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Unforced Surface Air Temperature Anomalies and their Opposite Relationship with the TOA Energy Imbalance at Local and Global Scales

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Introduction

- In the absence of external radiative forcings, global mean temperature (T) should be stable in the long run:

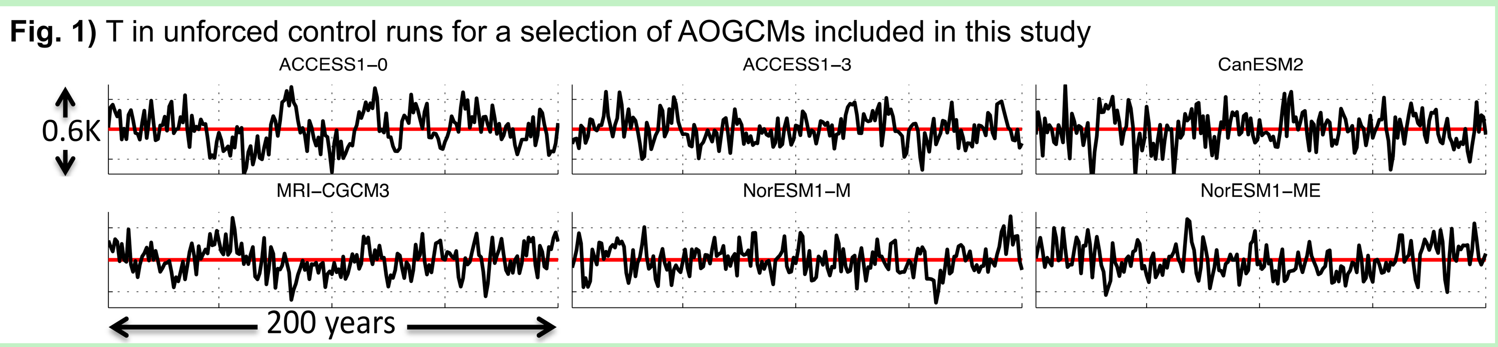


Fig. 1) T in unforced control runs for a selection of AOGCMs included in this study

- Why? Because of the 'Planck Response': $\lambda_{Plank} = -4\sigma T_e^3 \approx -3.8\,Wm^{-2}K^{-1}$

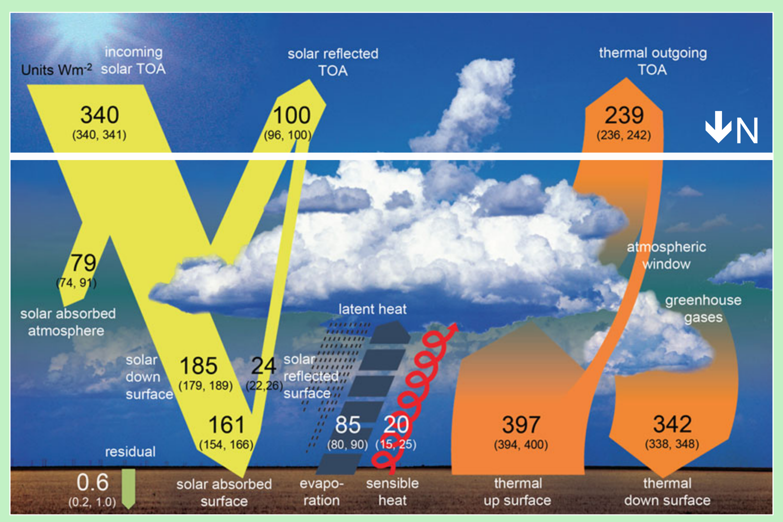


Image credit: Wild et al., AIP Conf. Proc. **1531**, 628 (2013)

- The Planck Response suggests that positive T anomalies will be associated with enhanced thermal outgoing radiation at the top of the atmosphere (TOA), which would cause a negative energy imbalance (N, positive downward), and thus an eventual return of T to its equilibrium value.

- Indeed, both satellite observations and Atmosphere-Ocean General Circulation Models (AOGCMs) show a negative N vs. T relationship for annual unforced variability:

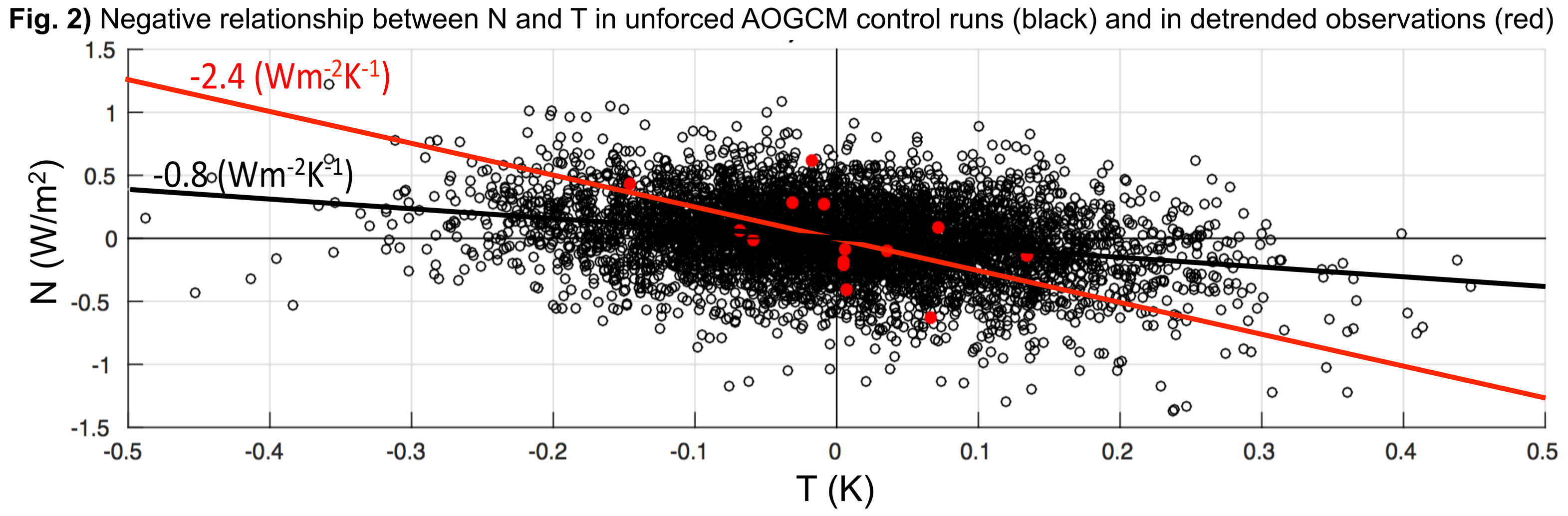


Fig. 2) Negative relationship between N and T in unforced AOGCM control runs (black) and in detrended observations (red)

- **However,** the same AOGCMs and observations demonstrate that, at the local spatial scale, the N(θ,ϕ) vs. T(θ,ϕ) relationship [where (θ,ϕ)=(latitude, longitude)] tends to be **positive** over most of the planet:

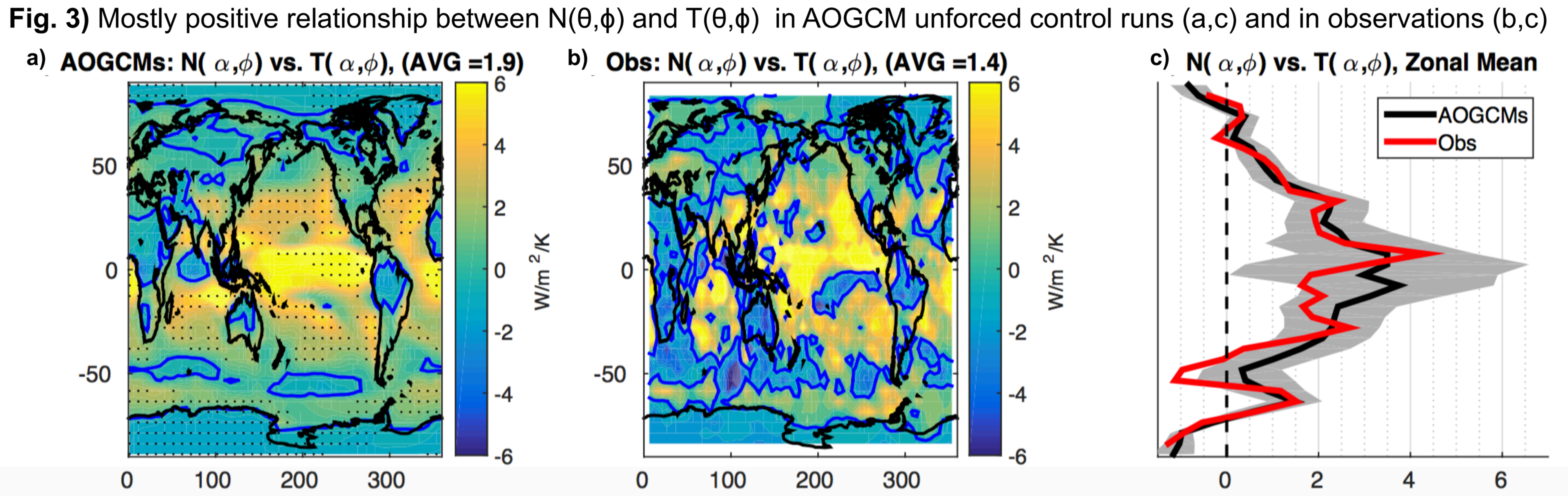


Fig. 3) Mostly positive relationship between N(θ,ϕ) and T(θ,ϕ) in AOGCM unforced control runs (a,c) and in observations (b,c)

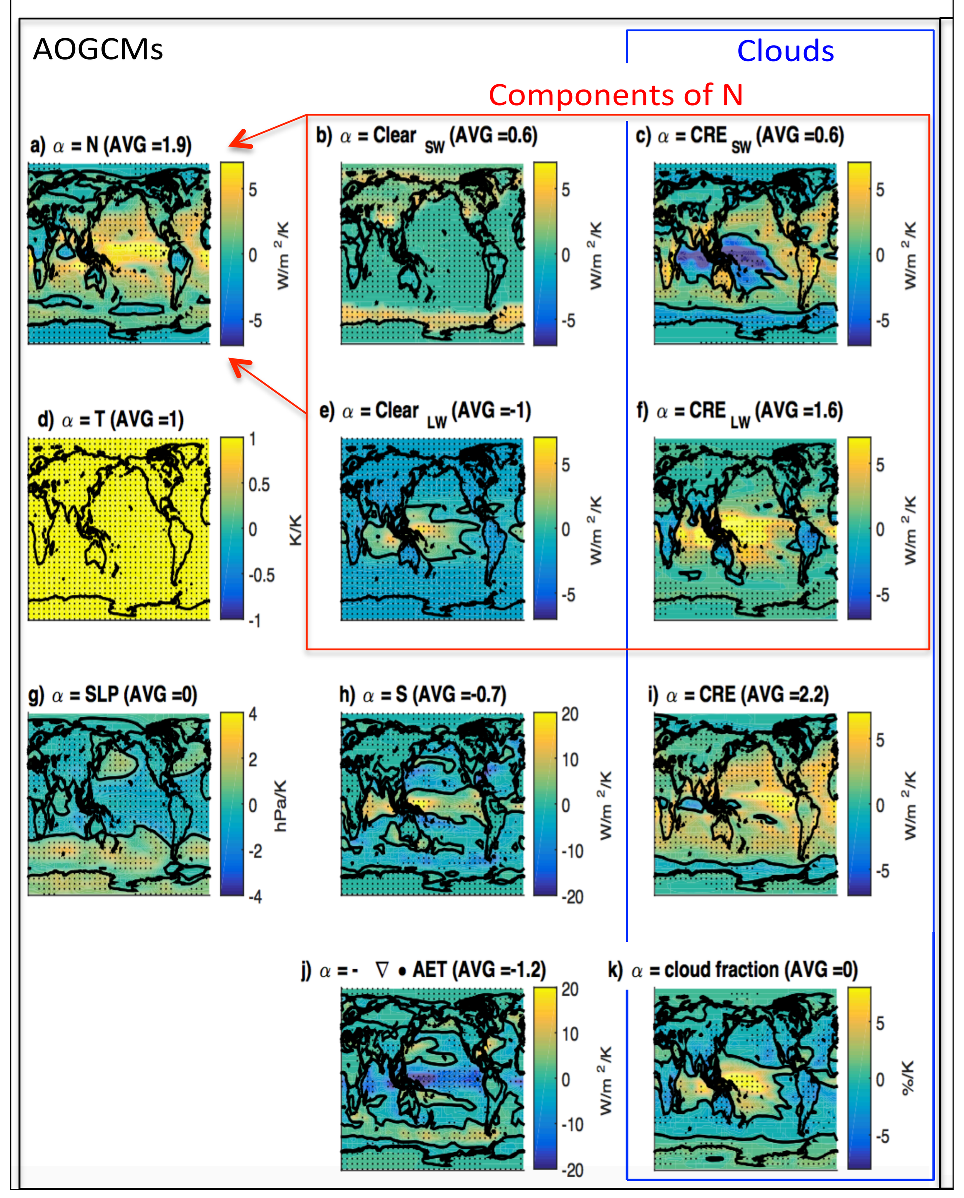
Scientific Questions

- What are the physical reasons for the mostly positive local N(θ,ϕ) vs. T(θ,ϕ) relationship?
- If the local N(θ,ϕ) vs. T(θ,ϕ) relationship is mostly positive, how precisely does global T restore equilibrium after a large unforced fluctuation?

Why is the local N(θ,Φ) vs. T(θ,Φ) relationship mostly positive?

Fig. 4) Linear relationship between **local** variables and **local** temperature

$$\gamma_\alpha(\theta,\emptyset) = \frac{\Delta[\alpha(\theta,\emptyset)]}{\Delta[T(\theta,\emptyset)]}\ (where\ \alpha = any\ variable)$$



- Due to the surface shortwave component (i.e., ice albedo) in regions with climatological T(θ,ϕ) near the freezing point of water (Fig. 4b)
- Due to the cloud shortwave component in regions with intermediate to high climatological T(θ,ϕ) (Fig. 4c)
- Due mostly to the longwave water vapor feedback over oceanic regions with the highest climatological T(θ,ϕ) (Fig. 4e)

Definitions of variables

$Clear_{SW} = [\downarrow SW - \uparrow SW_{clear\ sky}]$,

$Clear_{LW} = [-\uparrow LW_{clear\ sky}]$,

$CRE_{SW} = [\downarrow SW - \uparrow SW_{all\ sky}] - [\downarrow SW - \uparrow SW_{clear\ sky}] = \uparrow SW_{clear\ sky} - \uparrow SW_{all\ sky}$

$CRE_{LW} = [-\uparrow LW_{all\ sky}] - [-\uparrow LW_{clear\ sky}] = \uparrow LW_{clear\ sky} - \uparrow LW_{all\ sky}$.

$CRE = CRE_{SW} + CRE_{LW}$.

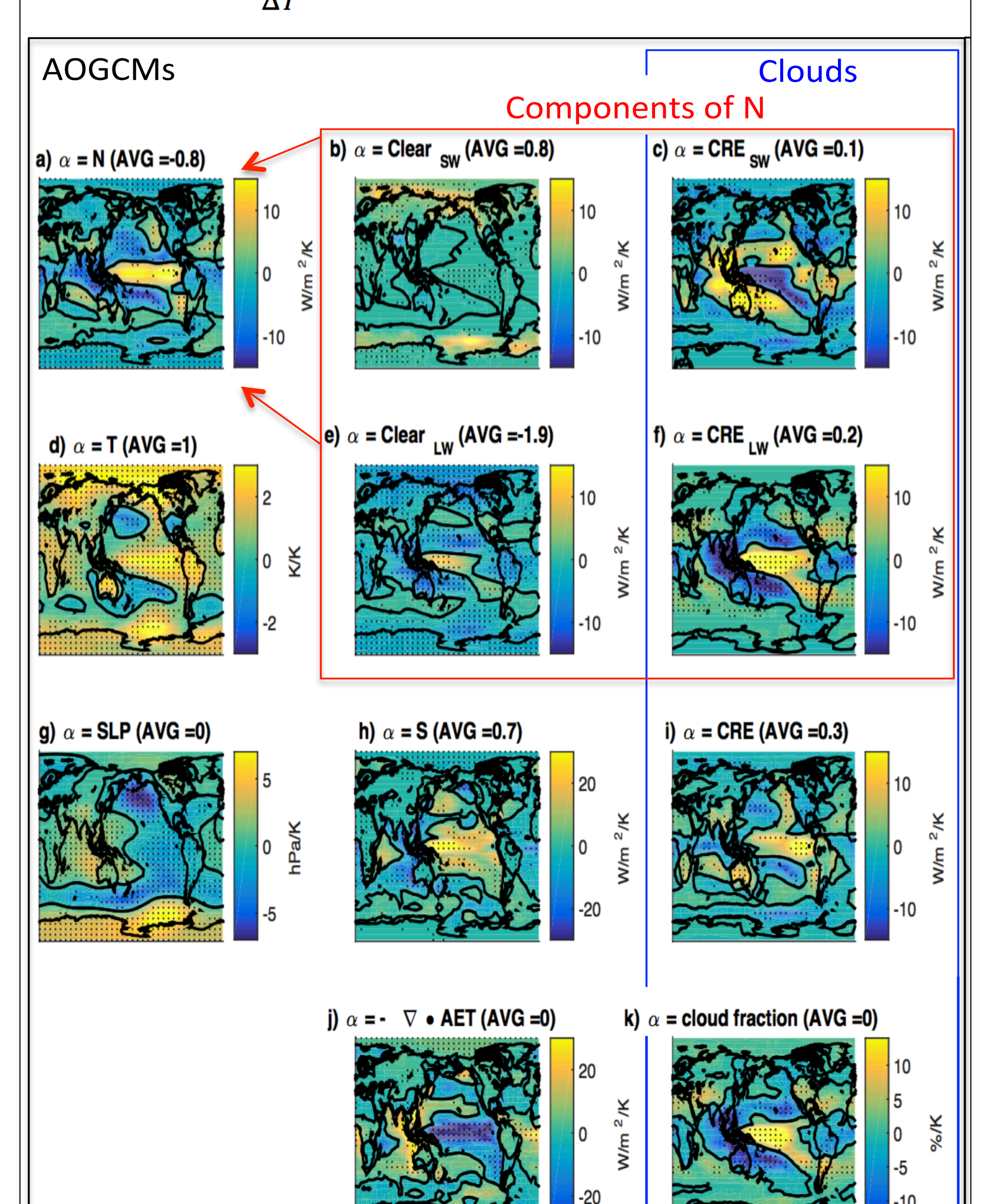
$S = \uparrow LE + \uparrow LH + [\uparrow SW_S - \downarrow SW_S] + [\uparrow LW_S - \downarrow LW_S]$,

$-\nabla \cdot AET(\theta,\phi) = -1 \cdot [N(\theta,\phi) + S(\theta,\phi)]$.

Why is the global N vs. T relationship negative?

Fig. 5) Linear relationship between **local** variables and **global** temperature

$$\zeta_\alpha(\theta,\emptyset) = \frac{\Delta[\alpha(\theta,\emptyset)]}{\Delta\bar{T}}\ (where\ \alpha = any\ variable)$$

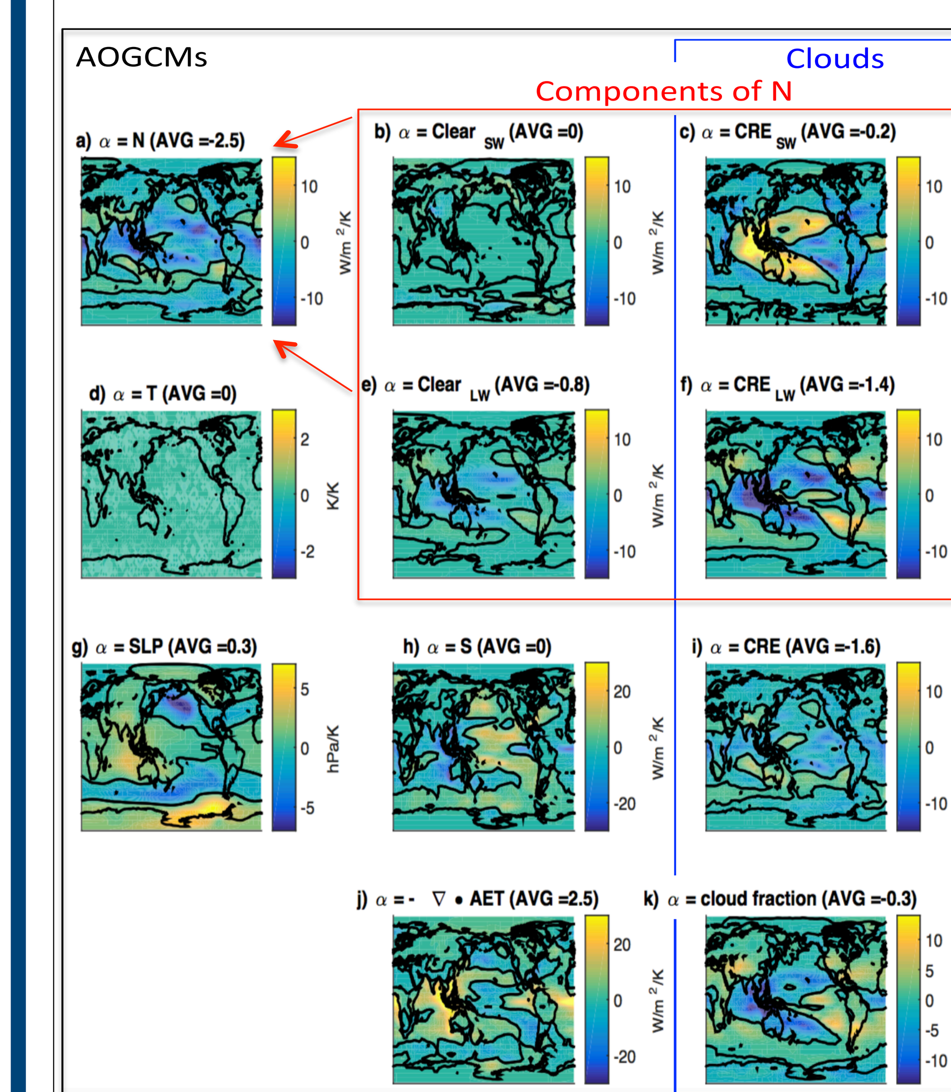


- Positive T anomalies associated with El Niño events (Fig. 5d)
- Large net surface flux (S) from the Pacific (Fig. 5h) into the atmosphere where local N(θ,ϕ) vs. T(θ,ϕ) relationship is positive (Fig. 4a)
- Large horizontal divergence (convergence) of atmospheric energy transport over the tropical Pacific (high latitudes) (Fig. 5j)
- Redistribution of energy helps create a characteristic T(θ,ϕ) vs. T pattern with a substantial amount of warmth at high latitudes (Fig. 5d) where the temperature anomaly can be easily damped to space (Fig. 5a)
- Characteristic T(θ,ϕ) vs. T pattern (Fig. 5d) contains anomalously cool T(θ,ϕ) regions where locally positive N(θ,ϕ) vs. T(θ,ϕ) relationship (Fig. 4a) promotes negative N(θ,ϕ)

How does global T restore equilibrium after a large fluctuation?

Fig. 6) The portion of the ζ_α(θ,ϕ) pattern (Fig. 5) that **is not** due to the characteristic surface temperature pattern associated with T variability (Fig. 5d) multiplied by the local feedback pattern (Fig. 4)

$$\omega_\alpha(\theta,\emptyset) = \zeta_\alpha(\theta,\emptyset) - \gamma_\alpha(\theta,\emptyset) \cdot \zeta_T(\theta,\emptyset)$$



- During a T maximum, a great rearrangement of large-scale atmospheric circulation in broad regions of the tropical and subtropical Indo-Pacific (Fig. 6g) causes:
  - Reduced cloud cover over descending branches of Hadley and Walker circulations (Fig. 6k)
  - Reduced water vapor over descending branches of Hadley and Walker circulations (Fig. 6e)
- Allows for much more efficient release of thermal outgoing radiation than would otherwise be expected from the T(θ,ϕ) vs. T pattern alone (Fig. 6a)

Conclusions

- The local N(θ,ϕ) vs. T(θ,ϕ) relationship tends to be positive, despite the Planck Response, because warm T(θ,ϕ) is accompanied by:
  - Low surface albedo near sea ice margins and over high altitudes
  - Low cloud albedo over much of the middle and low-latitudes
  - Large water-vapor greenhouse effect over the deep Indo-Pacific
- Global T can restore equilibrium after a large fluctuation because warm global T is accompanied by:
  - Large divergence (convergence) of atmospheric energy transport over the tropical Pacific (high latitudes) which creates large positive T(θ,ϕ) anomalies where they can be easily damped to space
  - Large-scale atmospheric circulation changes drive cloud reduction and atmospheric drying over large portions of the tropics and subtropics which allows for greatly enhanced thermal outgoing radiation

Implications

- The short-timescale relationship between N and T is heavily influenced by large-scale atmospheric circulation changes specific to El Niño dynamics
- These circulation changes (or at least their magnitude) are unlikely to be reproduced under long-term global warming
- Thus, there may be very little relationship between the climate feedback parameter diagnosed from annual or sub-annual timescale variability (i.e., ζ_N, Fig. 5a) and $2XCO_2$ equilibrium climate sensitivity

***This research is *in press* at:** Brown P. T., W. Li, J. H. Jiang, and H. Su, 2015: Unforced surface air temperature variability and its contrasting relationship with the anomalous TOA energy flux at local and global spatial scales, *Journal of Climate*, doi:10.1175/JCLI-D-15-0384.1