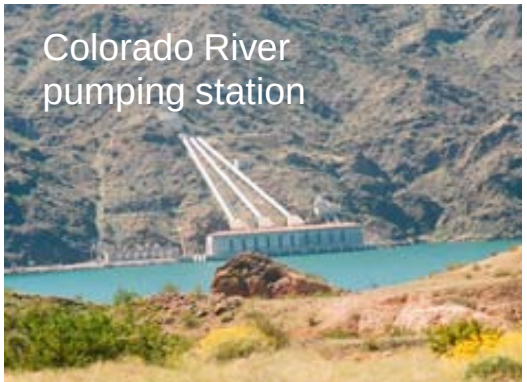
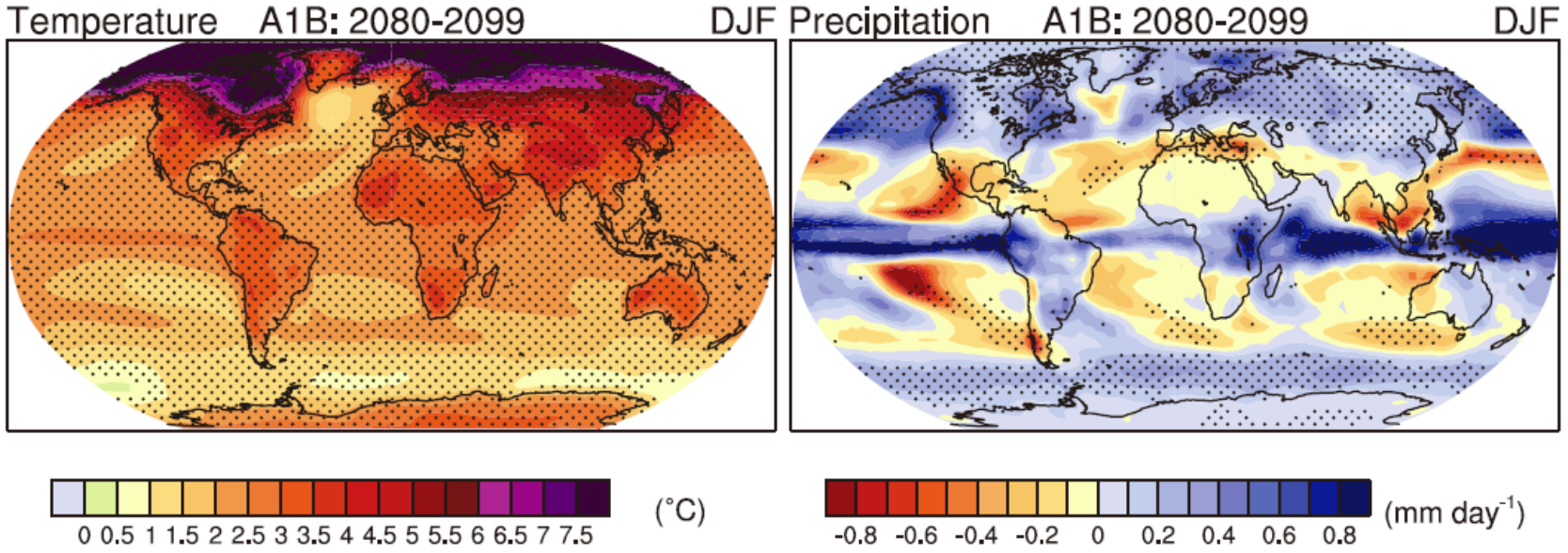
- What determines patterns & uncertainties of regional precip change?
- Annual vs. seasonal mean change.



Temperature warming is not uniform, and
precipitation change is to first order spatially variable.

Hypotheses:

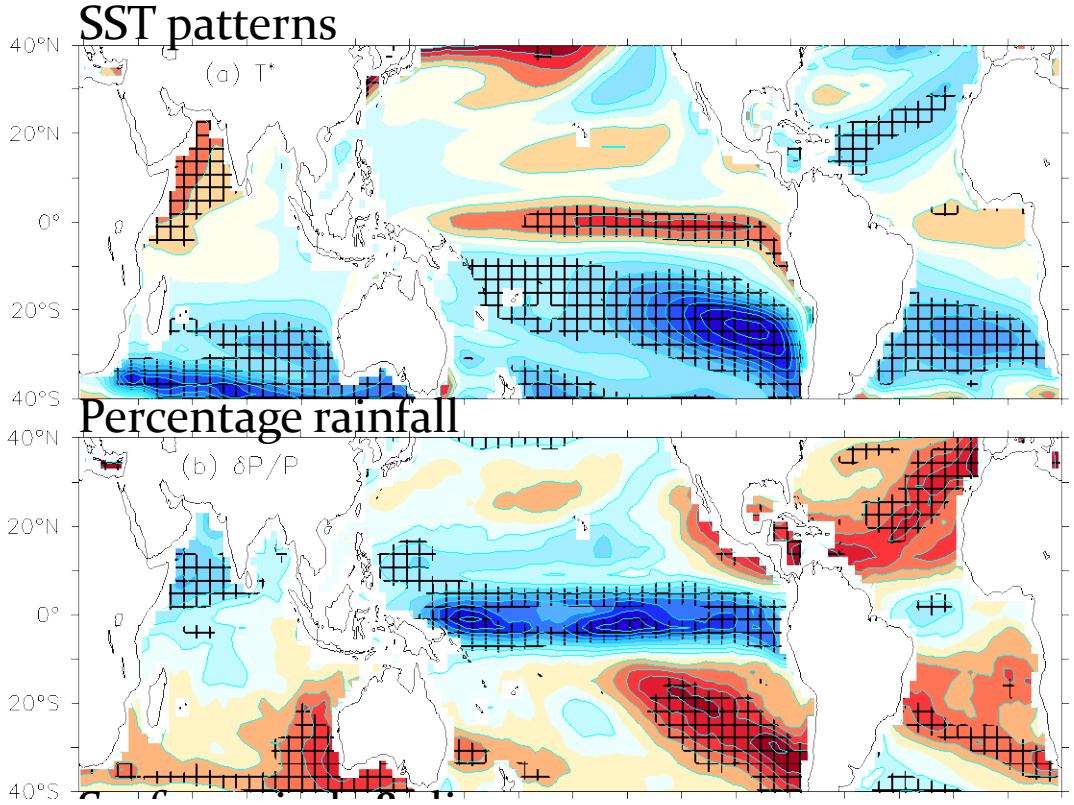
- Wet gets wetter;
- Warmer gets wetter.

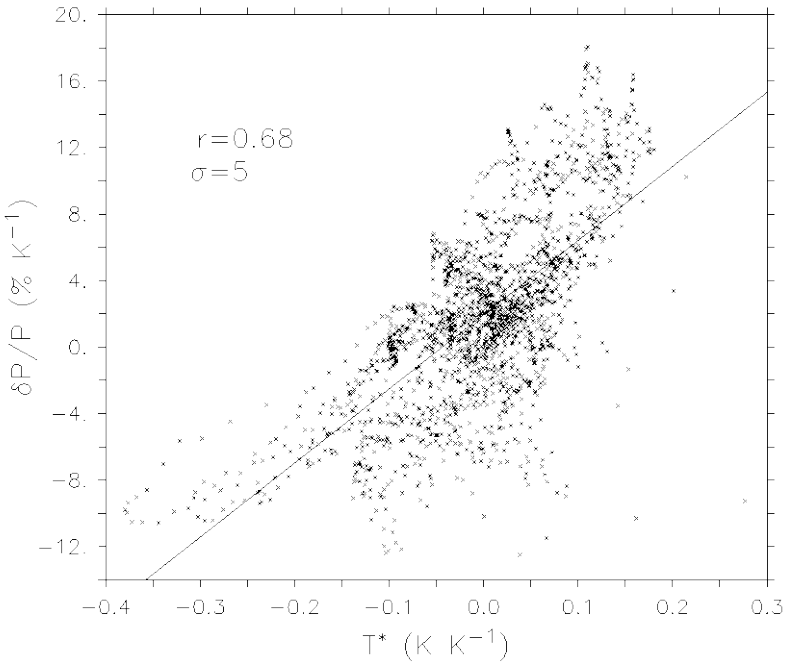


A1B multi-model ensemble mean (IPCC AR4, 2007)

CMIP3 A1B Ensemble Mean

Warmer gets wetter for annual mean





$$\delta P/P = \alpha\, T^* + \beta\, \overline{T}$$

SST pattern

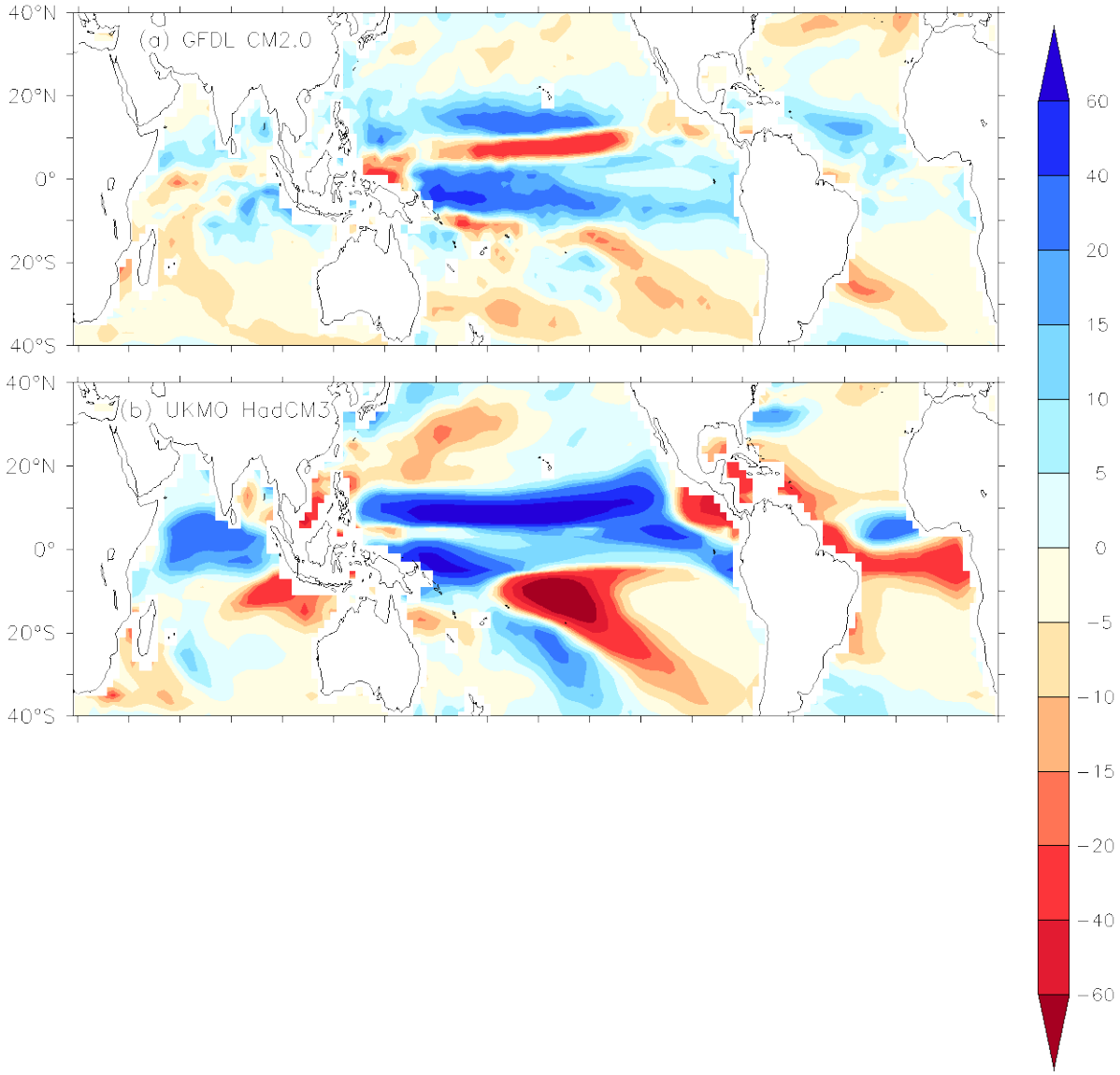
Tropical mean

α = 44% K^{-1}

β >> 7% K^{-1}

Inter-model Difference

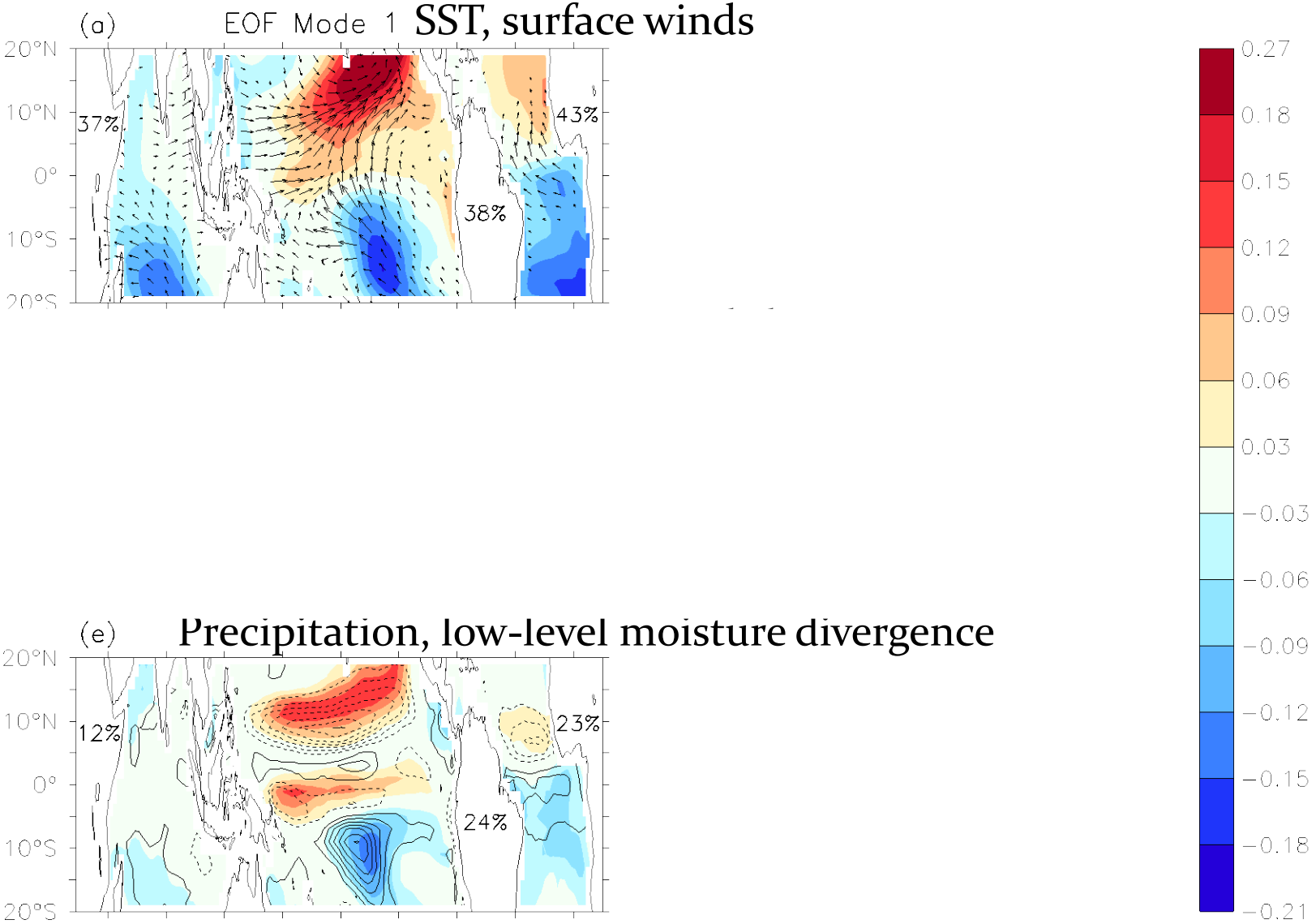
Ma & Xie (2013, JC)



- Two models
  - CMIP3
  - SRES A1B
- Rainfall changes
  - Very different
  - Correlation: -0.03
- Rainfall & SST
  - Correlation: 0.56

Inter-model Variations

SST, surface winds



Precipitation, low-level moisture divergence

Seasonal cycle of precip change

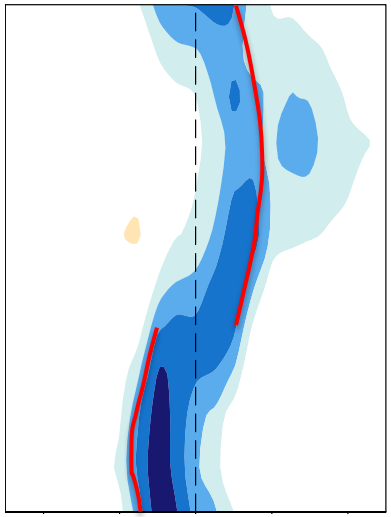
in CMIP5 multi-model ensemble (RCP4.5)

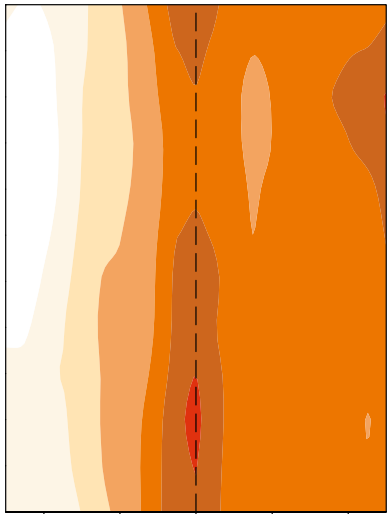
Huang, Xie et al. (2013, *Nature Geoscience*)

ΔP: hybrid of wet-get-wetter & warmer-get-wetter

- Marches back and forth across Eq., unlike ΔSST;
- Peaks on the Eq. flank of the climatological ITCZ.

Precip change

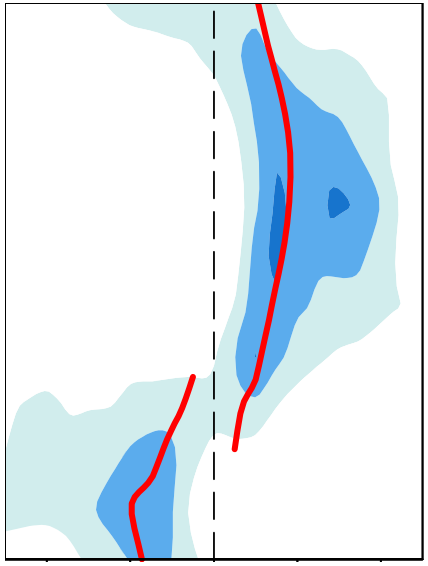




Atmospheric GCM experiments (prescribed A1B ΔSST)

- The wet gets wetter in SUSI;
- Equatorward shift of max ΔP is a ΔSST(y) effect.

Spatial-uniform SST increase

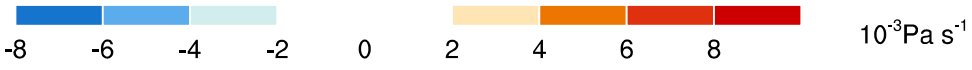


Atmospheric GCM experiments (prescribed SST)

- $\Delta\omega$ is weak in SUSI;
- $\Delta\omega$ is due to SST pattern.

Spatial-uniform SST increase

Spatial-patterned SST increase



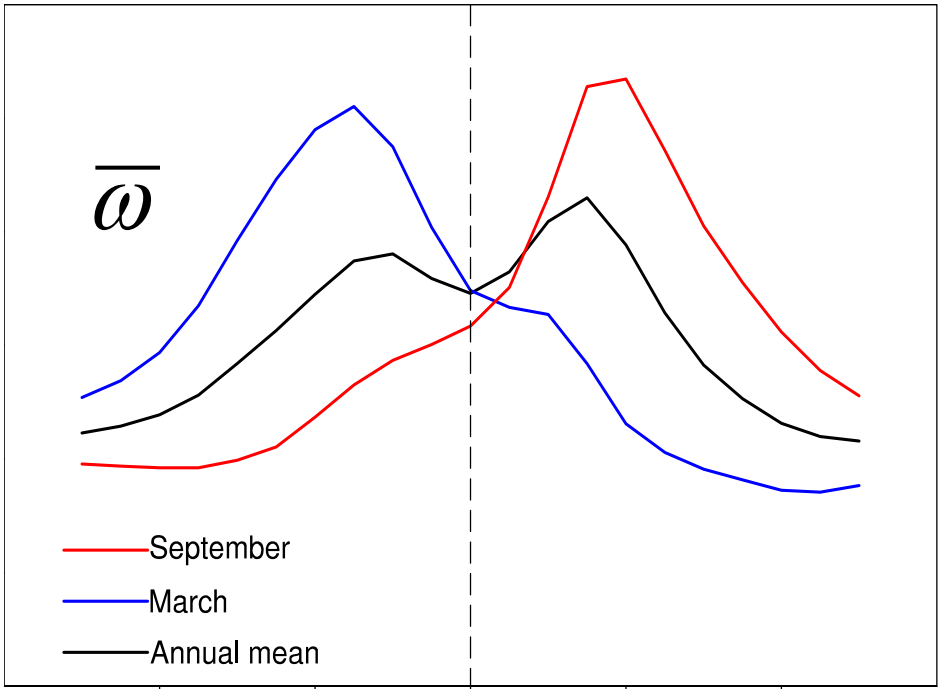
Warmer-get-wetter

$$\Delta P \sim \Delta\omega\bar{q} + \bar{\omega}\cdot\Delta q$$

at ITCZ

$$\frac{\Delta P}{\bar{P}} = \frac{\Delta\omega}{\bar{\omega}} + \frac{\Delta q}{\bar{q}} \approx \frac{\Delta\omega}{\bar{\omega}} + \beta\Delta SST$$

Wet-get-wetter



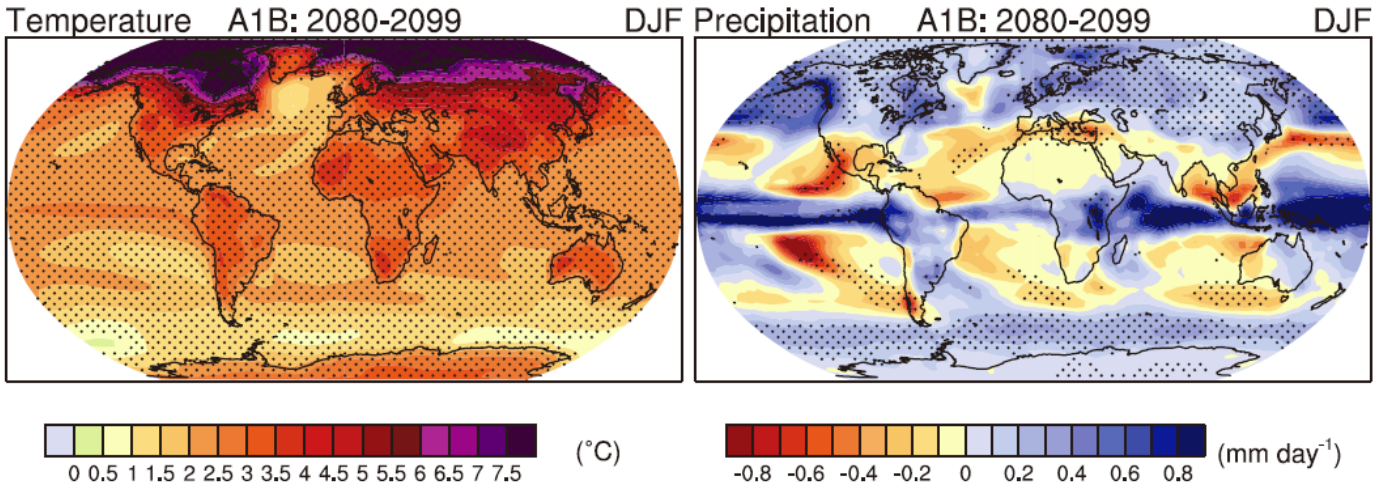
Annual mean follows warmer-get-wetter but the wet-get-wetter effect is obvious in seasonal mean.

- $\Delta\omega$: SST pattern effect with weak seasonal cycle;
- $\bar{\omega}$: > factor of two larger in seasonal than annual mean.

Summary

- SST pattern is important for precip change: The warmer get wetter.
- SST threshold for convection increases with the tropical mean SST
- Inter-model variability in SST pattern accounts for 1/3 of that in precip projection, and 80% of that in Walker/Hadley circulation change.

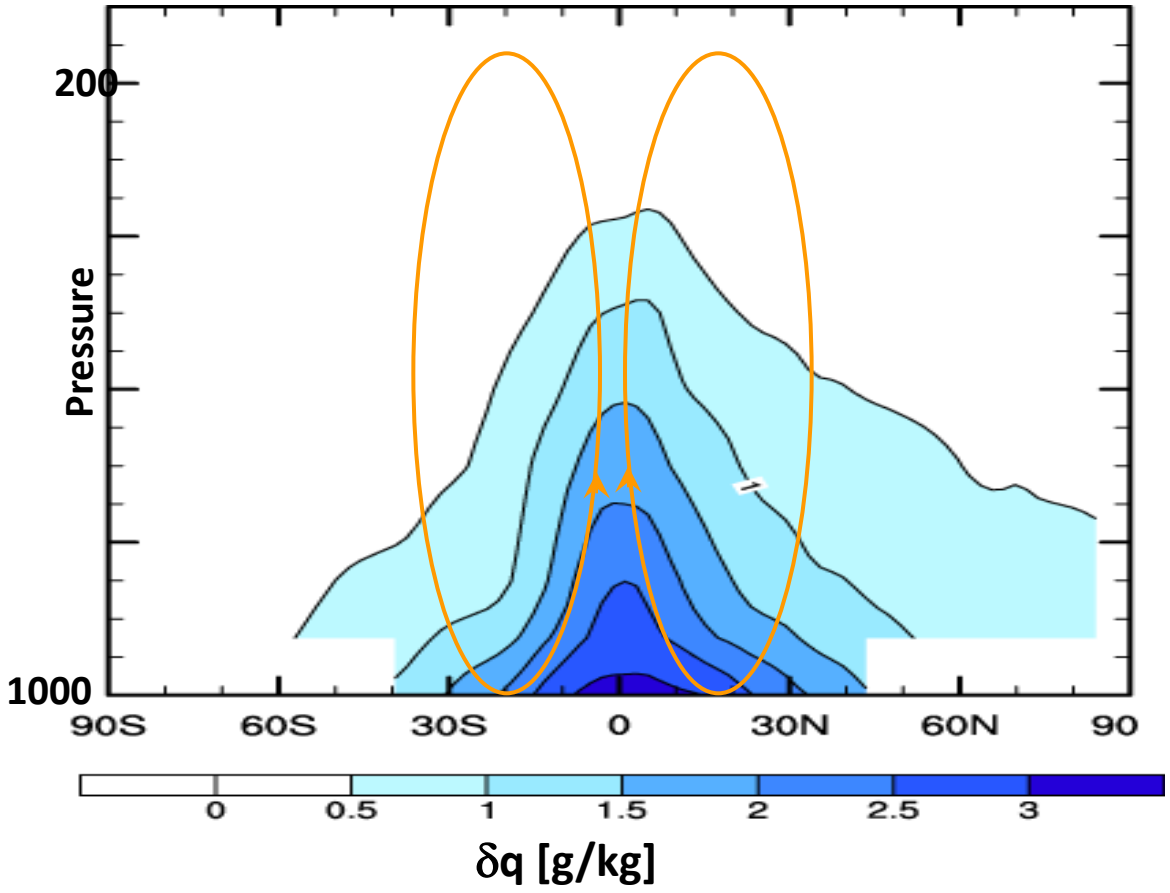
- SST pattern effect dominates the annual-mean precip change but the wet-get-wetter effect is obvious for the seasonal mean change.



What determines rainfall change?

The wet gets wetter

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

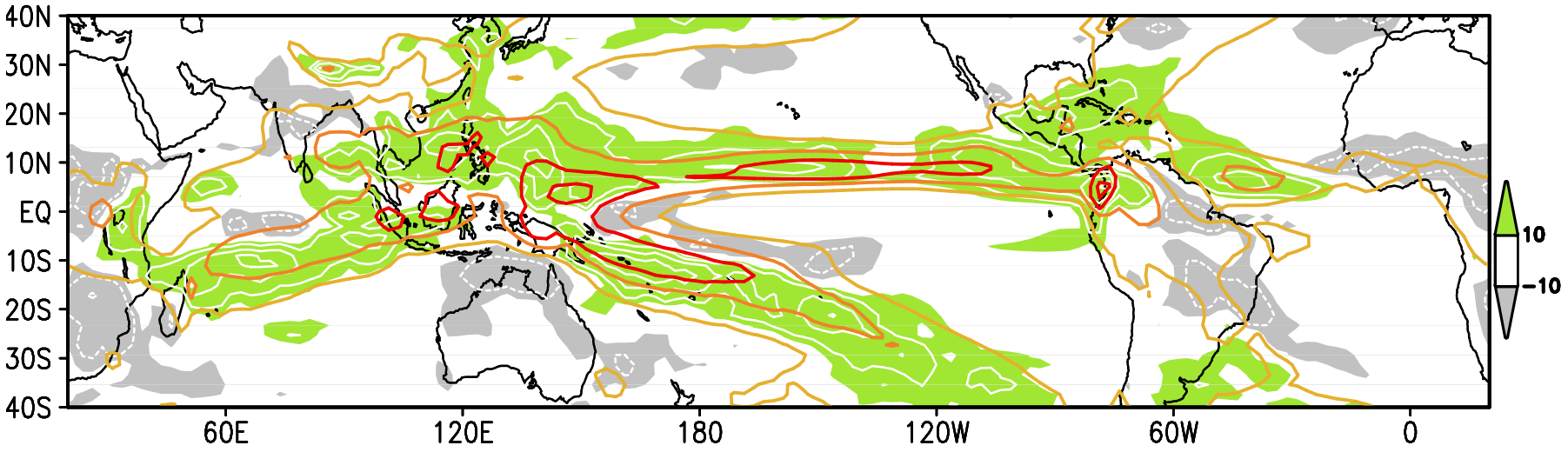


Zonal-mean change in specific humidity

The wet-get-wetter pattern (e.g., Neelin et al. 2003; Held & Soden 2006) is realized in atmospheric response to a uniform SST warming.

But what about in coupled simulations with patterned warming?

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.

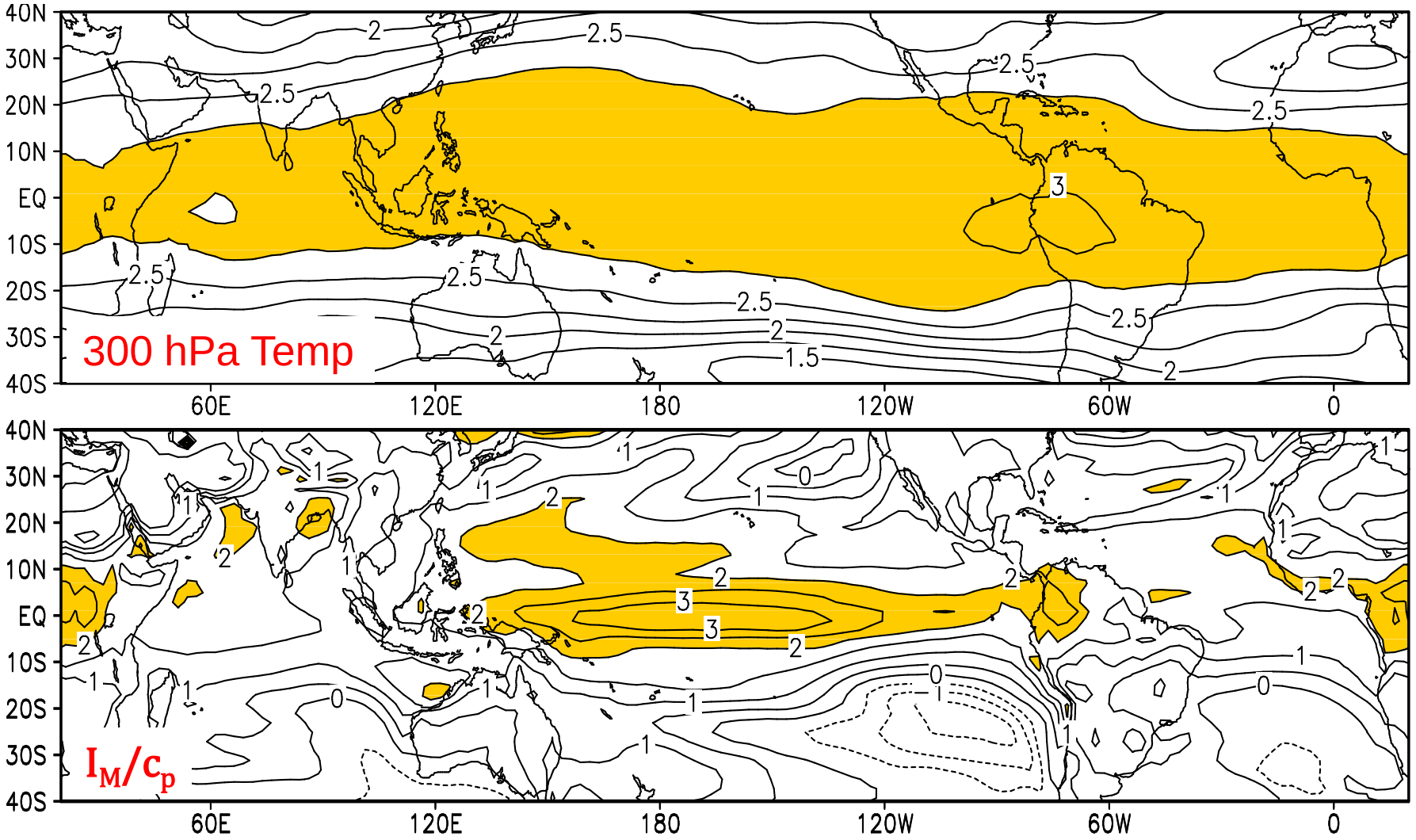


2K uniform SST warming: mean (contour) and change of precipitation

→ Wet-get-wetter pattern

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

- Flat warming in upper troposphere ← equatorial waves
- Convective instability follows closely SST patterns

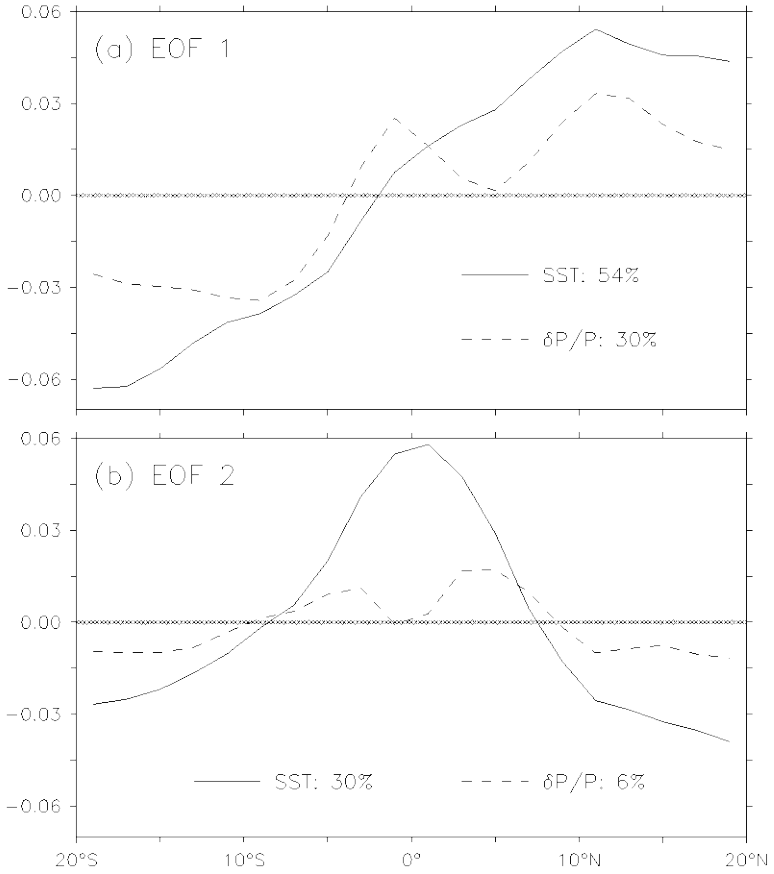


Inter-model variability in tropical rainfall and overturning circulation changes

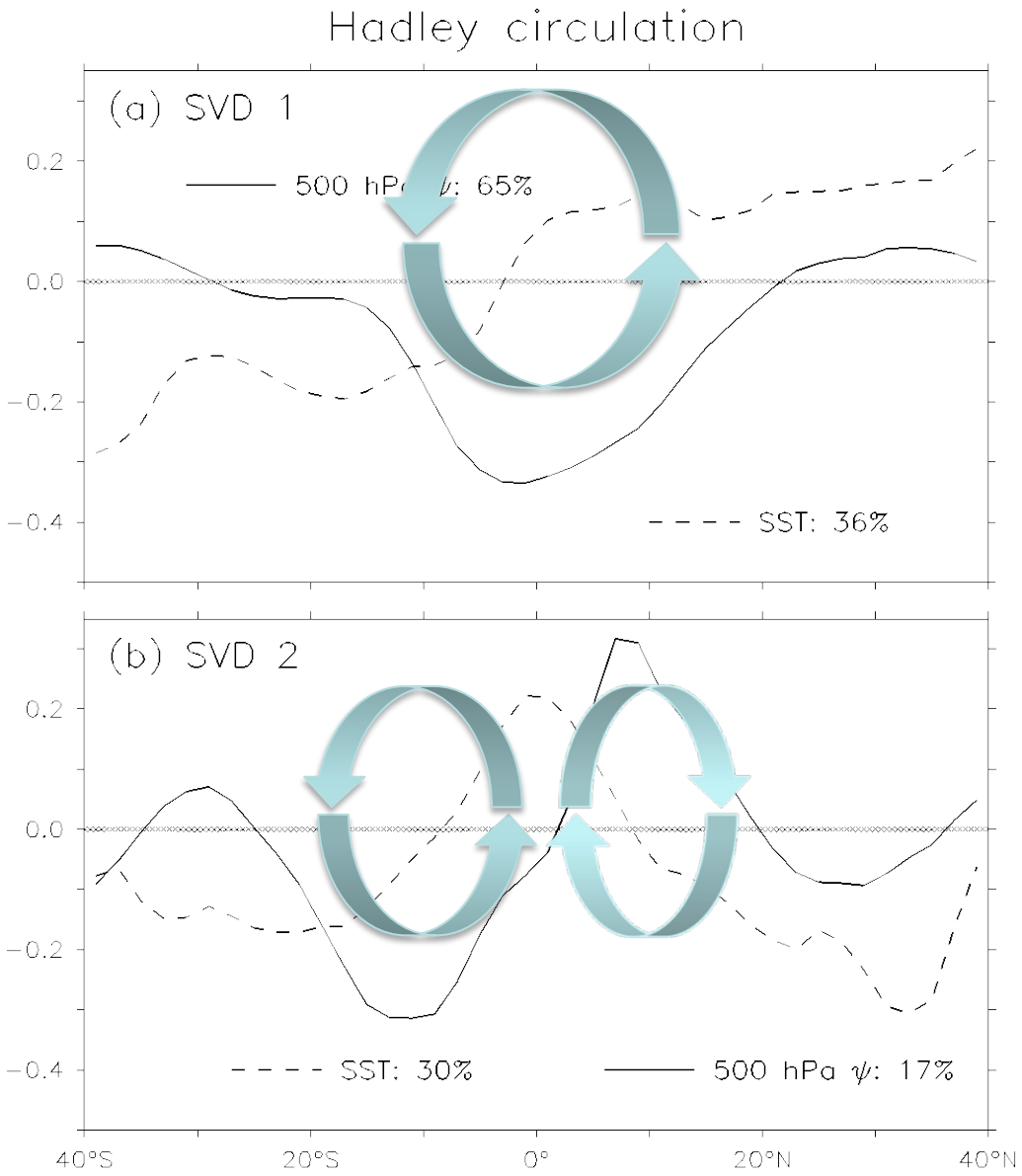
Ma, J., and S.-P. Xie, 2013: Regional patterns of sea surface temperature change: A source of uncertainty in future projections of precipitation and atmospheric circulation. *J. Climate*, 26, 2482-2501.

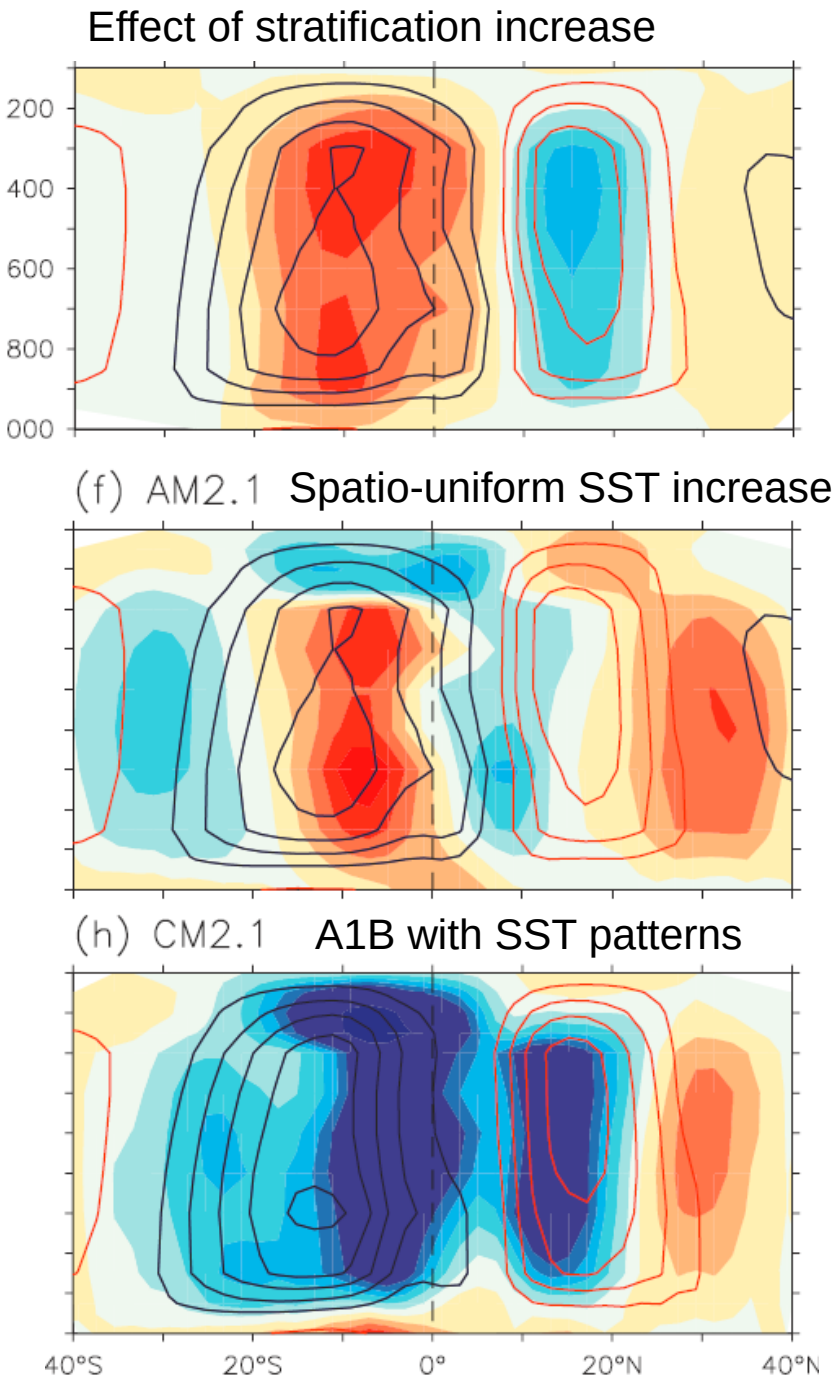
Zonal-mean EOF

- CMIP3 A1B



SVD: SST & Hadley Circulation

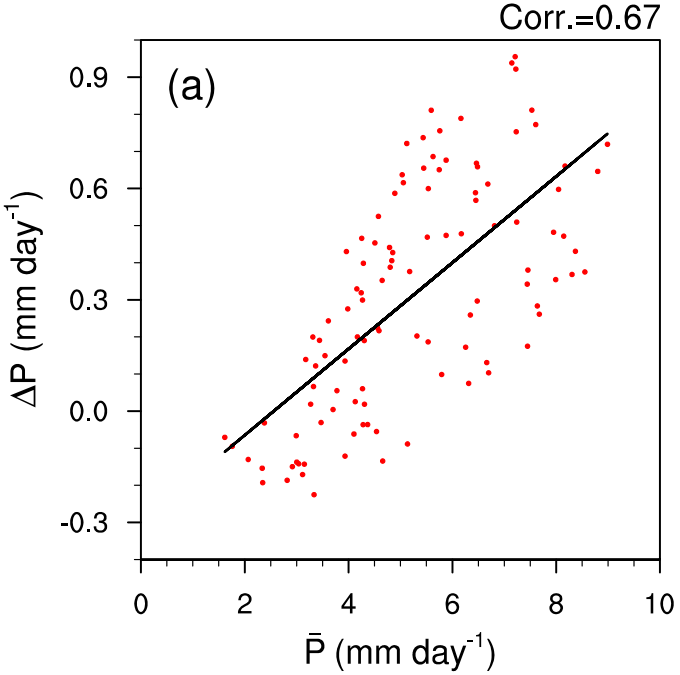


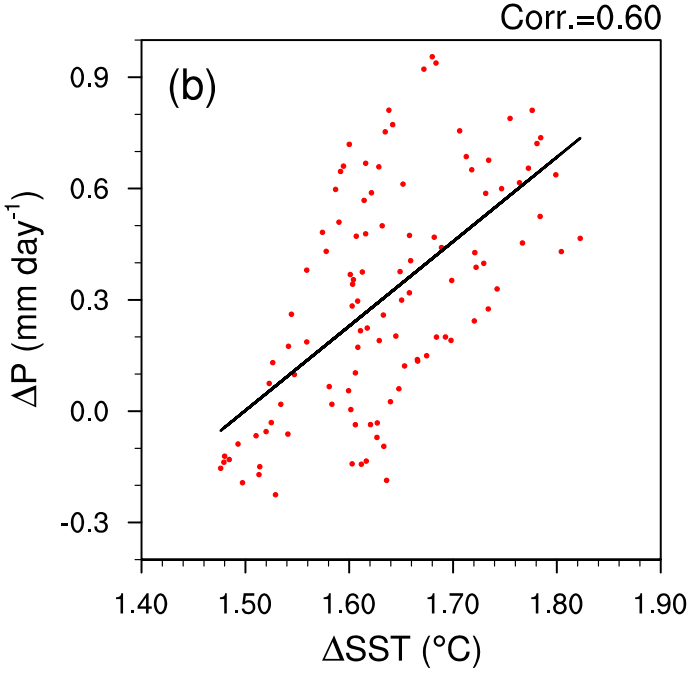


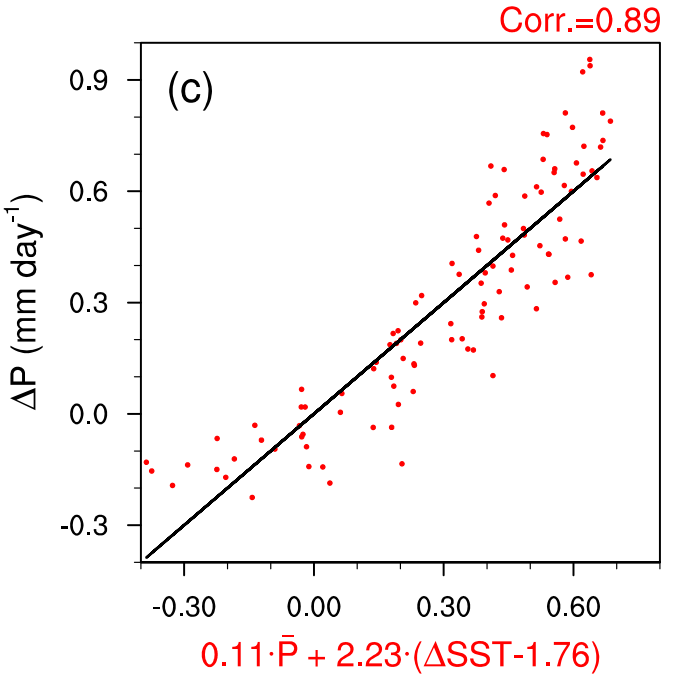
SST & Hadley Cell

Zonal-mean stream function

- NS SST gradient decelerates N cell but accelerates S cell.
- Eq. SST peak accelerates both N & S cells.







$$\Delta P = a\bar{P} + b\left(\Delta \mathrm{SST} - c\right)$$

a=β<ΔSST>, β=0.07 K^{-1}

c=<ΔSST>

<·> tropical mean