Unforced Surface Air Temperature Variability and Its Contrasting Relationship with the Anomalous TOA Energy Flux at Local and Global Spatial Scales*

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In the absence of external radiative forcings, global mean temperature (T) should be stable in the long run.
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• Why? Because of the ‘Planck Response’:

\[ \lambda_{Planck} = -4\sigma T_e^3 \approx 3.2 \text{ W m}^{-2} \text{ K}^{-1} \]
-2.4 (Wm$^{-2}$K$^{-1}$)
-0.8 (Wm$^{-2}$K$^{-1}$)

27 AOGCM control runs (5400 years)

CERES (14 years)
What does the local relationship \([N(\theta, \Phi) \text{ vs. } T(\theta, \Phi)]\) look like?
a) $\bar{N}$ vs. $\bar{T}$

$-0.8 \, (Wm^{-2}K^{-1})$

$-2.4 \, (Wm^{-2}K^{-1})$

b) AOGCMs: $N(\alpha, \phi)$ vs. $T(\alpha, \phi)$, (AVG = 1.9)

c) Obs: $N(\alpha, \phi)$ vs. $T(\alpha, \phi)$, (AVG = 1.4)

d) $N(\alpha, \phi)$ vs. $T(\alpha, \phi)$, Zonal Mean
• What are the physical reasons for the mostly positive local $N(\theta, \Phi)$ vs. $T(\theta, \Phi)$ relationship?

• If the local $N(\theta, \Phi)$ vs. $T(\theta, \Phi)$ relationship is mostly positive, how precisely does global $T$ restore equilibrium after a large unforced fluctuation?
Why is the local $N(\theta,\Phi)$ vs. $T(\theta,\Phi)$ relationship mostly positive?
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Why is the local $N(\theta, \Phi) \text{ vs. } T(\theta, \Phi)$ relationship mostly positive?

- Due mostly to the longwave water vapor feedback over oceanic regions with the highest climatological $T(\theta, \Phi)$

AOGCM control runs
Why is the local $N(\theta,\Phi)$ vs. $T(\theta,\Phi)$ relationship mostly positive?

- Planck Response evident in the Clear$_{\text{LW}}$ component elsewhere.
Why is the local $N(\theta,\Phi)$ vs. $T(\theta,\Phi)$ relationship mostly positive?

- Due to the cloud shortwave component in regions with intermediate to high climatological $T(\theta,\Phi)$
Why is the local $N(\theta,\Phi)$ vs. $T(\theta,\Phi)$ relationship mostly positive?

- Due to the surface shortwave component in regions with climatological $T(\theta,\Phi)$ near the freezing point of water.
Why is the local $N(\theta,\Phi)$ vs. $T(\theta,\Phi)$ relationship mostly positive?

Components of $N$

AOGCM control runs
Why is the local $N(\theta,\Phi)$ vs. $T(\theta,\Phi)$ relationship mostly positive?
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How precisely does global T restore equilibrium after a large unforced fluctuation?

AOGCM control runs
How precisely does global T restore equilibrium after a large unforced fluctuation?
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Regression against global T

AOGCM control runs
How precisely does global T restore equilibrium after a large unforced fluctuation?

- Positive T anomalies associated with El Niño events
How precisely does global T restore equilibrium after a large unforced fluctuation?

- Large horizontal divergence (convergence) of atmospheric energy transport over the tropical Pacific (high latitudes)

Regression against global T
How precisely does global T restore equilibrium after a large unforced fluctuation?

- Characteristic $T(\theta,\Phi)$ vs. T pattern with a substantial amount of warmth at high latitudes where the temperature anomaly can be easily damped to space.
How precisely does global T restore equilibrium after a large unforced fluctuation?

- Characteristic $T(\theta, \Phi)$ vs. $T$ pattern contains anomalously cool $T(\theta, \Phi)$ regions where locally positive $N(\theta, \Phi)$ vs. $T(\theta, \Phi)$ relationship promotes negative $N(\theta, \Phi)$
How precisely does global T restore equilibrium after a large unforced fluctuation?

Regression against global T

AOGCM control runs

Components of Clouds

Observations

Regression against global T

AOGCMs
How precisely does global T restore equilibrium after a large unforced fluctuation?

Regression against global T
How precisely does global T restore equilibrium after a large unforced fluctuation?

Regression against global T

AOGCM control runs
Is the characteristic $T(\theta,\Phi)$ vs. global $T$ pattern the whole story?

Regression against global $T$
Is the characteristic $T(\theta, \Phi)$ vs. global $T$ pattern the whole story?

- Test this by multiplying the ‘local feedback’ relationship by the characteristic surface temperature distribution associated with global $T$ variability...

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![Diagram of atmospheric column with equations for feedback]
Is the characteristic $T(\theta, \Phi)$ vs. global $T$ pattern the whole story?

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AOGCM control runs

\[ \Delta N(\theta, \phi) \]
\[ \Delta T \]

\[ \frac{\Delta N(\theta, \phi)}{\Delta [T(\theta, \phi)]} \]

\[ \frac{\Delta [T(\theta, \phi)]}{\Delta T} \]

Atmospheric column

TOA

Stationary ‘feedback’?

Surface
Is the characteristic $T(\theta,\Phi)$ vs. global $T$ pattern the whole story?

- Test this by multiplying the ‘local feedback’ relationship by the characteristic surface temperature distribution associated with global $T$ variability...
Is the characteristic $T(\theta, \phi)$ vs. global T pattern the whole story?

- Test this by multiplying the ‘local feedback’ relationship by the characteristic surface temperature distribution associated with global T variability...

**Regression against global T**

AOGCM control runs
Is the characteristic \( T(\theta,\Phi) \) vs. global T pattern the whole story?

- Test this by multiplying the ‘local feedback’ relationship by the characteristic surface temperature distribution associated with global T variability…

Regression against global T

AOGCM control runs

Components of Clouds × Components of Clouds = ?

\[ N(\alpha,\phi) \text{ vs. } T(\alpha,\phi), \text{ (AVG = 1.9)} \]

\[ N(\text{AVG = -0.8}) \]

\[ N(\text{AVG = 1.7}) \]
Is the characteristic $T(\theta, \Phi)$ vs. global $T$ pattern the whole story?

- Test this by multiplying the ‘local feedback’ relationship by the characteristic surface temperature distribution associated with global $T$ variability...

AOGCM control runs

Regression against global $T$

$N(\alpha, \phi) \times T(\alpha, \phi)$, $AVG = 1.9$

$= ?$

Negative

$N(\alpha, \phi)$, $AVG = -0.8$

Positive

$N(\alpha, \phi)$, $AVG = 1.7$
Is the characteristic $T(\theta,\Phi)$ vs. global $T$ pattern the whole story?

- Test this by multiplying the ‘local feedback’ relationship by the characteristic surface temperature distribution associated with global $T$ variability...

Regression against global $T$

- $N(\alpha,\phi) = \text{Positive}$
- $T(\text{AVG}=1)$
- $\times$
- $= ?$
- Negative
- $= ?$
- Positive
Is the characteristic $T(\theta,\Phi)$ vs. global $T$ pattern the whole story?

- Test this by multiplying the ‘local feedback’ relationship by the characteristic surface temperature distribution associated with global $T$ variability...

Regression against global $T$
Is the characteristic $T(\theta, \Phi)$ vs. global $T$ pattern the whole story?

- Subtract to get the contribution to $N$ that is NOT due to the characteristic $T(\theta, \Phi)$ vs. $T$ pattern
Why is the global $N$ vs. $T$ relationship negative?
Why is the global N vs. T relationship negative?

Components of N

AOGCM control runs
Why is the global N vs. T relationship negative?

- Enhanced Hadley circulation and reversed Walker Circulation cause reduced water vapor and cloud fraction/height over large swaths of tropics and subtropics.
Why is the global N vs. T relationship negative?

- Allows for much more efficient release of LW radiation than would otherwise be expected from the $T(\theta, \Phi)$ vs. T pattern alone.
Why is the global N vs. T relationship negative?

Components of N

- Clear $\text{SW (AVG = 0)}$
- CRE $\text{SW (AVG = -0.2)}$
- Clear $\text{LW (AVG = -0.8)}$
- CRE $\text{LW (AVG = -1.4)}$
Why is the global N vs. T relationship negative?

Components of N

- **Clear SW (AVG = 0.3)**
- **CRE SW (AVG = -2.6)**
- **Clear LW (AVG = -1.1)**
- **CRE LW (AVG = 0.2)**
The local $N(\theta, \phi)$ vs. $T(\theta, \phi)$ relationship tends to be positive, despite the Planck Response, because warm $T(\theta, \phi)$ is accompanied by:

- Low surface albedo near sea ice margins and over high elevations
- Low cloud albedo over much of the middle and low-latitudes
- Large water-vapor greenhouse effect over the deep Indo-Pacific
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- 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 $T(\theta, \phi)$ 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 OLR