Climate Sensitivities in Short and Long Time Scales

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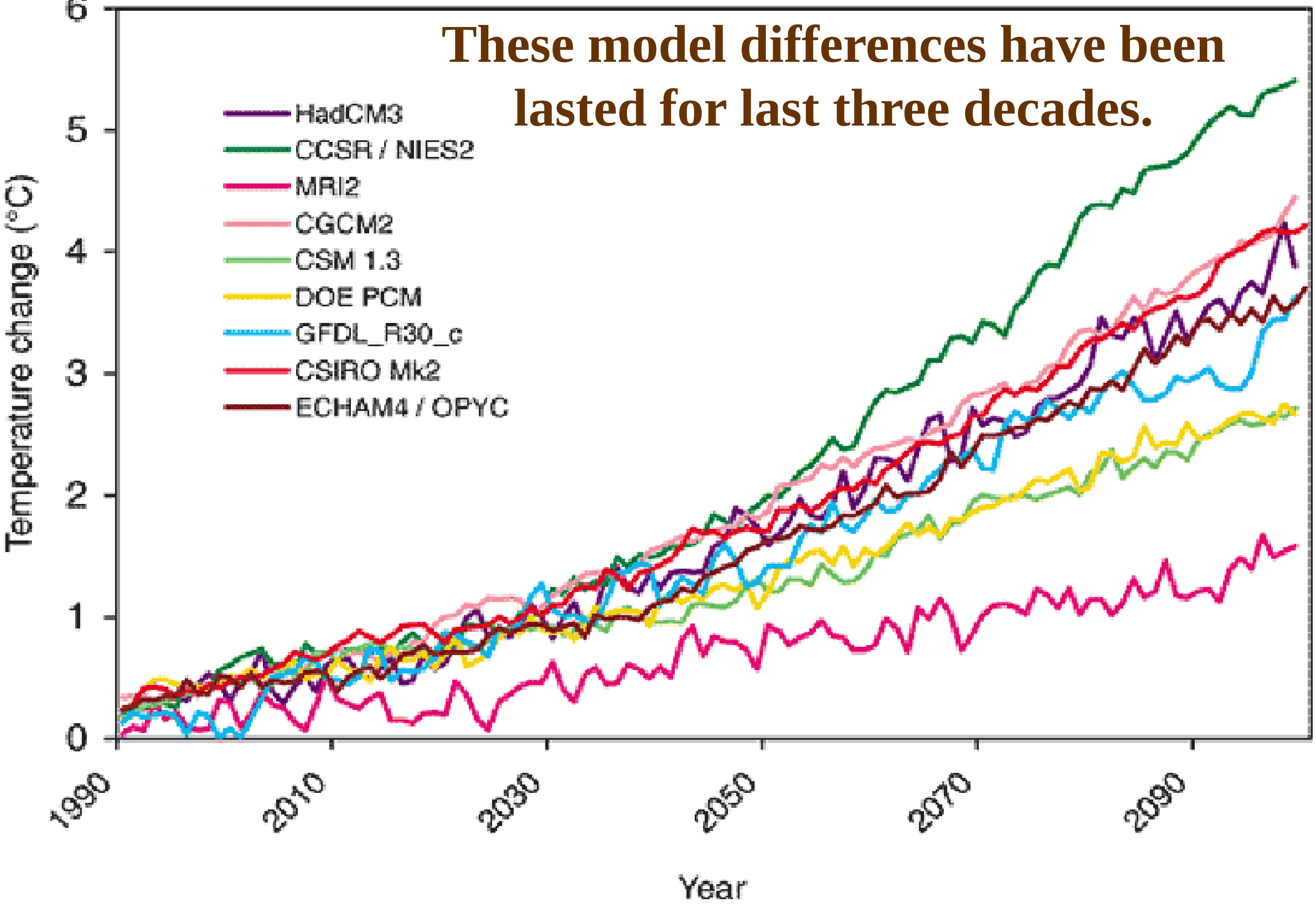
Large Uncertainties in Global Climate Model Predictions



These model differences have been lasted for last three decades.

Model predictions of the time evolution of the globally averaged temperature change.

Introduction

- Large uncertainty in GCM climate predictions
  - clouds, precipitation, ocean, bio-/cryo-spheres

strong nonlinear

- Climate sensitivity: ??? time scale dependence
  - short-term variations of Ts and Rnet
  - long-term relationship of Ts and Rnet

from weather to century time scales

- Questions for observations:
  - Can we 'retrieve' (estimate) the climate sensitivity and reduce the uncertainty from measurements?
  - What is the 'retrieval model' for the feedbacks? Need tools and methods in the analysis

Approaches

- Climate sensitivity estimations
  - complex enough for fundamental physics
  - simple enough to understand processes
  - observational-driven model studies

- Energy balance & perturbation

- Key forcing: atmospheric radiation

- Short- and long-term relationships

Climate perturbation

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

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:
$\Delta Ts = T$

$f_n = -3.3\ \mathrm{W/K/m^2}$

This is only for the equilibrium state of the climate. At short time scales, this feature cannot be found.

History

$$Cp\frac{dT}{dt} = -f_n T$$

short-time scale feedbacks

$$Cp\frac{dT}{dt} = F - f_n T + fT = F - f_s T$$

long-term feedbacks potentially exist

For steady state with small perturbation:

$$T = T_0 e^{-t/\tau} \qquad \tau = Cp/f_n$$

For forced small perturbation:

$$T = F(1 - e^{-t/\tau})/f_s \qquad \tau = Cp/f_s$$

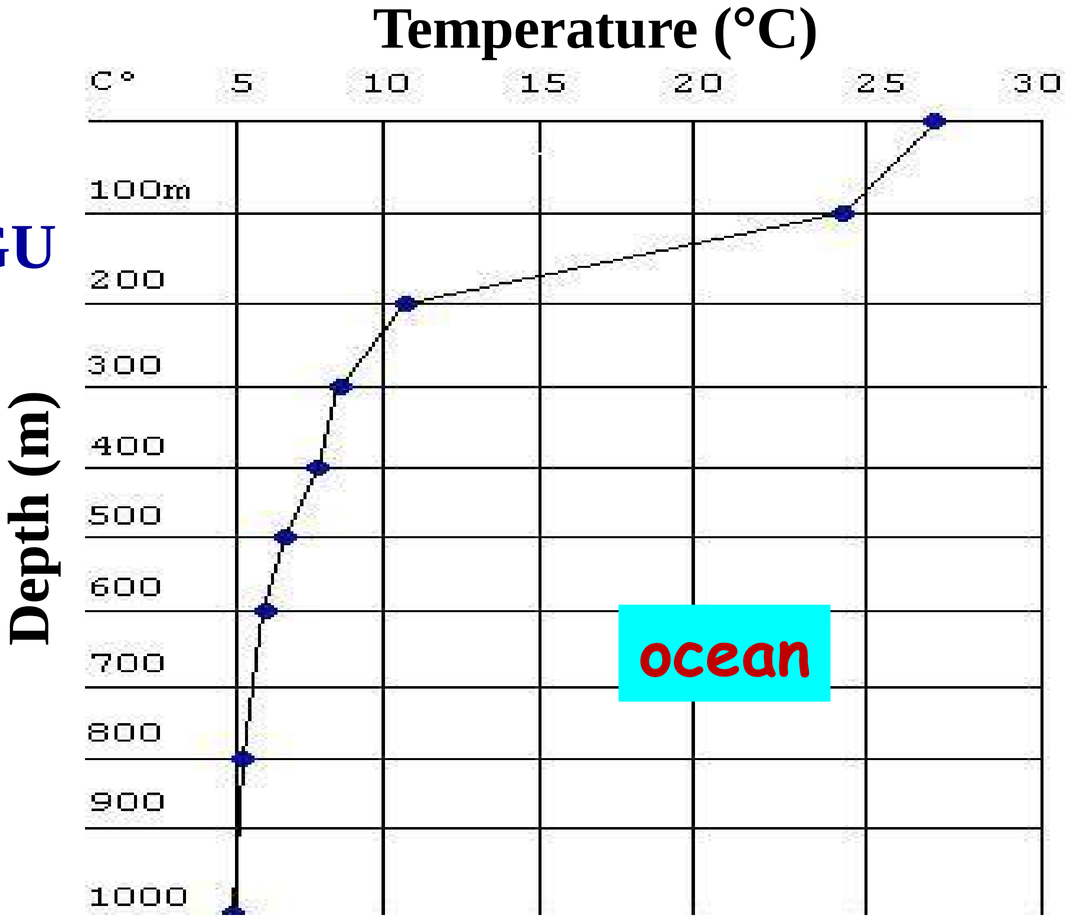
History (conti.)

Hansen et al. 1984 (Geophys. Monograph); Manabe 1990 (JPO)

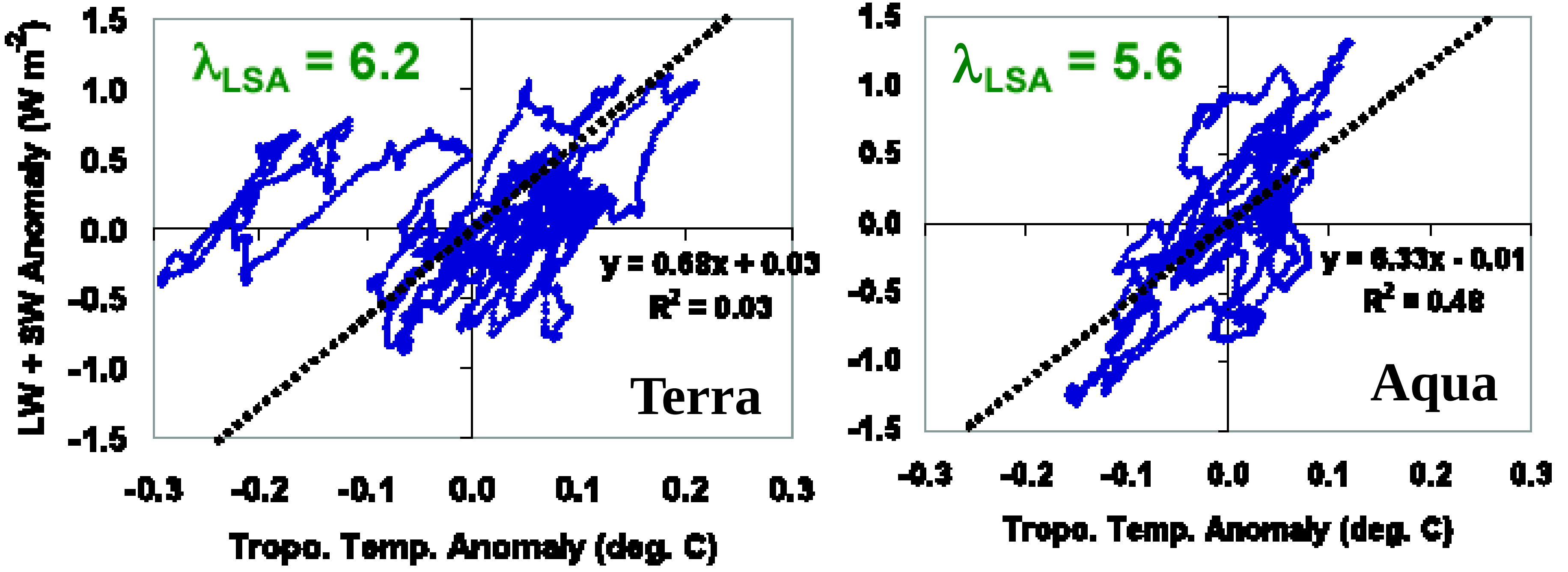
- **Estimate total feedback coefficient ftot (actually fs)**
- **Huge heat capacity due to oceans, thus “wait and see”**

Recent Progress:
Schwartz 2007 JGR
Spencer and Braswell 2009 AGU

$$Cp\frac{dT}{dt} = F - ftotT$$



short-term relation



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

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

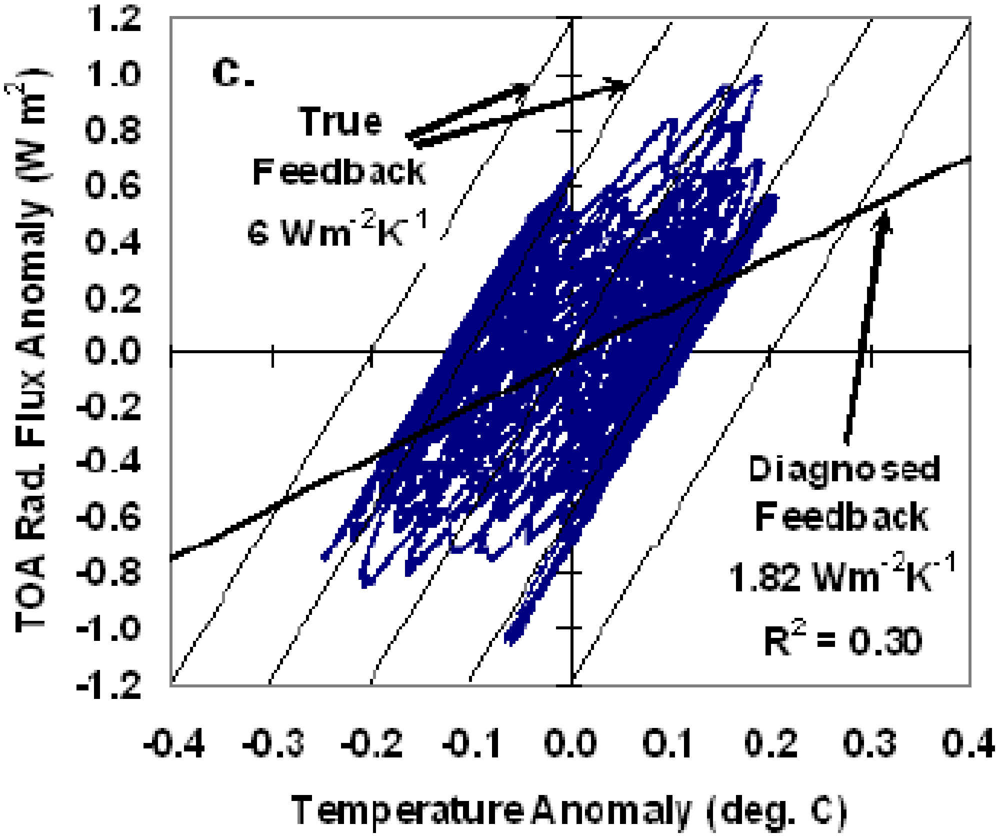
N: **non-radiative heating (daily)**

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

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

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

Cp: **50 m water**



Spencer and Braswell 2009

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) ↔ 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}: $f_{tot} = f_s + f_m$

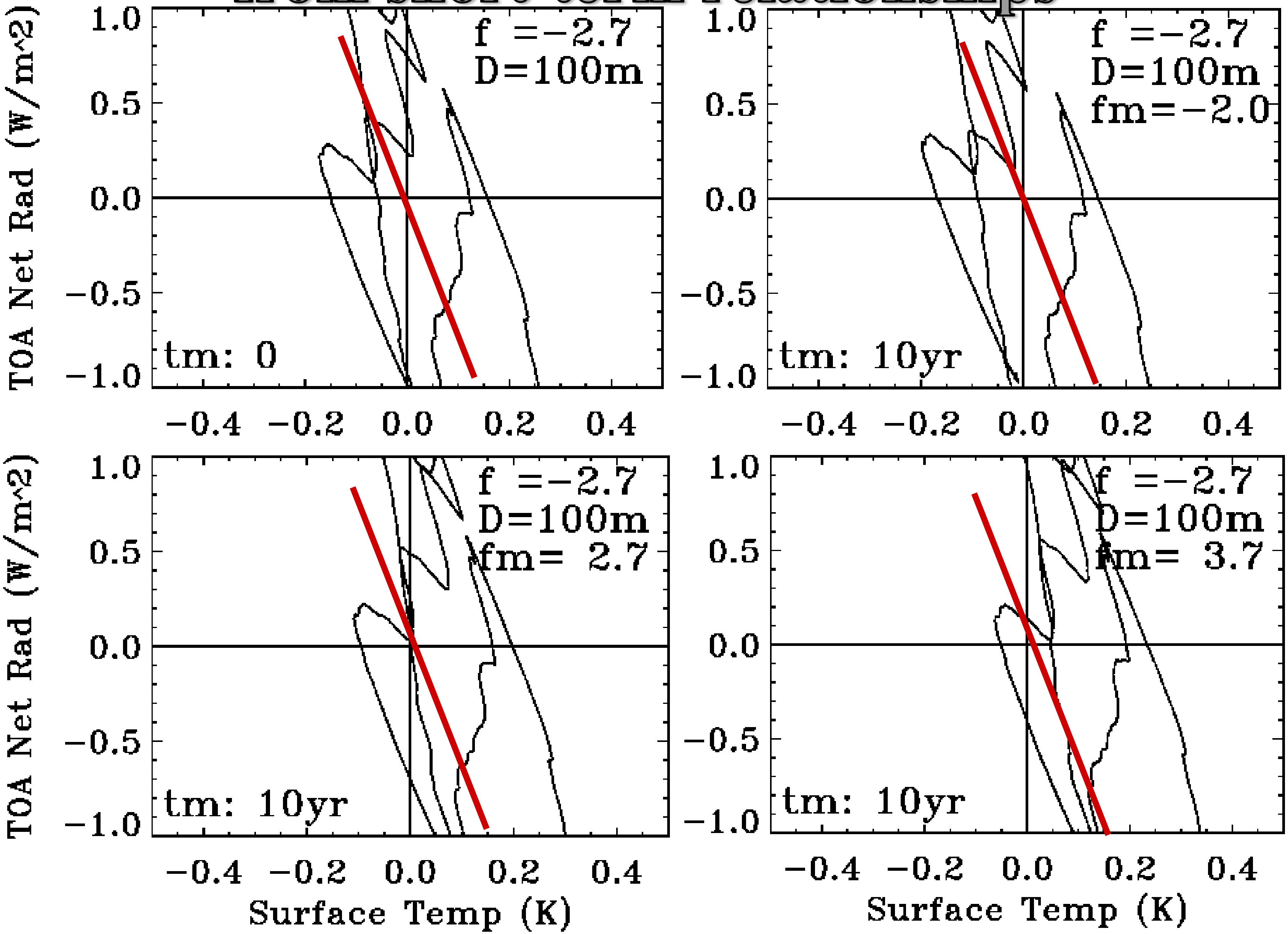
F: **F = 0 or removed**

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

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

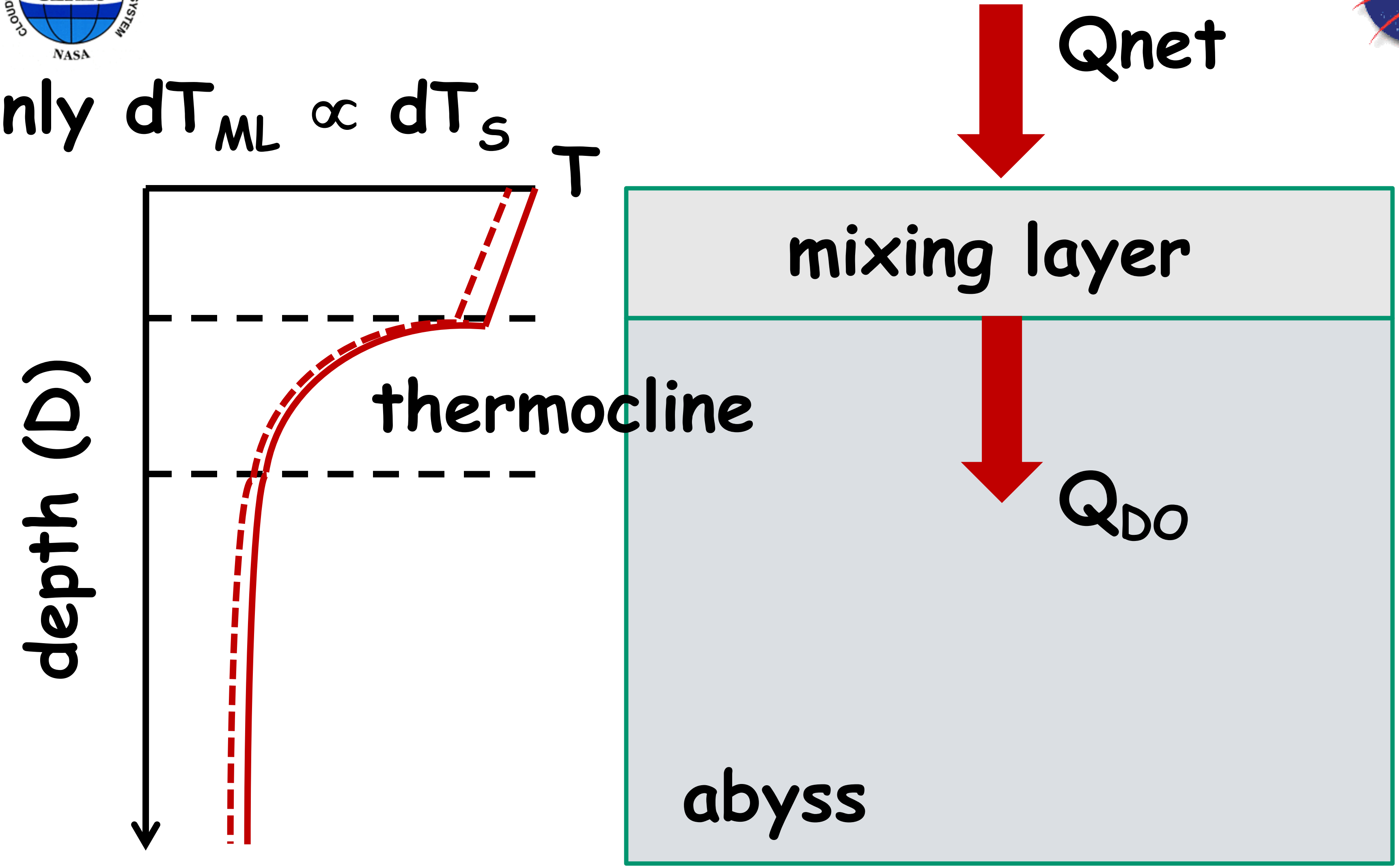
last 10-year results of 100-year run

May not determine total feedback from short-term relationships



Issues

only $dT_{ML} \propto dT_S$



1. Solving boundary conditions instead of initial conditions
2. D limits or deep ocean heat transport -- much longer time scale
3. Climate system memory – generalized feedback (e.g., ice sheets)

Perturbed Climate System

More general conditions are considered in this study

1. Boundary condition approach
2. System has memory with memory length t_0 (could be multi-cycles)
3. There is a deep ocean heat transport

$$Cp\frac{dT}{dt} = F - fsT + \frac{fm}{t0}\int_{t-t0}^{t} Tdt' - O$$

$$O = \mu\left(F - fsT + \frac{fm}{t0}\int_{t-t0}^{t} Tdt'\right)$$

$$f_{tot} = fs - fm$$

Analytic System

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

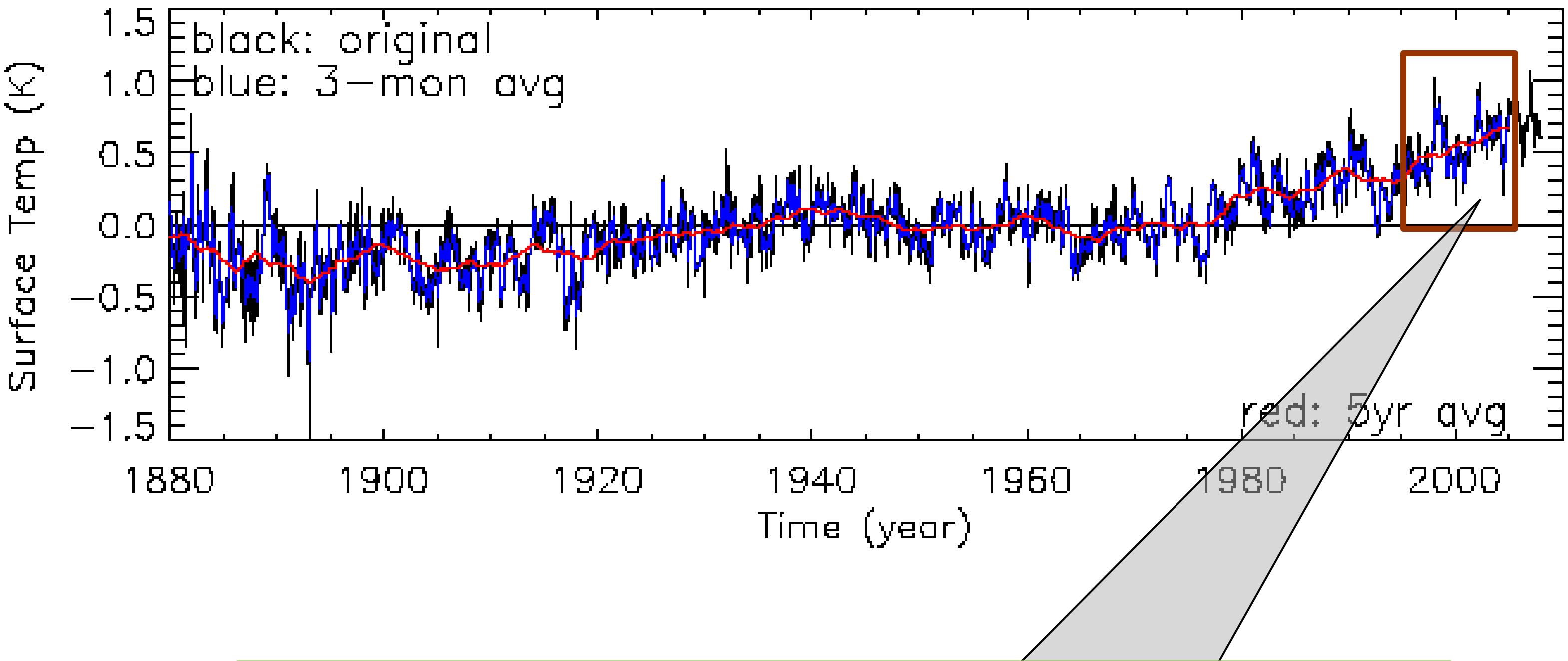
1. **Avoid the difficulty on deep ocean heat storage**
2. **Solution is not specifically dependent on mixing layer depth, only the ratio of D/η**
3. **Forcing: F = γt (F (t=0) =0; F(t=120yr) = 1.8W/m^2)**
4. **f$_S$= f$_n$ + f = 6 W/m^2/K; Thus, f$_{TOT}$ = f$_S$ -f$_m$**

Reduced forms:

1) t$_0$ approaches 0; & 2) Ocean heat transport = 0

→ 1st order ODE of Hansen, Manabe, Schwartz etc

Current solution

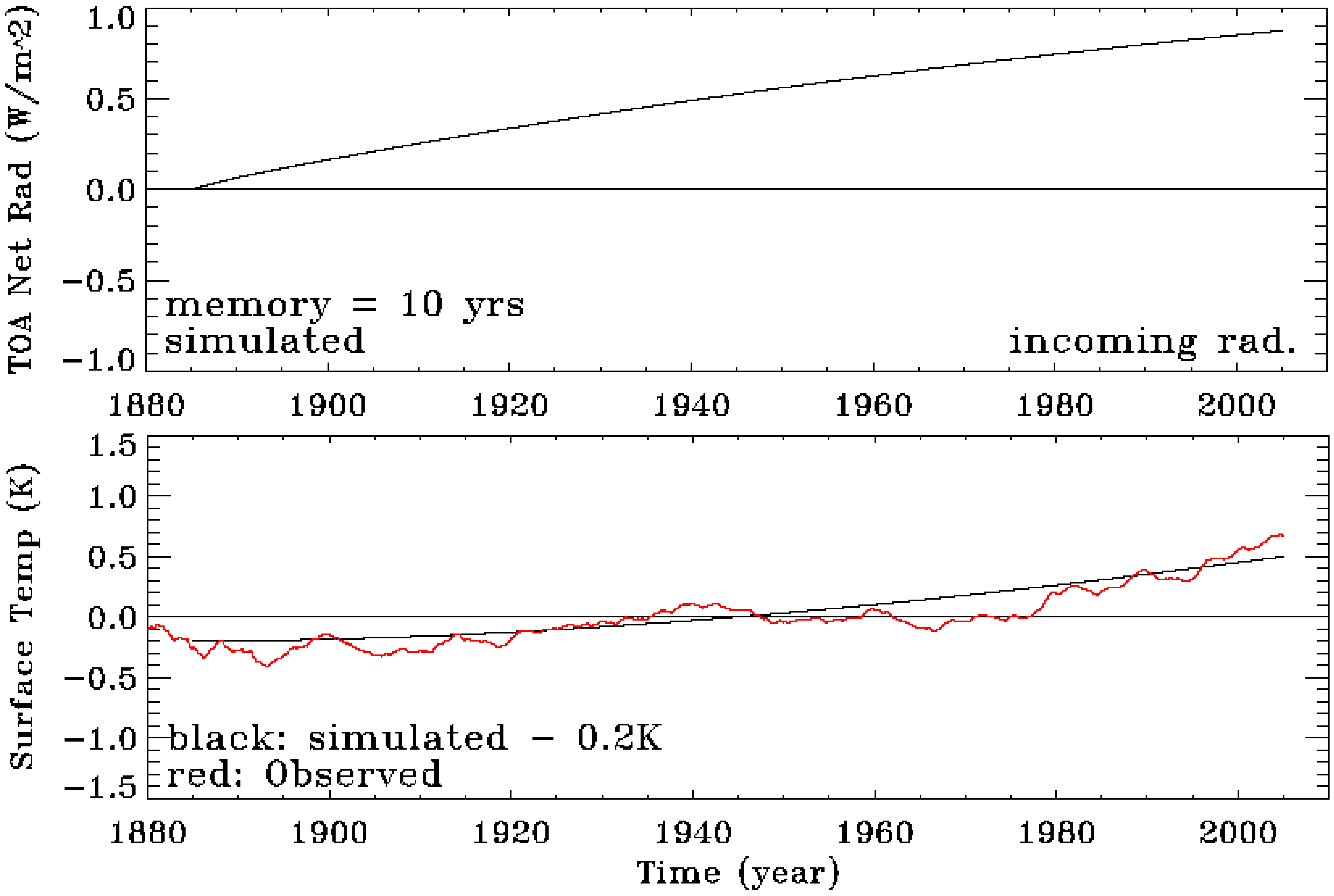


$T = 0.65$ K; $Q_{net} = 0.85$ W/m^2
constraints for the means of last 10 yrs

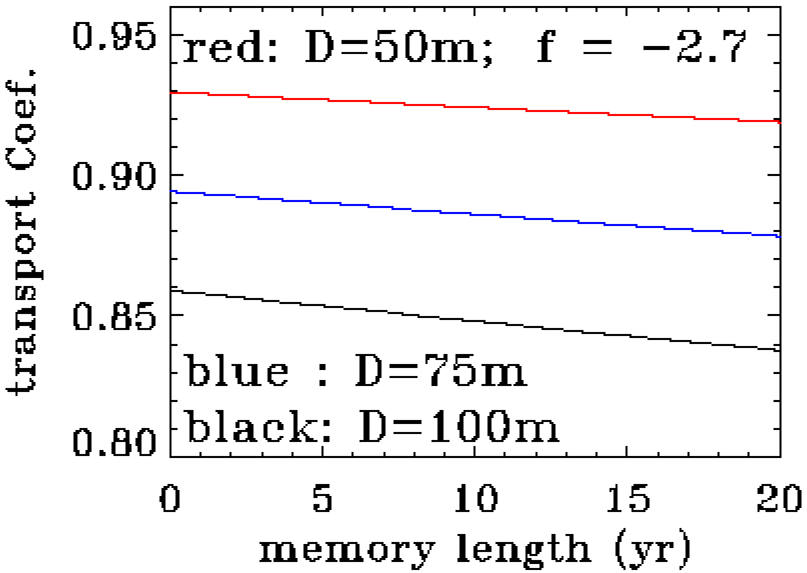
☑ **Numerical solution of f_m and η (or μ): easier**

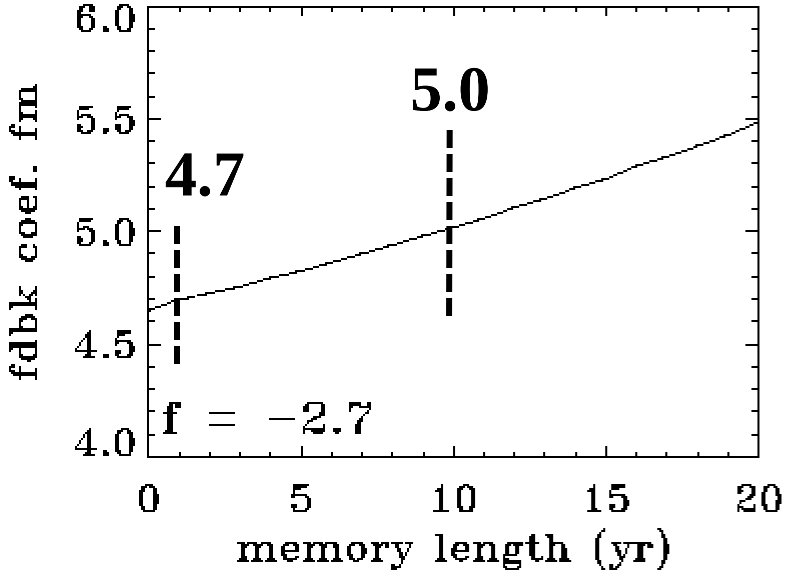
☐ **Analytic solution is also available**
(solving transcendental equations; more math)

Results


TOA Net Rad (W/m^2)
1.0
0.5
0.0
−0.5
−1.0
memory = 10 yrs
simulated
incoming rad.
1880
1900
1920
1940
1960
1980
2000
Surface Temp (K)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
black: simulated − 0.2K
red: Observed
1880
1900
1920
1940
1960
1980
2000
Time (year)

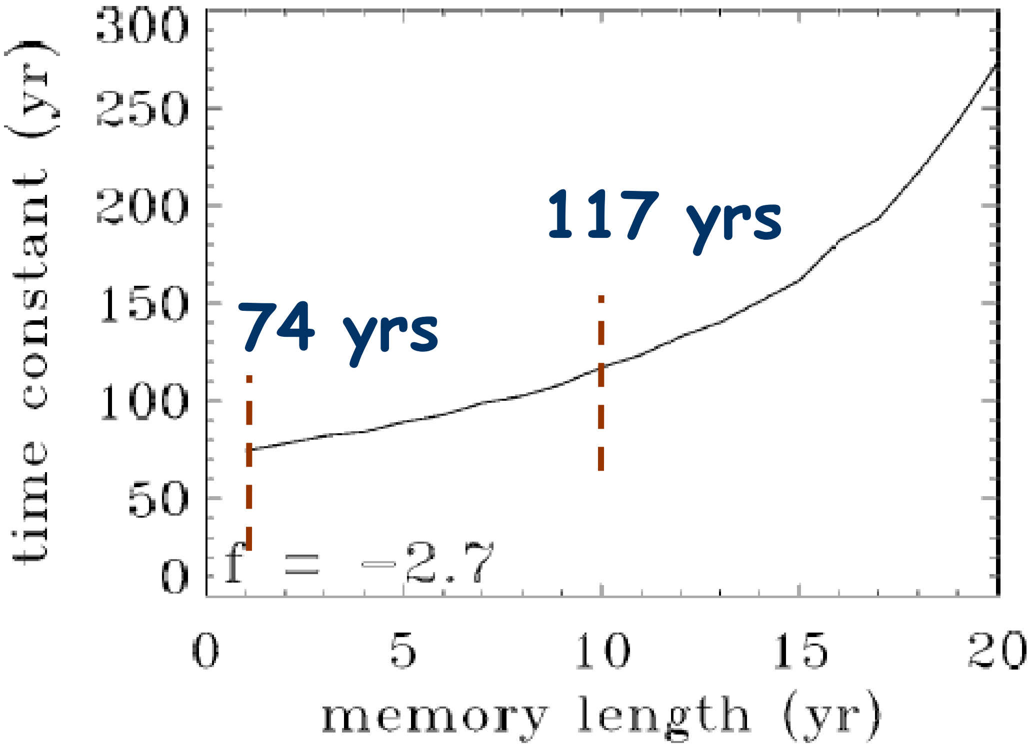
Results





1. **Most heat is transported to deep ocean ($\mu > 80\%$).**
2. **Total feedback coefficients: $f_{tot} = 6 - 4.7 = 1.3$ ($t_0 = 1$ yr);**
   $f_{tot} = 6 - 5.0 = 1.0$ ($t_0 = 10$yr)
3. **Positive feedback obtained:**
   feedback coefficients: $fc = 4.7 - 2.7 = 2.0$
   $fc = 5.0 - 2.7 = 2.3$

Results



gradually increases in the constant for memory length < 15 yrs

With deep ocean heat transport, the time constant of climate system is much longer, maybe about 70 ~ 120 yrs.

Linearized Approximation

$$Cp\frac{dT}{dt} = F - fsT + \frac{fm}{t0}\int_{t-t0}^{t} Tdt' - O$$

$$Cp\frac{dT}{dt} = F - ftotT$$

$$ftot = (F - Cp\frac{dT}{dt})/T$$

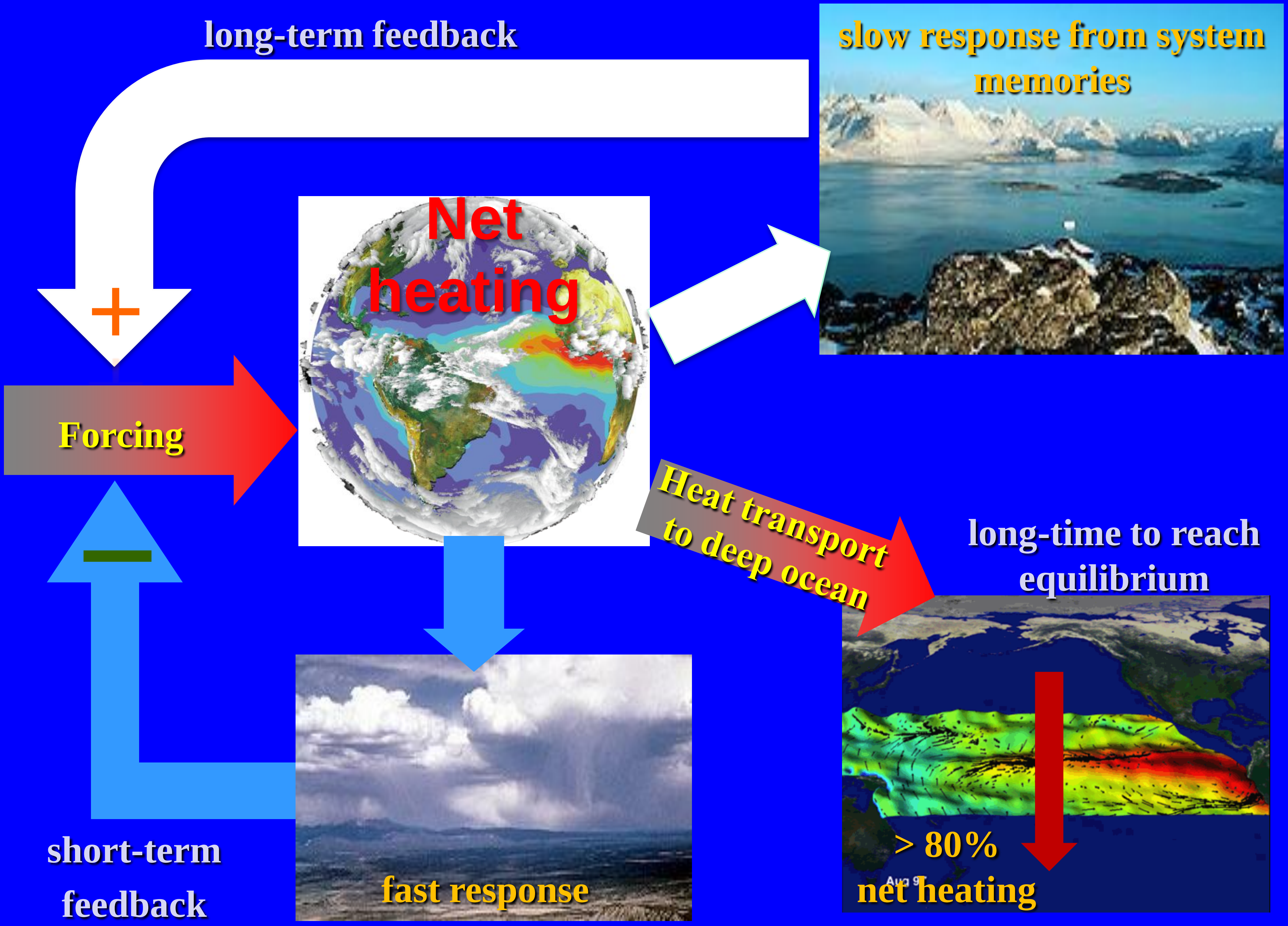
$$ftot = (F - Qnet)/T$$

$$ftot = (1.8 - 0.85)/0.65 = 1.46$$

$u = 0.91$ assuming 100m mixed layer

Reduced forms: resulted in slightly weaker positive feedback than those of the perturbation model calculations

Data needed: surface temperature & TOA net radiation



long-term feedback

slow response from system memories

Net heating

+

Forcing

−

Heat transport to deep ocean

long-time to reach equilibrium

> 80%
net heating

short-term feedback

fast response

Summary

- There are large uncertainties in the climate predictions from present global climate models.
- Energy balance model is used for explanation of observed TOA net radiation (or ocean heat storage) and surface temperature.
- Major physical processes of the climate system, such as deep ocean heat transport and system memory, are considered.
- This study targets at boundary instead of classic initial condition problems (actual climate issue).

Summary

- Short-time scale climate system adjustment (or relaxation) alone cannot mimic climate change: different scales, different physics

- For the best estimate of Qnet, estimated feedback factor is 1.0 ~ 1.3, or, 2×CO_2 (or 3.7 W/m^2) warming about 2.85 ~ 3.7 K. Results is sensitive to Qnet, not Ts and fs.

  (only provide a tool for public)

- There is a strong desire for long-term radiation missions with calibrations of high accuracy and precision, such as CLARREO & CERES.

Thank You!

- Lin et al. 2010, *ACP*
- Lin et al. 2010, *JQSRT*