Sensitivity of Tropical Tropospheric Temperature to Sea Surface Temperature Forcing

Hui Su, J. David Neelin and Joyce E. Meyerson, U.C.L.A.

• Observed tropical-average atmospheric temperature response appears linear - why?
• Do SST anomalies in climatologically warm regions dominate?
• Precipitation vs. temperature response
Tropical Tropospheric Temperature-response to Sea Surface Temperature

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Observations JFM 1998

SST Anomaly (C) JFM 1998

Precip. Anomaly (mm day⁻¹) JFM 1998

Temp. Anomaly (C) (850-200 mb) JFM 1998
Observations NDJ 1994/’95

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Precip. Anomaly (mm day⁻¹) NDJ 1994/’95

Temp. Anomaly (C) (850-200 mb) NDJ 1994/’95
Quasi-equilibrium Tropical circulation model:

- Primitive equations projected onto vertical basis functions from convective quasi-equilibrium analytical solutions for Betts-Miller (1986) convective scheme, accurate vertical structure in deep convective regions for low vertical resolution
- Baroclinic instability crudely resolved
- Less than 5min/yr on a Sun 2 at 5.6x3.75 degree resolution
- GCM-like parameters but easier to analyze

Radiation/cloud parameterization:

- Longwave and shortwave schemes simplified from GCM schemes (Harshvardhan et al. 1987, Fu and Liou 1993)
- Deep convective cloud, CsCc fraction param. on precip

Simple land model:

- 1 soil moisture layer; evapotranspiration with stomatal/root resistance dep. on surface type (e.g., forest, desert, grassland)
- Low heat capacity; Darnell et al 1992 albedo
QTCM regions of validity

- Primitive equations projected onto vertical basis functions from quasi-equilibrium based analytical solutions
- for Betts-Miller (1986) convective scheme, accurate vertical structure in deep convective regions for low vertical resolution
QT CM Anomalies NDJ ‘94/’95

(a) Precip. Anomaly NDJ ‘94/’95

(b) Temp. Anomaly (850 - 200 hpa) NDJ ‘94/’95
Tropical averaged (25S-25N) tropospheric temperature anomalies versus tropical averaged SST anomalies

- **MSU temperature (1982-1993)**
- **QTTCM simulation using observed SST from 1982-1998**

Slopes of linear fits to each dataset:
Tropical averaged (25S-25N) tropospheric temperature anomalies versus tropical averaged SST anomalies

- MSU temperature (1982-1993)
- QTCM simulation using observed SST from 1982-1998

Slopes of linear fits to each dataset:
Sum of ENSOPAC subregions - Climatology

Precip. Anomaly  JFM 1998  ENSOPAC.sum4 - CLIM

Temp. Anomaly  (850 - 200 hpa)  JFM 1998
ENSOPAC subregion - Climatology

(a) Precip. Anomaly  JFM 1998  ENSOPAC.g4.1 - CLIM

(b) Temp. Anomaly  (850 - 200 hpa)  JFM 1998
Small subregion - Climatology

Precip. Anomaly  JFM 1998  ENSOPAC.12b - CLIM

Temp. Anomaly  (850 - 200 hpa)  JFM 1998
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.
Regional 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 examples of the SST anomaly forcing used in the experiments.
Tropical-average (25S-25N) tropospheric temperature and regional precipitation anomalies versus tropical-average SST anomalies

- **Uniform SST anomalies of amplitude -5°C to 5°C added to climatological SST in three subregions**
- Dots - results of the experiments
- Dashed - linearization for small SST anomalies (-0.5 to 0.5°C)
Tropical-average (25S-25N) tropospheric temperature and regional precipitation anomalies versus tropical-average SST anomalies over a climatologically non-precipitating region

- numbers next to the dots are the amplitudes of SST anomalies added in the subregion
Sensitivity parameter and % tropospheric temp. anomalies

JFM 1998

Sensitivity parameter to SSTAl (C C⁻¹ (10⁻¹² m⁻²))

Percentage of tropospheric temperature anomalies

14% 30% 34% 22%
Sensitivity parameter and % tropospheric temp. anomalies
NDJ 1994/'95

Sensitivity parameter to SSTA \( \left( \text{C C}^{-1} \left(10^{-12} \text{ m}^{-2}\right)\right)\)

Percentage of tropospheric temperature anomalies

\[
\begin{array}{cccc}
0.012 & 0.009 & 0.009 & 0.007 \\
36\% & 29\% & 21\% & 15\%
\end{array}
\]
Analytical Explanation

• Simplifications based on atm. model moist static energy equation
• Main feature: integrating over large regions typical of tropospheric temperature response averages out transport terms

\[ \hat{a}_1 (\partial_t + D_{T_1}) T_1 + \hat{b}_1 (\partial_t + D_{q_1}) q_1 + M_1 \nabla \cdot \mathbf{v}_1 = (g/p_T) (F_{\text{rad}} + H + E) \]

Consider perturbations from mean state
\[ A' = A - \bar{A} \]
Averaged over a large horizontal area
L.H.S. (transport) \( \approx 0 \)
\[ F'_{\text{rad}} + H' + E' \approx 0 \]

Net radiative fluxes linear with \( T'_1, q'_1, T'_s \) and \( \alpha' \)
\[ F'_{\text{rad}} = \epsilon_{T_1} T'_1 + \epsilon_{q_1} q'_1 + \epsilon_{T_s} T'_s + CRF' \]

Sensible and latent heat fluxes
\[ H' = \rho_a C_D \bar{V}_s (T'_s - a_{1s} T'_1) \]
\[ E' = \rho_a C_D \bar{V}_s [q'_{\text{sat}}(T_s) - b_{1s} q'_1] \]

Cloud radiative forcing as a feedback:
\[ CRF' \approx c_t P' \quad (c_t = 0.06) \]

Precip (convective heating) by moisture budget:
\[ P' = M_{q_1} \nabla \cdot \mathbf{v}' - (\mathbf{v} \cdot \nabla q_1)' + E' \]

Approximate balance
\[ \epsilon_{T_1} T'_1 + \epsilon_{q_1} q'_1 + \epsilon_{T_s} T'_s + H' + (1 + c_t) E' \approx 0 \]

Using
\[ \epsilon_{T_1} = -2.89; \quad \epsilon_{q_1} = -1.11; \quad \epsilon_{T_s} = 5.98 \]

\[ \bar{T}_s = 295.0 \sim 304.0 \ (K), \quad \bar{V}_s = 5.00 \sim 10.0 \ (m/s), \]
\[ q'_1 \approx (0.6 \sim 1.6) T'_1 \]

\[ \Rightarrow \quad \hat{T}' = \hat{a}_1 T'_1 \approx (0.78 \sim 2.0) T'_s \]
Summary

• Strong precipitation anomalies are local to the region of SST anomalies. Tropospheric temperature response is on large spatial scales.

• Tropical avg. tropospheric temperature anomaly \(<\hat{T}'>\) response is approximately linear with the spatial integral of SST forcing.

• Nonlinearity in \(<\hat{T}'>\) response can be modest even when local precipitation response is highly nonlinear.

• Although regions over climatological warm water (i.e. west-central Pacific) are slightly more sensitive, Eastern Pacific subregions of El Nino SST anomalies also contribute substantially to \(<\hat{T}'>\).

• Approximate linearity of \(<\hat{T}'>\) due to:
  (1) transport terms become small in the large-area avg.;
  (2) dependence on temperature of the TOA and surface fluxes only weakly nonlinear.