Quantifying Tropical Air-sea Interactions

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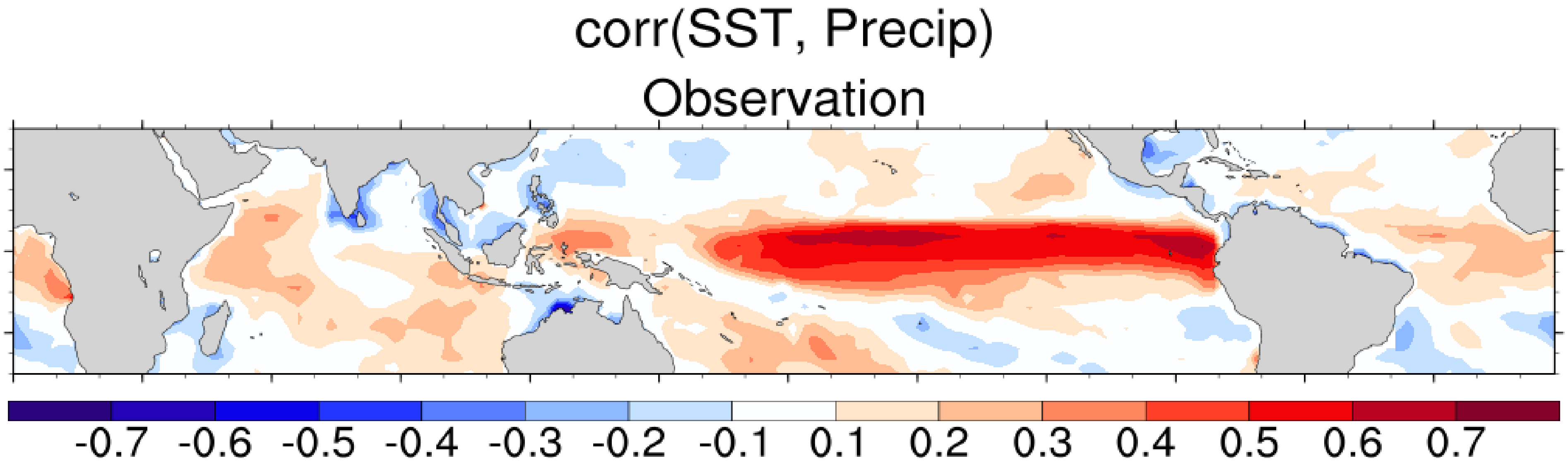
The 2-way air-sea interaction



- *Positive corr*: SST forcing precipitation
- *Negative corr*: precipitation forcing SST

How does convection respond to SST anomalies?

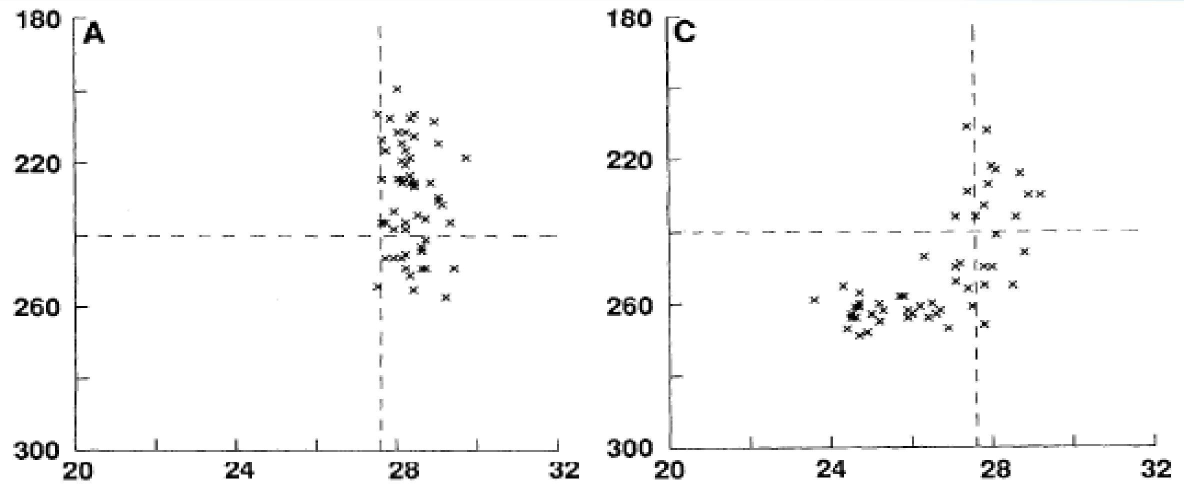
SST > 27.5°C

SST ~ 27.5°C

strong convection

weak convection

OLR W/m^2

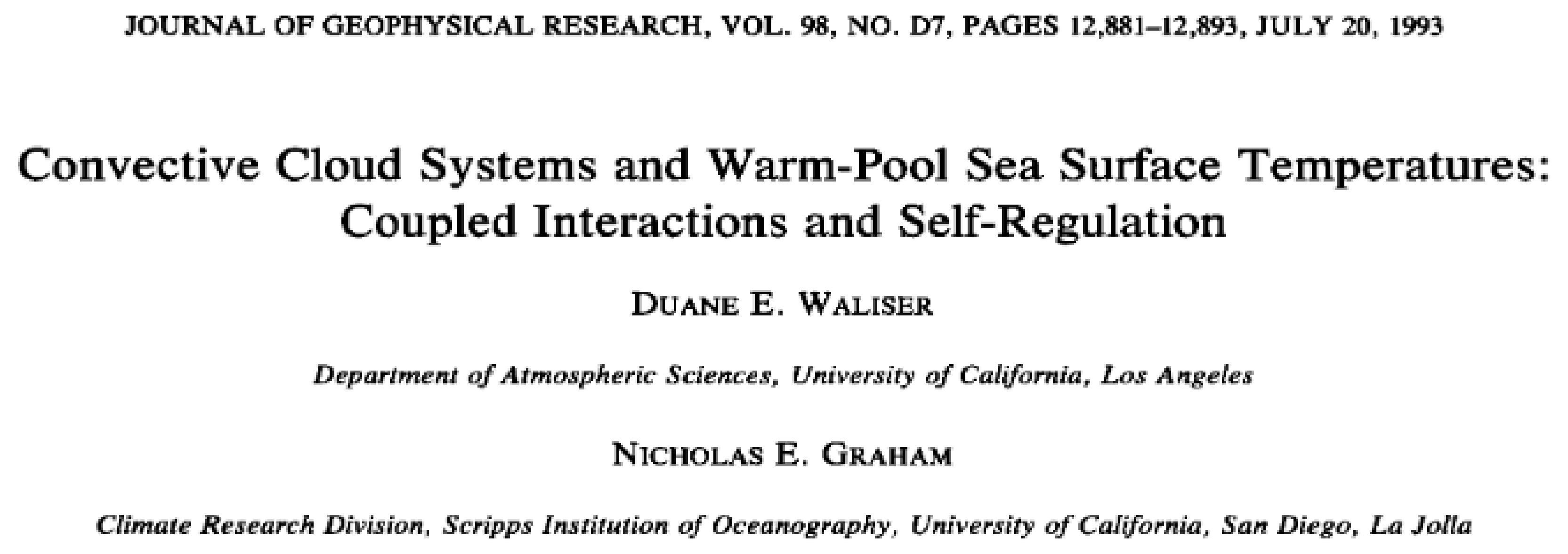


SST °C

(Graham and Barnett 1987, *Science*)

- Weak SST-convection relationship in warm pool regions.

Atmospheric Intrinsic Variability



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Convective Cloud Systems and Warm-Pool Sea Surface Temperatures: Coupled Interactions and Self-Regulation

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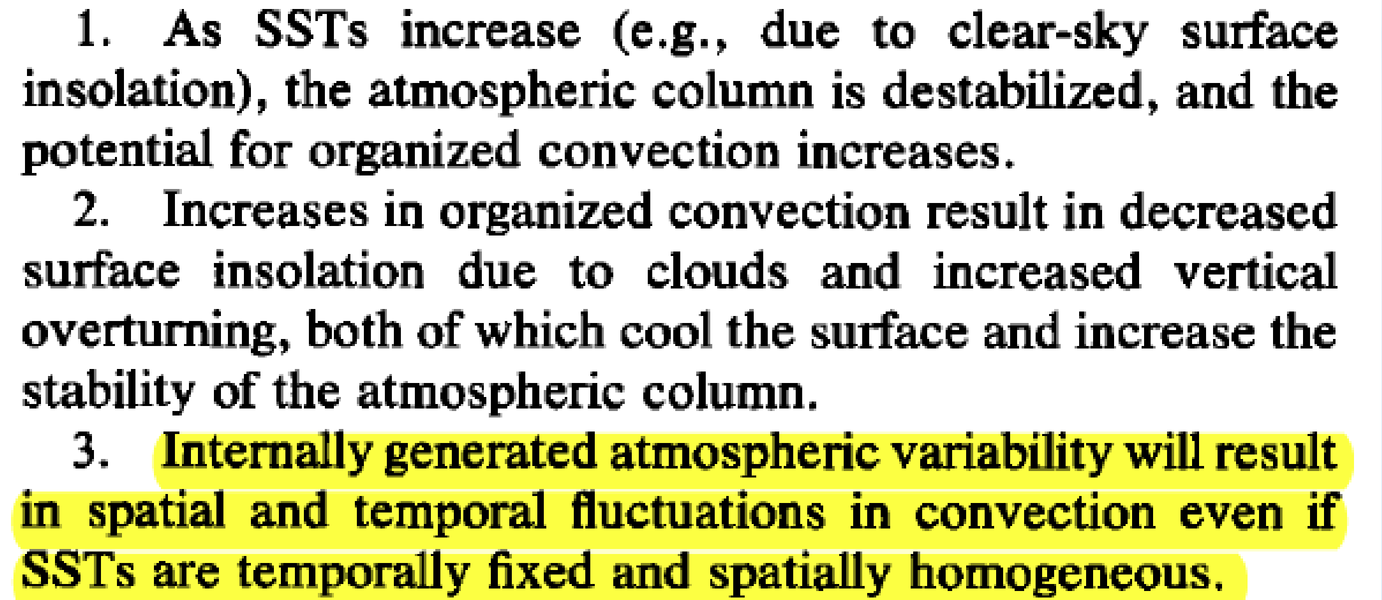
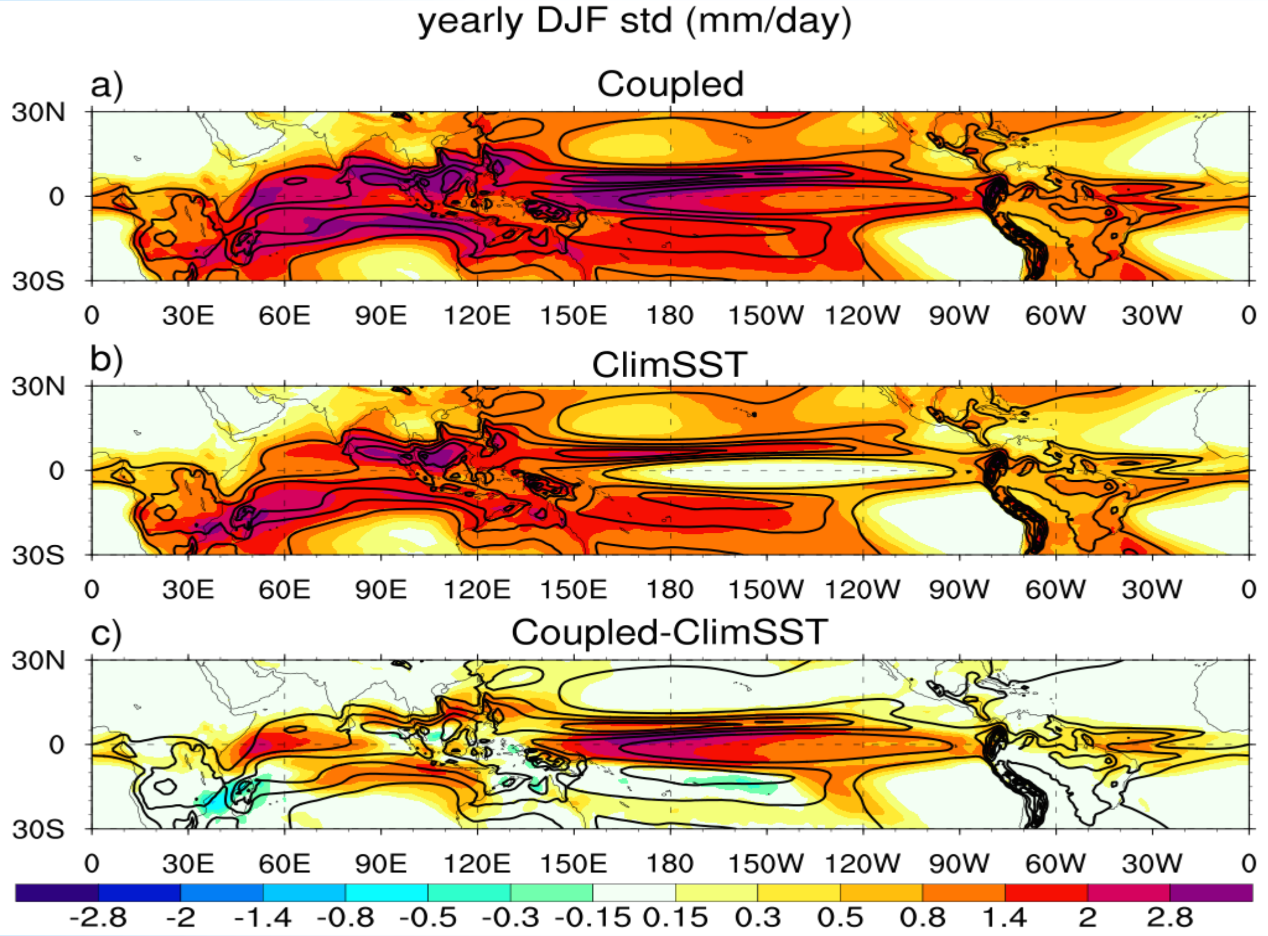


1. As SSTs increase (e.g., due to clear-sky surface insolation), the atmospheric column is destabilized, and the potential for organized convection increases.
2. Increases in organized convection result in decreased surface insolation due to clouds and increased vertical overturning, both of which cool the surface and increase the stability of the atmospheric column.
3. Internally generated atmospheric variability will result in spatial and temporal fluctuations in convection even if SSTs are temporally fixed and spatially homogeneous.

Atmospheric intrinsic variability



Total

Atmospheric intrinsic

Ocean driven

He et al. 2017 *J. Climate*

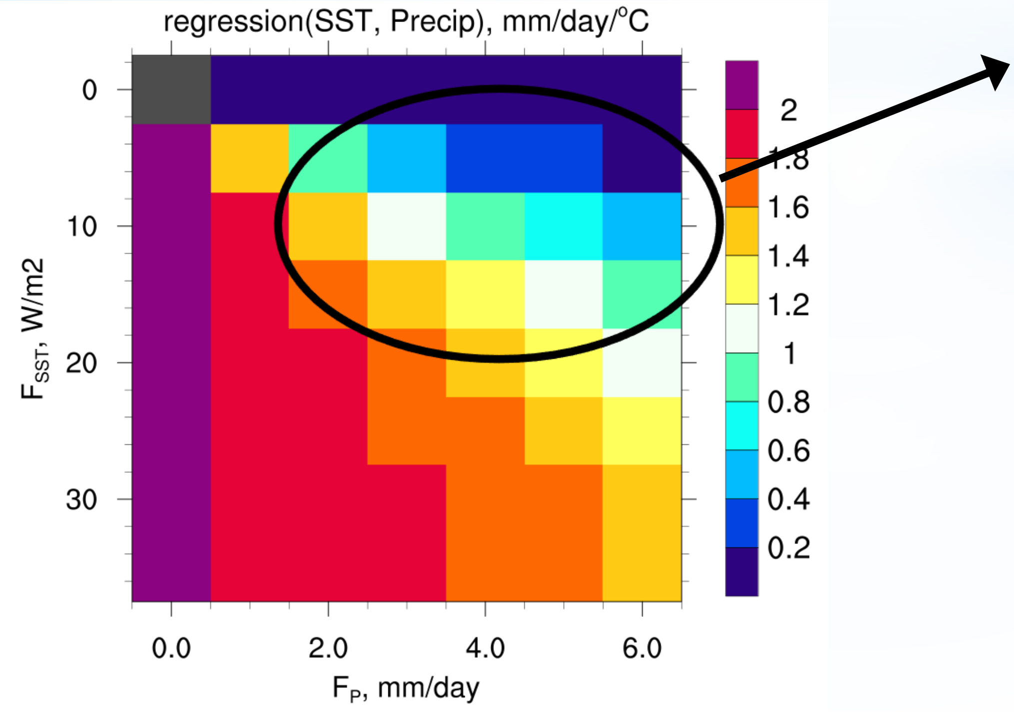
- Substantial amount of precip variability can be driven by atmospheric intrinsic dynamics.

SST-P relationship in coupled systems

$$P' = a \cdot SST' + F_P$$

$$\frac{dSST'}{dt} = \frac{1}{c_p r_w H}(b \cdot P' + F_{SST})$$

a=2 (mm/day)/°C; b=-3 (W/m^2)/(mm/day)

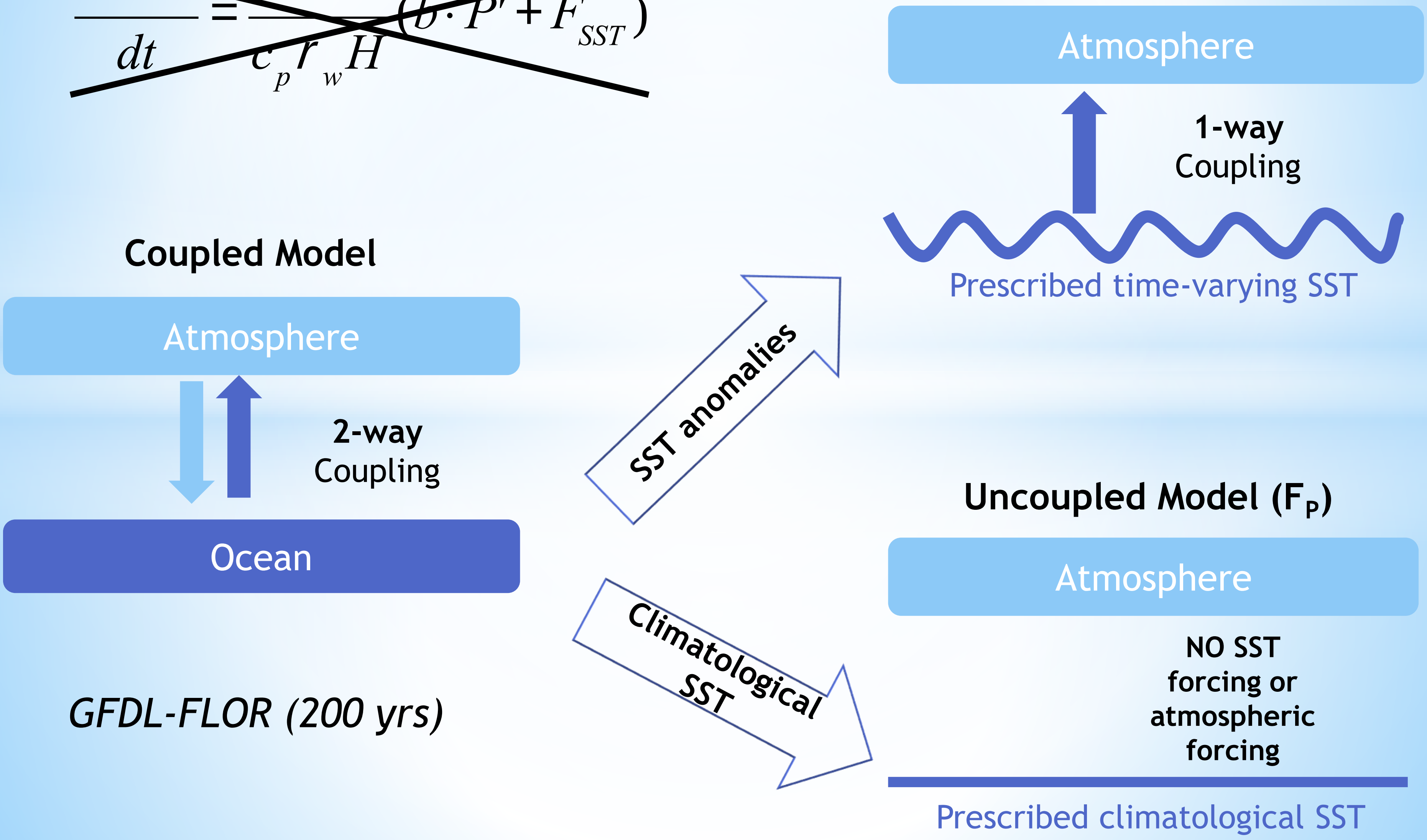


If F_P is large and F_{SST} is small (e.g., ITCZ), it would appear in a coupled system that the SST forcing is much less than 2 (mm/day)/°C.

SST-P relationship in uncoupled systems

$$P' = a \times SST' + F_P$$

$$\xcancel{\frac{dSST'}{dt} = \frac{1}{c_p r_w H}(b \cdot P' + F_{SST})}$$



Coupled Model

Atmosphere

2-way
Coupling

Ocean

GFDL-FLOR (200 yrs)

SST anomalies

Climatological SST

Uncoupled Model (a)

Atmosphere

1-way
Coupling

Prescribed time-varying SST

Uncoupled Model (F_P)

Atmosphere

NO SST forcing or atmospheric forcing

Prescribed climatological SST

A Linear Framework

$$\frac{\partial SST'}{\partial t} = \frac{1}{c_p r_w H}(SW' + LW' - E' - SH')$$

uncoupled
SST anomalies

uncoupled
clim SSTs

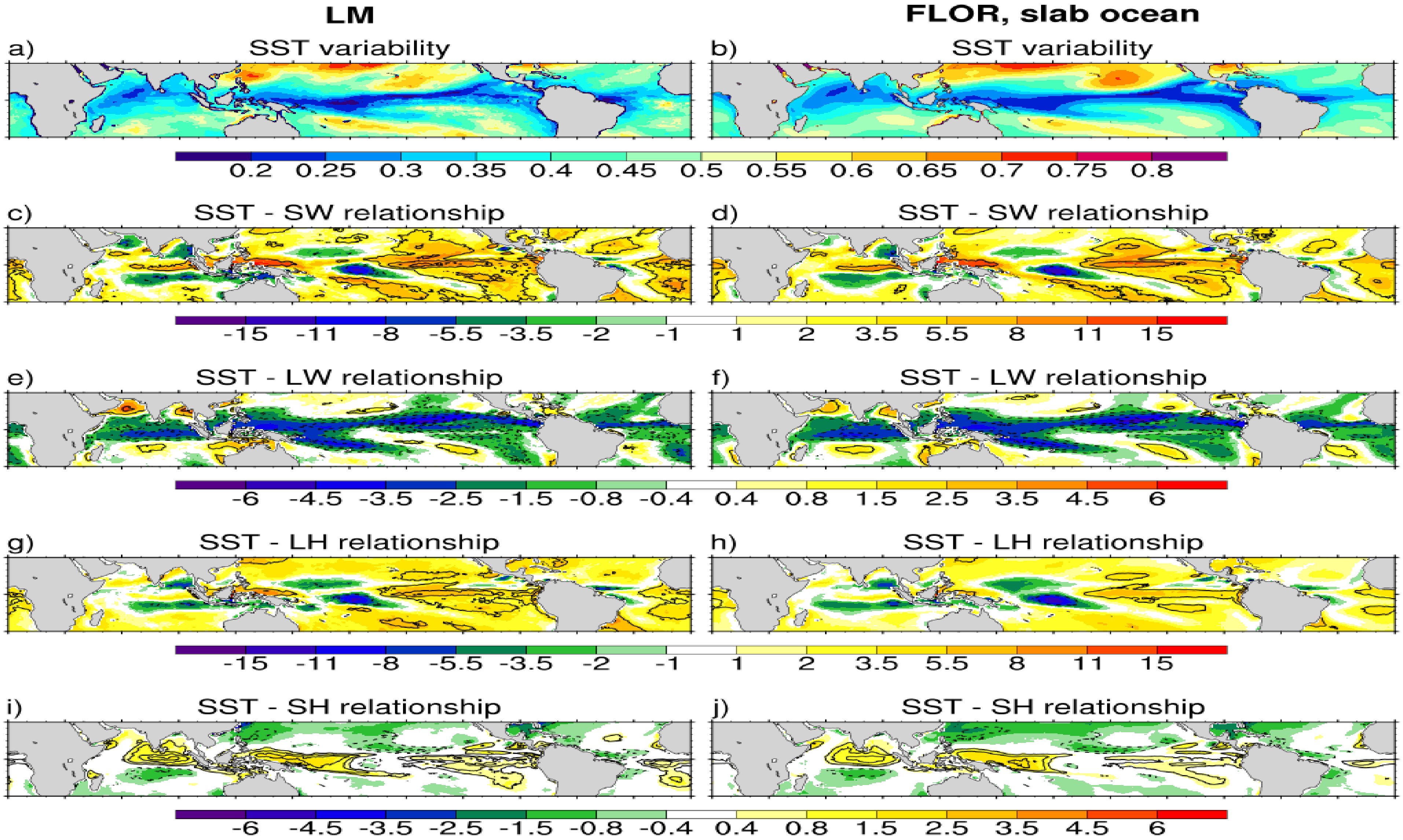
$$SW' = \frac{\partial SW}{\partial SST} \cdot SST' + F_{SW}$$

$$LW' = \frac{\partial LW}{\partial SST} \cdot SST' + F_{LW}$$

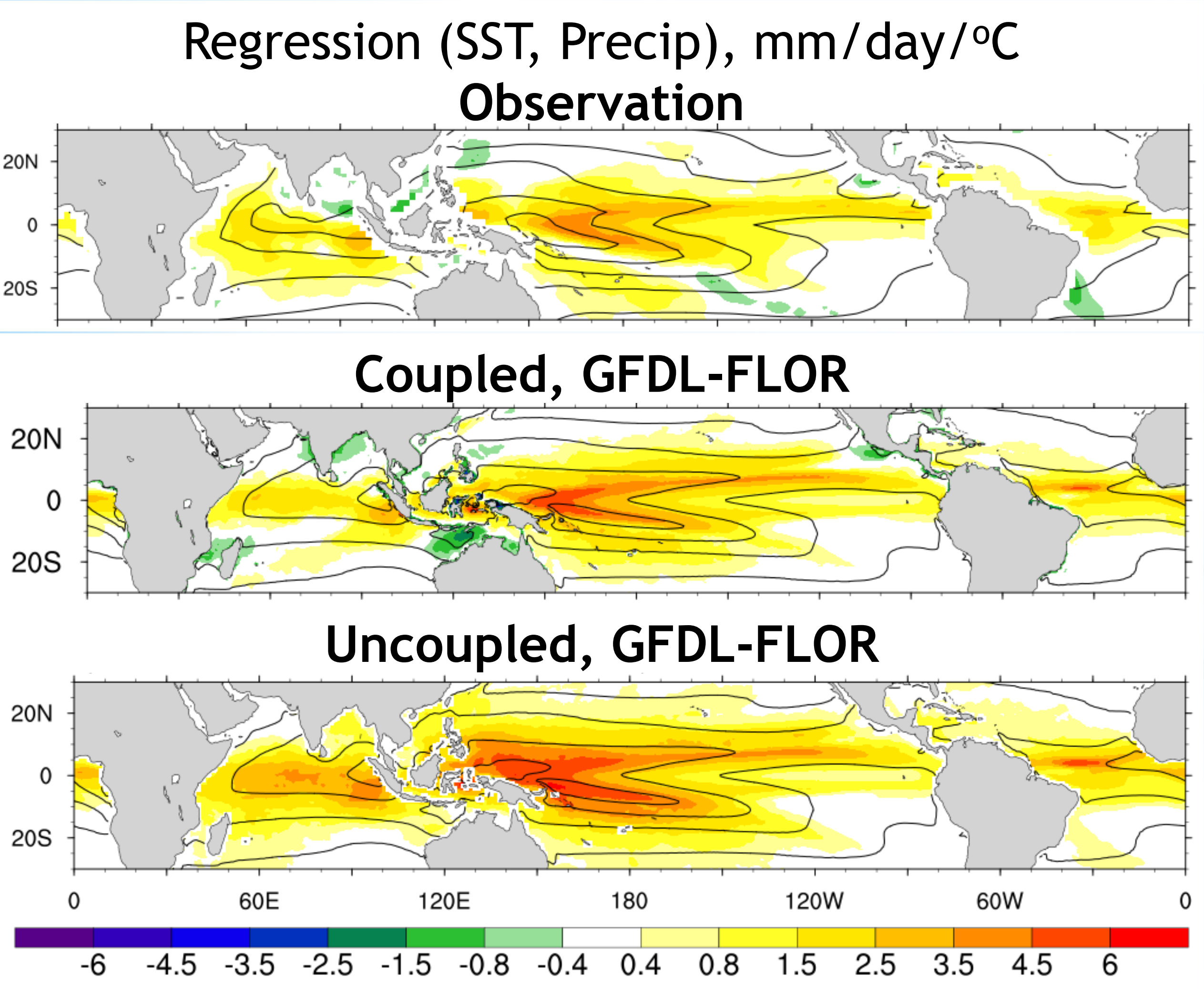
$$E' = \frac{\partial E}{\partial SST} \cdot SST' + F_{E}$$

$$SH' = \frac{\partial SH}{\partial SST} \cdot SST' + F_{SH}$$

Linear Model vs. CGCM (slab ocean)



Convection sensitivity to SST variability

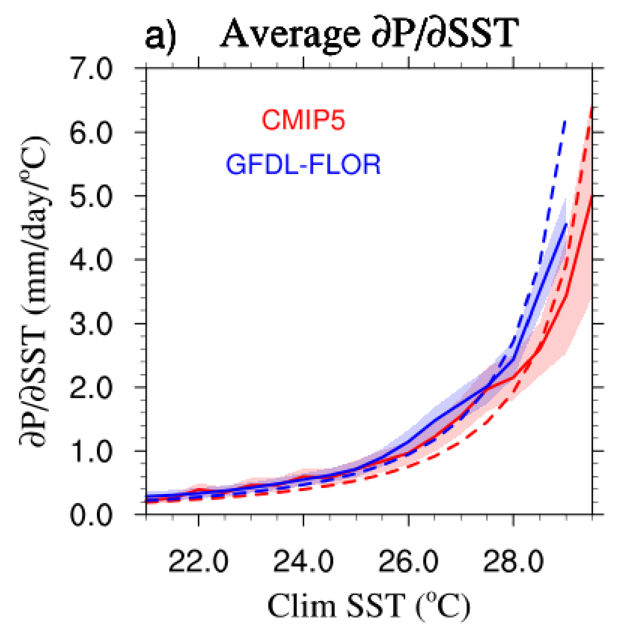


Regression (SST, Precip), mm/day/^{o}C

Observation

Coupled, GFDL-FLOR

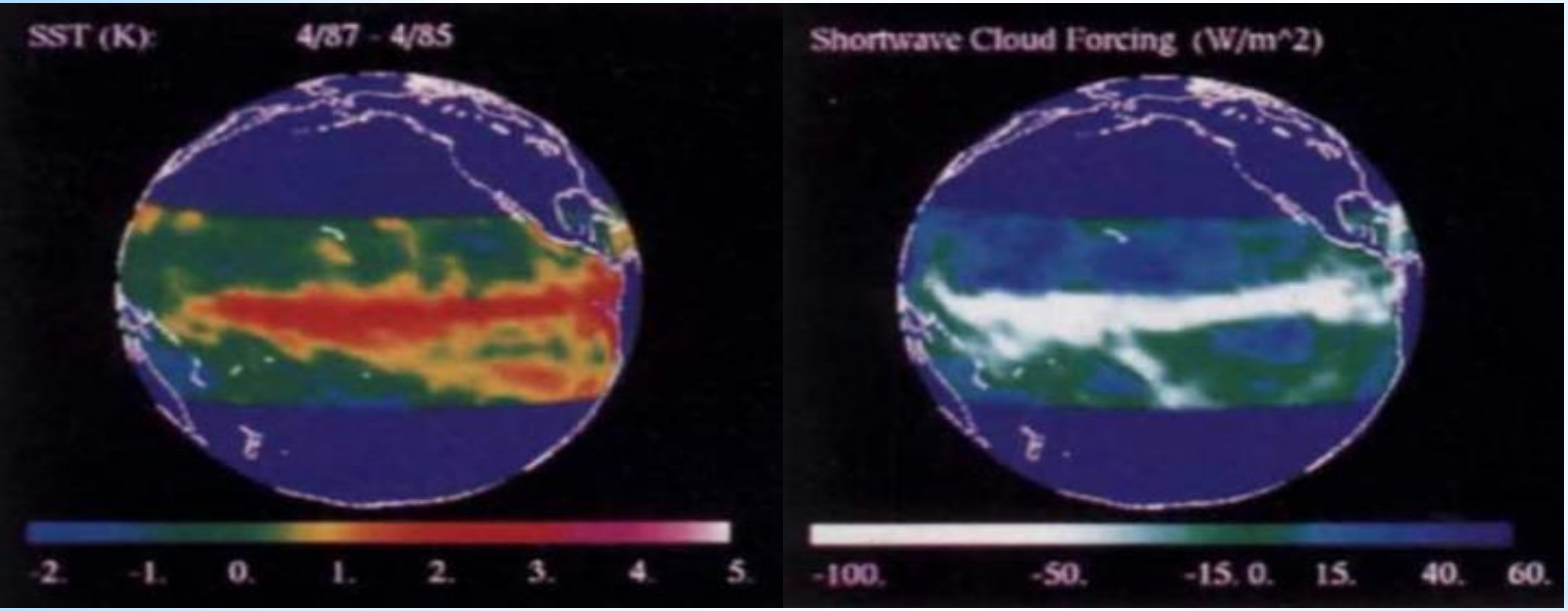
Uncoupled, GFDL-FLOR



a) Average ∂P/∂SST

He et al. 2018, Precipitation sensitivity to local variations in tropical sea surface temperature. *J. Climate*, doi:10.1175/JCLI-D-18-0262.1.

Atmospheric regulation of SST variability



“Cirrus cloud thermostat”

Ramanathan & Collins 1991 *Nature*

Lebsock et al. 2009 *J. Climate*

Lloyd et al. 2012 *J. Climate*

Wall et al. 2018 *J. Climate*

Counter arguments

Fu et al. 1992 *Nature*

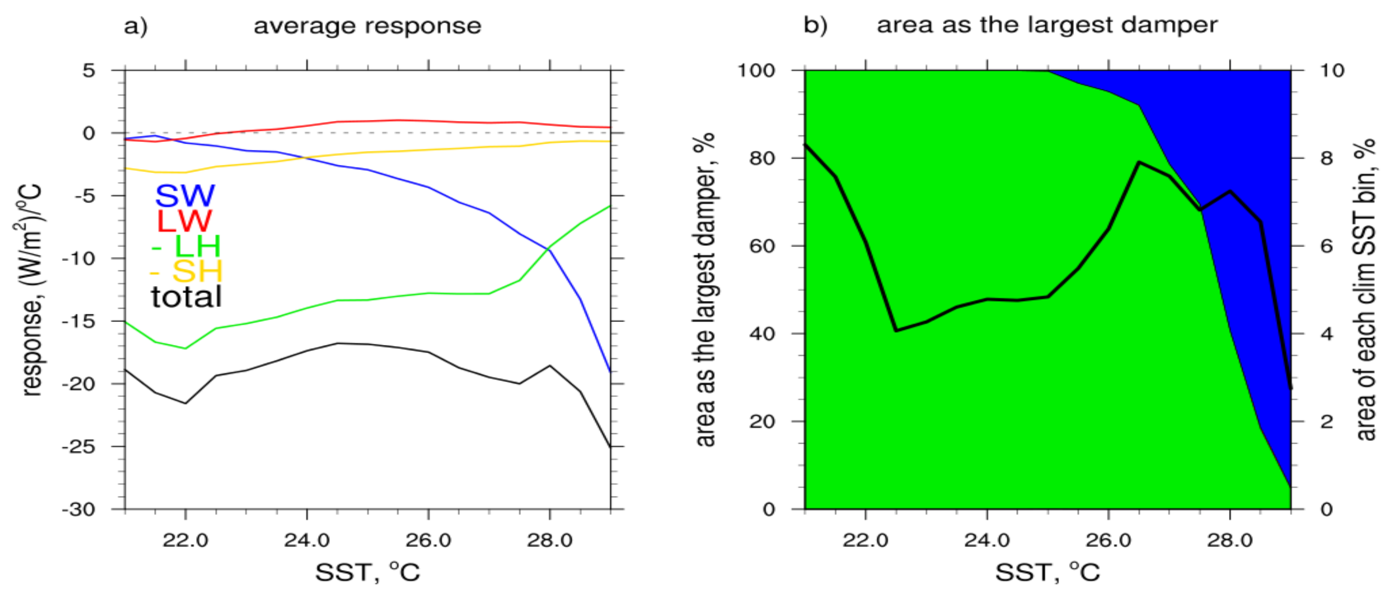
Hartmann & Michelsen 1993 *J. Climate*

Arking & Ziskin, 1994 *J. Climate*

Xue et al. 2014 *JGR*

Atmospheric regulation of SST variability

$$FLX' = a \cdot SST' + F_{FLX}$$



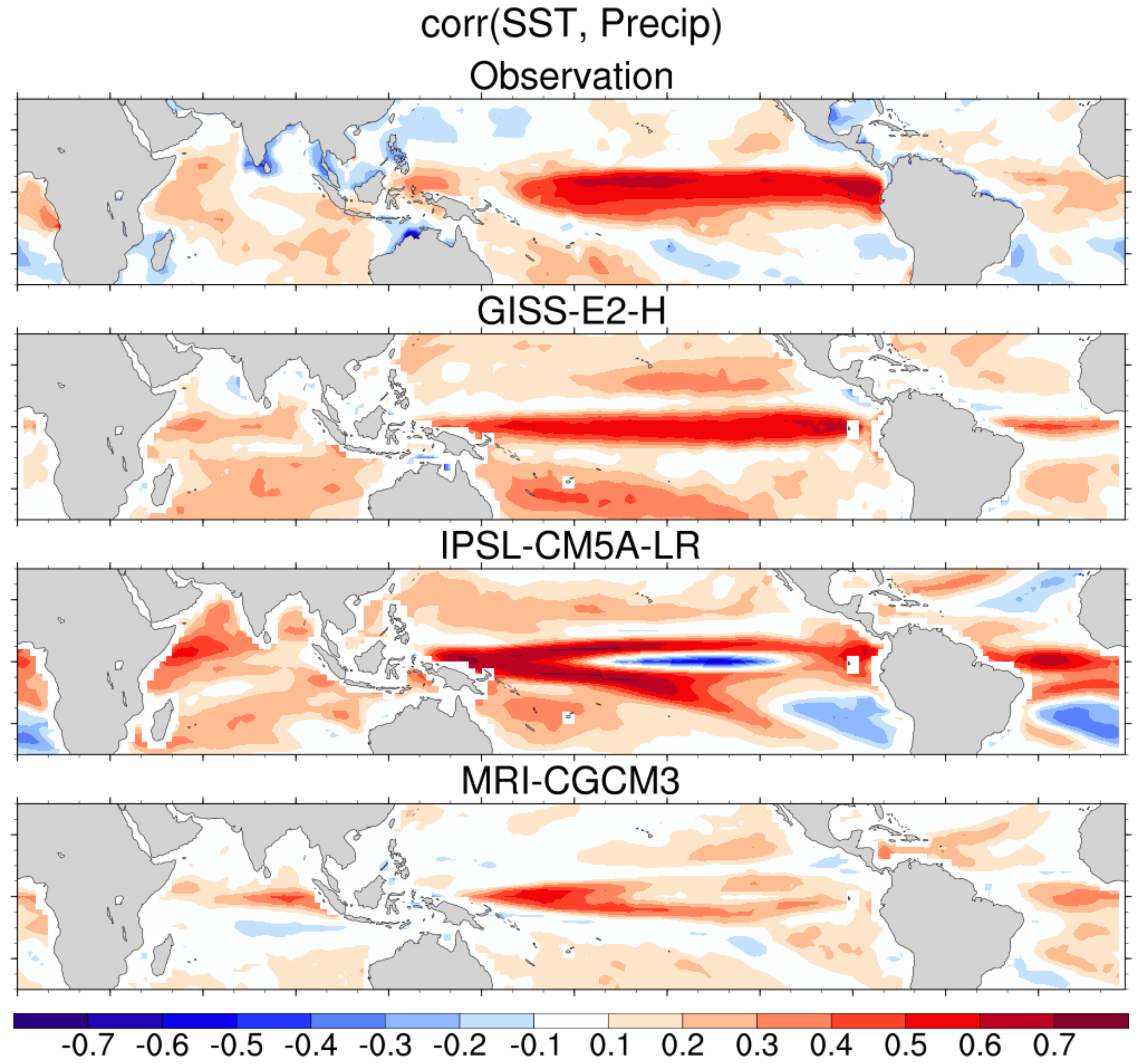
- Convection is the strongest damping mechanism at high SSTs
- Evaporation is the strongest damping mechanism at low SSTs.

Summary

- Uncoupled simulations can be ideal tools for dissecting and quantifying atmospheric and oceanic forcing.
- SST forcing of precipitation is a monotonically increasing function of the base SST.
- Convection provides the strongest damping mechanism for SST variability at high SSTs, whereas evaporation is the strongest damping mechanism at low SSTs.

Thank you

AGCM as a diagnostic tool?



- Large biases in the simulation of air-sea relationship from current CGCMs.
- AGCM can be used to dissect atmospheric forcing and oceanic forcing.

A Linear Framework

$$\frac{\partial SST'}{\partial t} = \frac{1}{c_p r_w H}(SW' + LW' - E' - SH' + F_{dyn})$$

ENSO related ocean dynamic forcing

uncoupled SST anomalies

uncoupled clim SSTs

$$LW' = \frac{\partial LW}{\partial SST} \cdot SST' + F_{LW}$$

$$SH' = \frac{\partial SH}{\partial SST} \cdot SST' + F_{SH}$$

$$E' = \frac{\partial E}{\partial SST} \cdot SST' + F_{E}$$

$$SW' = \frac{\partial SW}{\partial SST} \cdot SST' + F_{SW} \left\{ \begin{array}{l} SW' = C_{SW} \cdot P' \\ C_{SW} = regression(P, SW) \\ P' = \dfrac{\partial P}{\partial SST} \cdot SST' + F_{P} \end{array} \right.$$

Tropical SST variability

$$\frac{dSST'}{dt} = \frac{1}{c_p r_w H}(SW' + LW' - E' - SH' + F_{dyn})$$

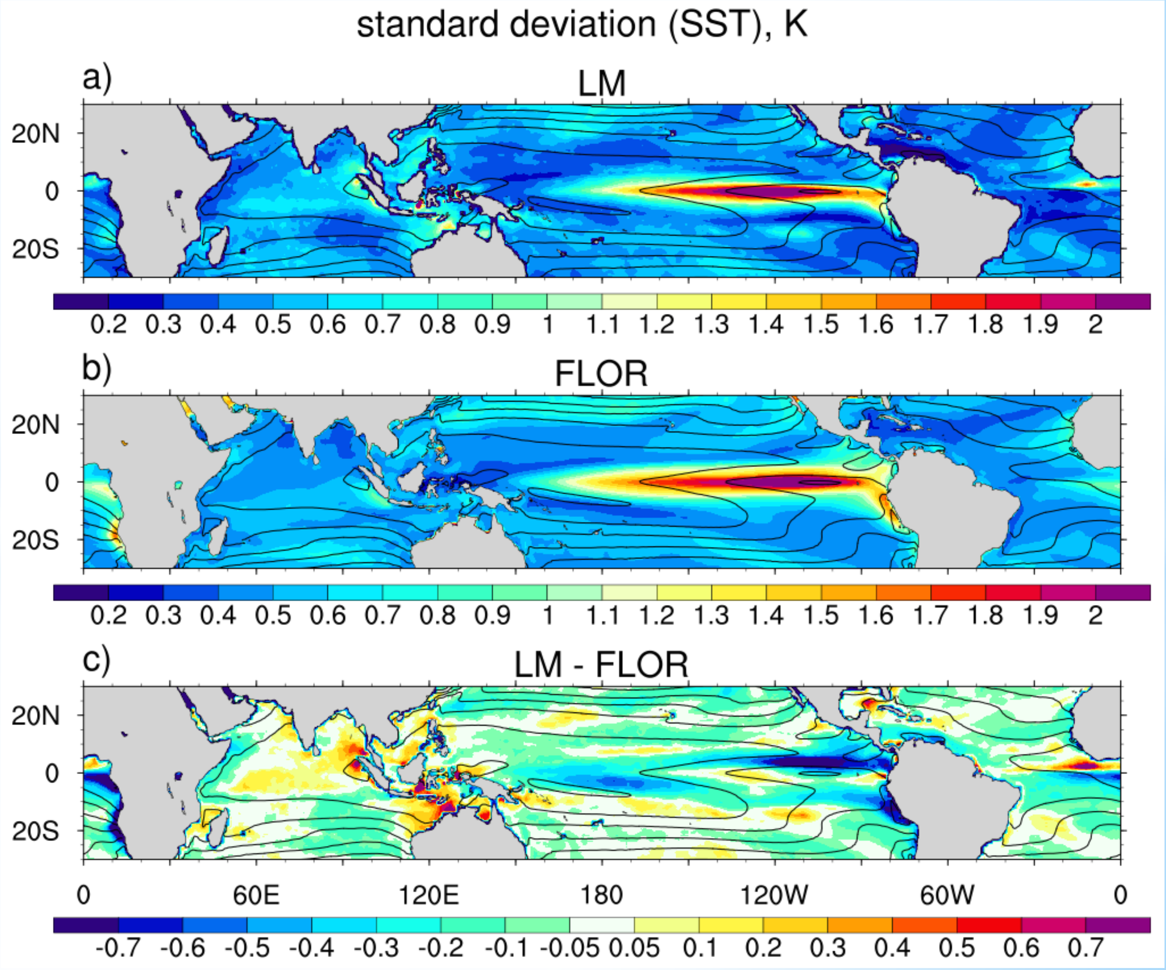
$$LW' = \frac{\partial LW}{\partial SST} \cdot SST' + F_{LW}$$

$$E' = \frac{\partial E}{\partial SST} \cdot SST' + F_E$$

$$SH' = \frac{\partial SH}{\partial SST} \cdot SST' + F_{SH}$$

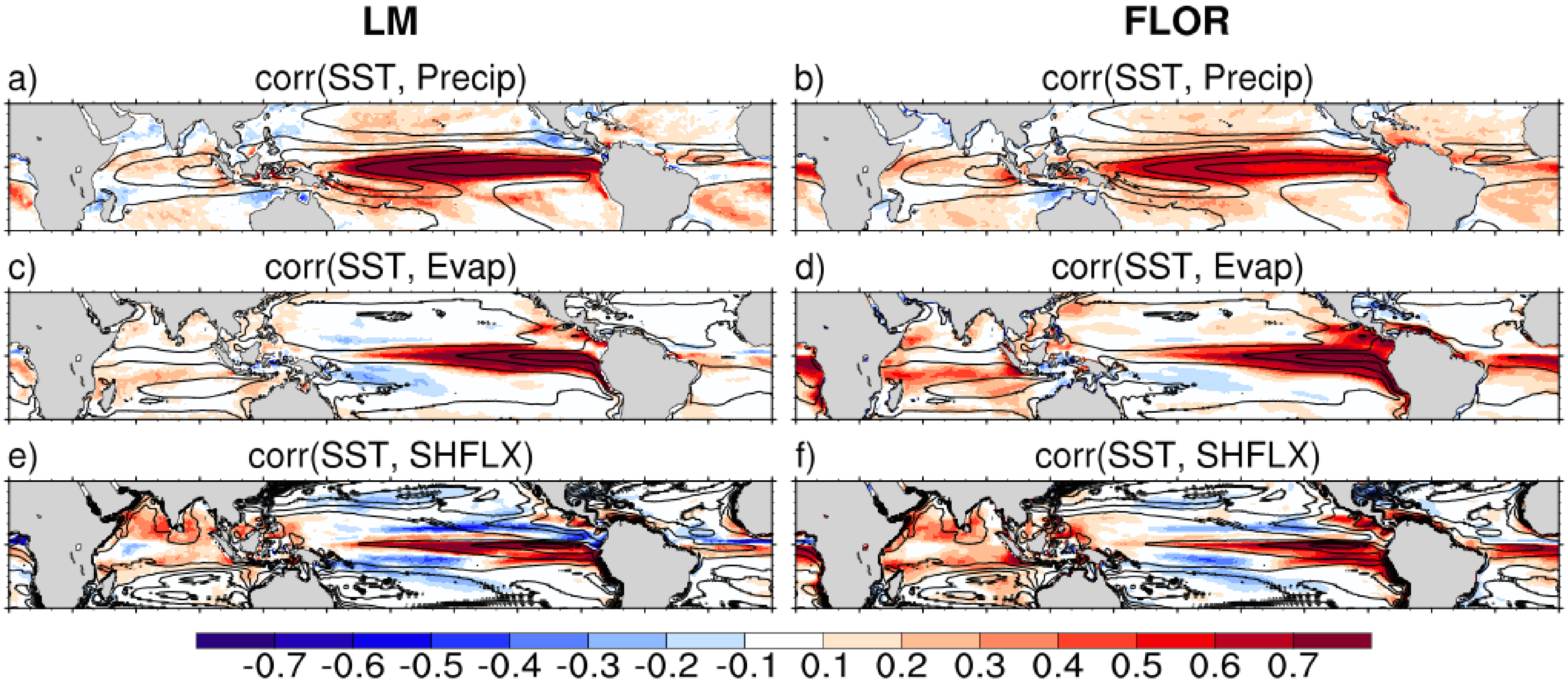
$$P' = \frac{\partial P}{\partial SST} \cdot SST' + F_P$$

$$SW' = C_{SW} \cdot P'$$



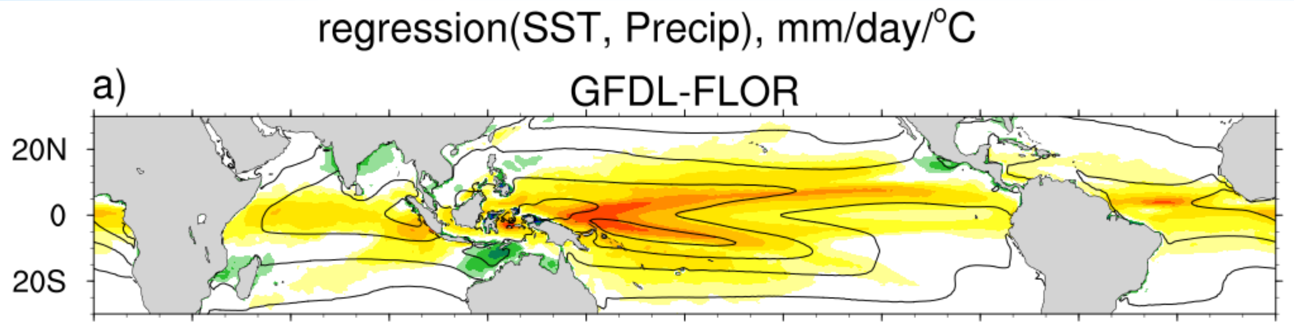
- LM simulates tropical SST variability reasonably well.

Local air-sea relationship



- LM reasonably reproduces the local air-sea relationship from the CGCM.

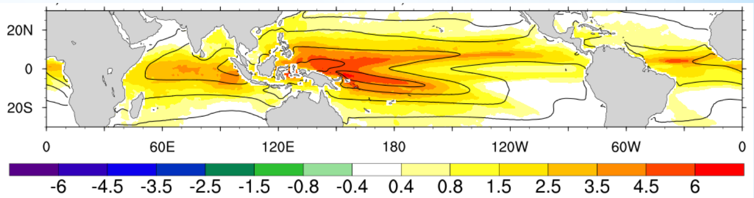
Coupled SST-P relationship


regression(SST, Precip), mm/day/°C

$$P' = a \cdot SST' + F_P$$

$$\frac{dSST'}{dt} = \frac{1}{c_p r_w H}(b \cdot P' + F_{SST})$$

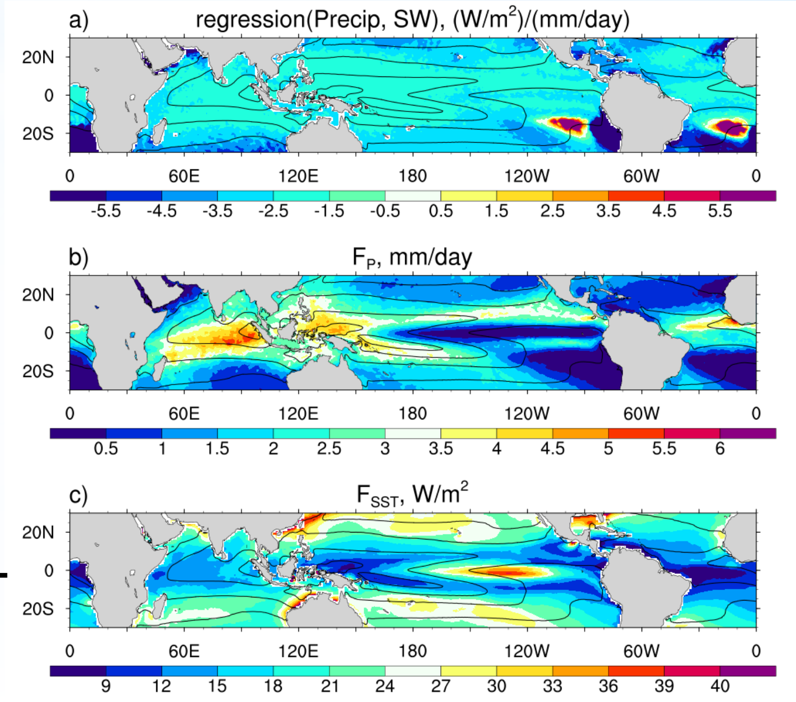
a



b

F_P

F_{SST}


a) regression(Precip, SW), (W/m^2)/(mm/day)

b) F_P, mm/day

c) F_{SST}, W/m^2