The Paradox of Tropical-Averaged Precipitation Anomalies

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

• **Expectation:**

• **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

- 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

Slope of linear fit = 0.006

GPCP: Global Precipitation Climatology Project
Tropical averaged precipitation anomalies versus tropical averaged SST anomalies


Slope of linear fit = -0.26

CMAP: CPC Merged Analysis of Precipitation
Tropical averaged precipitation anomalies versus tropical averaged SST anomalies


Slope of linear fit = -0.2

TRMM: Tropical Rainfall Measuring Mission
Tropical averaged precipitation anomalies versus tropical averaged SST anomalies

NSIPP 5 Ensembles 1982 - 1998 (3 month mean)

Tropical Average Precip. vs. SST Anom.

Tropical Average Troptemp vs. SST Anom.

25S-25N Average

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 \(-\hat{Q}_q' = \hat{Q}_c' = P'\);

\[ F'_T = \langle D'_T \rangle, \quad F'_q = \langle D'_q \rangle: \] 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
\[ F'_{rad} \approx -\epsilon_T \tilde{T}' - \epsilon_q \tilde{q}' + \epsilon_T s T_s' + C R F' \]

Evaporation
\[ E' = \rho_a C_H V_s \left[ q_{s\alpha l}'(T_s) - q_{\alpha}' \right] + \tilde{E} \]
\[ = \epsilon_H \gamma (T_s' - nT') + \tilde{E} \]

where \(\epsilon_H = \rho_a C_H V_s\), \(q_{\alpha}' = \gamma nT'\), \(\gamma = \left( \frac{d q_{s\alpha l}}{dT} \right)_{T_s}\)

For \(V_s = 5 \text{ m.s}^{-1}\), \(\epsilon_H \approx 5 \text{ W.m}^{-2}\text{K}^{-1}\)

For \(T_s = 300\text{ K}\), \(\gamma = 3 \text{ K.K}^{-1}\); \(\gamma n = 1.73\)
Tropical Mean Troposphere Temperature vs. SST

\[
\langle \hat{T}' \rangle = \frac{\epsilon_{T_s} + \epsilon_H\gamma}{\epsilon_T + \epsilon_H\gamma n} \langle T_s' \rangle - \frac{1}{\epsilon_T + \epsilon_H\gamma n} (F_T' - F_q' - \langle \tilde{E}' \rangle)
\]

Tropical Mean Precipitation vs. SST

\[
\langle P' \rangle = \frac{\epsilon_H\gamma (\epsilon_T - n\epsilon_{T_s})}{\epsilon_T + \epsilon_H\gamma n} \langle T_s' \rangle
\]

\[
+ \frac{\epsilon_H\gamma n}{\epsilon_T + \epsilon_H\gamma n} F_T' + \frac{\epsilon_T}{\epsilon_T + \epsilon_H\gamma n} F_q' + \frac{\epsilon_T}{\epsilon_T + \epsilon_H\gamma n} \langle \tilde{E}' \rangle
\]

A Simple Case: ignore all fluxes except evaporation

\[
\langle \hat{T}' \rangle = \frac{n^{-1}}{1.73CC^{-1}} \langle T_s' \rangle - (\epsilon_H\gamma n)^{-1} (F_T' - F_q' - \langle \tilde{E}' \rangle)
\]

\[
\langle P' \rangle = F_T'
\]
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.
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:

\[
\langle \hat{T}' \rangle = \langle T'_s \rangle = \frac{\varepsilon_{T_s} + \varepsilon_H \gamma}{\varepsilon_T + \varepsilon_H \gamma n} - \frac{1}{\varepsilon_T + \varepsilon_H \gamma n}(F'_T - F'_q - \langle \tilde{E} \rangle)
\]

\[
\langle P' \rangle = \frac{\varepsilon_H \gamma (\varepsilon_T - n\varepsilon_{T_s})}{\varepsilon_T + \varepsilon_H \gamma n} \langle T'_s \rangle + \frac{\varepsilon_H \gamma n}{\varepsilon_T + \varepsilon_H \gamma n} F'_T + \frac{\varepsilon_T}{\varepsilon_T + \varepsilon_H \gamma n} F'_q + \frac{\varepsilon_T}{\varepsilon_T + \varepsilon_H \gamma n} \langle \tilde{E} \rangle
\]

Simple Case:

\[
\langle \hat{T}' \rangle = n^{-1} \langle T'_s \rangle - (\varepsilon_H \gamma n)^{-1}(F'_T - F'_q - \langle \tilde{E} \rangle)
\]

\[
\langle P' \rangle = \frac{F'_T}{2.01 W/m^2}
\]
## Key Processes and Adjustment Time Scales

<table>
<thead>
<tr>
<th></th>
<th>Characteristic Parameters</th>
<th>Typical Time Scales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporation</td>
<td>$\langle \epsilon_H \rangle^{-1}$</td>
<td>2 days <em>(Fast)</em></td>
</tr>
<tr>
<td>Convection</td>
<td>$\tau_C$</td>
<td>2 hours <em>(Fast)</em></td>
</tr>
<tr>
<td>Wave Dynamics</td>
<td>$L/ C$</td>
<td>5-30 days</td>
</tr>
<tr>
<td>Radiation</td>
<td>$\langle \epsilon_T \rangle^{-1}$</td>
<td>10 days <em>(Slow)</em></td>
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[Diagram showing the processes of convective adjustment, wave dynamics, and radiation with time scales and processes labeled.]
Role of Convection

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

Quasi-equilibrium convective adjustment

\[ Q_c = \frac{(T_c - T)}{\tau_c}, \quad \text{if} \ (T_c - T) > 0 \]
\[ = 0, \quad \text{otherwise}, \]

* Tropospheric temperature is not dominated by the amount of **convective heating** because of the small time scale \( \tau_c \)

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

* 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

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

Energy input from ocean to atmosphere

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.