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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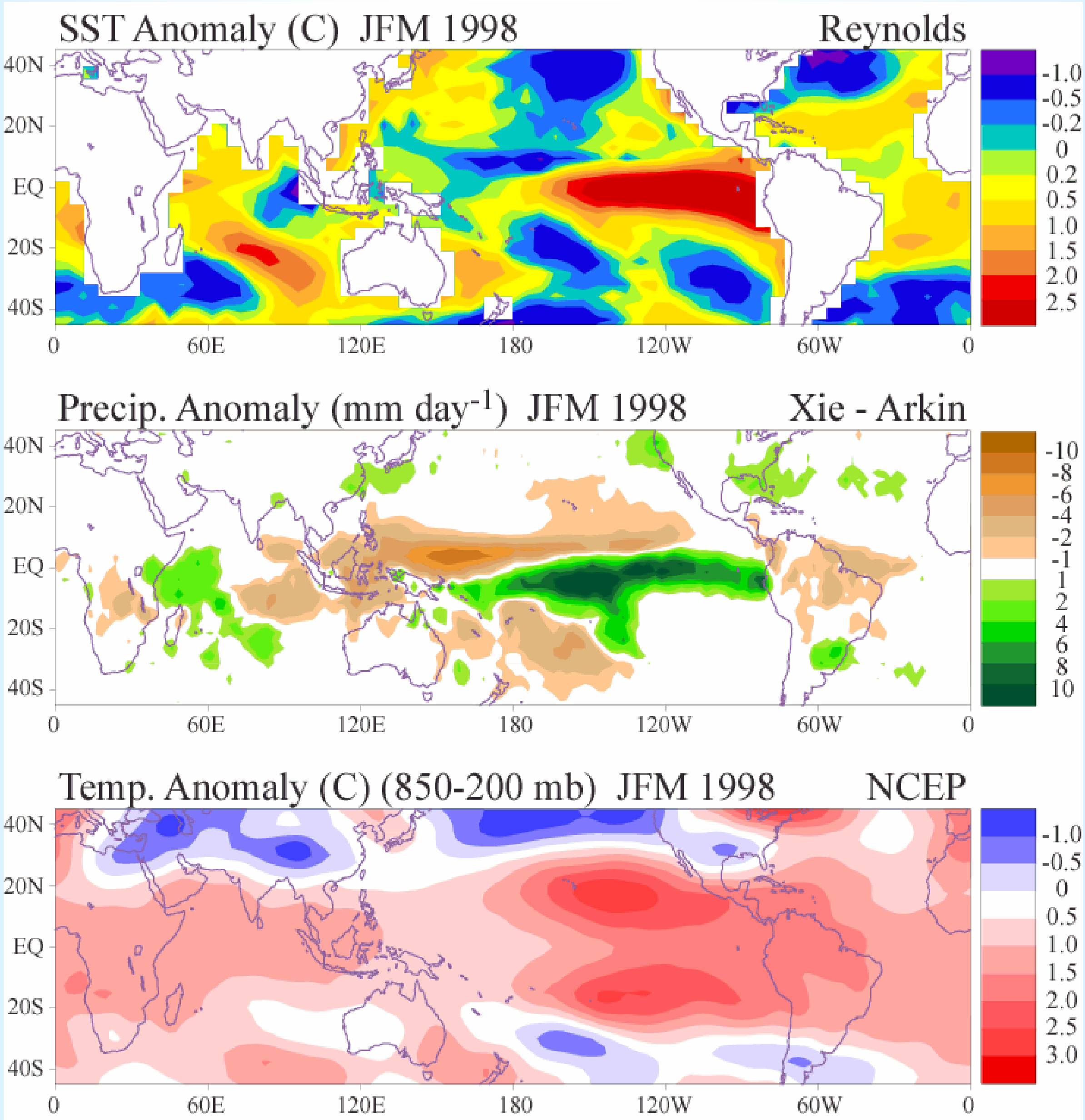
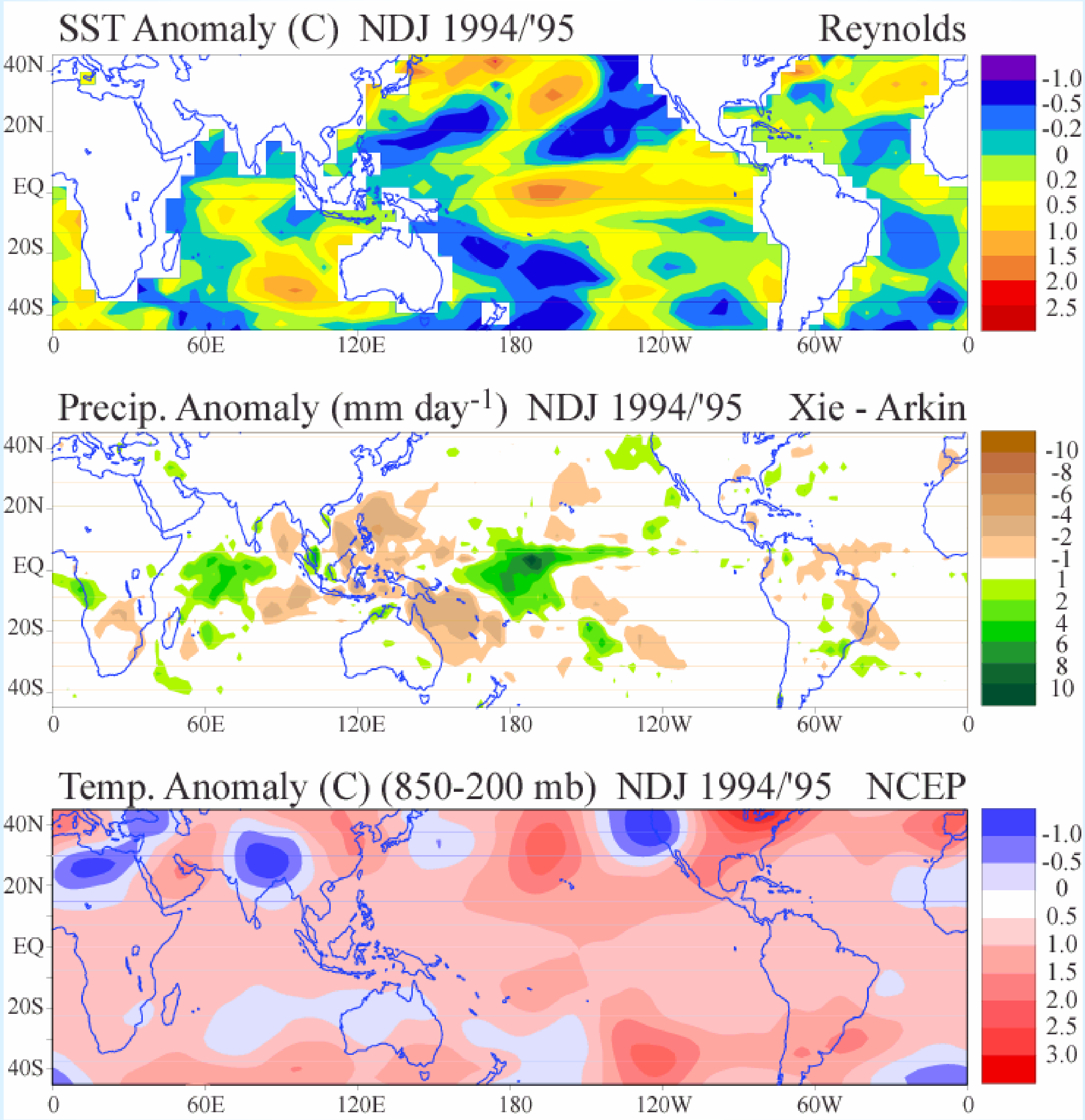
Observations JFM 1998



Observations 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
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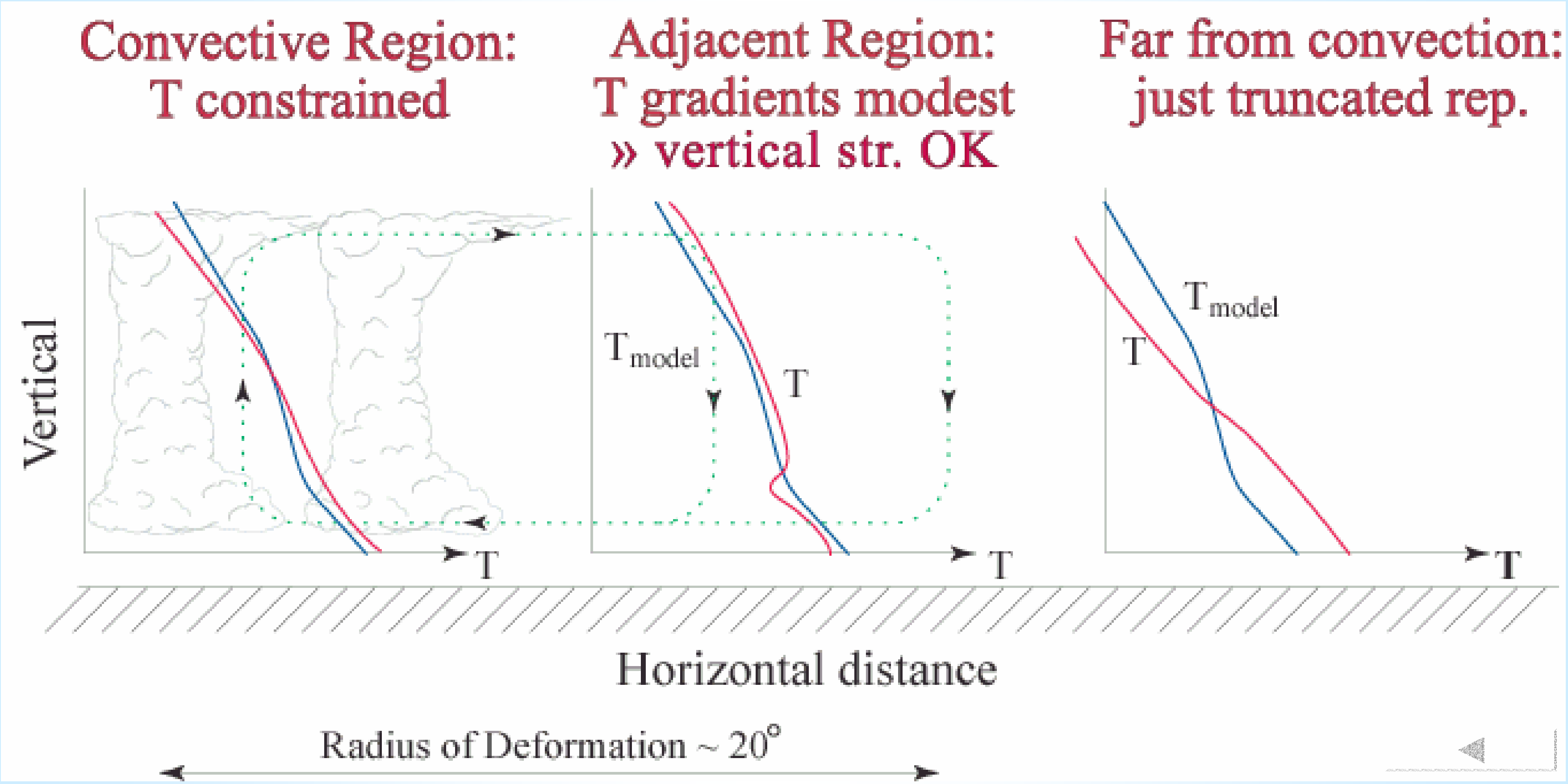
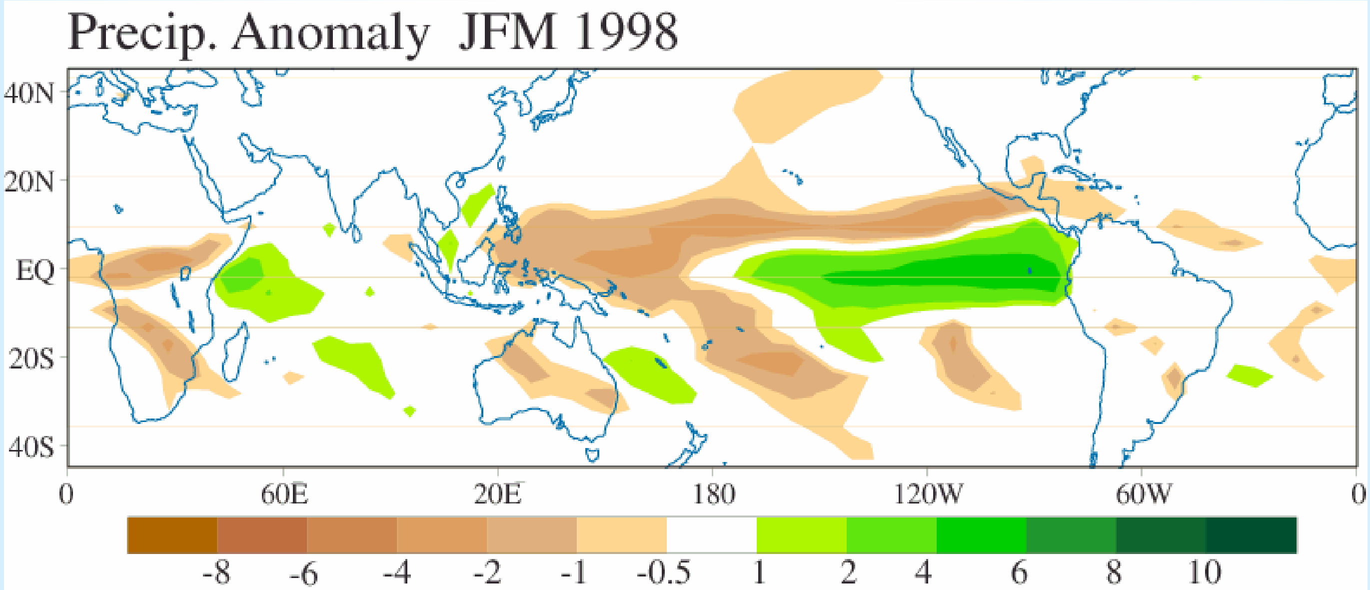
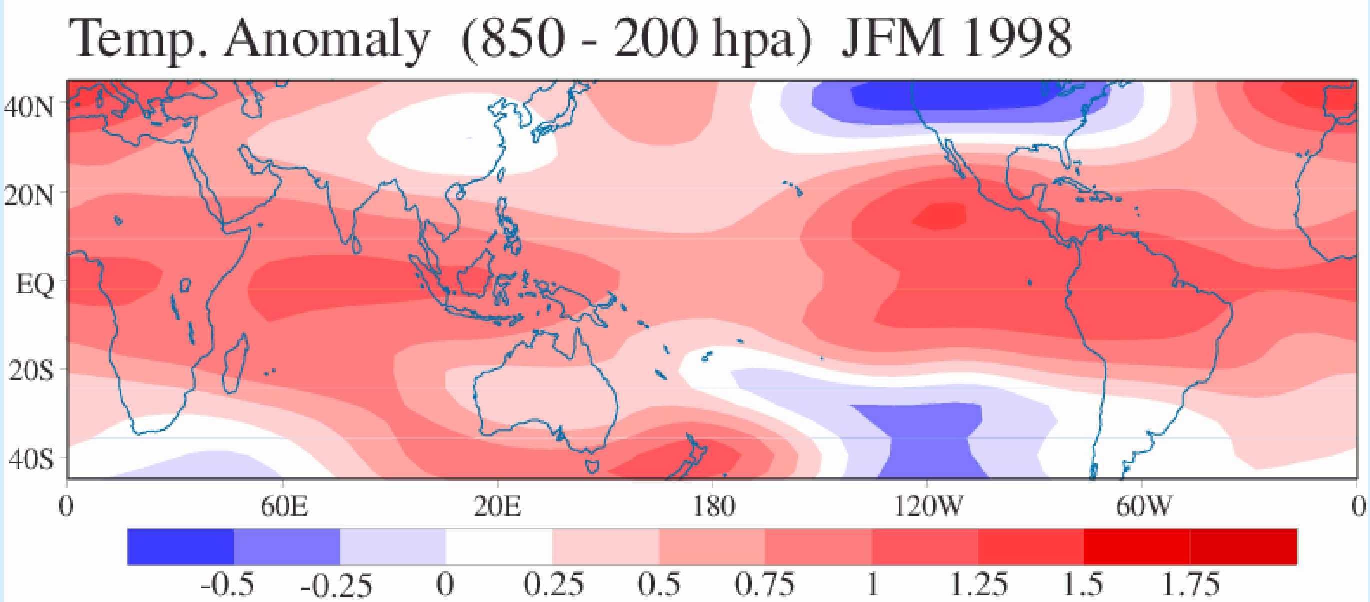
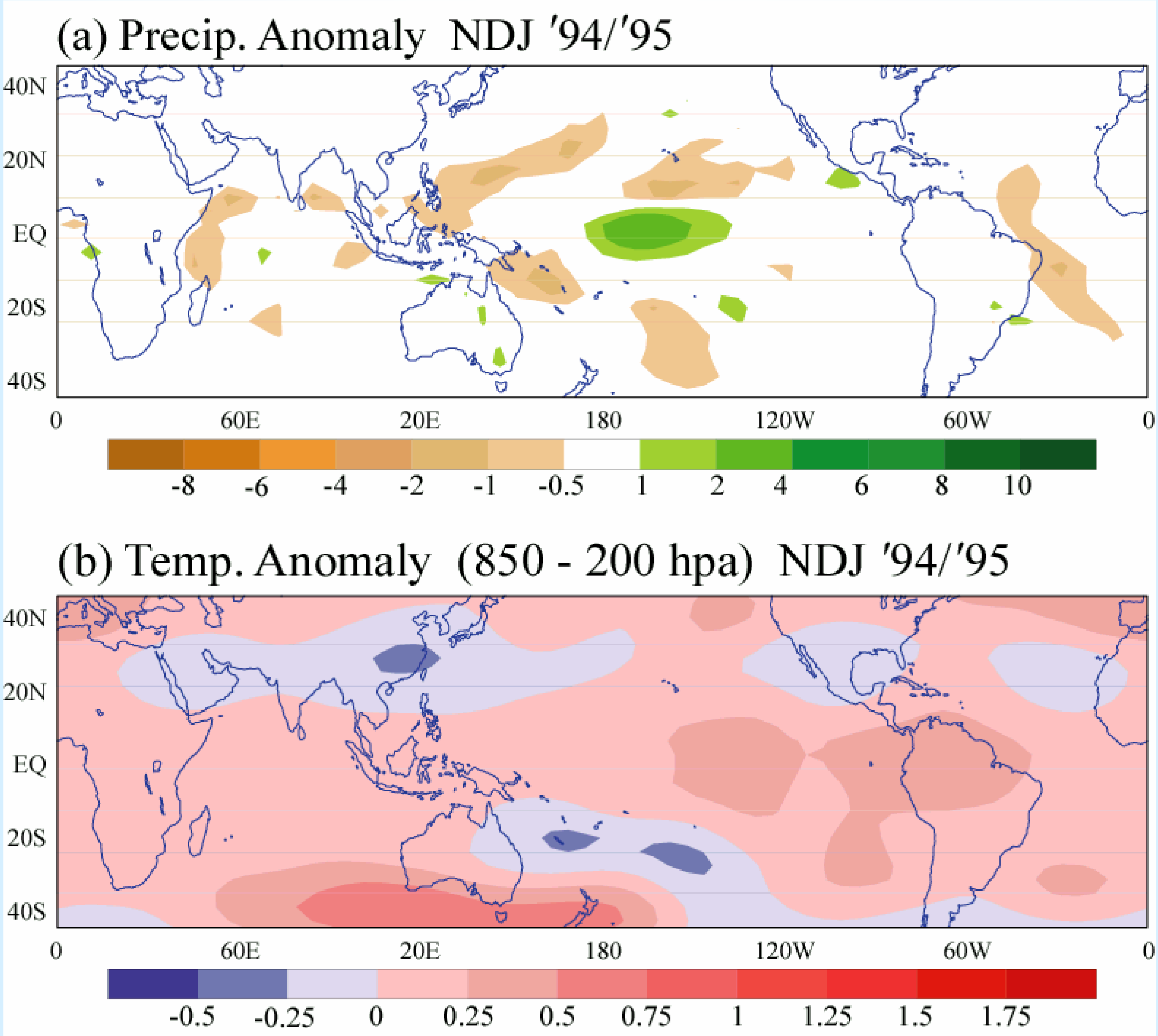


QTCM Anomalies JFM '98



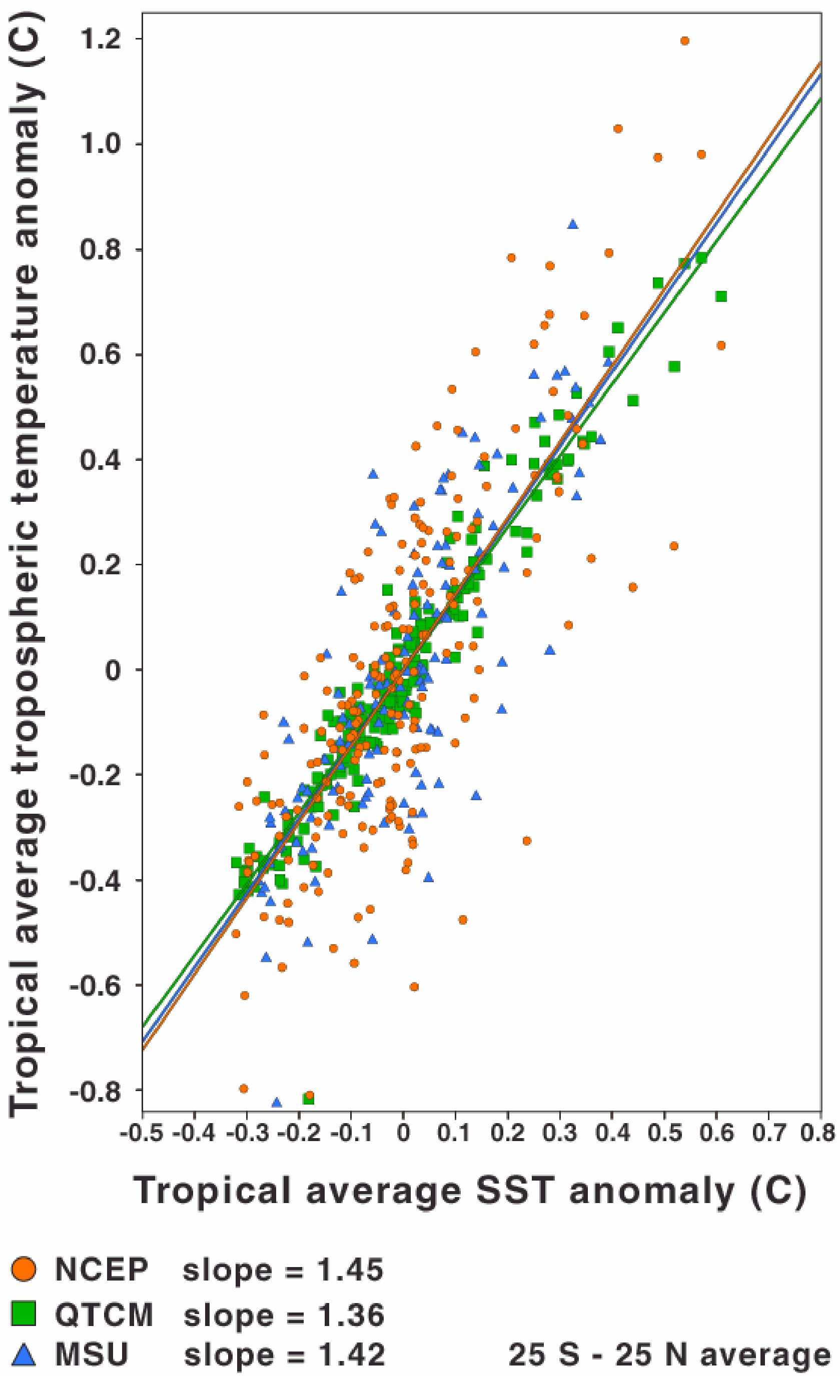


QTCM Anomalies NDJ ‘94/’95



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



Slopes of linear fits to each dataset:

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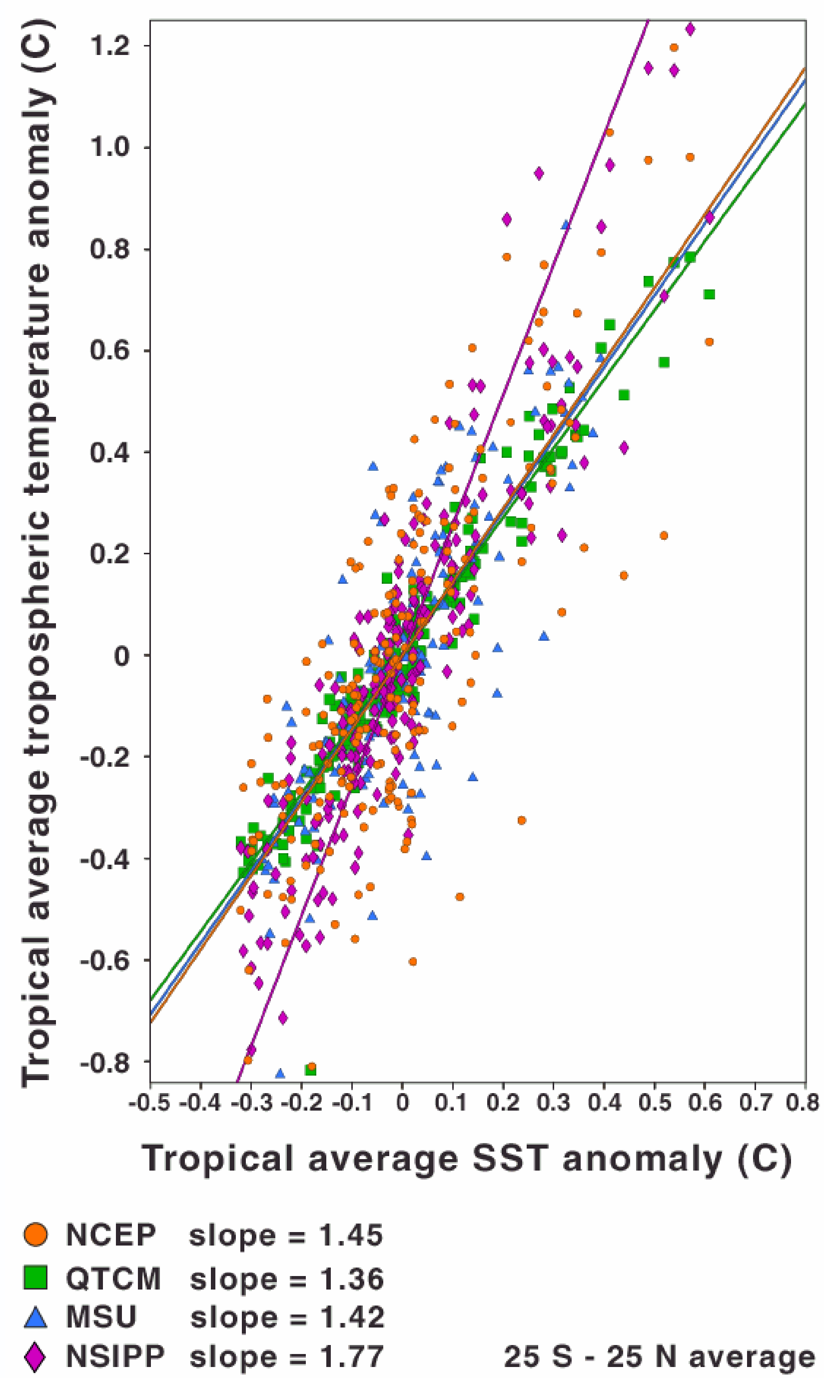
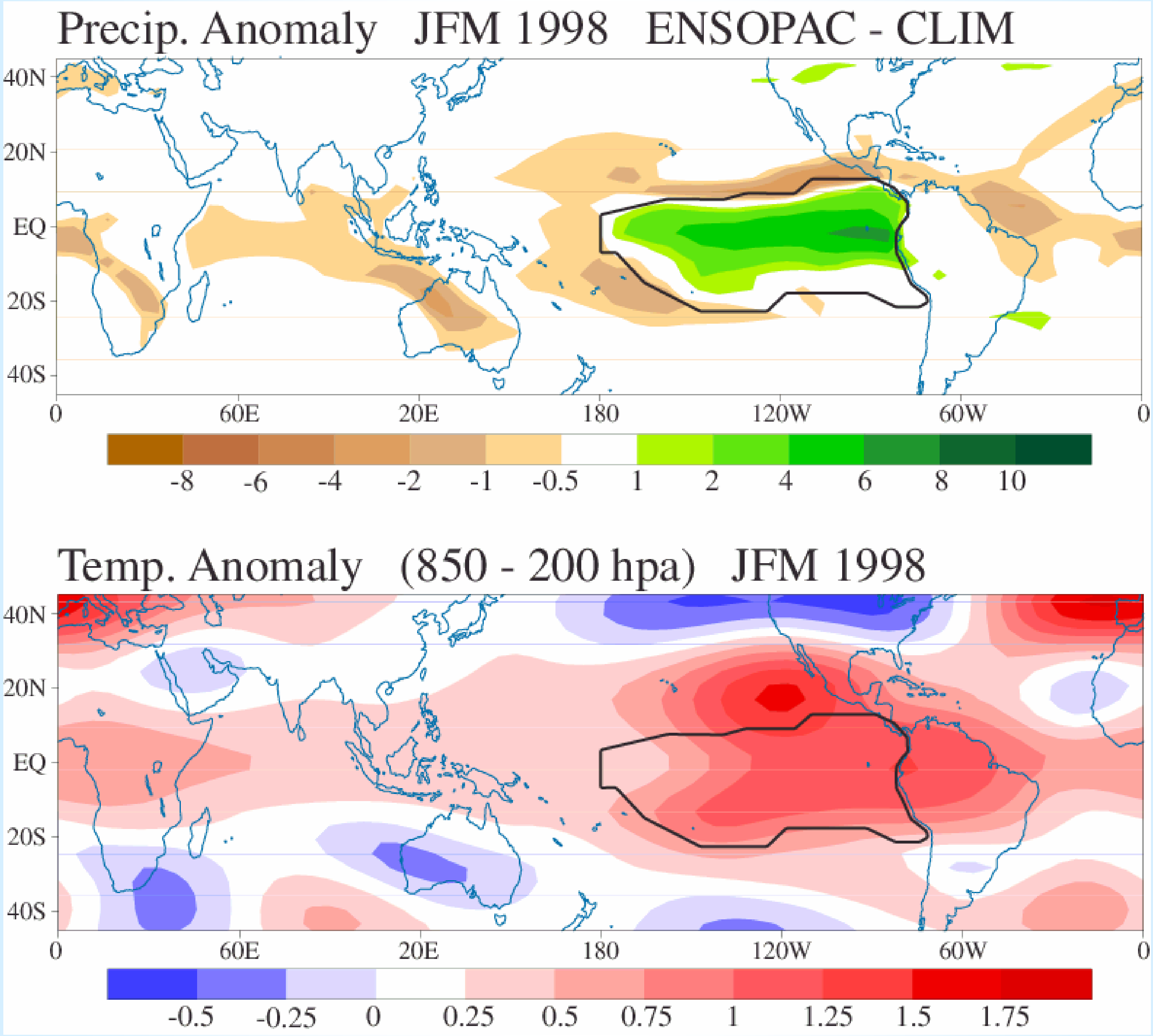
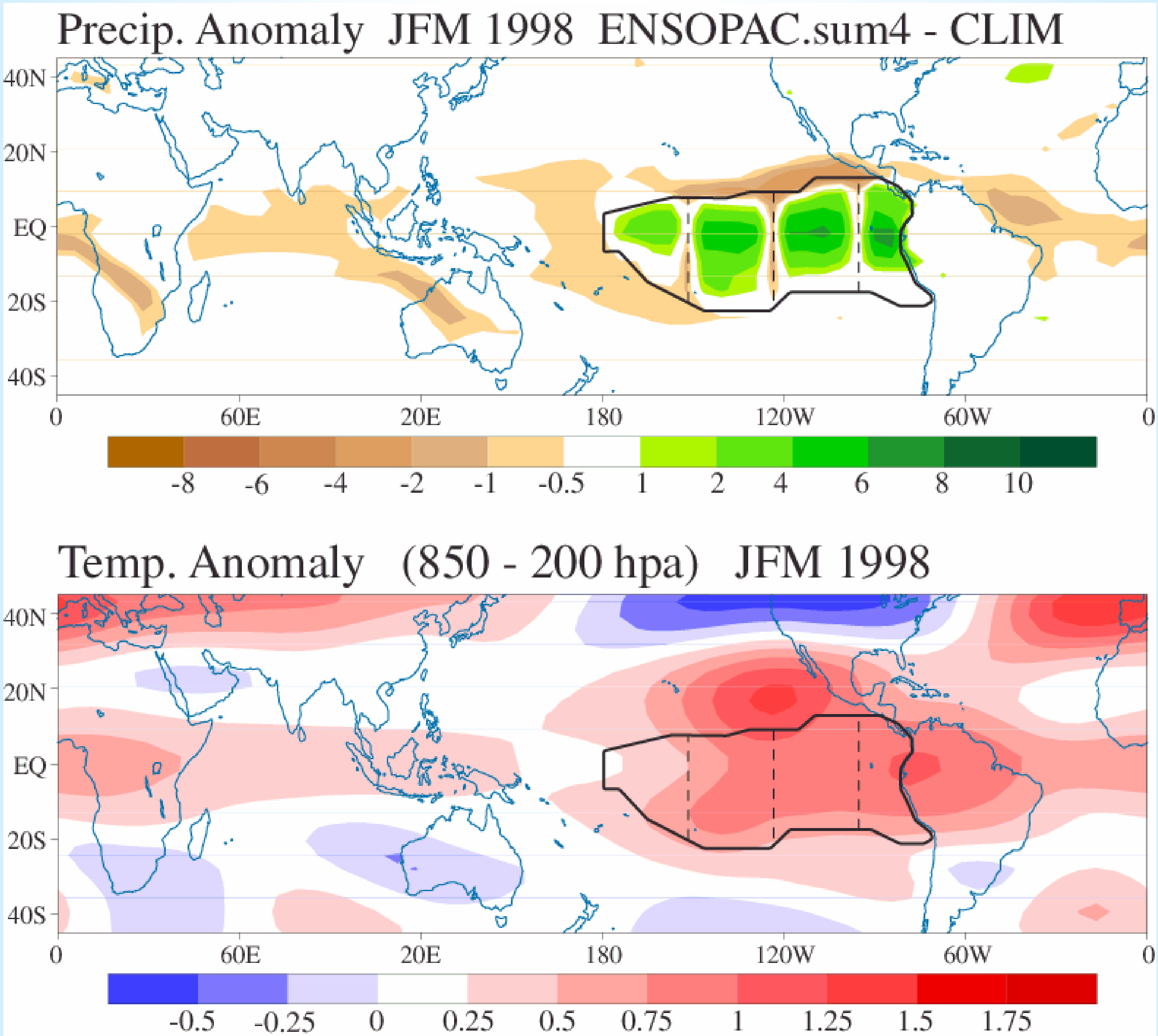


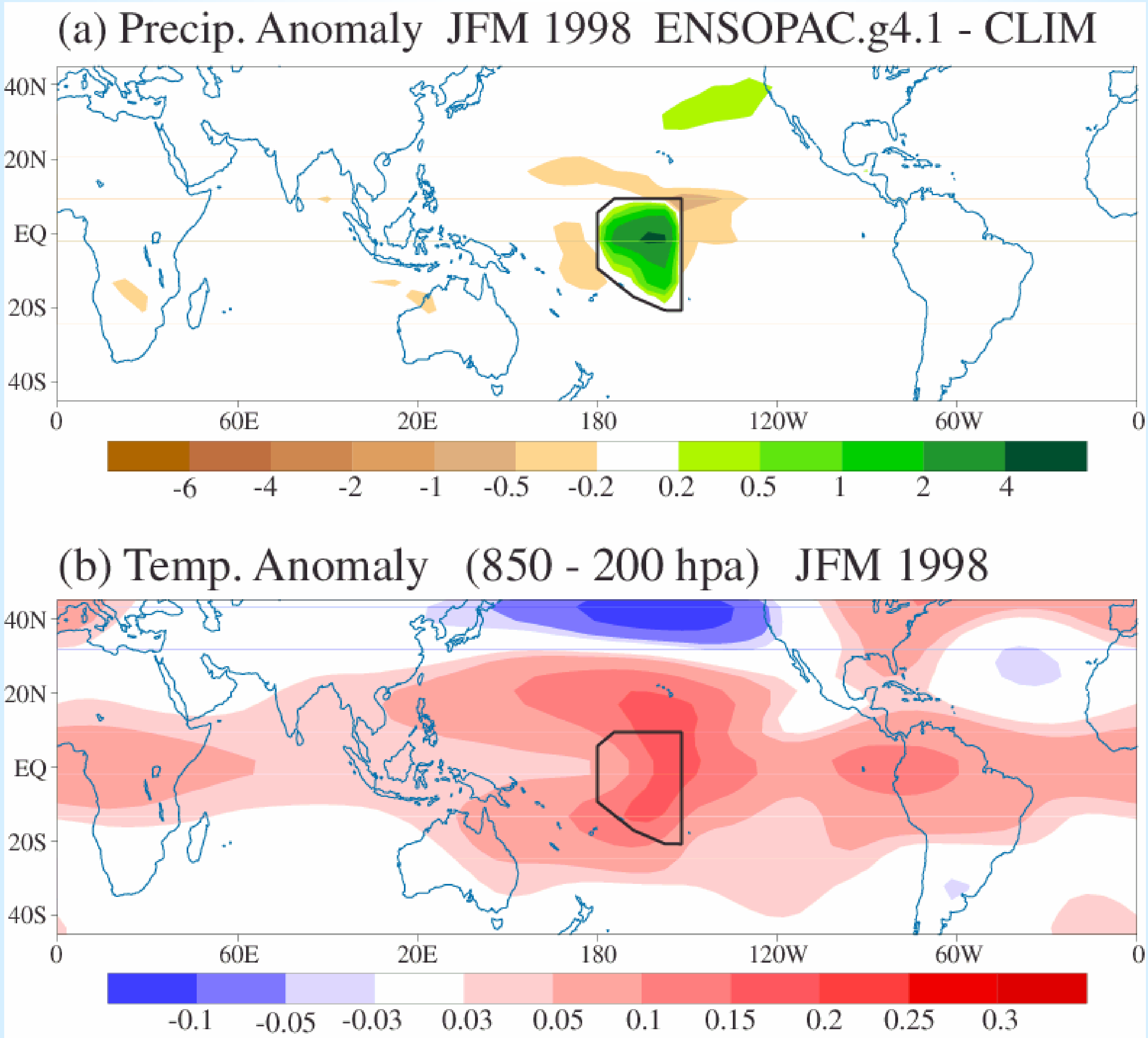
ENSOPAC region - Climatology



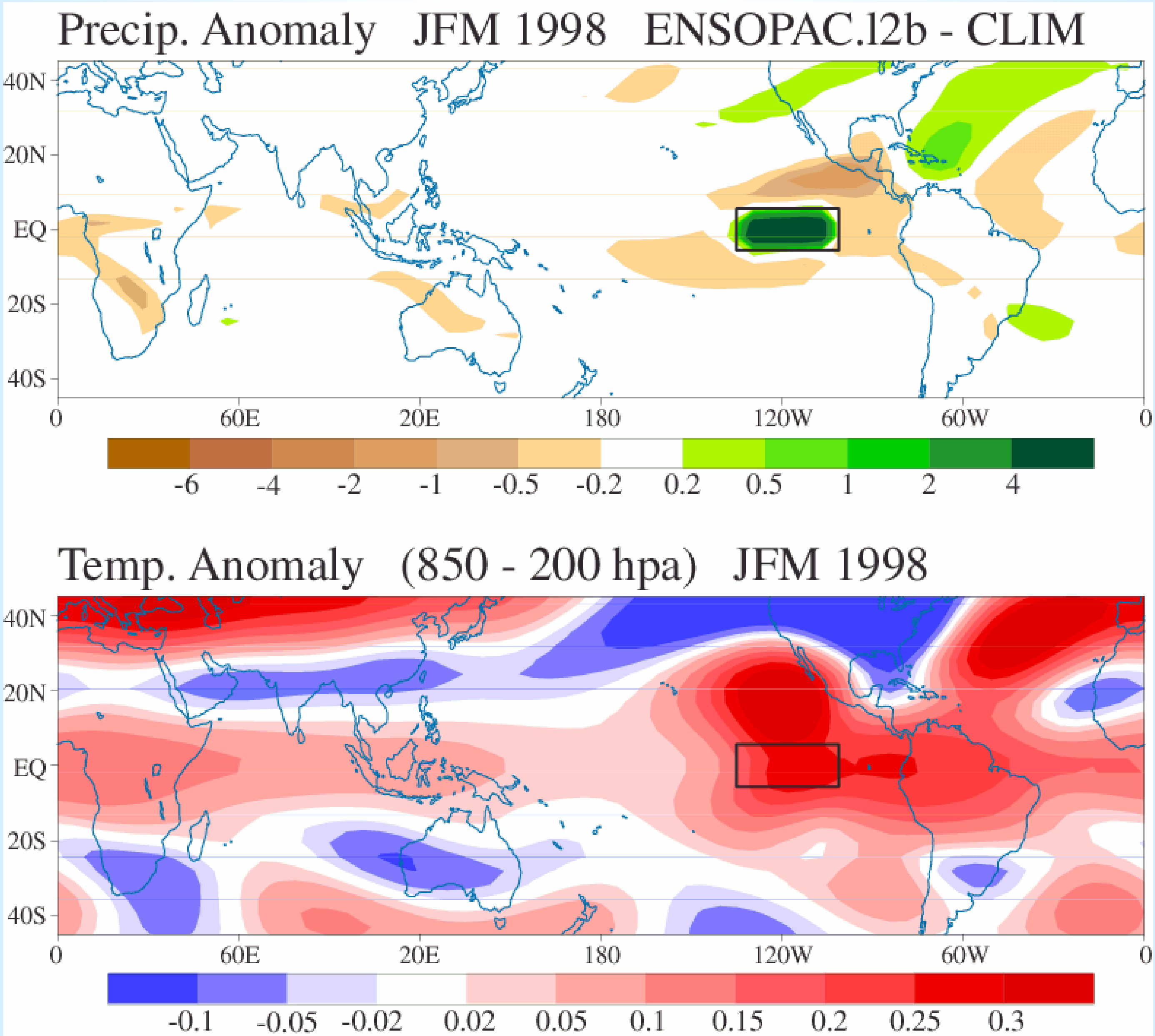
Sum of ENSOPAC subregions - Climatology



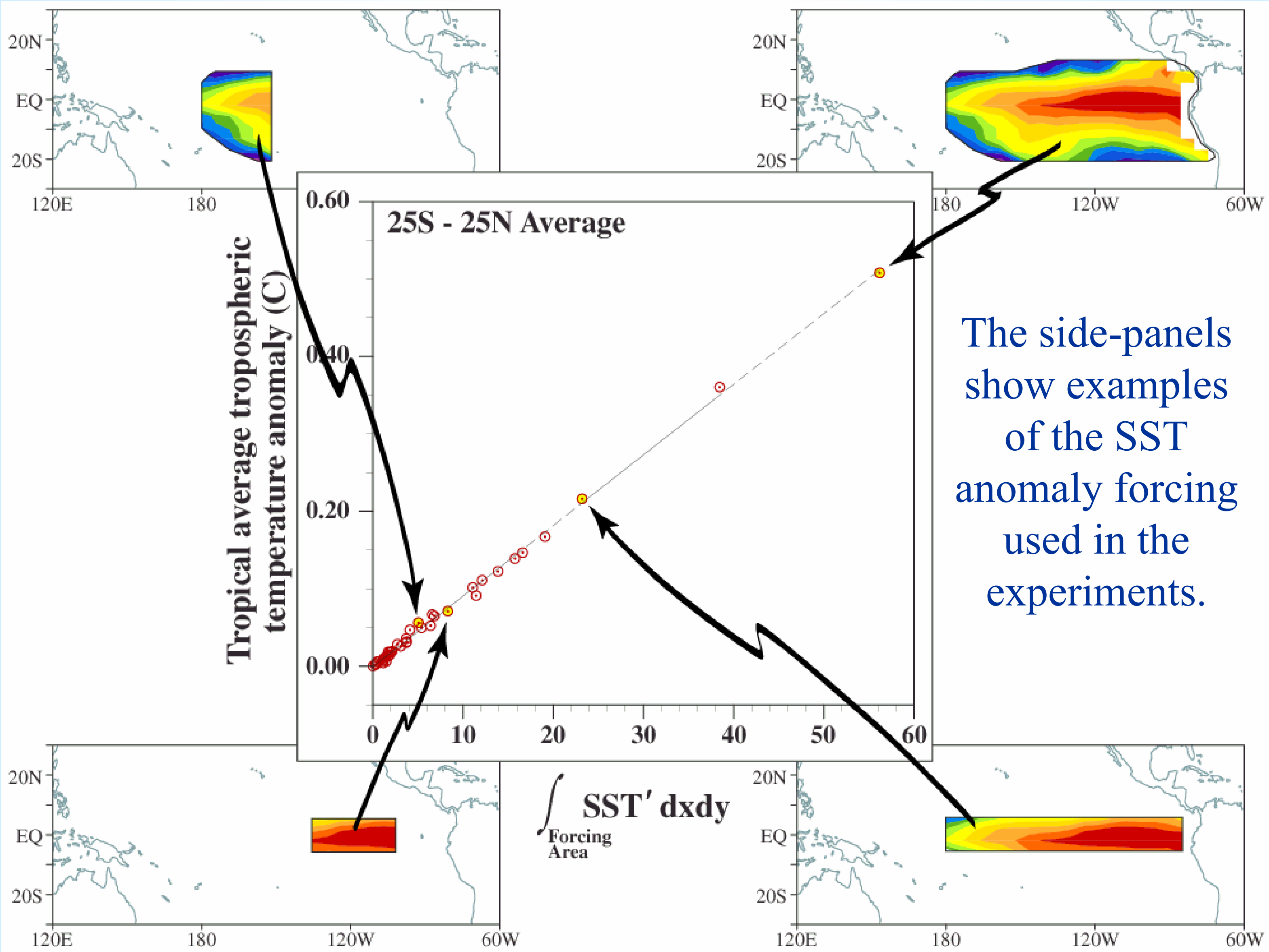
ENSOPAC subregion - Climatology



Small subregion - Climatology

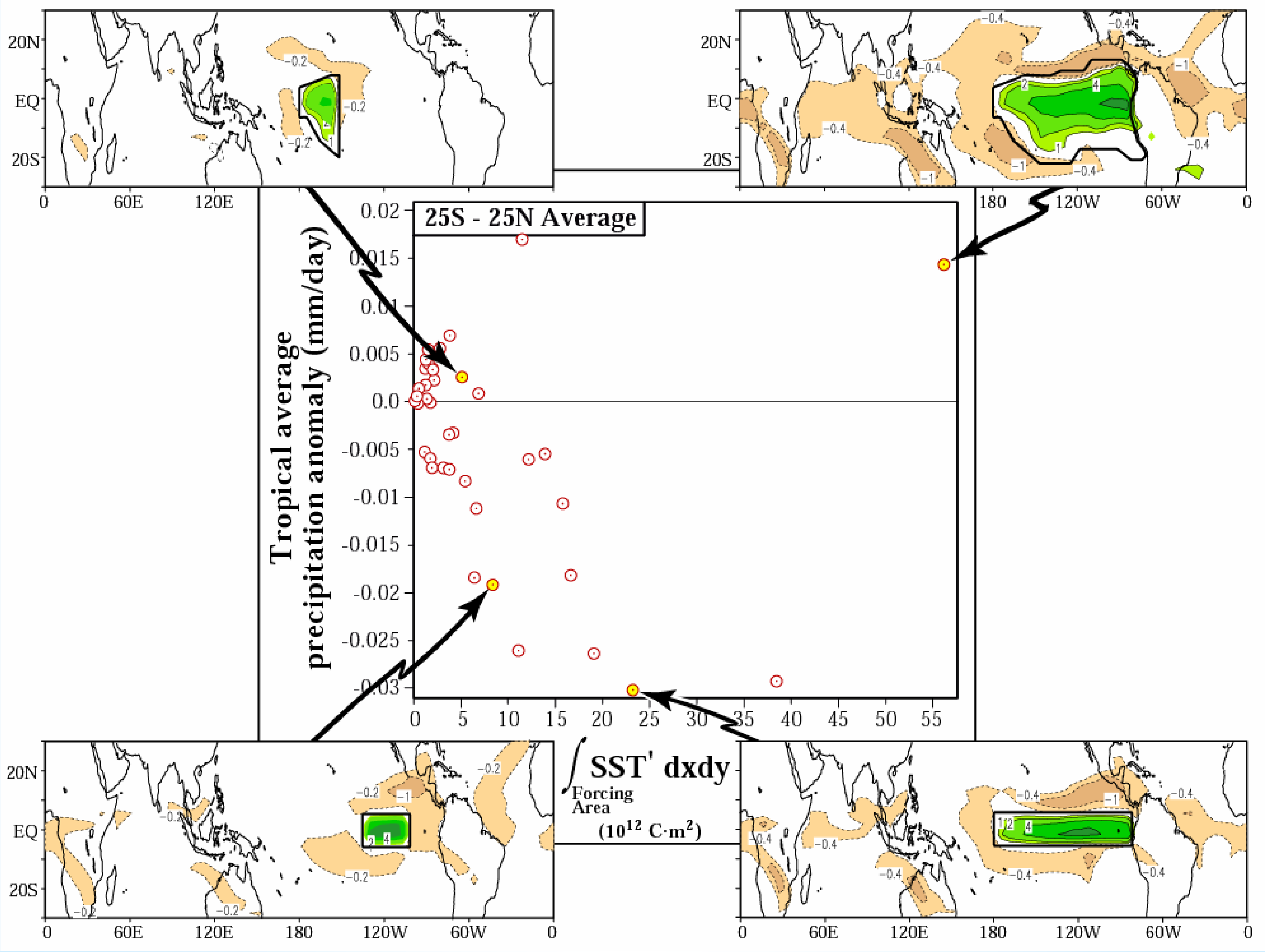


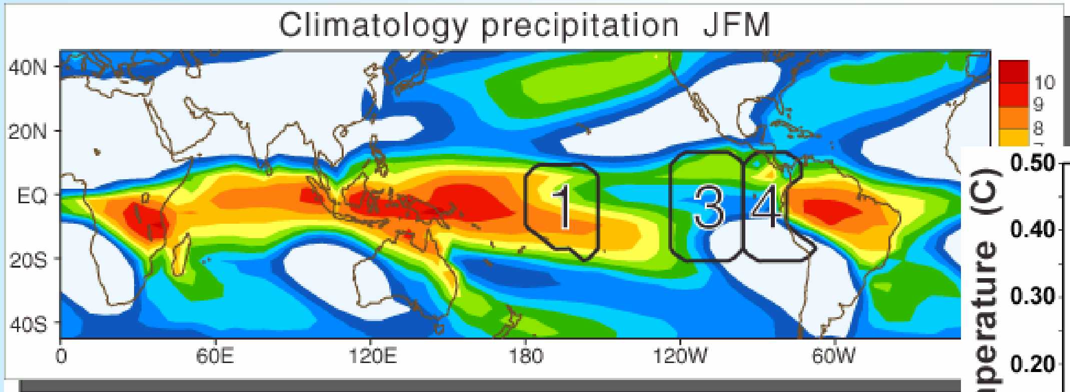
Tropical averaged (25S-25N) tropospheric temperature anomalies versus the spatial integral of SST anomaly forcing for experiments with subregions of the 1998 JFM El Niño SST anomaly



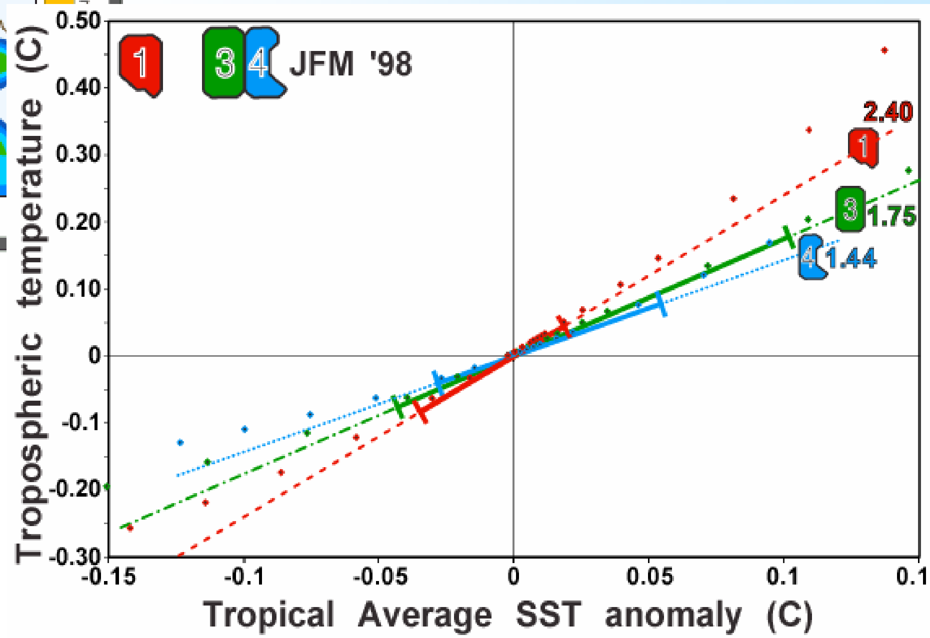
The side-panels show examples of the SST anomaly forcing used in the experiments.

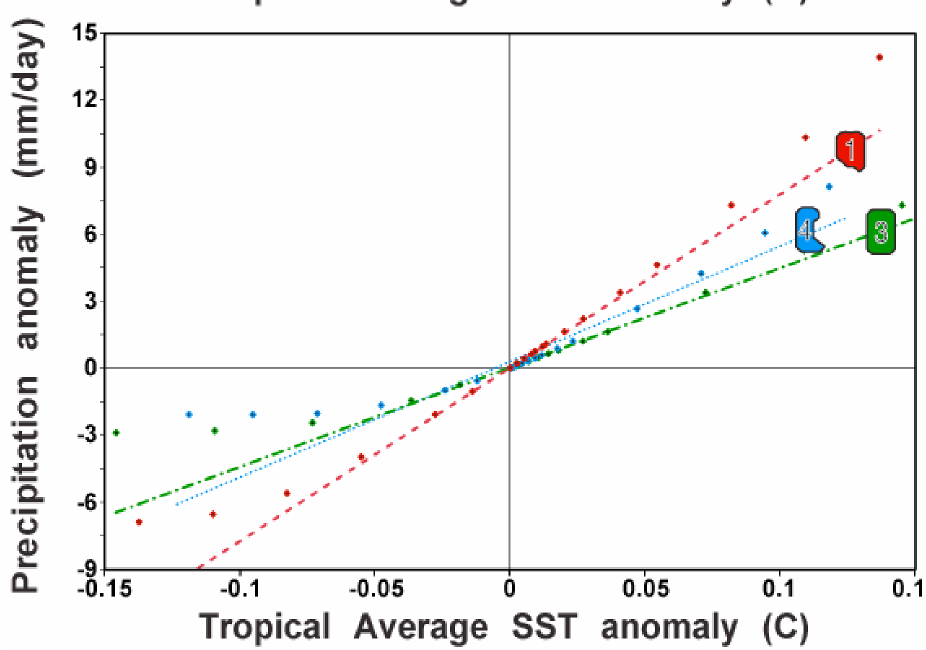
Regional averaged (25S-25N) precipitation anomalies versus the spatial integral of SST anomaly forcing for experiments with subregions of the 1998 JFM El Niño SST anomaly



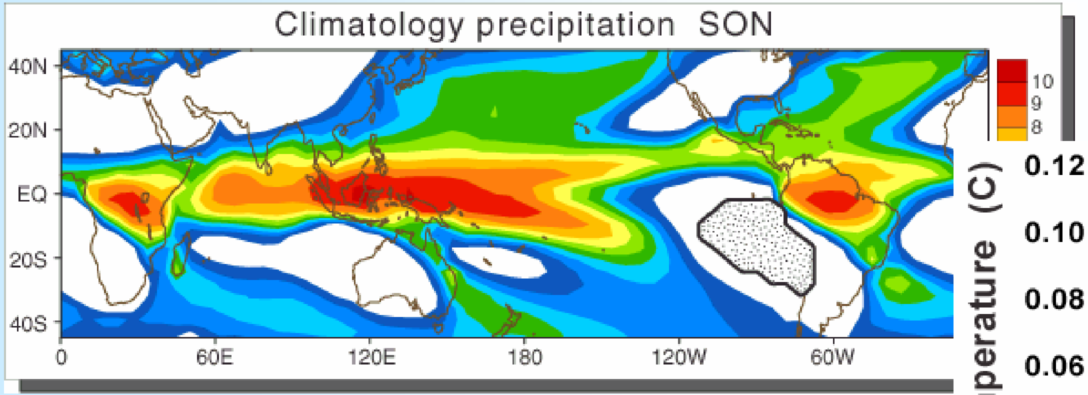


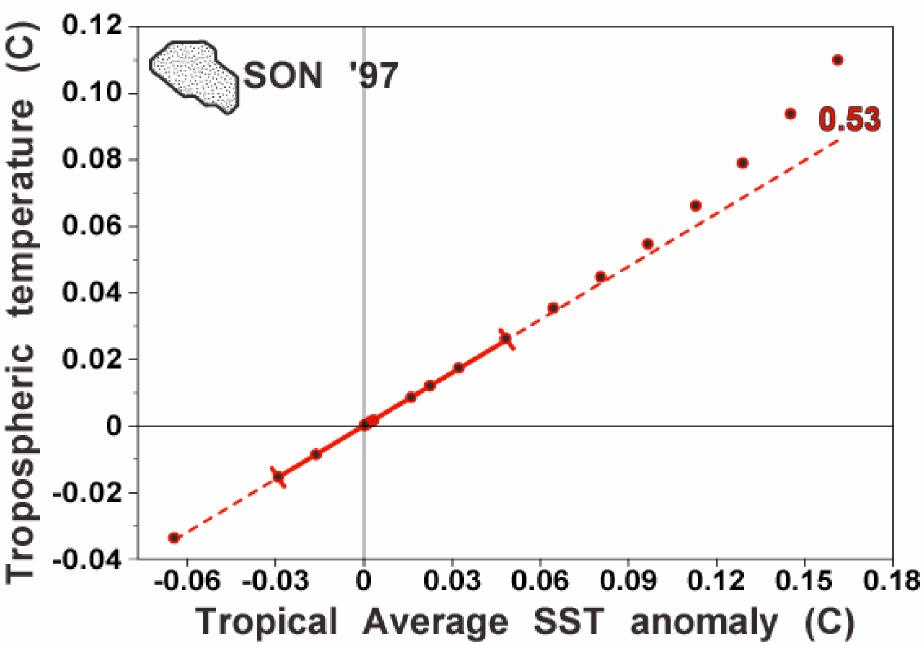
Tropical-average (25S-25N) tropospheric temperature and regional precipitation anomalies versus tropical-average SST anomalies

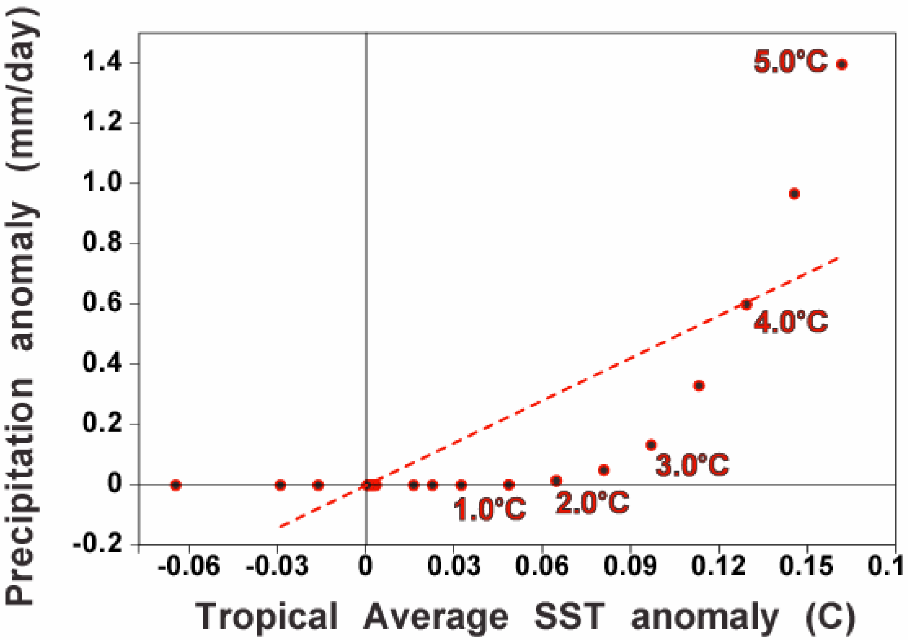




- Uniform SST anomalies of amplitude -5C to 5C added to climatological SST in three subregions
- Dots - results of the experiments
- Dashed - linearization for small SST anomalies (-0.5 to 0.5 C)



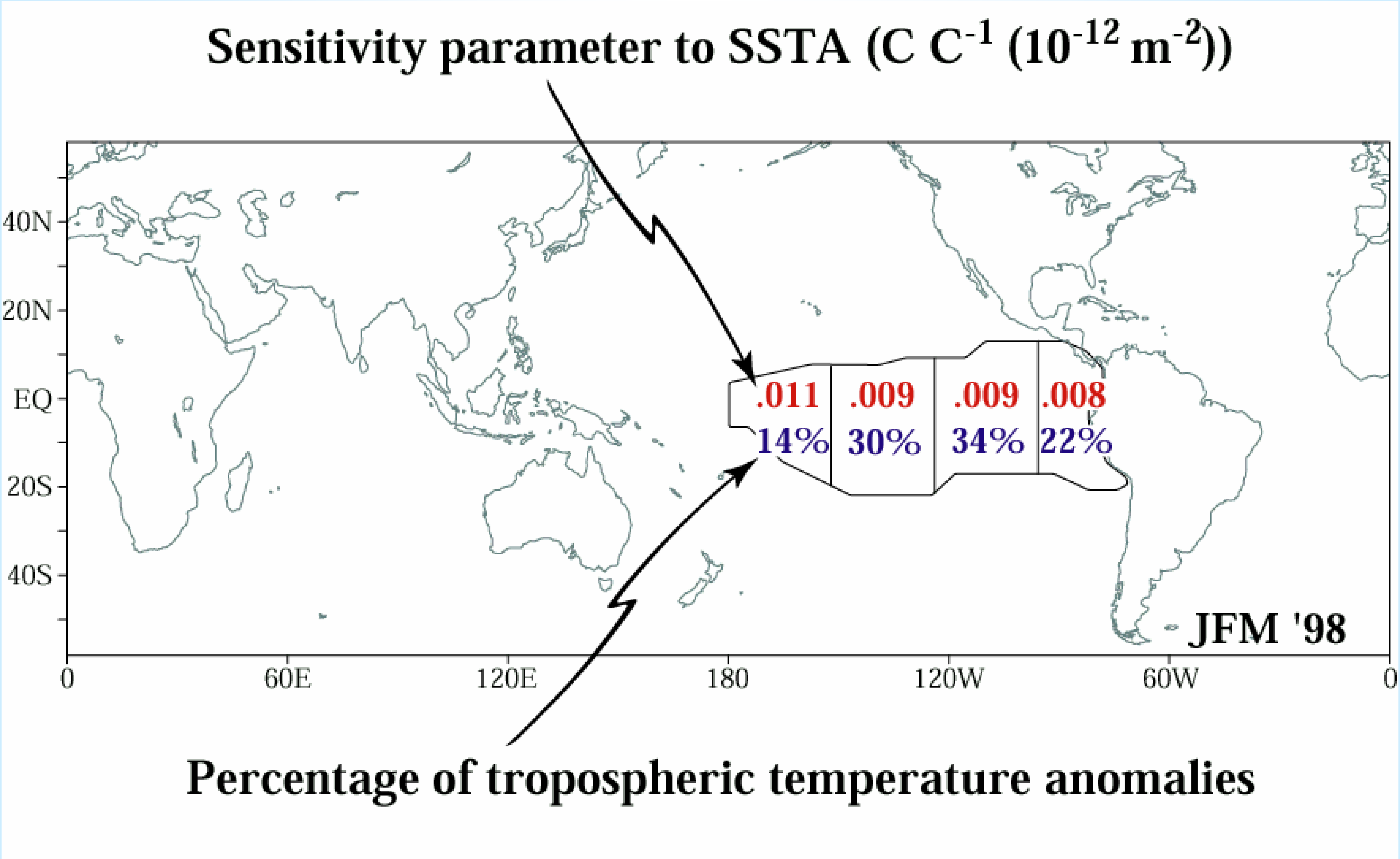




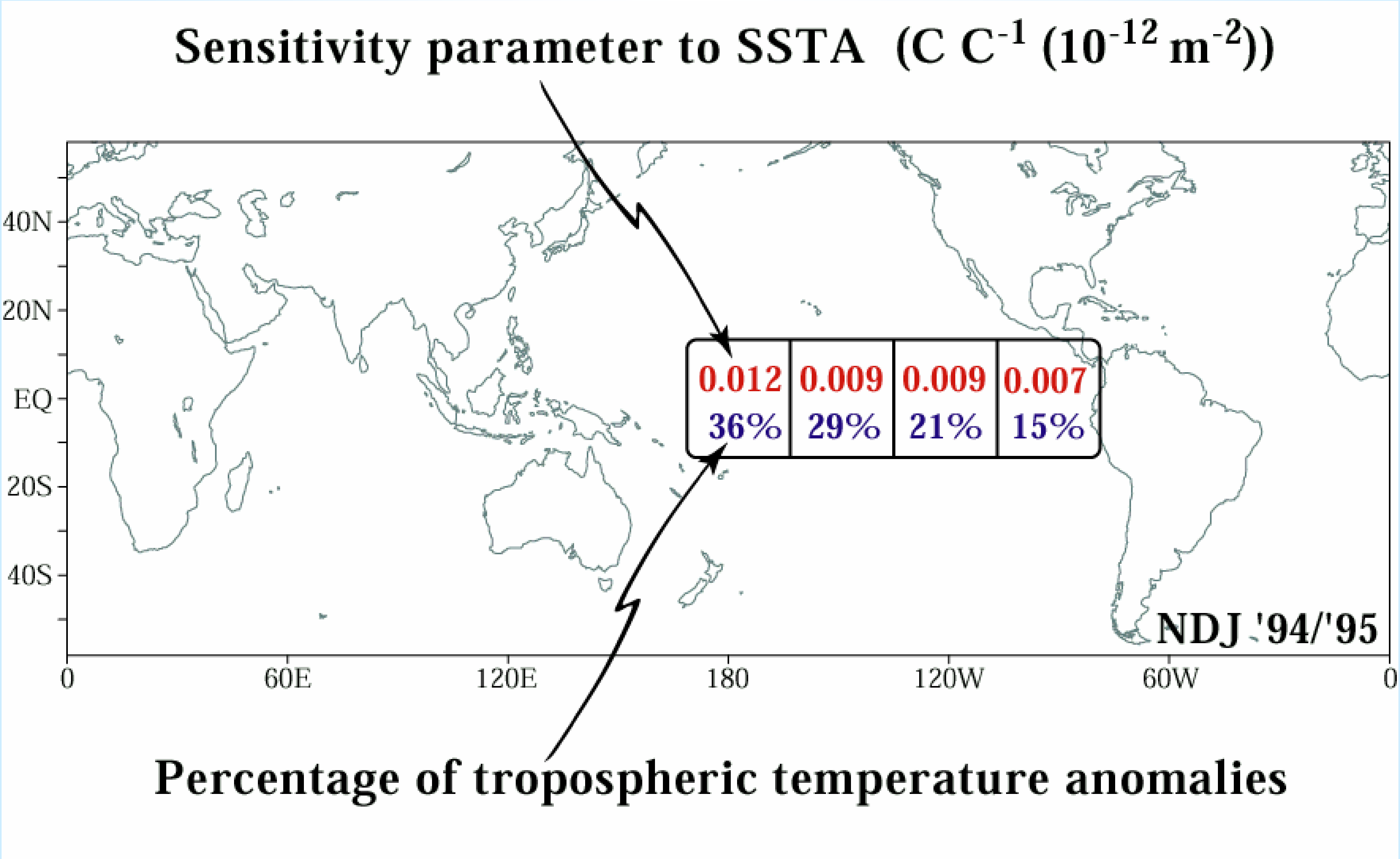
Tropical-average (25S-25N) tropospheric temperature and regional precipitation anomalies versus tropical-average SST anomalies over a climatologically non-precipitating region

- 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 and % tropospheric temp. anomalies NDJ 1994/'95



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

$$\hat{a}_1(\partial_t + \mathcal{D}_{T1})\,T_1 + \hat{b}_1(\partial_t + \mathcal{D}_{q1})\,q_1 + M_1 \nabla \cdot \mathbf{v}_1 = (g/p_T)\,(F_{rad} + H + E)$$

Consider perturbations from mean state

$$A' = A - \bar{A}$$

Averaged over a large horizontal area

$$\text{L.H.S. (transport)} \approx 0$$

$$F'_{rad} + H' + E' \approx 0$$

Net radiative fluxes linear with T'_1, q'_1, T'_s and α'

$$F'_{rad} = \epsilon_{T1} T'_1 + \epsilon_{q1} q_1{\prime} + \epsilon_{Ts} T'_s + CRF'$$

Sensible and latent heat fluxes

$$H' = \rho_a C_D \bar{V}_s \,(T'_s - a_{1s} T'_1)$$

$$E' = \rho_a C_D \bar{V}_s \,[q'_{sat}(T_s) - b_{1s} q'_1]$$

Cloud radiative forcing as a feedback:

$$CRF' \approx c_t P' \;\; (c_t = 0.06)$$

Precip (convective heating) by moisture budget:

$$P' = M_{q1} \nabla \cdot \mathbf{v}' - \langle \mathbf{v} \cdot \nabla q_1 \rangle' + E'$$

Approximate balance

$$\epsilon_{T1} T'_1 + \epsilon_{q1} q_1{\prime} + \epsilon_{Ts} T'_s + H' + (1 + c_t) E' \approx 0$$

Using

$$\epsilon_{T_1} = -2.89;\; \epsilon_{q_1} = -1.11;\; \epsilon_{T_s} = 5.98$$

$$\overline{T}_s = 295.0 \sim 304.0\ (K),\;\; \overline{\mathrm{V}}_s = 5.00 \sim 10.0\ (m/s),$$

$$q'_1 \approx (0.6 \sim 1.6)\ T'_1$$

$$\Rightarrow \quad \widehat{T}' = \hat{a}_1 T'_1 \approx (0.78 \sim 2.0)\ T'_s$$

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 $\langle \hat{T}' \rangle$ response is approximately linear with the spatial integral of SST forcing.
- Nonlinearity in $\langle \hat{T}' \rangle$ 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 $\langle \hat{T}' \rangle$.
- Approximate linearity of $\langle \hat{T}' \rangle$ 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.