The Paradox of Tropical-Averaged Precipitation Anomalies

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- **Approximate Linear Relationship Between Tropical Tropospheric Temperature Anomalies and SST Anomalies**

- ***Expectation*:**

  SST Anom.=> Convective Heating (Prec.) Anom.=>Temp. Anom.

  ***Observation*:**

  Scattered Tropical-Average Precipitation Anomalies

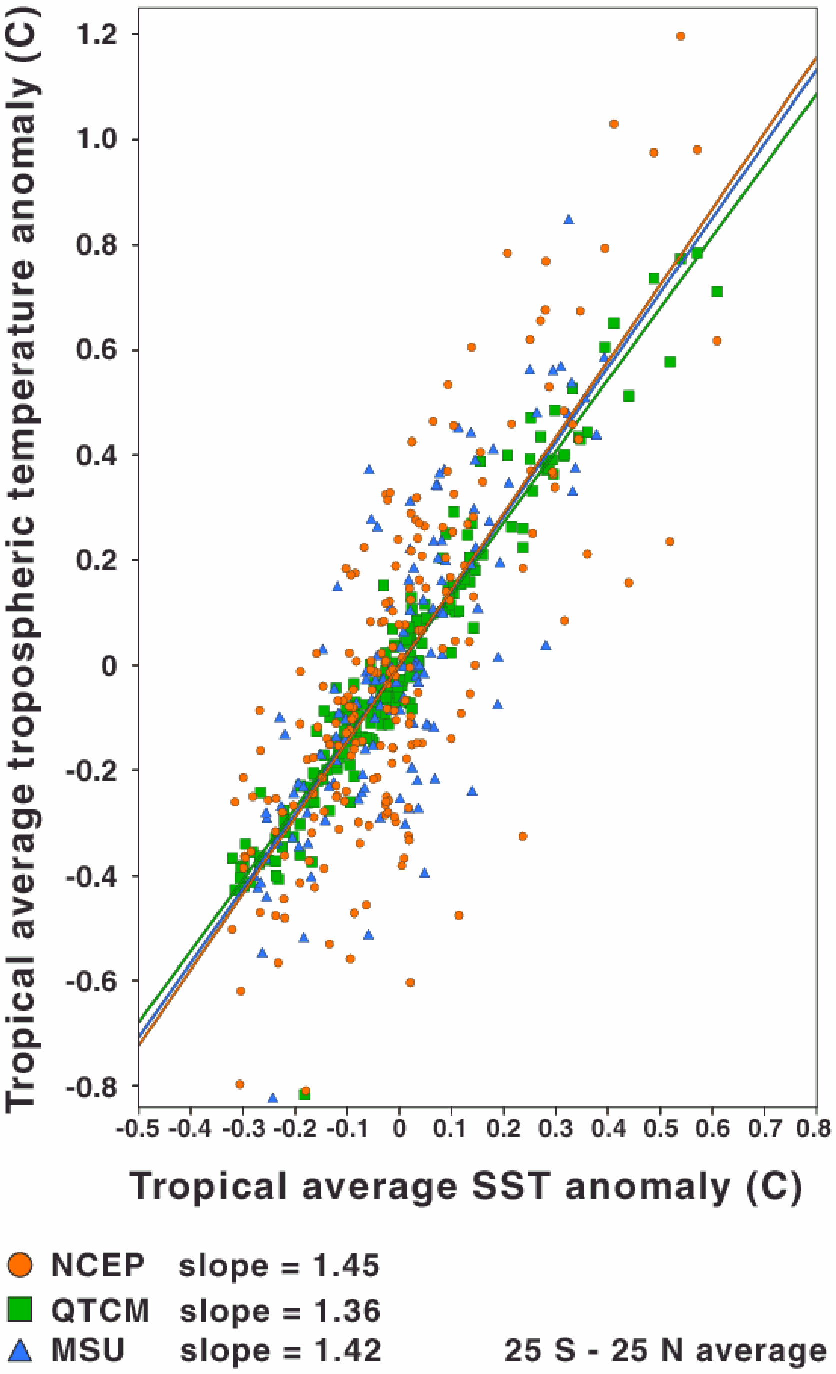
  No Simple Relation to SST Anomalies

- **Reconcile Tropical SST, Precipitation and Tropospheric Temperature Relationship Using a Simple Analytical Model**

Tropical averaged (25S-25N) tropospheric temperature anomalies versus tropical averaged SST anomalies

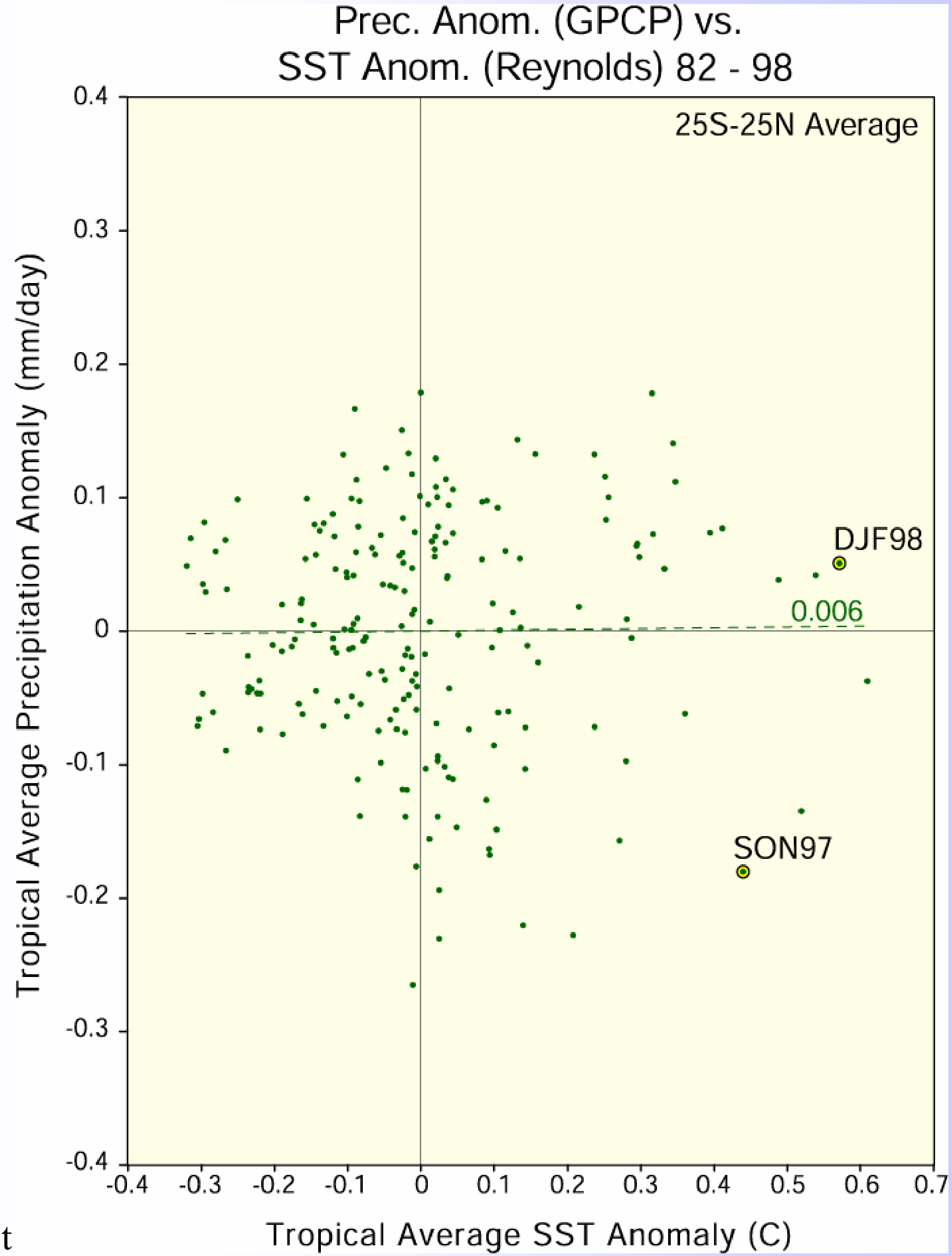
- NCAR/NCEP reanalysis (1982-1998)
- MSU temperature (1982-1993)
- QTCM simulation using observed SST from 1982-1998 (Su et al. 2003)

Slopes of linear fits to each dataset:



Tropical averaged precipitation anomalies versus tropical averaged SST anomalies

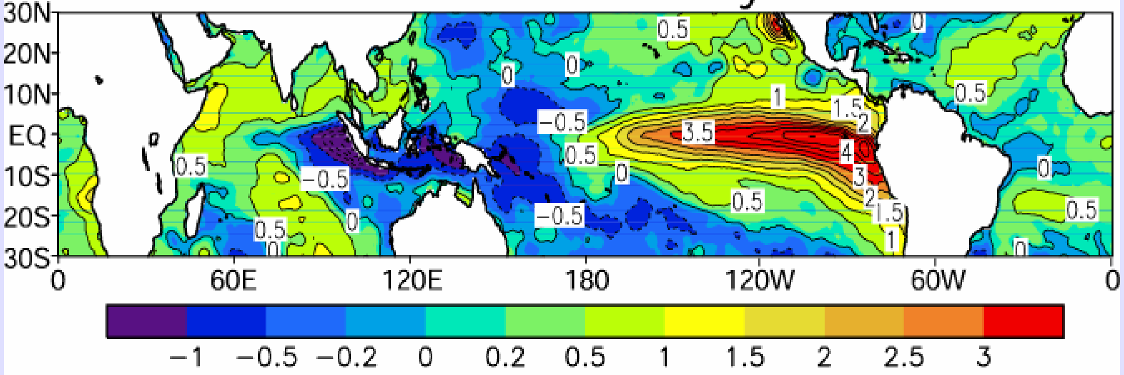
- **GPCP (Huffman et al., 1997) Precipitation from 1982-1998**

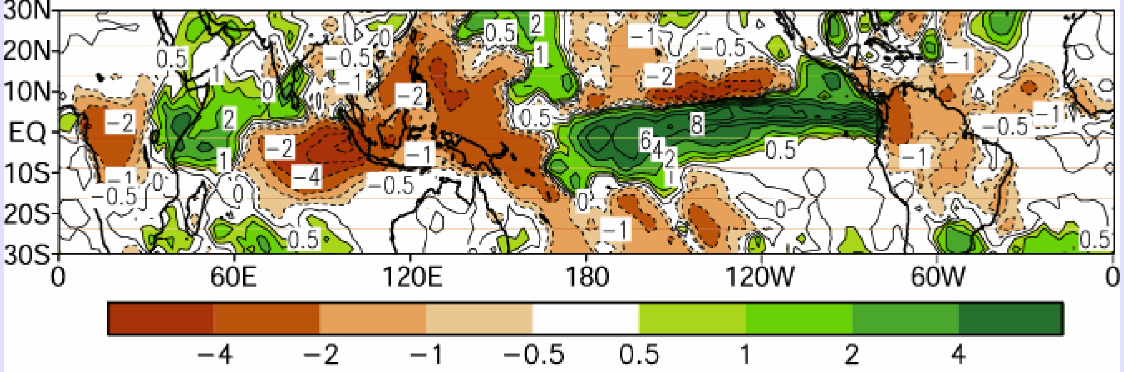


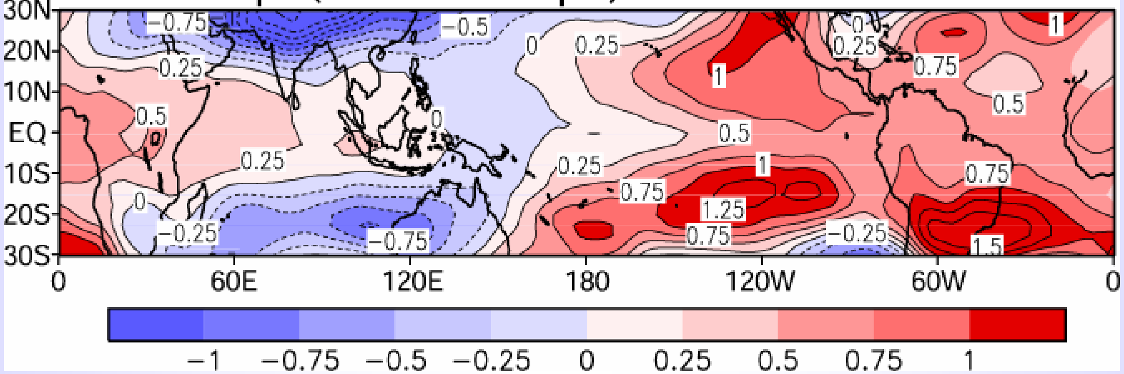
Prec. Anom. (GPCP) vs.
SST Anom. (Reynolds) 82 - 98

Slope of linear fit = 0.006

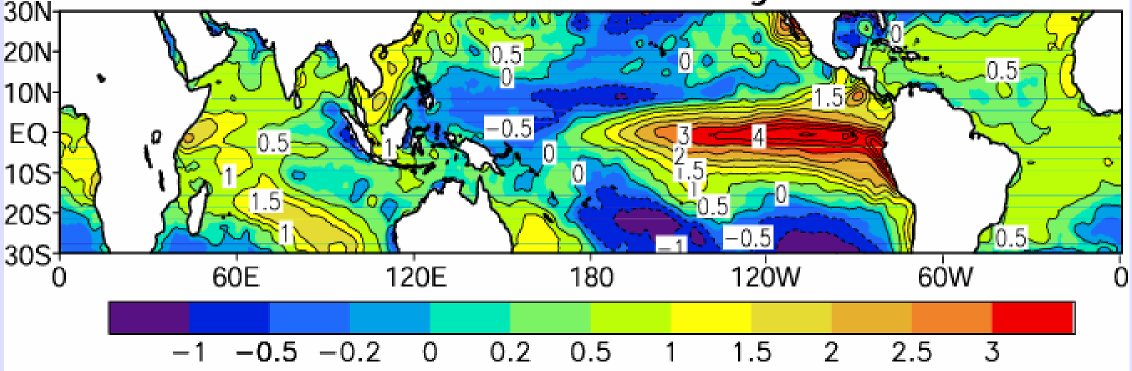
GPCP: Global Precipitation Climatology Project


SST Anom. SON 1997 Reynolds OI V2

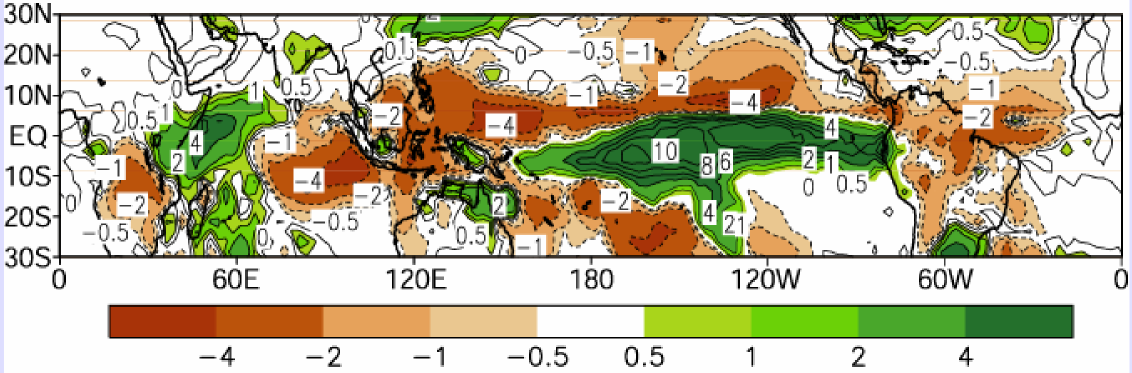

Prec Anom. SON 1997 GPCP


Temp. (850 - 200 hpa) SON 1997 NCEP

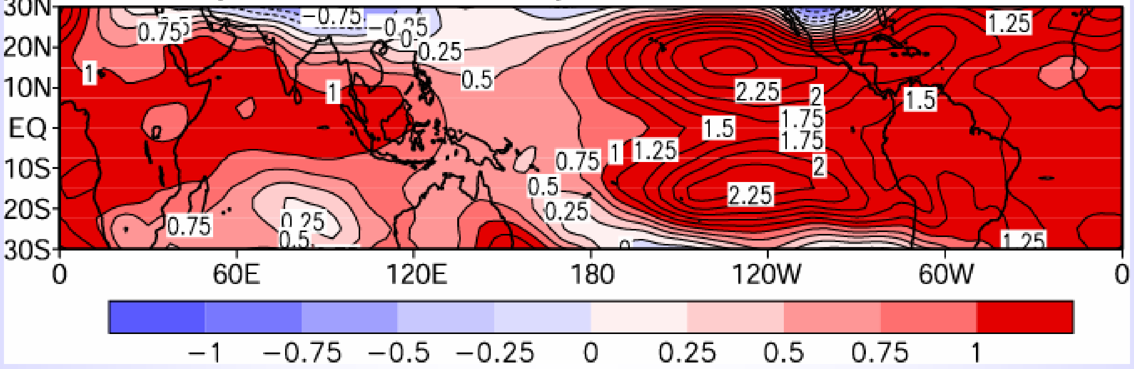
SST Anom. DJF 1998 Reynolds OI V2



Prec Anom. DJF 1998 GPCP



Temp. (850 - 200 hpa) DJF 1998 NCEP

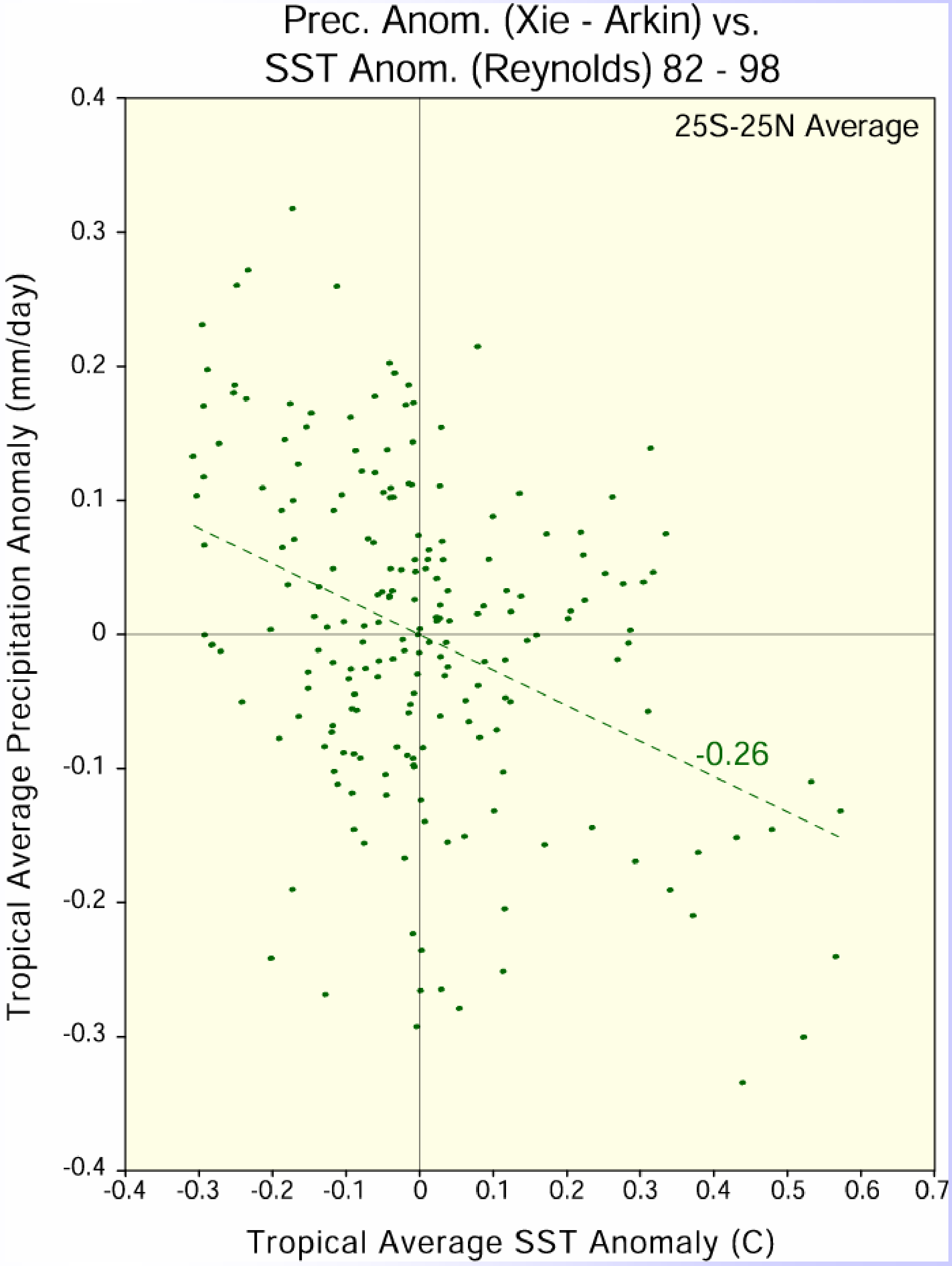


Tropical averaged precipitation anomalies versus tropical averaged SST anomalies

- **CMAP (Xie & Arkin, 1997) Precipitation from 1982-1998**

Slope of linear fit = -0.26

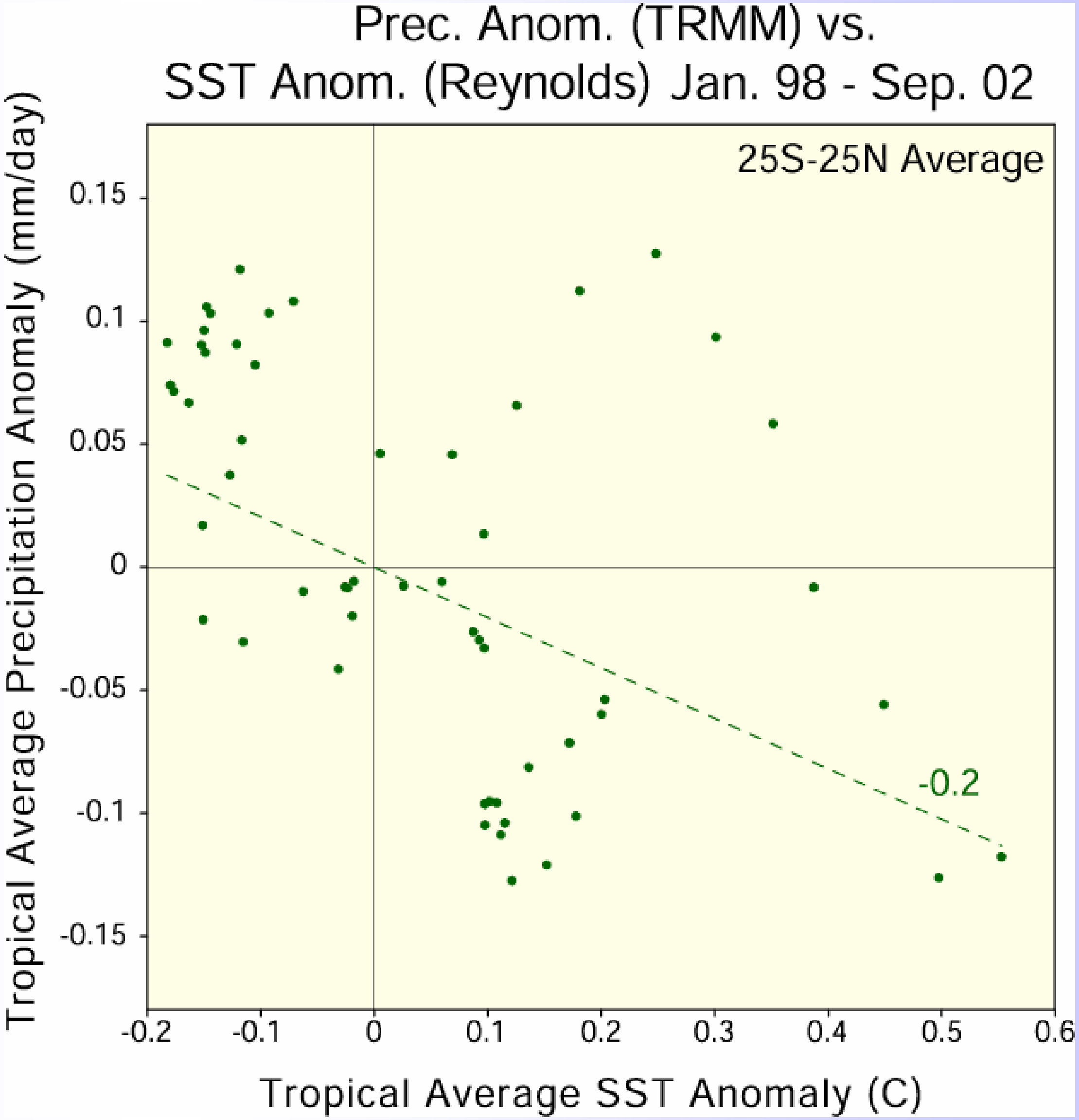
CMAP: CPC Merged Analysis of Precipitation



Prec. Anom. (Xie - Arkin) vs.
SST Anom. (Reynolds) 82 - 98

Tropical averaged precipitation anomalies versus tropical averaged SST anomalies

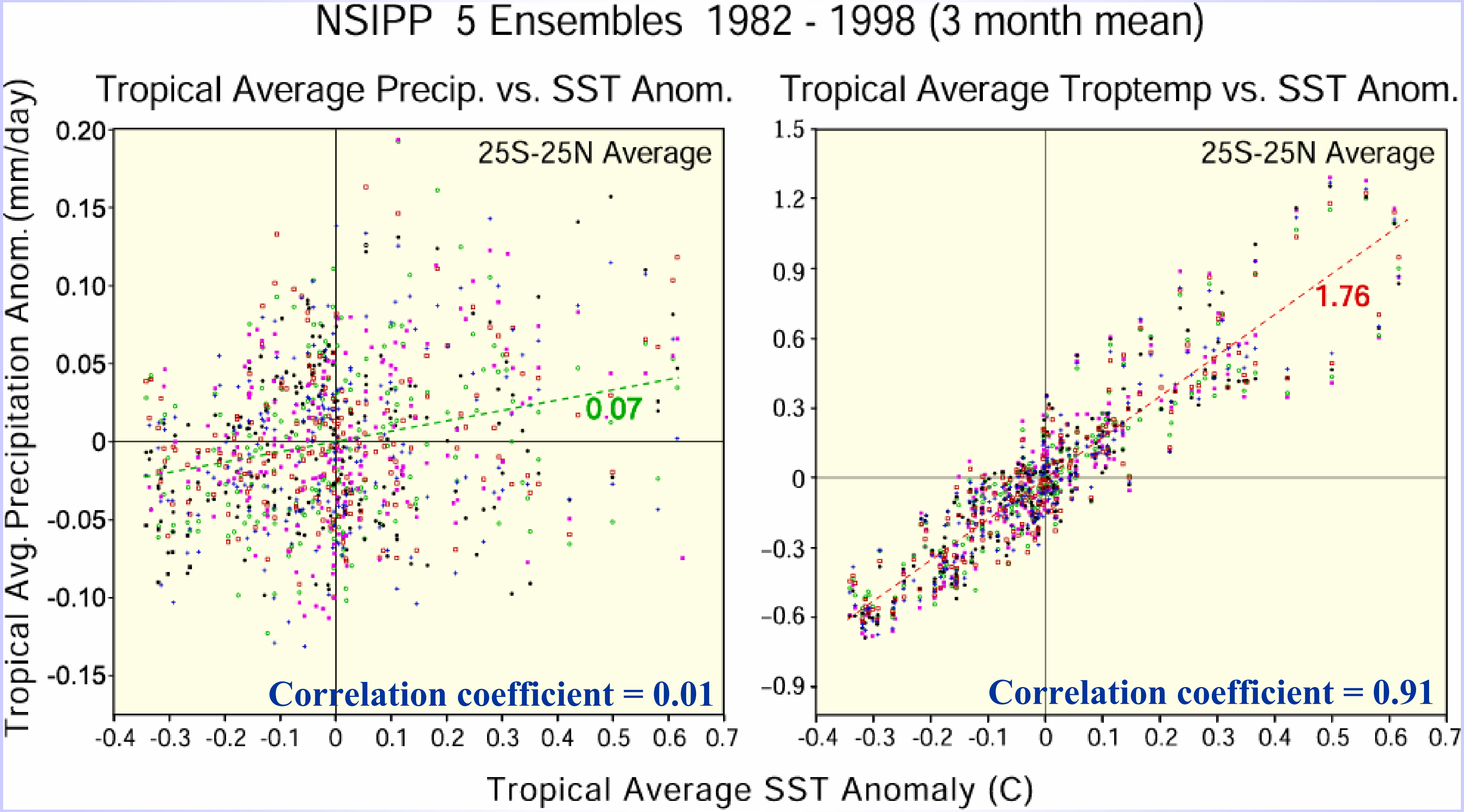
- **TRMM (2002) Precipitation from Jan. 1998 - Sep. 2002**



Slope of linear fit = -0.2

TRMM: Tropical Rainfall Measuring Mission

Tropical averaged precipitation anomalies versus tropical averaged SST anomalies

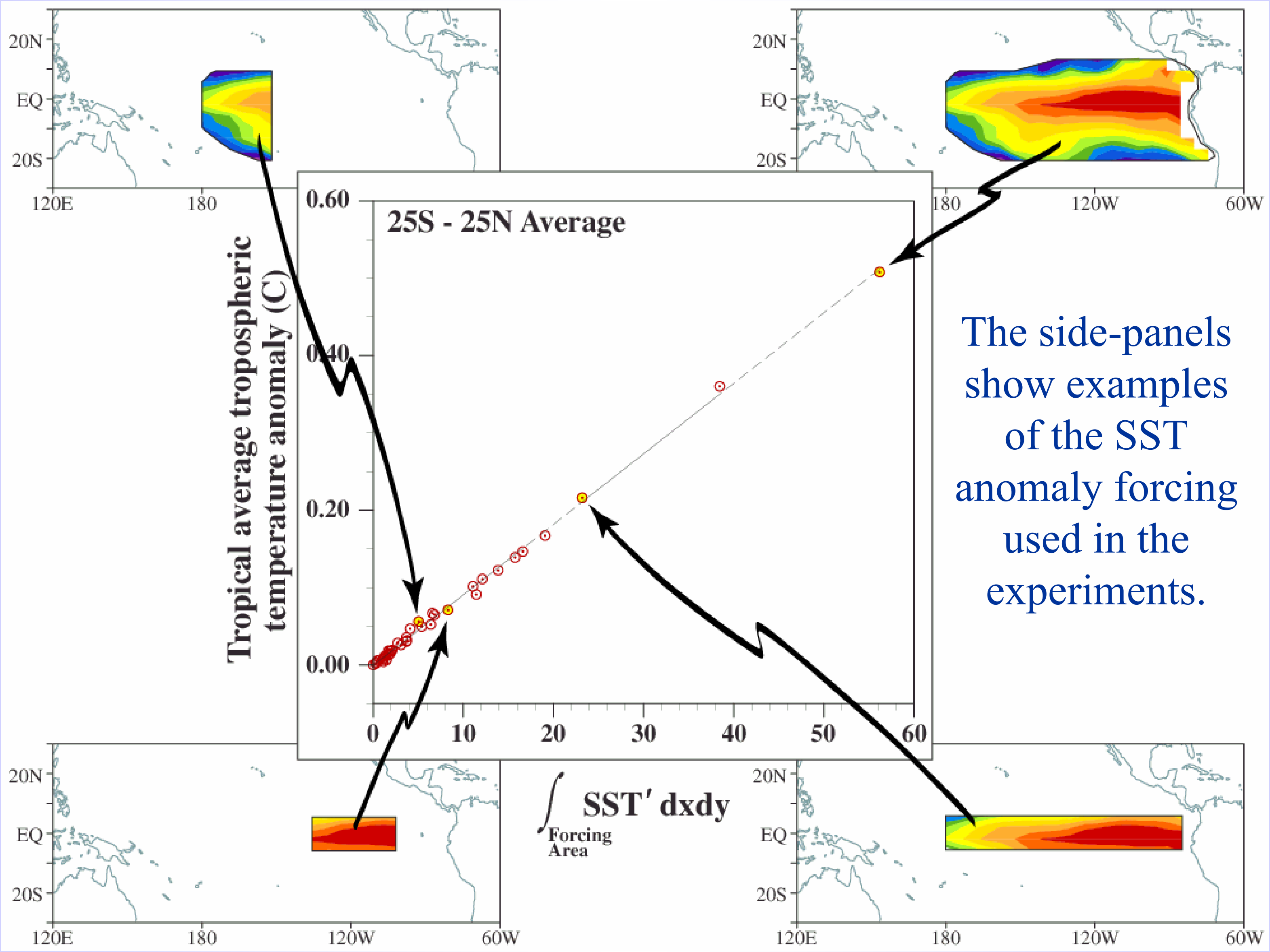


Correlation coefficient = 0.01

Correlation coefficient = 0.91

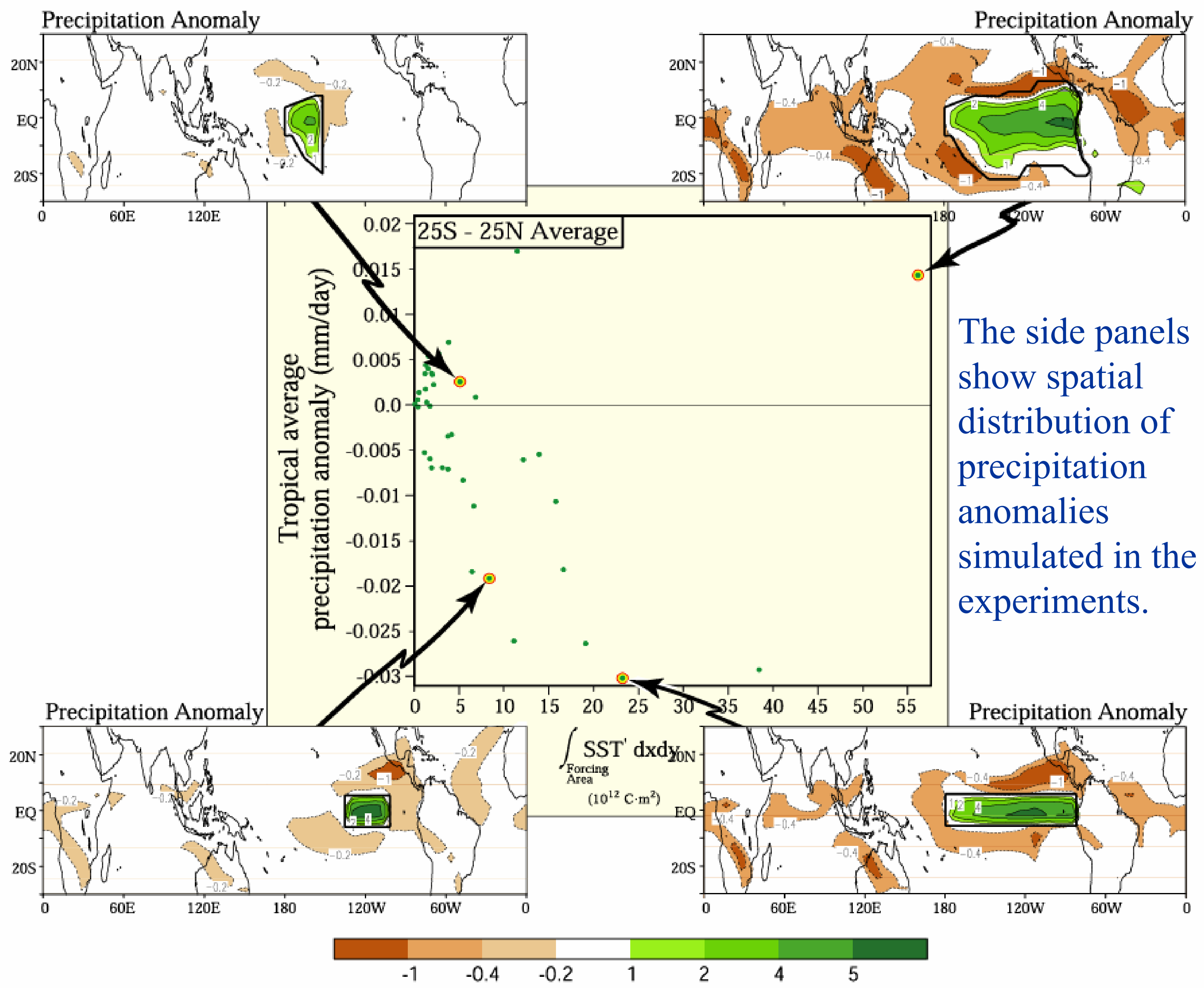
NSIPP: NASA Seasonal to Interannual Prediction Project

Tropical averaged (25S-25N) tropospheric temperature anomalies versus the spatial integral of SST anomaly forcing for experiments with subregions of the 1998 JFM El Niño SST anomaly



The side-panels show examples of the SST anomaly forcing used in the experiments.

Tropical averaged (25S-25N) precipitation anomalies versus the spatial integral of SST anomaly forcing for experiments with subregions of the 1998 JFM El Niño SST anomaly



The side panels show spatial distribution of precipitation anomalies simulated in the experiments.

Column-averaged Temperature and Moisture Eqs

$$D_T{}' = \hat{Q}'_c + F'_{rad} + H'$$

$$-D_q{}' = \hat{Q}'_q + E'$$

where $-\hat{Q}'_q = \hat{Q}'_c = P'$;

$F_T{}' = \langle D_T{}' \rangle$, $F_q{}' = \langle D_q{}' \rangle$: Dry static energy and Moisture transports from the tropics;

Column-averaged Moist Static Energy Eq

$$F'_{rad} + H' + E' = F_T{}' - F_q{}'$$

Net radiative flux

$$F'_{rad} \approx -\underbrace{\epsilon_T}_{6}\,\hat{T}' - \cancel{\underbrace{\epsilon_q}_{2}}\,\hat{q}' + \underbrace{\epsilon_{Ts}}_{6}\,T'_s + \cancel{\underbrace{CRF'}_{0.1\,E'}}$$

Evaporation

$$E' = \rho_a C_H \mathrm{V}_s \left[q'_{sat}(T_s) - q'_a\right] + \tilde{E}$$

$$= \underbrace{\epsilon_H \gamma}_{15}\left(T_s{}' - nT'\right) + \tilde{E}$$

where $\epsilon_H = \rho_a \mathrm{C_H} V_s\,,\quad q'_a = \gamma n T'\,,\quad \gamma = \left(\frac{d\,q_{\mathrm{sat}}}{dT}\right)_{T_s}$

For $\mathrm{V}_s = 5\,ms^{-1}$, $\epsilon_H \approx 5\,Wm^{-2}K^{-1}$

For $T_s = 300K$, $\gamma = 3\,KK^{-1}$; $\gamma n = 1.73$

Tropical Mean Troposphere Temperature vs. SST

$$\left\langle \hat{T}' \right\rangle = \underbrace{\frac{\epsilon_{T_s} + \epsilon_H \gamma}{\epsilon_T + \epsilon_H \gamma n}}_{1.4CC^{-1}} \langle T_s' \rangle - \underbrace{\frac{1}{\epsilon_T + \epsilon_H \gamma n}}_{0.068C(W/m^2)^{-1}} \left(F_T' - F_q' - \langle \tilde{E} \rangle \right)$$

Tropical Mean Precipitation vs. SST

$$\langle P' \rangle = \underbrace{\frac{\epsilon_H \gamma \left(\epsilon_T - n \epsilon_{T_s} \right)}{\epsilon_T + \epsilon_H \gamma n}}_{0.09(mm/day)C^{-1}} \langle T_s' \rangle$$

$$+ \underbrace{\frac{\epsilon_H \gamma n}{\epsilon_T + \epsilon_H \gamma n}}_{0.6} F_T' + \underbrace{\frac{\epsilon_T}{\epsilon_T + \epsilon_H \gamma n}}_{0.4} F_q' + \underbrace{\frac{\epsilon_T}{\epsilon_T + \epsilon_H \gamma n}}_{0.4} \langle \tilde{E} \rangle$$

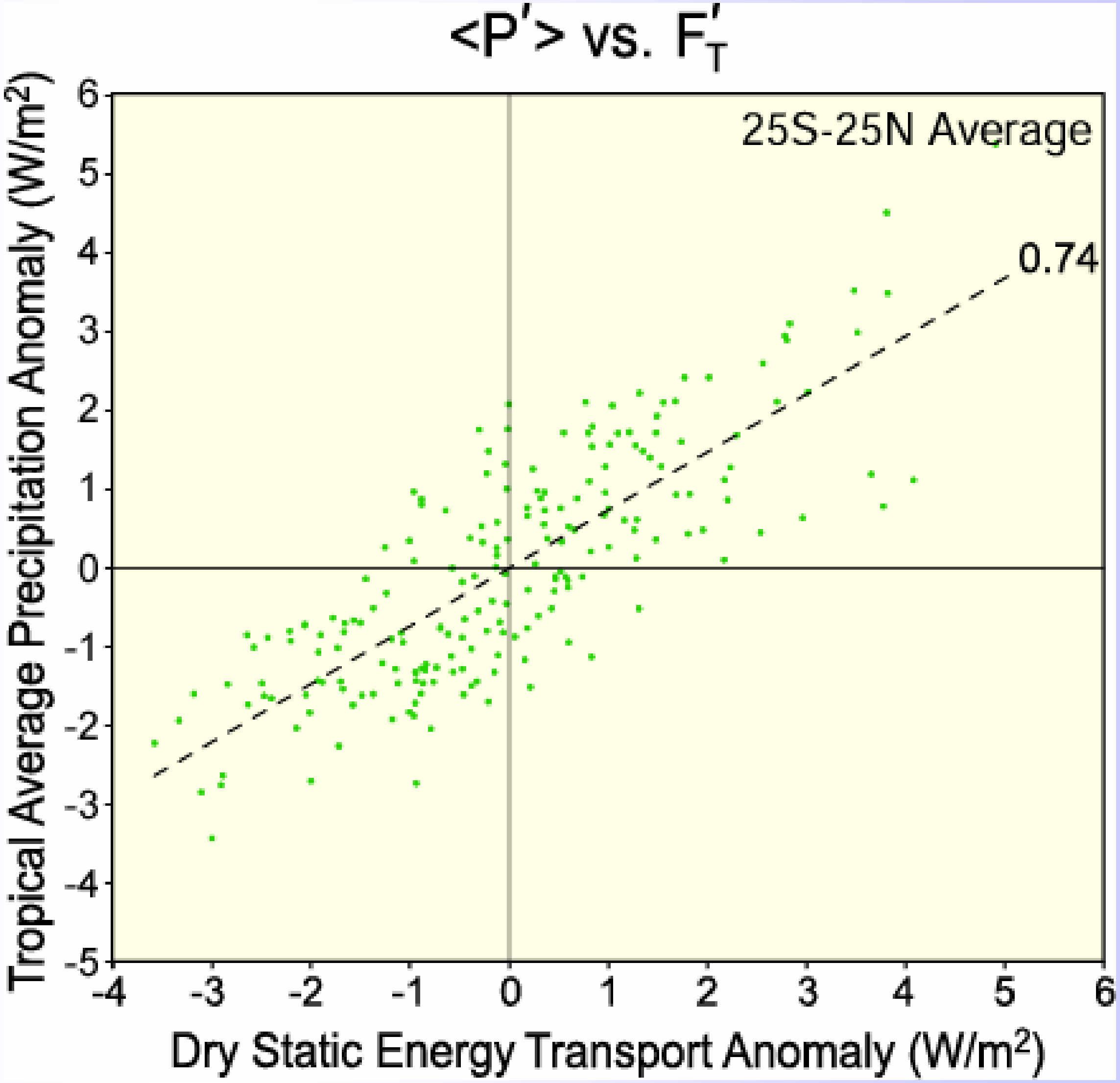
A Simple Case: ignore all fluxes except evaporation

$$\left\langle \hat{T}' \right\rangle = \underbrace{n^{-1}}_{1.73CC^{-1}} \langle T_s' \rangle - \underbrace{(\epsilon_H \gamma n)^{-1}}_{0.12C(W/m^2)^{-1}} \left(F_T' - F_q' - \langle \tilde{E} \rangle \right)$$

$$\langle P' \rangle = F_T'$$

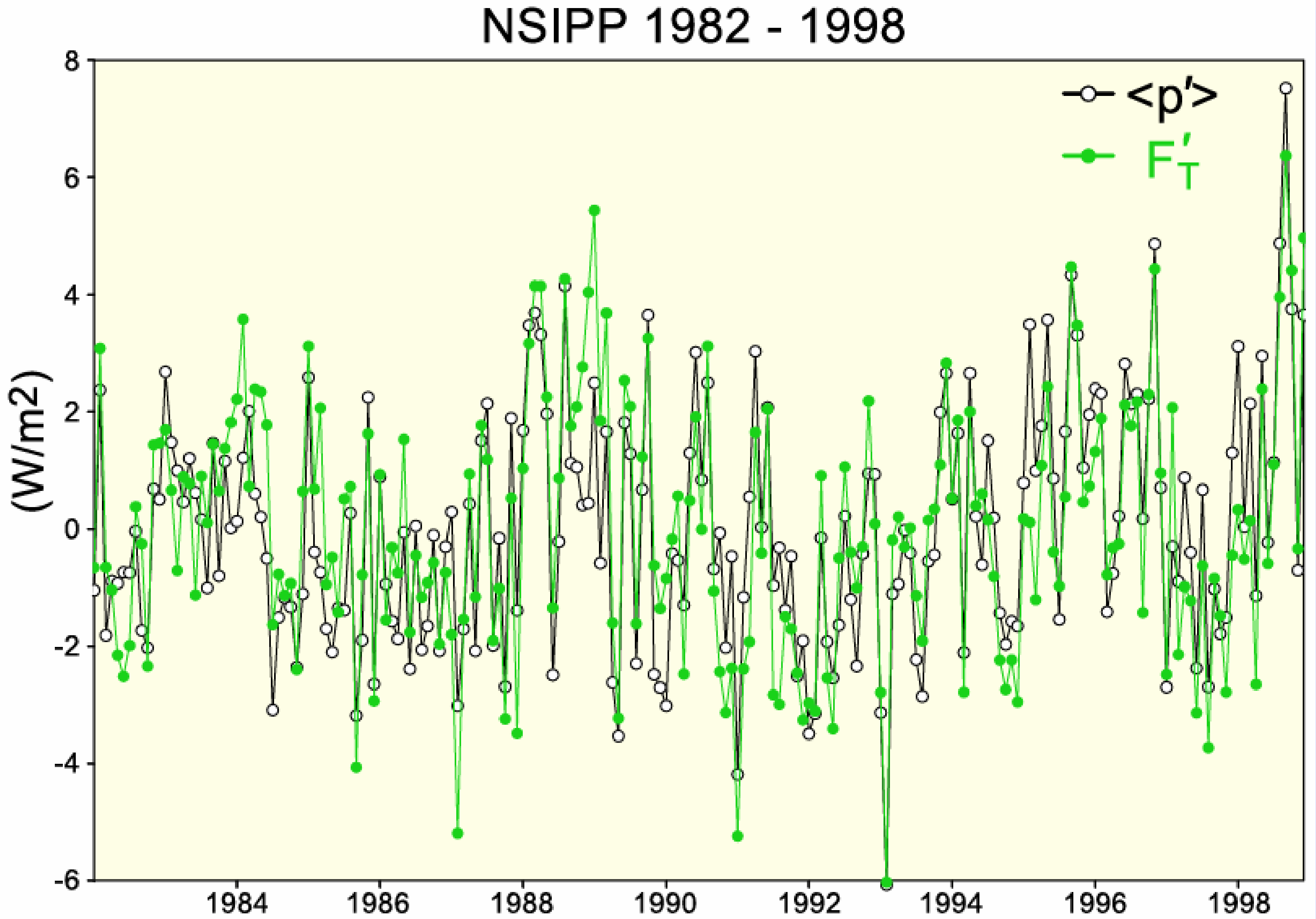
Tropical average precipitation anomaly vs. dry static energy transport anomaly

- **1 NSIPP AGCM experiment 1982 - 1998 (3 month mean)**



Slope of linear fit = 0.74

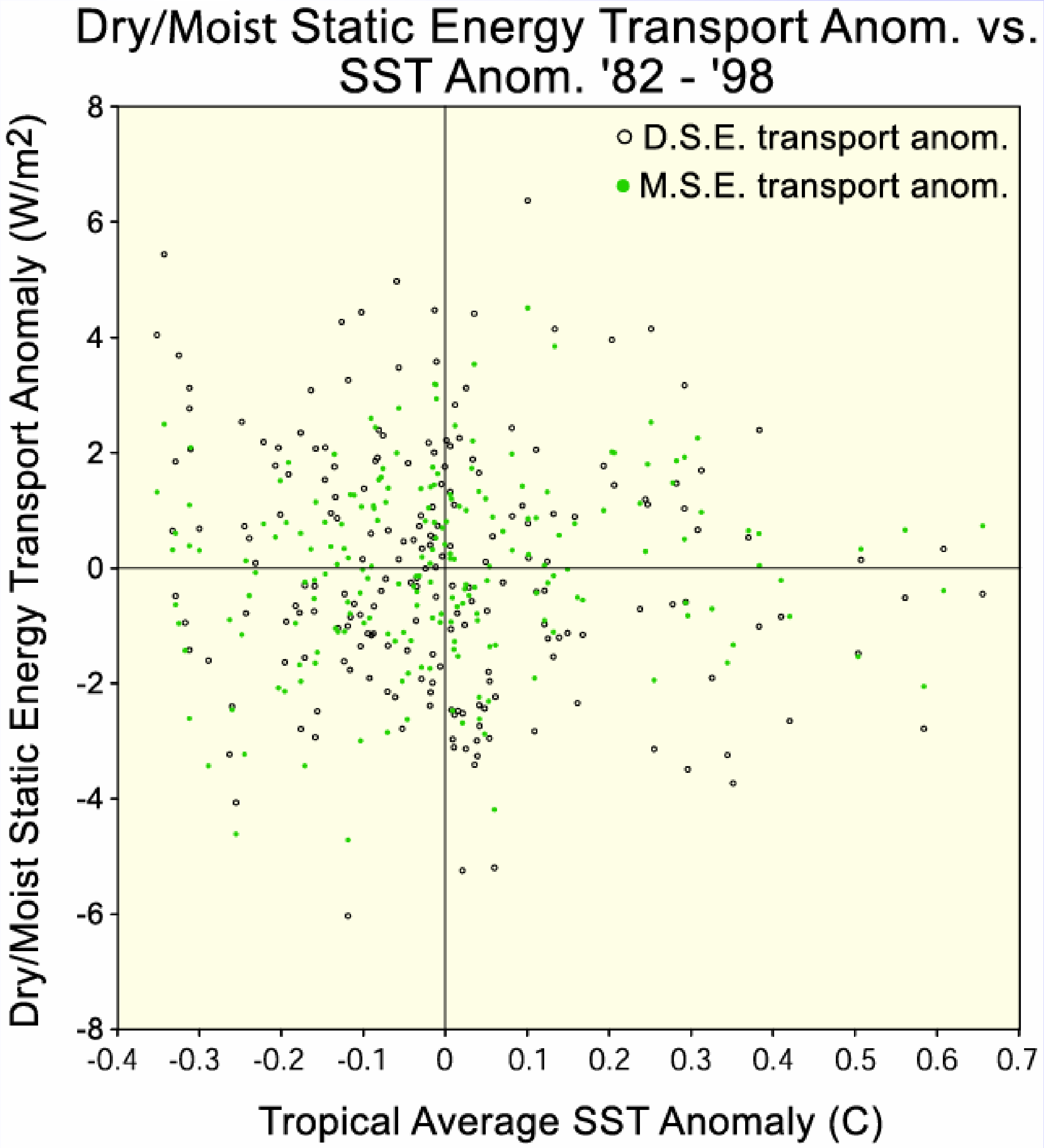
Tropical averaged precipitation anomalies follow the dry static energy transport anomalies



- **1 NSIPP AGCM experiment 1982 - 1998**

Anomalies of the export of dry static energy and moist static energy from the tropics (25S - 25N) vs. tropical averaged SST anomalies

- 1 NSIPP AGCM experiment 1982 - 1998



Comparing Standard Deviations of Dominant Terms

General Case:

$$\underbrace{\left\langle \hat{T}' \right\rangle}_{0.36C} = \underbrace{\frac{\epsilon_{T_s} + \epsilon_H \gamma}{\epsilon_T + \epsilon_H \gamma n} \langle T_s' \rangle}_{0.25C} - \underbrace{\frac{1}{\epsilon_T + \epsilon_H \gamma n} (F_T' - F_q'}_{0.10C} - \langle \tilde{E} \rangle)$$

$$\underbrace{\langle P' \rangle}_{2.01W/m^2} = \underbrace{\frac{\epsilon_H \gamma \left(\epsilon_T - n \epsilon_{T_s}\right)}{\epsilon_T + \epsilon_H \gamma n} \langle T_s' \rangle}_{0.5W/m^2}$$

$$+ \underbrace{\frac{\epsilon_H \gamma n}{\epsilon_T + \epsilon_H \gamma n} F_T'}_{1.3W/m^2} + \frac{\epsilon_T}{\epsilon_T + \epsilon_H \gamma n} F_q' + \frac{\epsilon_T}{\epsilon_T + \epsilon_H \gamma n} \langle \tilde{E} \rangle$$

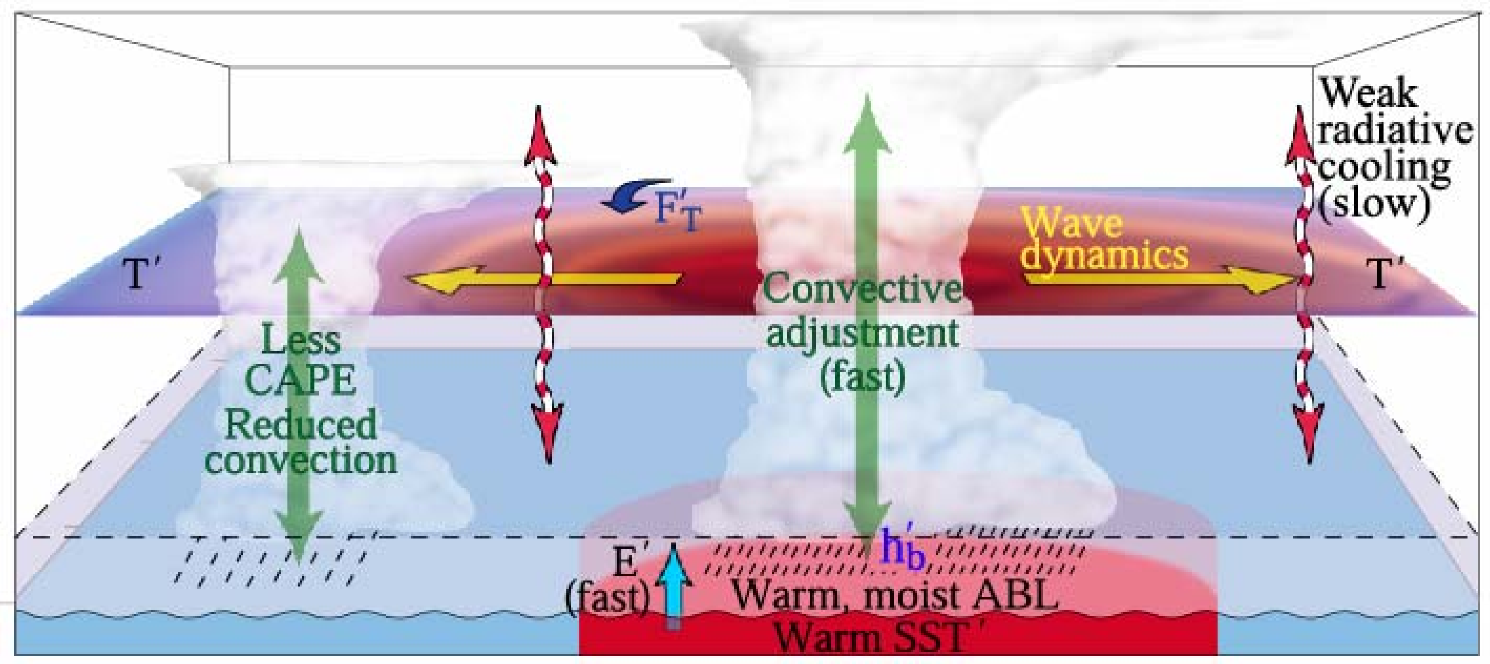
Simple Case:

$$\underbrace{\left\langle \hat{T}' \right\rangle}_{0.36C} = \underbrace{n^{-1} \langle T_s' \rangle}_{0.29C} - \underbrace{(\epsilon_H \gamma n)^{-1} (F_T' - F_q'}_{0.16C} - \langle \tilde{E} \rangle)$$

$$\underbrace{\langle P' \rangle}_{2.01W/m^2} = \underbrace{F_T'}_{2.15W/m^2}$$

Key Processes and Adjustment Time Scales

	Characteristic Parameters	Typical Time Scales
Evaporation	$\langle \varepsilon_H \gamma \rangle^{-1}$	2 days (Fast)
Convection	τ_c	2 hours (Fast)
Wave Dynamics	L / C	5-30 days
Radiation	$\langle \varepsilon_T \rangle^{-1}$	10 days (Slow)



Role of Convection

* Convection is important in transporting boundary layer forcing upward to constrain the tropospheric temperature

Quasi-equilibrium convective adjustment

$$
\begin{aligned}
Q_c &= (T^c - T)/\tau_c, && \text{if } (T^c - T) > 0 \\
&= 0, && \text{otherwise,}
\end{aligned}
$$

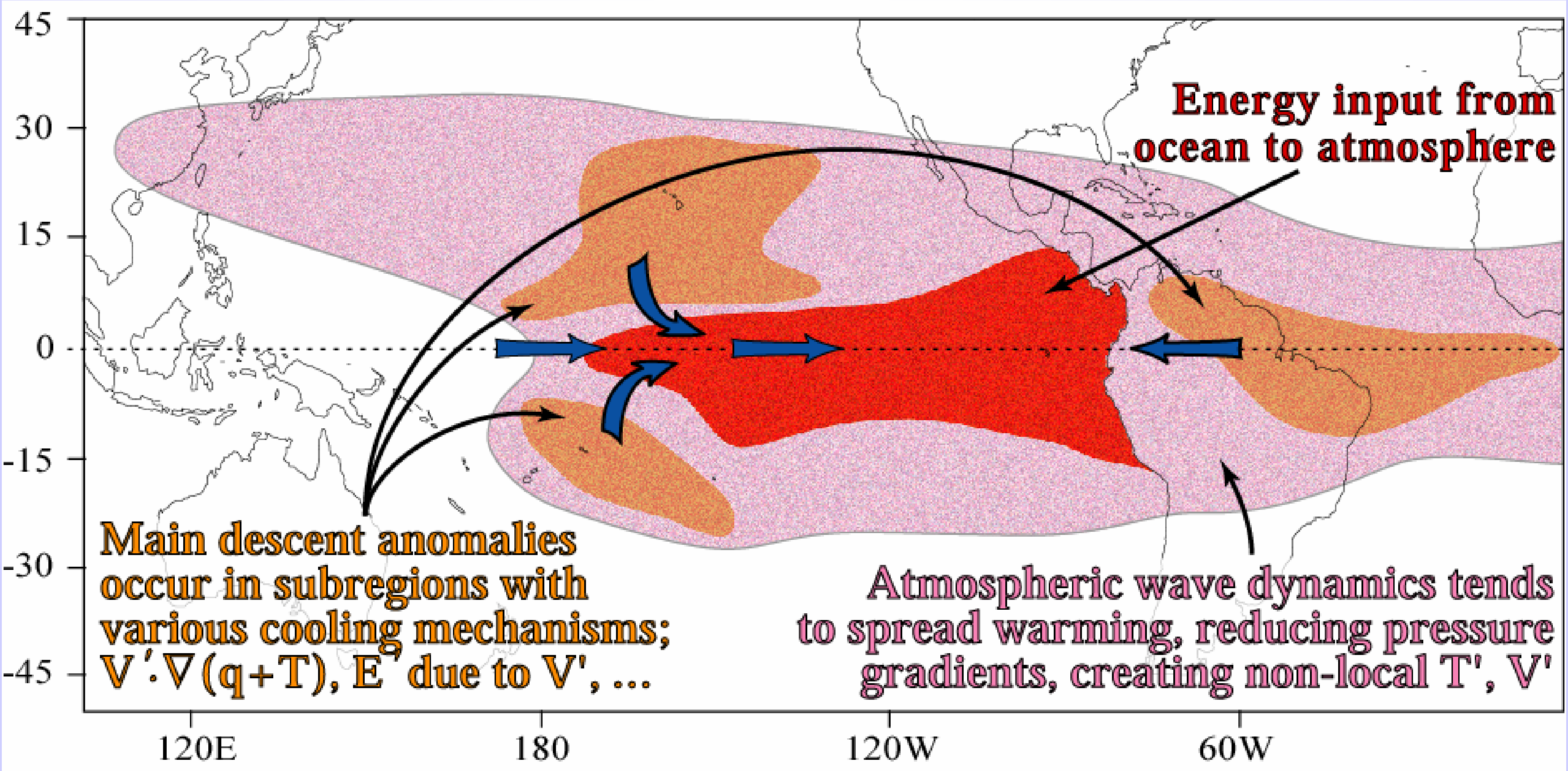
* Tropospheric temperature is not dominated by the amount of convective heating because of the small time scale τ_c

$$\langle \hat{T}' \rangle = \langle \hat{T}'_c \rangle - \tau_c \langle \hat{Q}'_c \rangle$$

* the amount of convective heating is a by-product, subject to complex balances with various cooling mechanisms

$$\langle \hat{Q}'_c \rangle = F'_T + \epsilon_T \langle \hat{T}' \rangle - \epsilon_{T_s} \langle {T_s}' \rangle$$

Teleconnection Mechanisms for Tropical Pacific Descent Anomalies During El Niño



Energy input from ocean to atmosphere

Main descent anomalies occur in subregions with various cooling mechanisms; $V'\cdot\nabla(q+T)$, E' due to V', ...

Atmospheric wave dynamics tends to spread warming, reducing pressure gradients, creating non-local T', V'

(Su and Neelin 2002)

Conclusions

- Tropical average precipitation anomalies are *scattered* in relation to tropical SST anomalies, while the tropical average tropospheric temperature anomalies are approximately *linear* with SST changes.

- The interannual tropical average precipitation anomaly is not a sensible measure of sensitivity of tropical hydrological cycle to ENSO. It does not provide a good proxy for what might occur under global warming.

- *Convection* is important in transporting boundary layer forcing upward to constrain the tropospheric temperature; However, the amount of *convective heating* has no simple relation to the tropospheric temperature changes.

❖ Anomalous dry static energy transport into or out of the tropics appears to be a leading factor in the variability of tropical average precipitation anomalies.

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