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 — **few years**
    seasonal & annual means
    both external & internal forcings were considered.

  - Lindzen and Choi: GRL 2009 — **~1 years**
    events, radiation changes

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

- **Short-term variations of Ts & Rnet**

Energy Balance Analysis

- Energy balance:
  - TOA radiation changes
  - surface temperature variations EB
- Earth's heat reservoirs:
  - Ocean mixed layer
  - Deep oceans
  - Internal forcing -- heat transports among reservoirs
- Sensitivity: $-\partial R/\partial T$

$$R(F, T, N) = R_0 + (\partial R/\partial F)\Delta F + (\partial R/\partial T)\Delta T + (\partial R/\partial N)\Delta N + \text{higher order terms}$$

($R_0 = 0$; No N terms if entire climate system is considered)

$$R(F, T, N) - (\partial R/\partial F)\Delta F = (\partial R/\partial T)\Delta T + (\partial R/\partial N)\Delta N$$

$$\Delta R = (\partial R/\partial T)\Delta T + (\partial R/\partial N)\Delta N \rightarrow \text{empirical: } \Delta R \text{ vs } \Delta T$$

Background: Climate perturbation

$$Cp\frac{dTs}{dt} = (1-\alpha)So - \varepsilon\sigma Ts^4$$

Cp: equivalent heat capacity

equilibrium state: $\Delta\alpha = \Delta\varepsilon = 0$

$$Cp\frac{d\Delta Ts}{dt} = -\frac{4\varepsilon\sigma Ts^4}{Ts}\Delta Ts$$

$$= -\frac{4\times 237}{288}\Delta Ts = -3.3\Delta Ts$$

define: $\Delta Ts = T$

fn = -3.3 $Wm^{-2}K^{-1}$ (only for the equilibrium state)

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

Energy Balance Analysis

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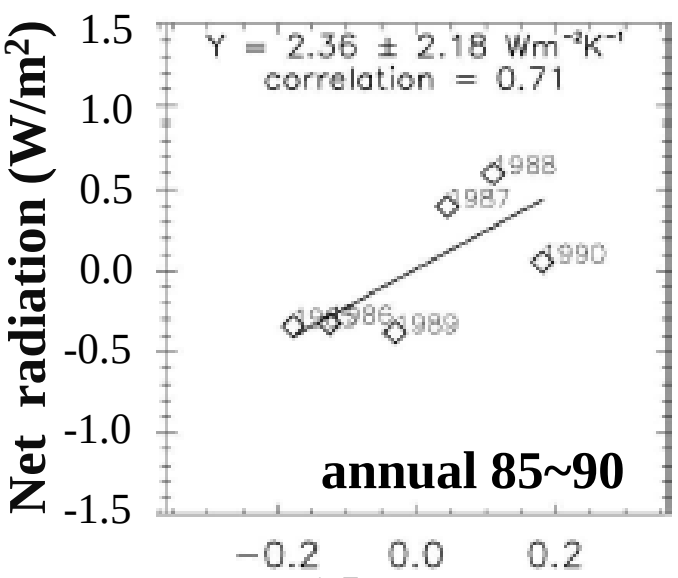
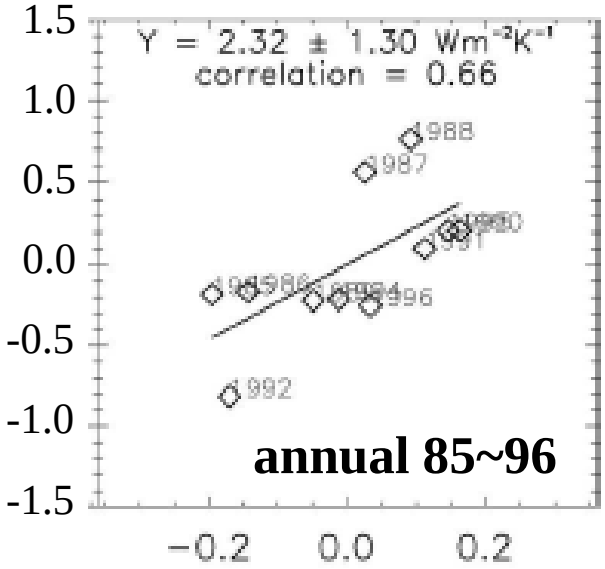
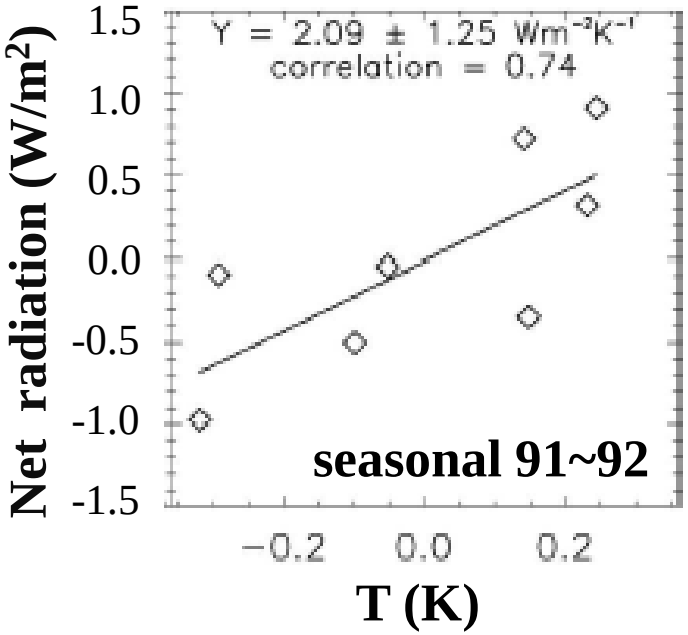
short-term relation







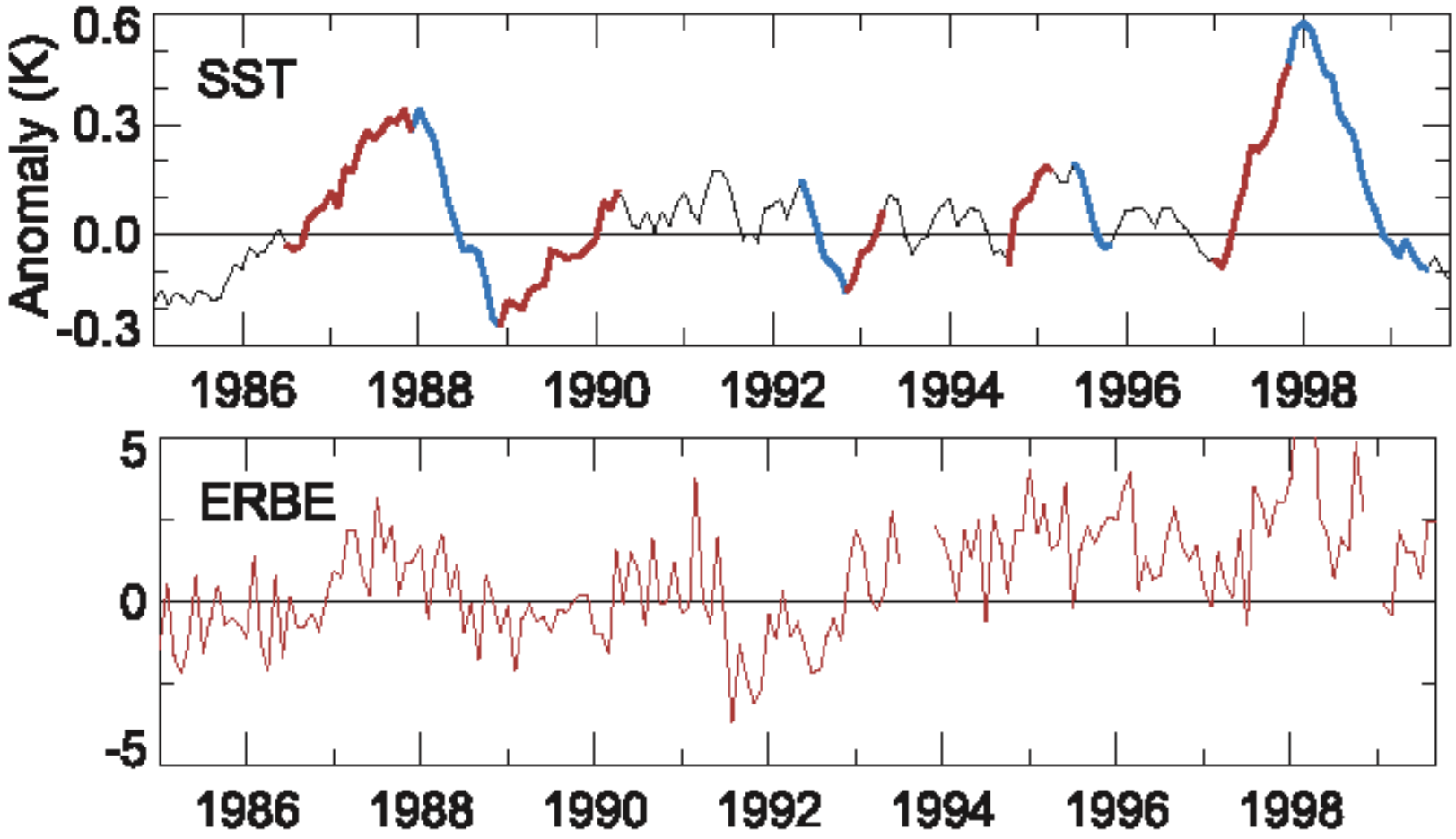
weak positive feedback

data for different time periods

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

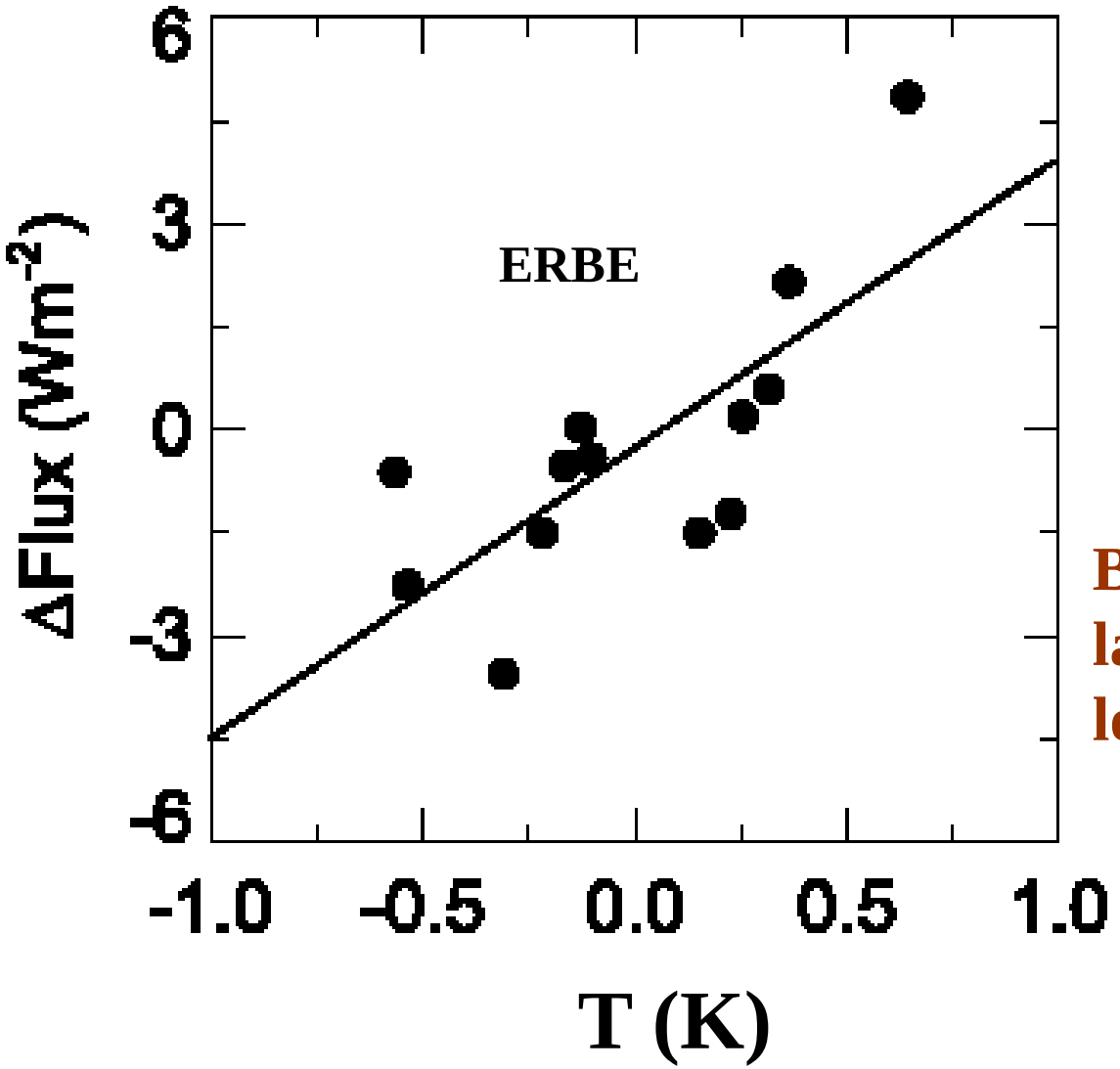
Forster & Gregory: JC 2006

short-term relation: cont



Lindzen and Choi GRL 2009

short-term relation: cont

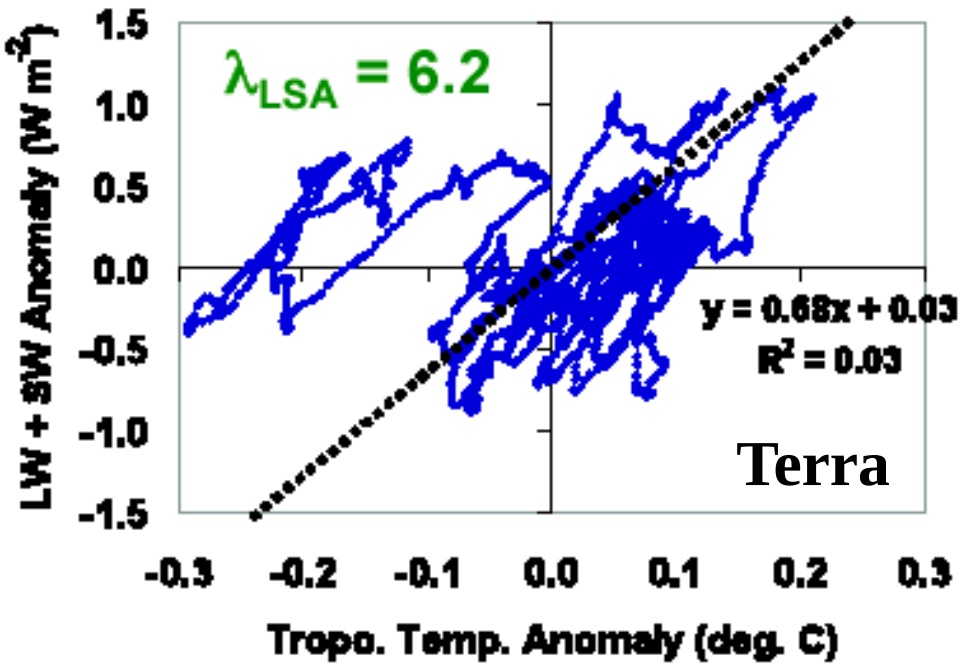


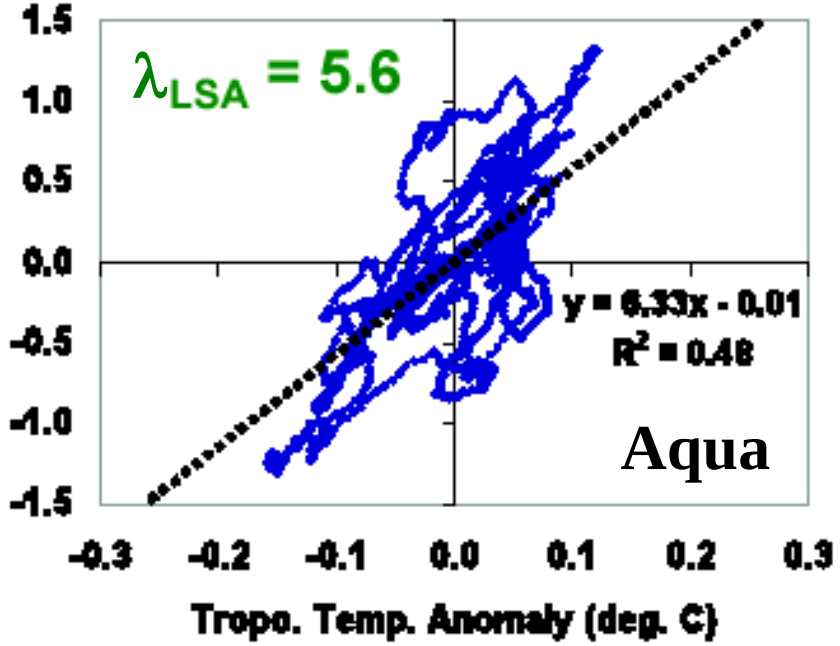
negative feedback
$f = -4.5\ W\ m^{-2}\ K^{-1}$

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

Lindzen and Choi GRL 2009

short-term relation: cont





Global Oceanic LW+SW Anomaly
Total Feedback Parameter of ~6.0 W m^{-2} K^{-1}

Spencer and Braswell 2009

Observation Explanation

Perturbation model: energy balance

$$Cp\frac{dT}{dt} = F + ftotT + N + S$$

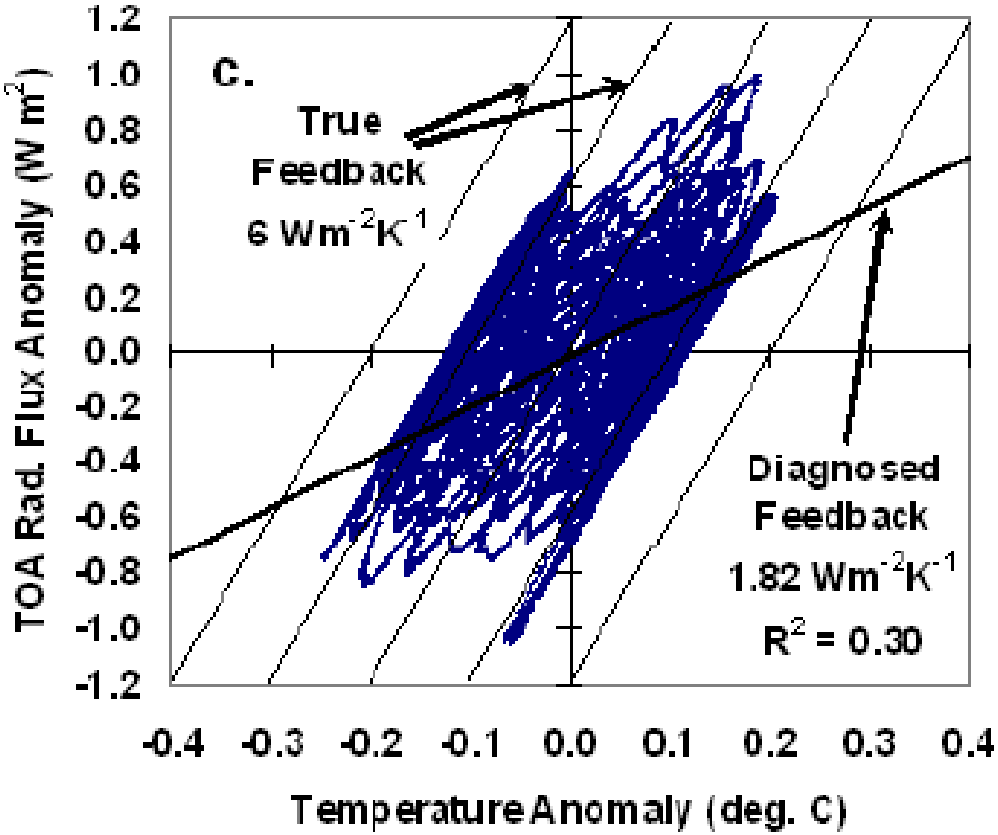
N: non-radiative heating (daily)

S: non-feedback natural radiative variability (5-yr cyc)

f_{tot}: $f_n + f$ = -6 $Wm^{-2}K^{-1}$

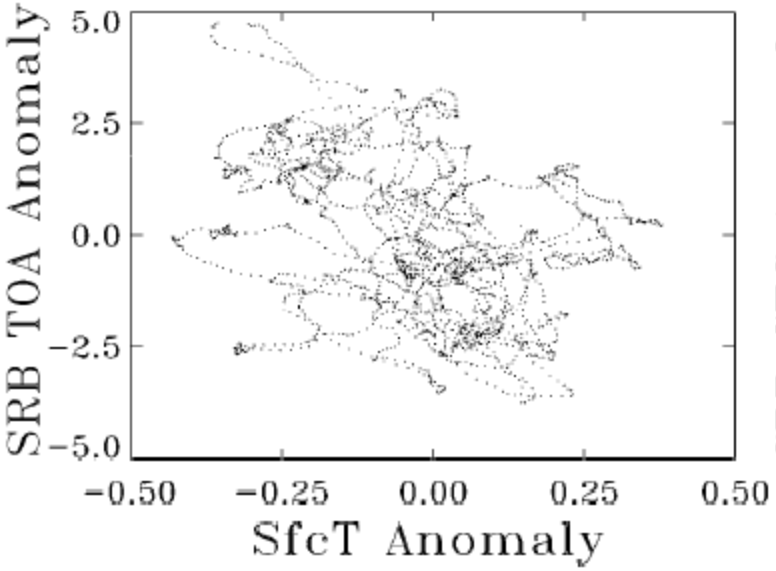
F: *F* = 0 or removed

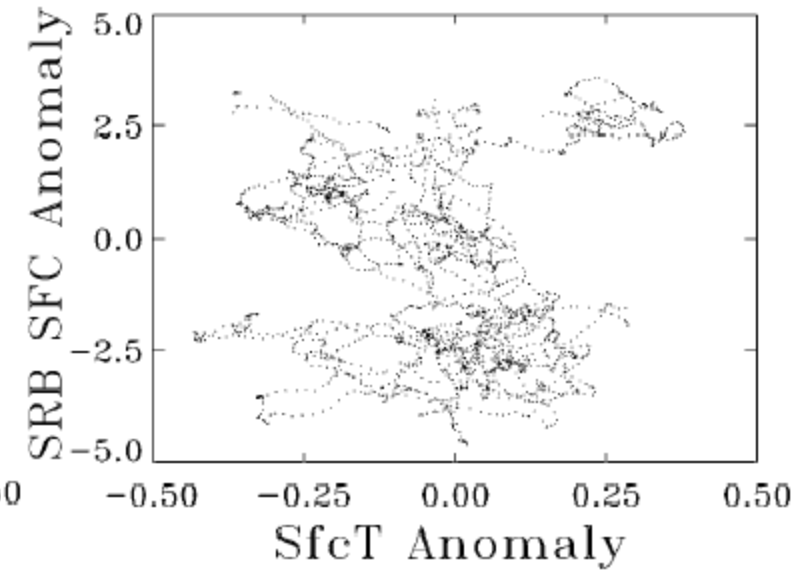
Cp: 50 m water

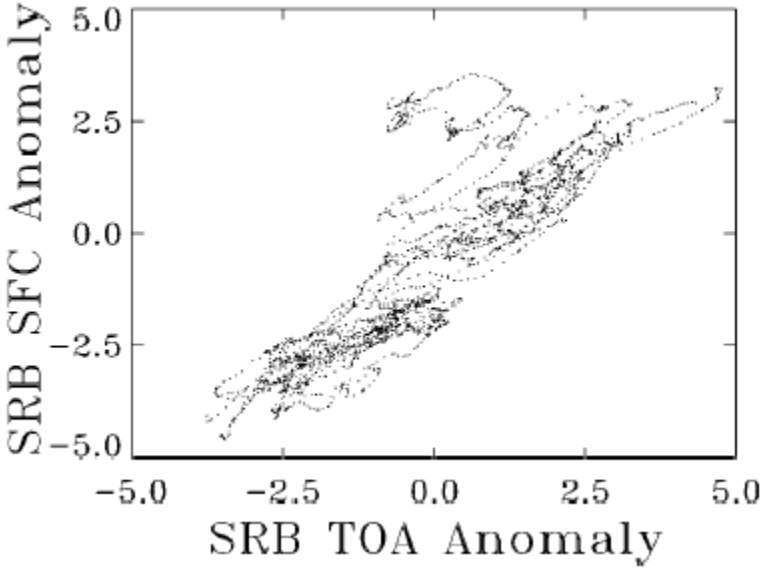


Spencer and Braswell 2009

SRB Results

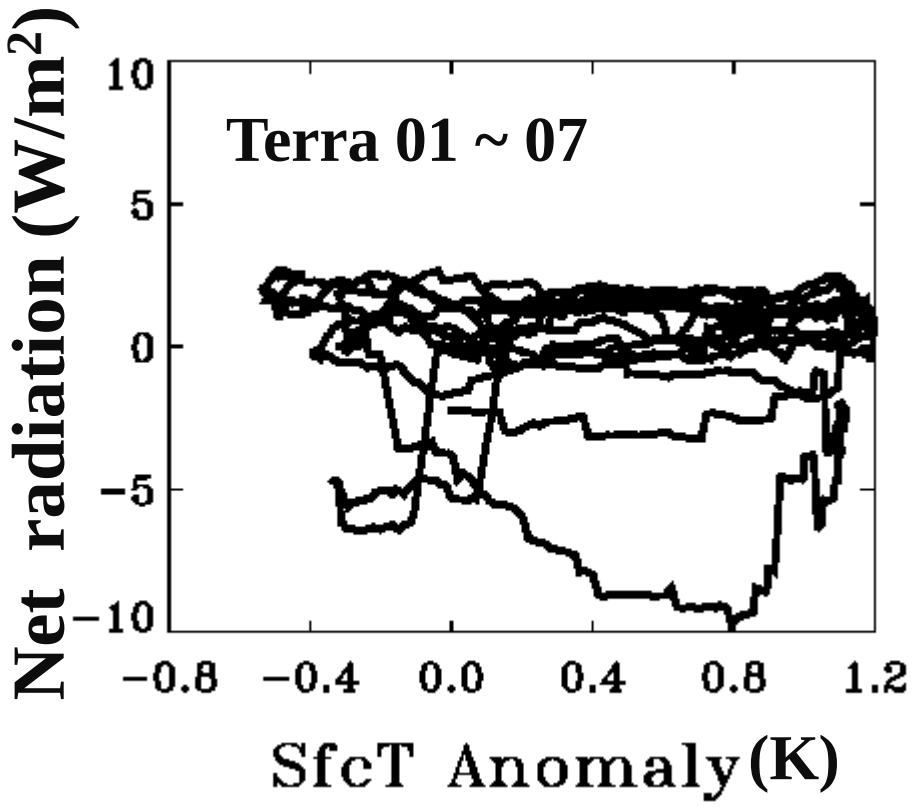






previous version of SRB data

CERES observations



90-day running mean

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

Sfc Temp from CERES MOA

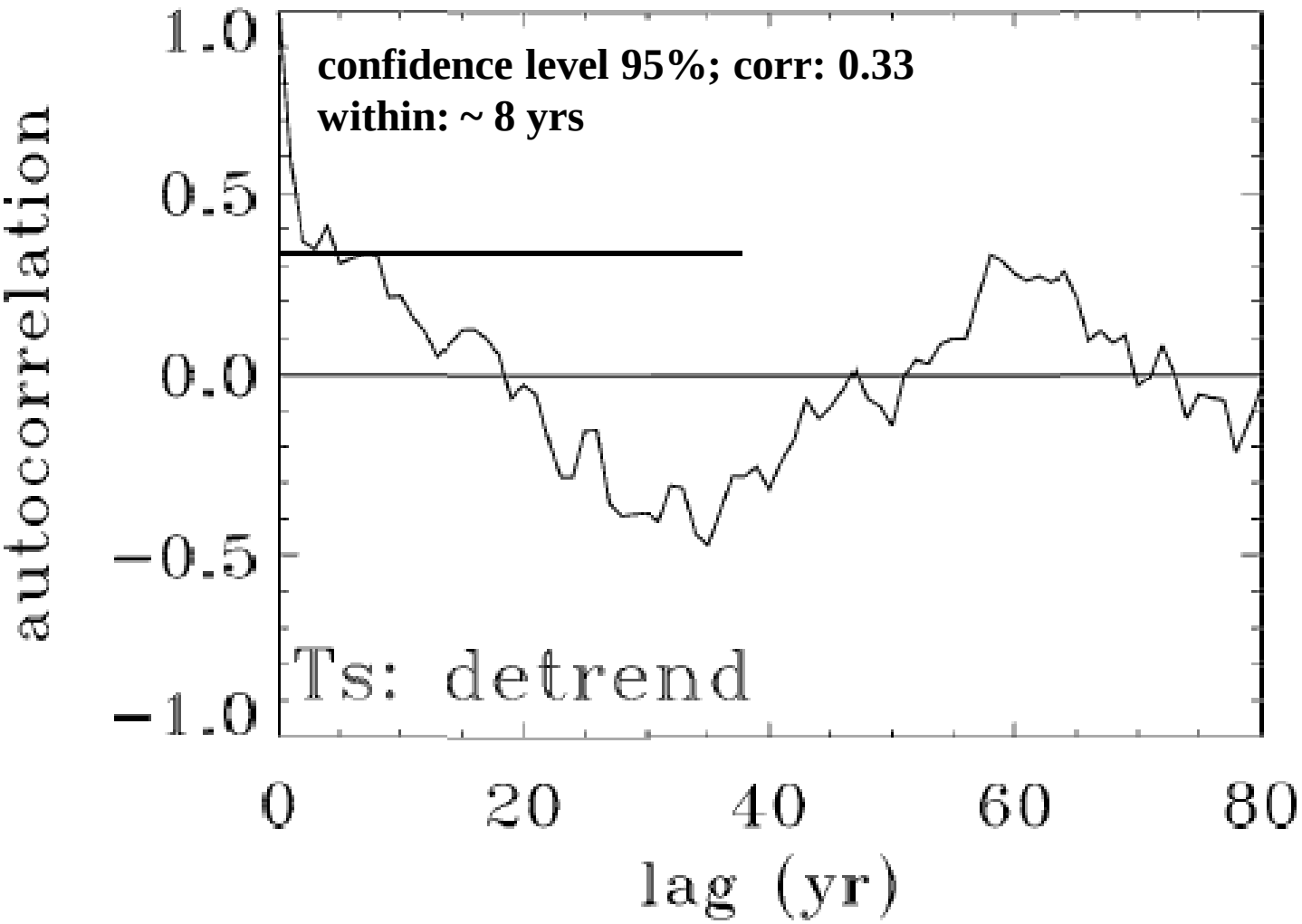
Analysis Approach

- **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

Modeling Considerations

Perturbation theory: energy balance model

$$Cp\frac{dT}{dt} = F + fsT + N + S + \frac{fm}{t0}\int_{t-t0}^{t} T dt'$$

***N*: non-radiative heating (daily) ↔ avg N = 0**

***S*: non-feedback natural radiation (5-yr cycle) ↔ avg S = 0**

f_s: $f_s = f_n + f$ = -6 $Wm^{-2}K^{-1}$; f = -2.7 $Wm^{-2}K^{-1}$

f_{tot}: $f_{tot} = f_s + f_m$

***F*: *F* = 0 or removed**

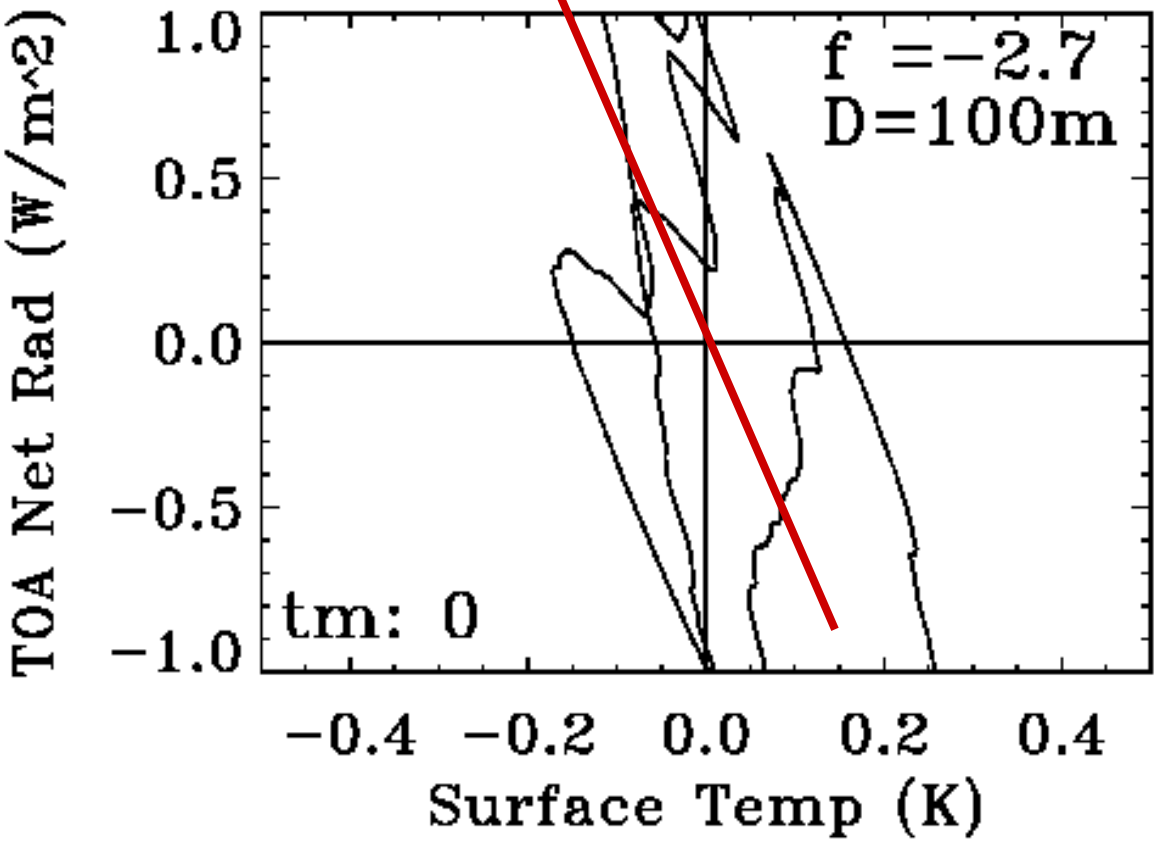
t_0: memory length ↔ minimal (1 year); other lengths also tested

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

last 10-year results of 100-year run

System without memory

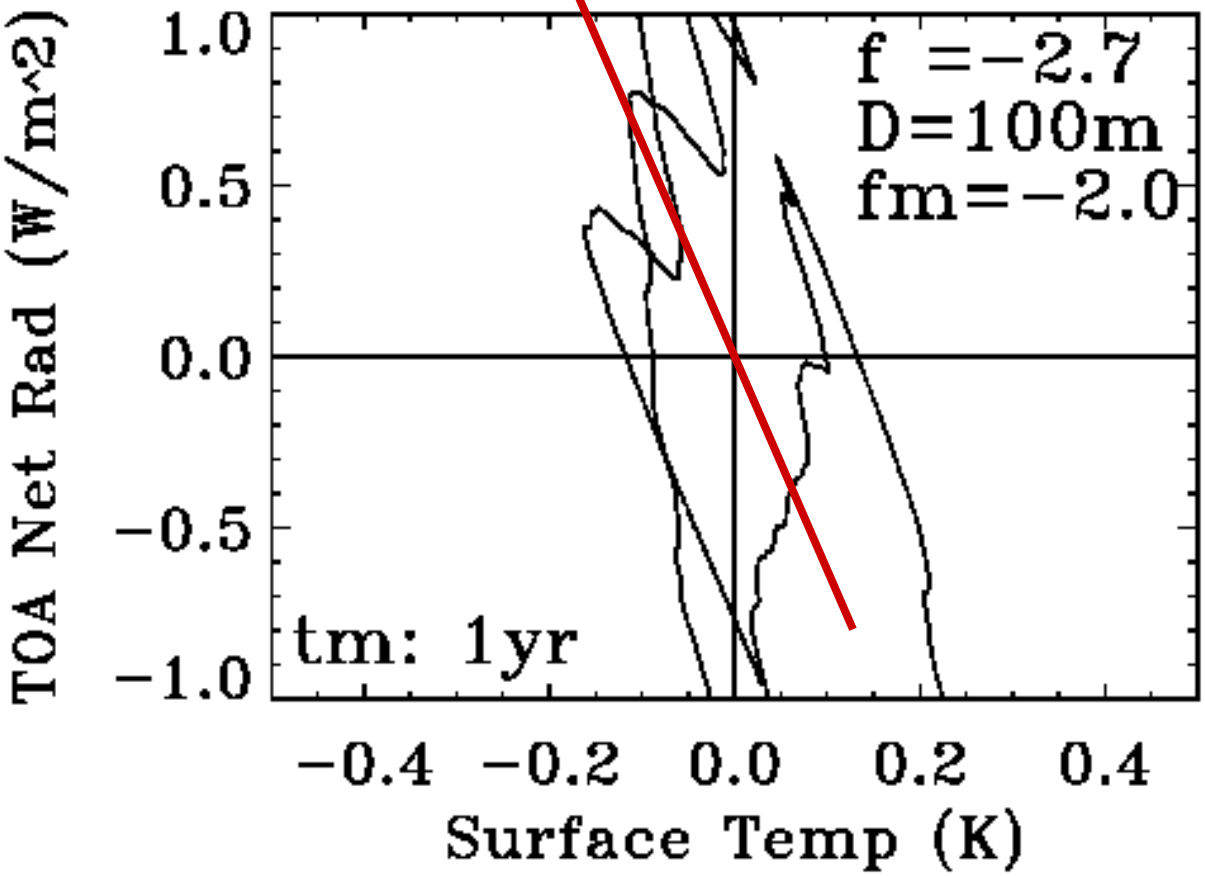
Slope: $f_s = f_n + f = -6\ \mathrm{Wm^{-2}K^{-1}}$



Similar results as previous studies

memory system

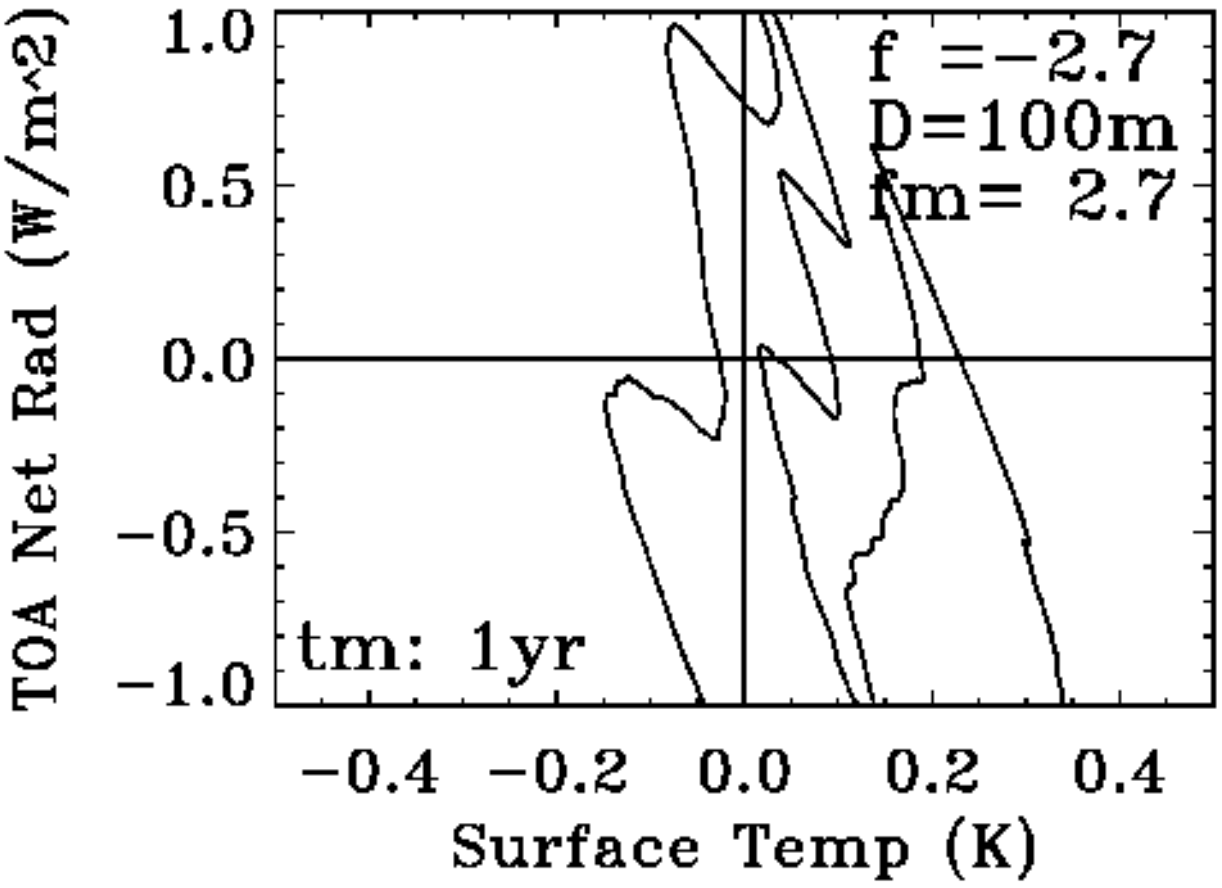
Slope: $f_s = f_n + f = -6\ \mathrm{Wm^{-2}K^{-1}}$



Extreme strong negative feedback system

Total feedback parameter: $f_{tot} = f_s + f_m = -8\ \mathrm{Wm^{-2}K^{-1}}$

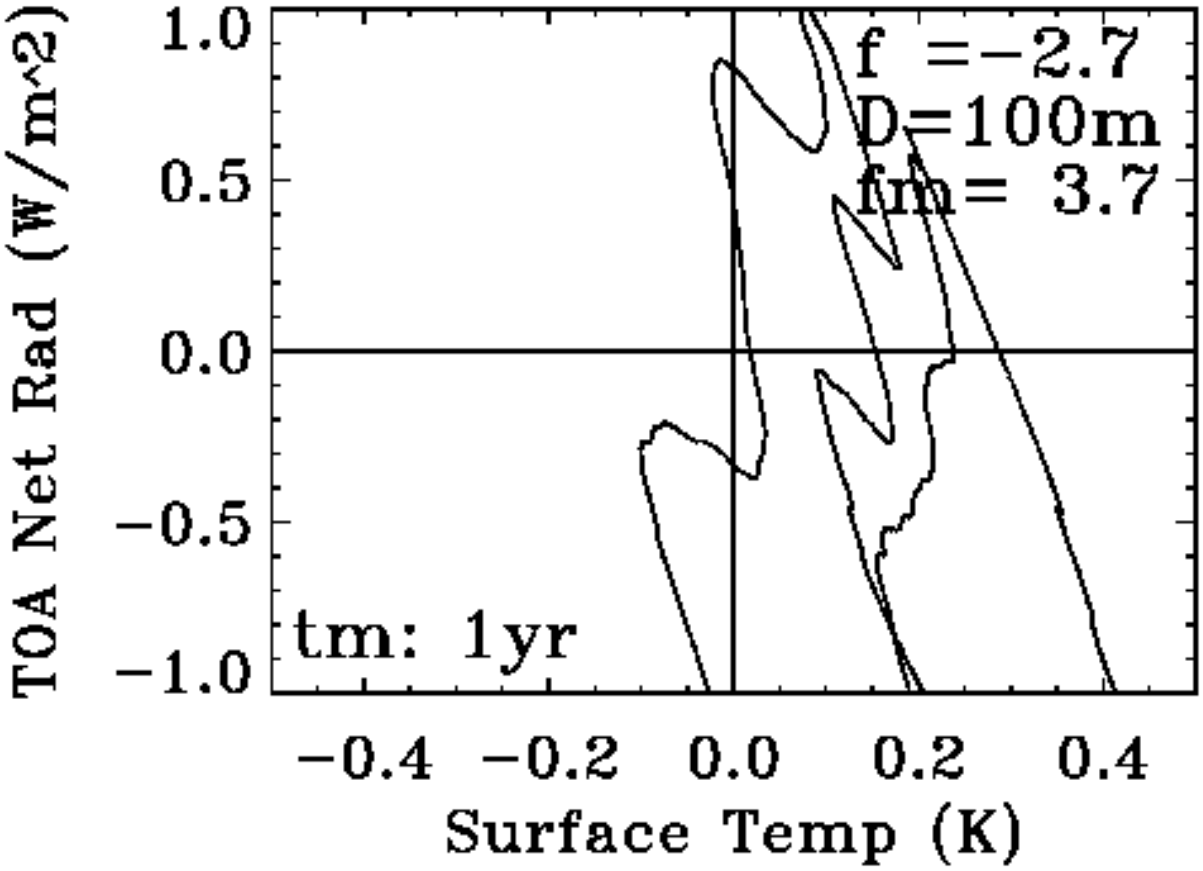
memory system



Neutral feedback system

Total feedback parameter: $f_{tot} = f_s + f_m = -3.3\ \mathrm{Wm^{-2}K^{-1}}$

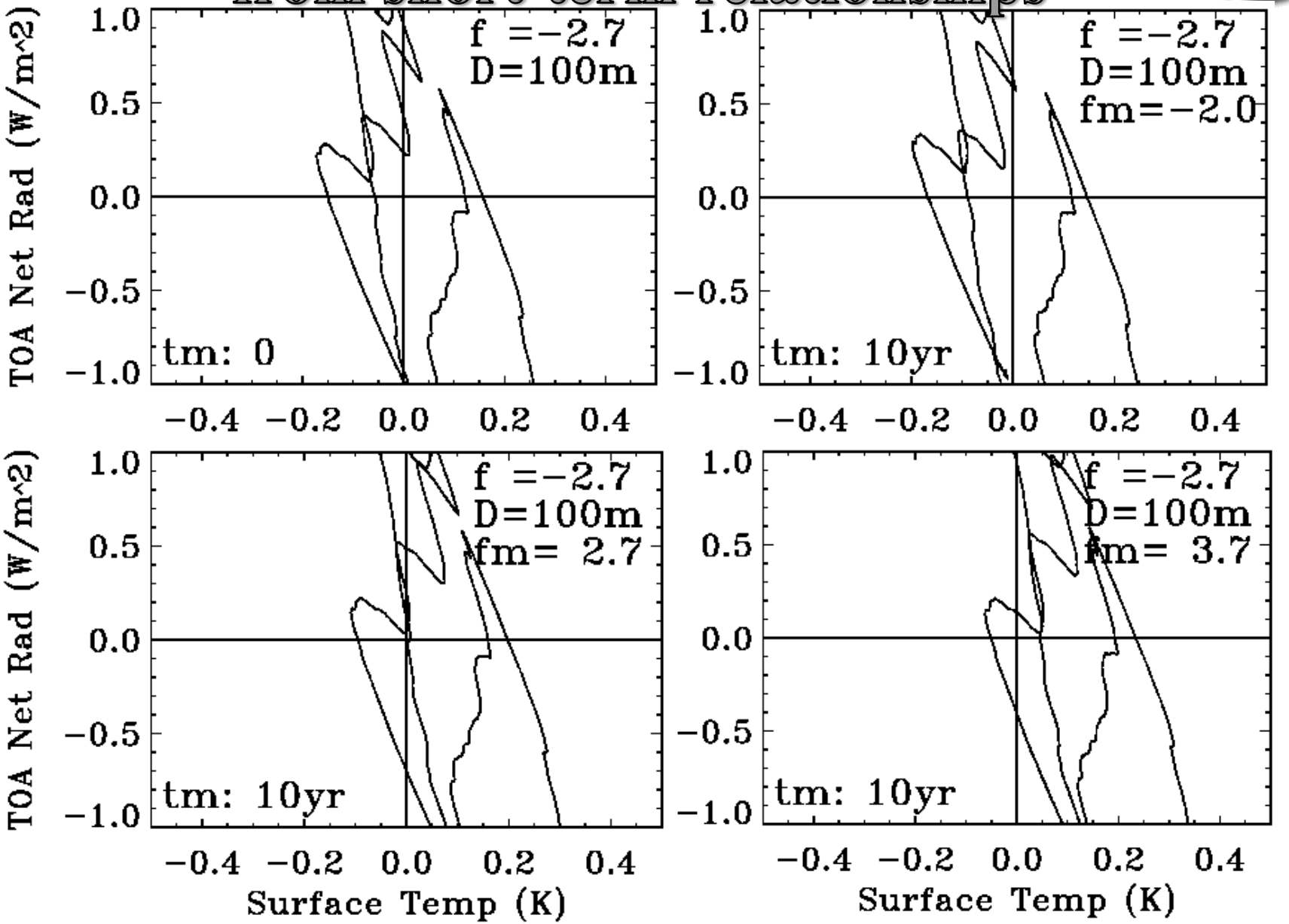
memory system



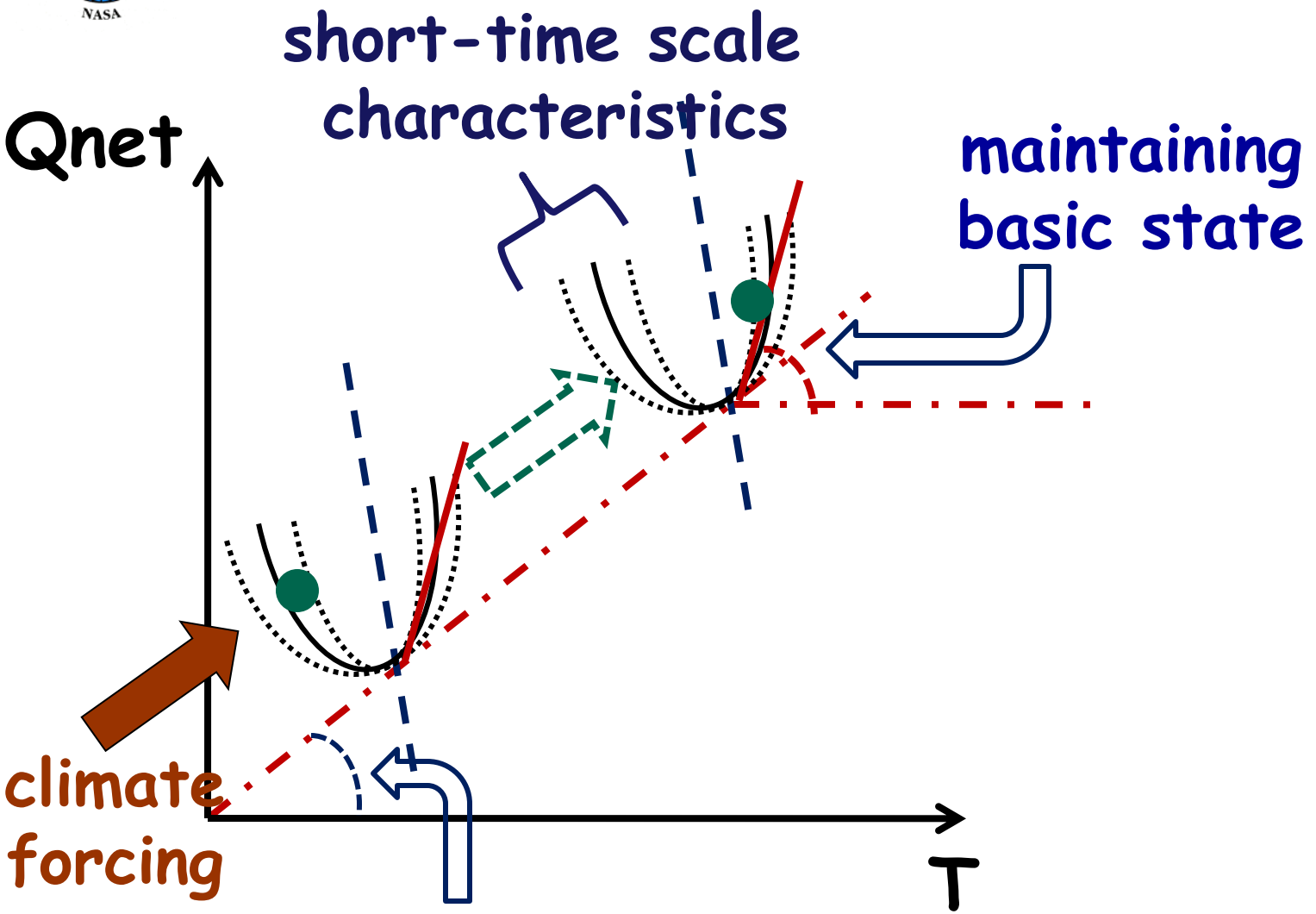
Slightly positive feedback system

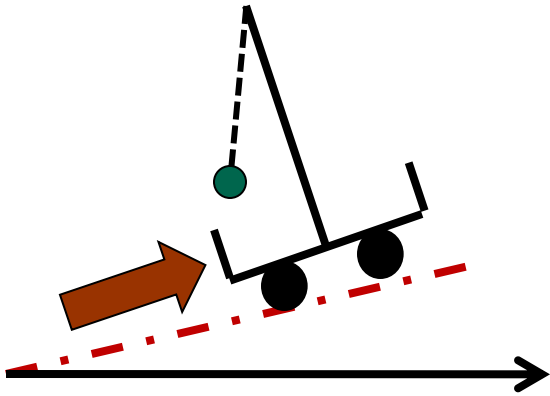
Total feedback parameter: $f_{tot} = f_s + f_m = -2.3\ \mathrm{Wm^{-2}K^{-1}}$

May not determine total feedback from short-term relationships



climate sensitivity





Summary

- Energy balance model for explanation of the anomolies 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

Acknowledgement

Many people, especially David Young, Gary Gibson, and Don Garber, have significant supports for this study.