Climate sensitivity and short-term relationship of top-of-atmosphere net radiation and surface temperature

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Outline

- Large uncertainty in GCMs ↔ simplified models
  - physical processes: clouds, precipitation, energy balance

- Satellite & model studies:
  - relationships among Ts, Rnet, external & internal forcings

  - Forster & Gregory: JC 2006
    - seasonal & annual means
    - both external & internal forcings were considered.

  - Lindzen and Choi: GRL 2009
    - events, radiation changes

  - Spencer and Braswell: AGU 2009 & CERES STM 2009
    - certain Rnet & Ts phase states, chaotic system

- Short-term variations of Ts & Rnet
Energy Balance Analysis

- **Energy balance:**
  - TOA radiation changes
  - Surface temperature variations

- **Earth’s heat reservoirs:**
  - Ocean mixed layer
  - Deep oceans
  - Internal forcing -- heat transports among reservoirs

- **Sensitivity:** \(-\frac{\partial R}{\partial T}\)

\[
R (F, T, N) = R_0 + (\frac{\partial R}{\partial F})\Delta F + (\frac{\partial R}{\partial T})\Delta T + (\frac{\partial R}{\partial N})\Delta N + \text{higher order terms}
\]

\((R_0 = 0; \text{ No N terms if entire climate system is considered})\)

\[
R (F, T, N) - (\frac{\partial R}{\partial F})\Delta F = (\frac{\partial R}{\partial T})\Delta T + (\frac{\partial R}{\partial N})\Delta N
\]

\[
\Delta R = (\frac{\partial R}{\partial T})\Delta T + (\frac{\partial R}{\partial N})\Delta N \rightarrow \text{empirical: } \Delta R \text{ vs } \Delta T
\]
Background: Climate perturbation

\[ Cp \frac{dT_s}{dt} = (1 - \alpha) So - \varepsilon \sigma T_s^4 \]

**equilibrium state:** \( \Delta \alpha = \Delta \varepsilon = 0 \)

\[ Cp \frac{d\Delta T_s}{dt} = - \frac{4\varepsilon \sigma T_s^4}{T_s} \Delta T_s \]

\[ = - \frac{4 \times 237}{288} \Delta T_s = -3.3 \Delta T_s \]

\( f_n = -3.3 \text{ Wm}^{-2}\text{K}^{-1} \) (only for the equilibrium state)

At short time scales, this feature is mixed with other processes.
Energy Balance Analysis

- Energy balance:
  - TOA radiation changes
  - Surface temperature variations

- Earth's heat reservoirs:
  - Ocean mixed layer
  - Deep oceans
  - Internal forcing -- heat transports among reservoirs

- Sensitivity: \(-\frac{\partial R}{\partial T}\)

\[ R(F, T, N) = R_0 + \left(\frac{\partial R}{\partial F}\right)\Delta F + \left(\frac{\partial R}{\partial T}\right)\Delta T + \left(\frac{\partial R}{\partial N}\right)\Delta N \]
+ higher order terms

\[ R_0 = 0, \text{ No } N \text{ terms if entire climate system is considered} \]

\[ R(F, T, N) - \left(\frac{\partial R}{\partial F}\right)\Delta F = \left(\frac{\partial R}{\partial T}\right)\Delta T + \left(\frac{\partial R}{\partial N}\right)\Delta N \]

\[ \Delta R = \left(\frac{\partial R}{\partial T}\right)\Delta T + \left(\frac{\partial R}{\partial N}\right)\Delta N \rightarrow \text{empirical: } \Delta R \text{ vs } \Delta T \]
short-term relation

Forster & Gregory: JC 2006

weak positive feedback

Net radiation (W/m²)

annual 85~90

Y = 2.36 ± 2.18 Wm⁻²K⁻¹

Y = 2.32 ± 1.30 Wm⁻²K⁻¹

correlation = 0.71

correlation = 0.66

annual 85~96

seasonal 91~92

Y = 2.09 ± 1.25 Wm⁻²K⁻¹

correlation = 0.74

data for different time periods

But ?? : avg. N = 0; long-term feedback removed

T (K)
short-term relation: cont

Lindzen and Choi  GRL 2009
short-term relation: cont

negative feedback

\[ f = -4.5 \text{ W m}^{-2} \text{ K}^{-1} \]

But: cannot be verified; lat. heat transports; long-term feedbacks

Lindzen and Choi  GRL 2009
Global Oceanic LW+SW Anomaly
Total Feedback Parameter of $\sim 6.0 \text{ W m}^{-2} \text{ K}^{-1}$

Spencer and Braswell 2009
Perturbation model: energy balance

\[ Cp \frac{dT}{dt} = F + f_{\text{tot}}T + N + S \]

\( N \): non-radiative heating (daily)
\( S \): non-feedback natural radiative variability (5-yr cyc)
\( f_{\text{tot}} : f_n + f = -6 \text{ Wm}^{-2}\text{K}^{-1} \)
\( F \): \( F = 0 \) or removed
\( Cp \): 50 m water

Spencer and Braswell 2009
SRB Results

previous version of SRB data
CERES observations

90-day running mean

some indication of short-term responses of radiation to sfc T

Sfc Temp from CERES MOA

Net radiation (W/m$^2$)

Terra 01 ~ 07

SfcT Anomaly (K)
Analysis Approach

- **Energy balance:**
  - Spencer and Braswell: 2009 (AGU & CERES STM)
  - Lin et al. 2010 ACP

- **Basic physical components:**
  - ocean mixed layer
  - internal and external forcing
  - TOA radiation

- **Additional considerations:**
  - climate system memory
  - different feedback tests
System memory

Ts: detrended GISS sfc T

confidence level 95%; corr: 0.33 within: ~ 8 yrs
Modeling Considerations

Perturbation theory: energy balance model

\[ Cp \frac{dT}{dt} = F + f_s T + N + S + \frac{f_m}{t_0} \int_{t-t_0}^t T dt' \]

\(N\): non-radiative heating (daily) \(\leftrightarrow\) avg \(N = 0\)

\(S\): non-feedback natural radiation (5-yr cycle) \(\leftrightarrow\) avg \(S = 0\)

\(f_s\):

\[ f_s = f_n + f = -6 \text{ Wm}^{-2}\text{K}^{-1}; f = -2.7 \text{ Wm}^{-2}\text{K}^{-1} \]

\(f_{tot}\):

\[ f_{tot} = f_s + f_m \]

\(F\): \(F = 0\) or removed

\(t_0\): memory length \(\leftrightarrow\) minimal (1 year); other lengths also tested

\(Cp\): 100 m mixed layer ocean (slab ocean)

last 10-year results of 100-year run
System without memory

Slope: $f_s = f_n + f = -6 \text{ Wm}^{-2}\text{K}^{-1}$
memory system

Slope: \( f_s = f_n + f = -6 \text{ Wm}^{-2}\text{K}^{-1} \)

Extreme strong negative feedback system
Total feedback parameter: \( f_{tot} = f_s + f_m = -8 \text{ Wm}^{-2}\text{K}^{-1} \)
memory system

Neutral feedback system
Total feedback parameter: \( f_{\text{tot}} = f_s + f_m = -3.3 \text{ Wm}^{-2}\text{K}^{-1} \)
memory system

Slightly positive feedback system
Total feedback parameter: \( f_{tot} = f_s + f_m = -2.3 \text{ Wm}^{-2}\text{K}^{-1} \)
May not determine total feedback from short-term relationships.
climate sensitivity

short-time scale characteristics

maintaining basic state

long-term climate sensitivity

climate forcing
Summary

• Energy balance model for explanation of the anomalies of TOA net radiation and surface temperature.

• Major physical processes of the climate system, such as internal and external forcing, and system memory, are considered.

• Internal non-radiative heating is needed due to slab ocean approximation (no vertical heat transport) and chaotic feature of the climate.

• Cannot use short-time relationships between sfc temp and net radiation of the climate system to mimic the feedbacks of climate change: different scales, different physics
Many people, especially David Young, Gary Gibson, and Don Garber, have significant supports for this study.