Climate perturbation, energy balance and feedback

[1]Bing Lin, [1]Lin Chambers, [1]Bruce Wielicki, [2]William Rossow, [1]Yongxiang Hu, [1]Patrick Minnis, [1]Paul Stackhouse, [1]Norman Loeb, [3]Wenbo Sun, [4]Gerald Potter, [5]Qilong Min, [1]Gregory Schuster, [6]Tai-Fang Fan

[1]NASA Langley Research Center, [2]CUNY-City College, [3]Hampton University, [4]UC Davis, [5]SUNY-Albany, [6]SSAI

CERES Science Team Meeting

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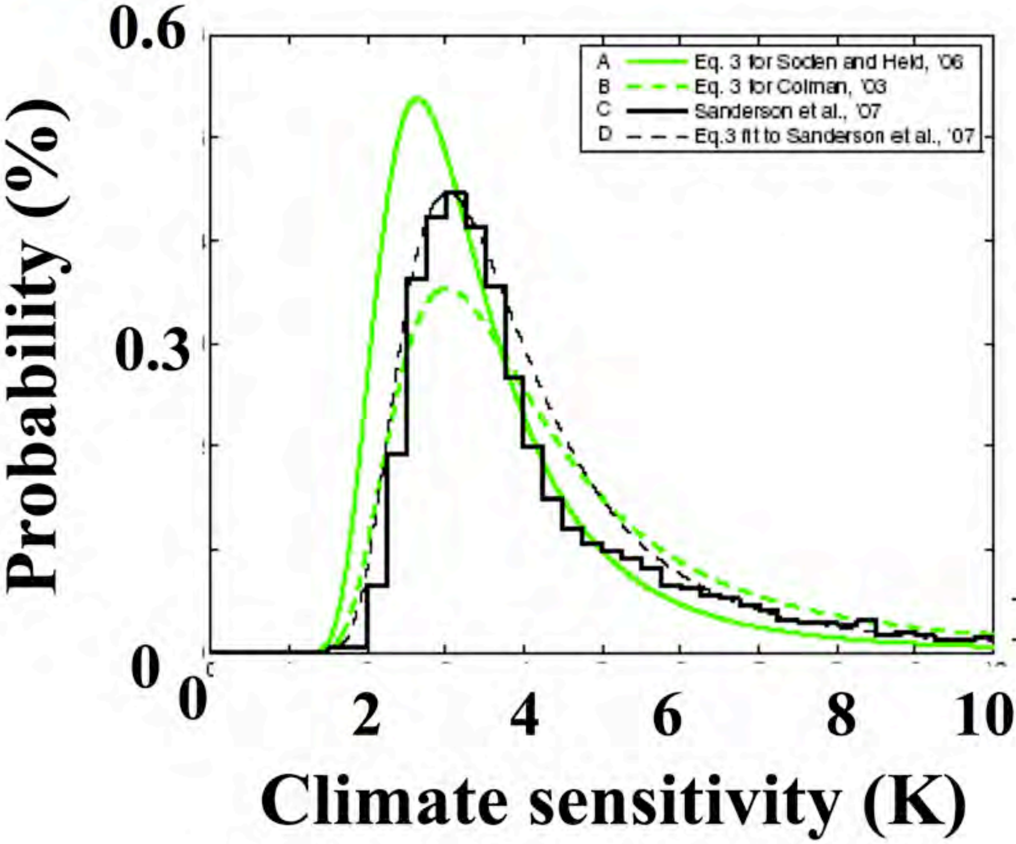
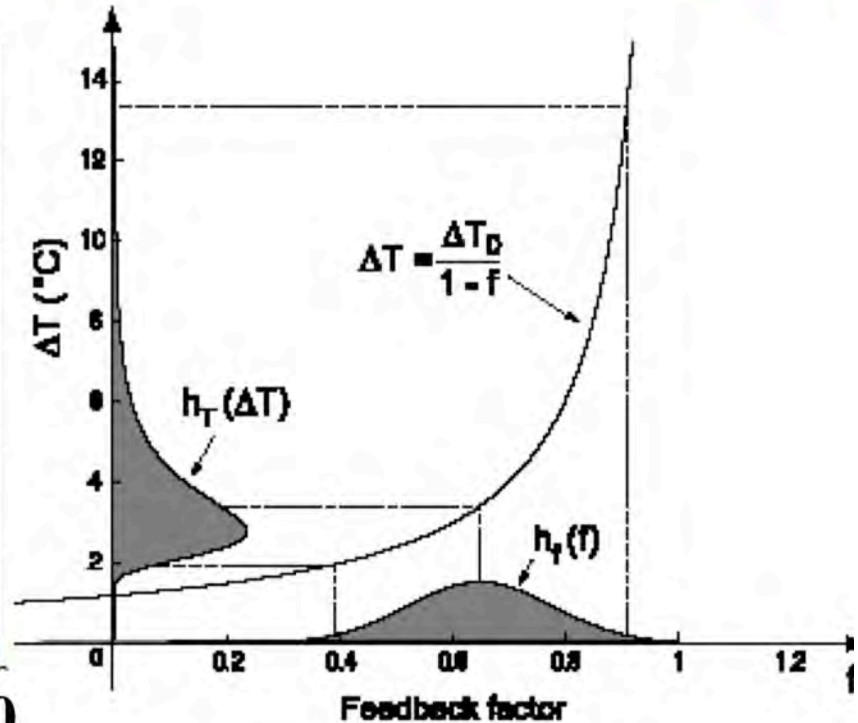
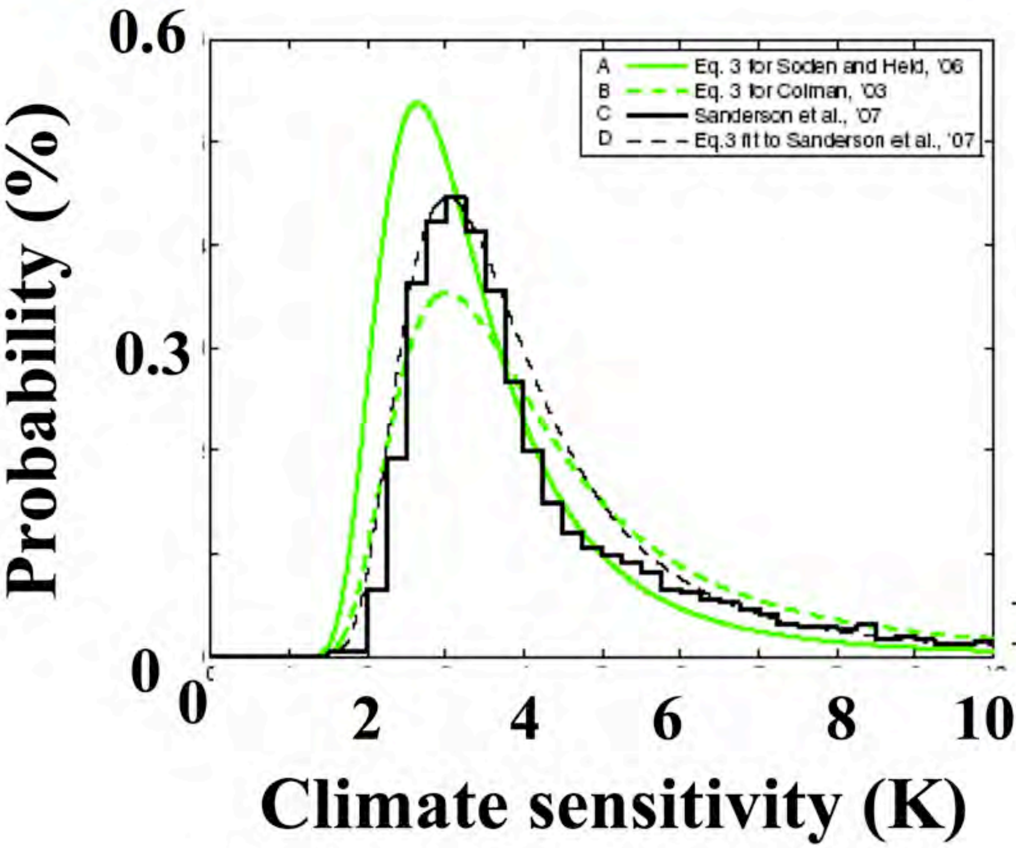
Motivation

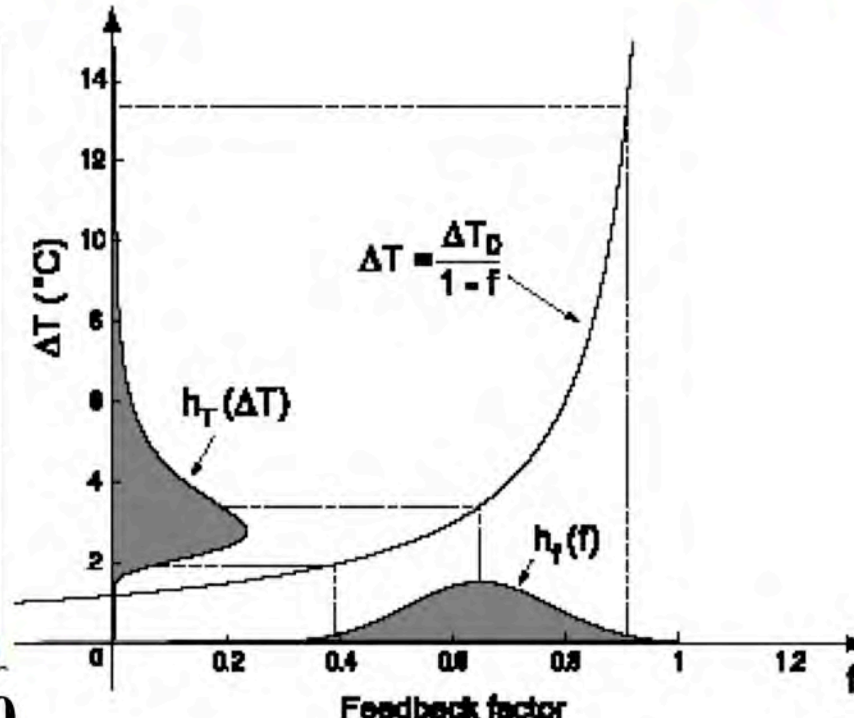




Roe & Baker (2007) Science

Motivation





Observations: 'retrieval' (estimate) or providing a key tool to reduce the uncertainty in climate sensitivity.

What is the 'retrieval model' for the feedback?

Climate perturbation

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

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

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define:
$\Delta Ts = T$

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At short time scales, this feature cannot be found.

History

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

For steady state with small perturbation:

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

History

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

short-time scale feedback

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

For steady state with small perturbation:

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

For forced small perturbation:

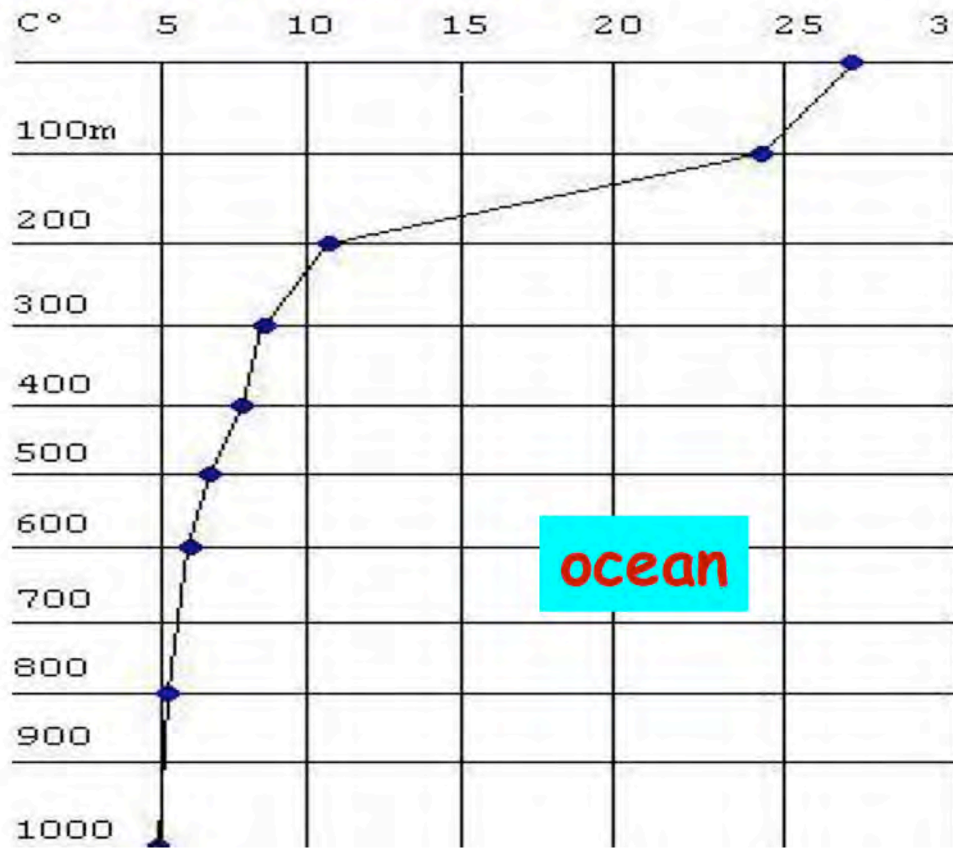
$$T = F(1 - e^{-t/\tau}) / f_s \qquad \tau = Cp / f_s$$

History (conti.)

Hansen et al. 1984 (Geophys. Monograph); Manabe ????;

- **Estimate feedback coefficient fs**
- **Huge heat capacity due to oceans, thus "wait and see"**
- **Coupled GCM**

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



Recent results

Schwartz (2007, JGR):

Equivalent heat capacity: ocean heat measurements

$$Cp = \frac{dH}{dT} \Rightarrow D = 100 \sim 110m$$

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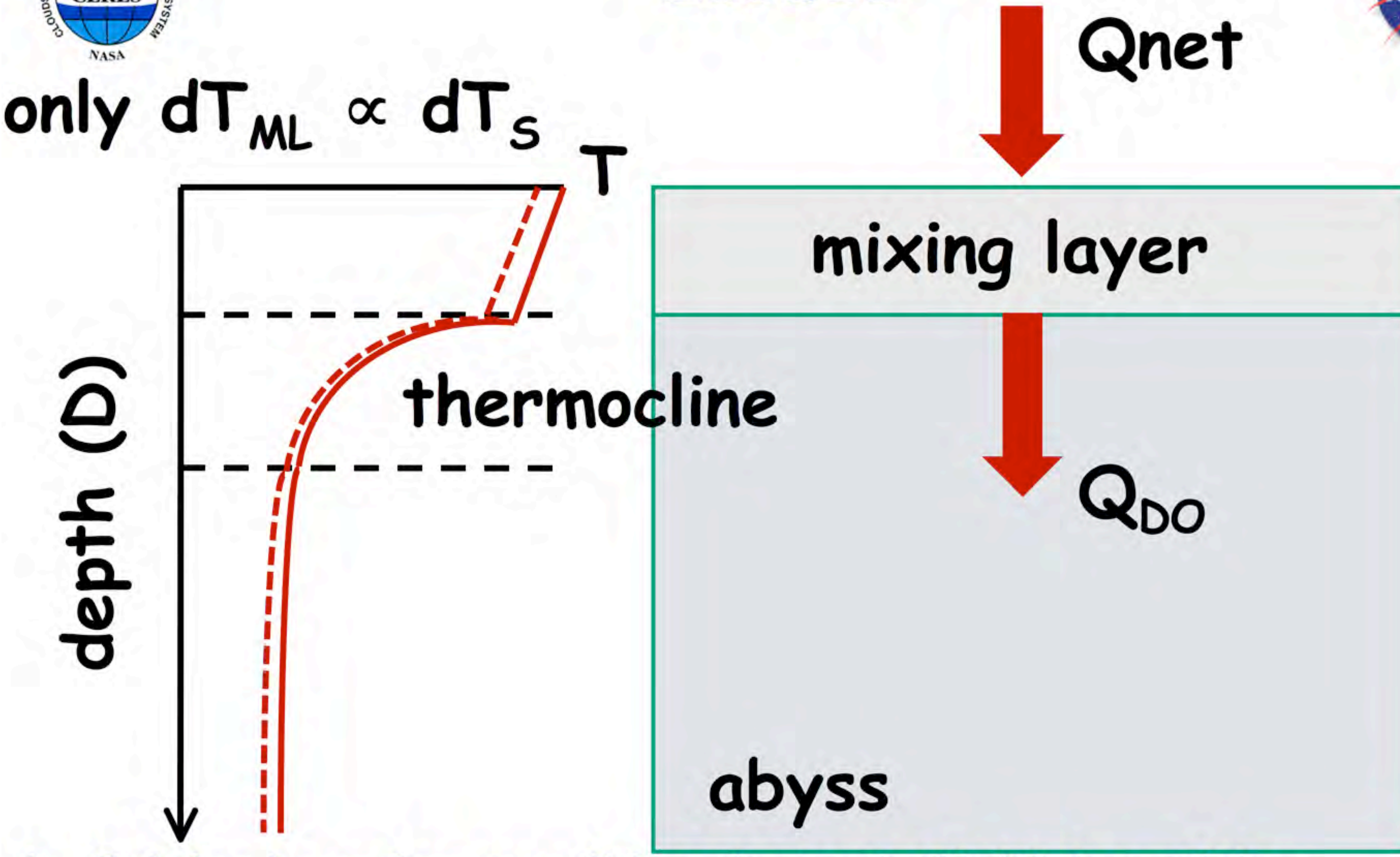
Resulted in fs = 3.3 W/m^2/K, i.e., neutral feedback
Or, 2×CO_2 forcing → 1.1K

Issues



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)

Current Approach

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

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

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

$$ftot = fs - fm$$

Current Approach

$$\frac{Cp}{(1-\mu)}\frac{dT}{dt} = F - fsT + \frac{fm}{t_0}\int_{t-t_0}^{t} Tdt'$$

$$Cp'\frac{dT}{dt} = F - fsT + \frac{fm}{t_0}\int_{t-t_0}^{t} Tdt'$$

$$Cp' = \rho SwV/\eta = \rho SwAD/\eta$$

$$\eta = 1-\mu; T(t \le 0) = 0$$

Current Approach

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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, $f_{TOT} = f_S - f_m$**

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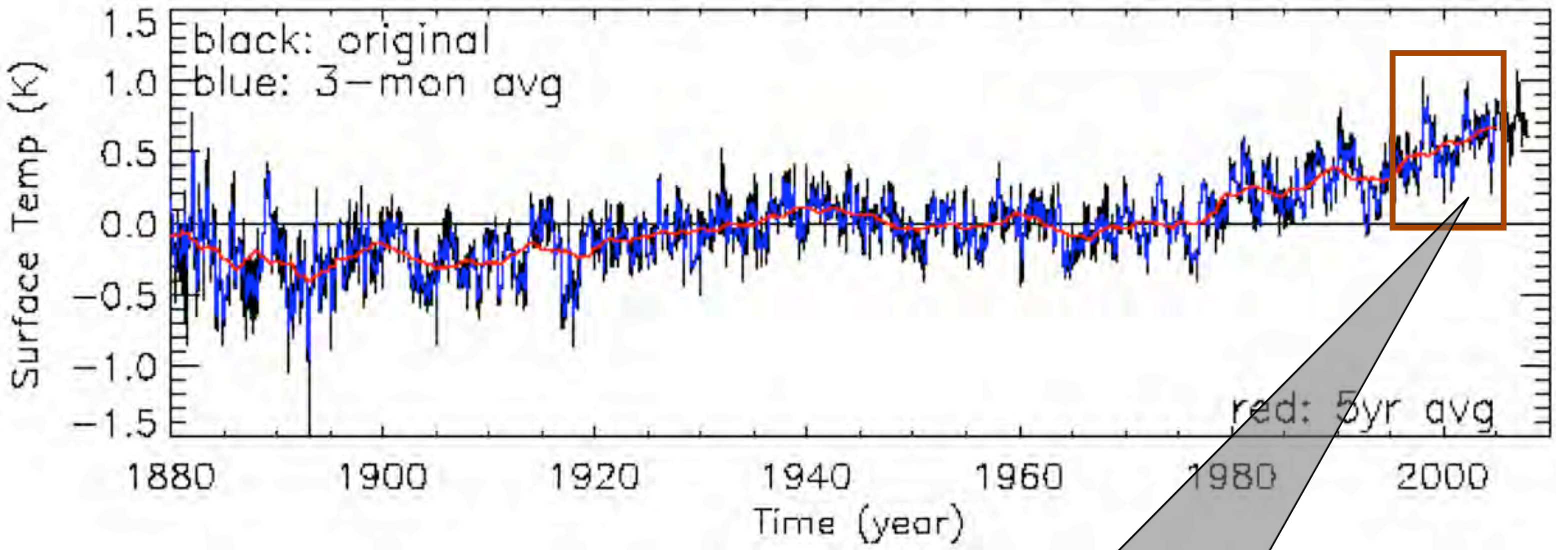
Reduced forms:

1) $t_0 = 0 \rightarrow 1^{st}$ order ODE
2) Ocean heat transport = 0 → 1^{st} order ODE of Hansen, Schwartz etc

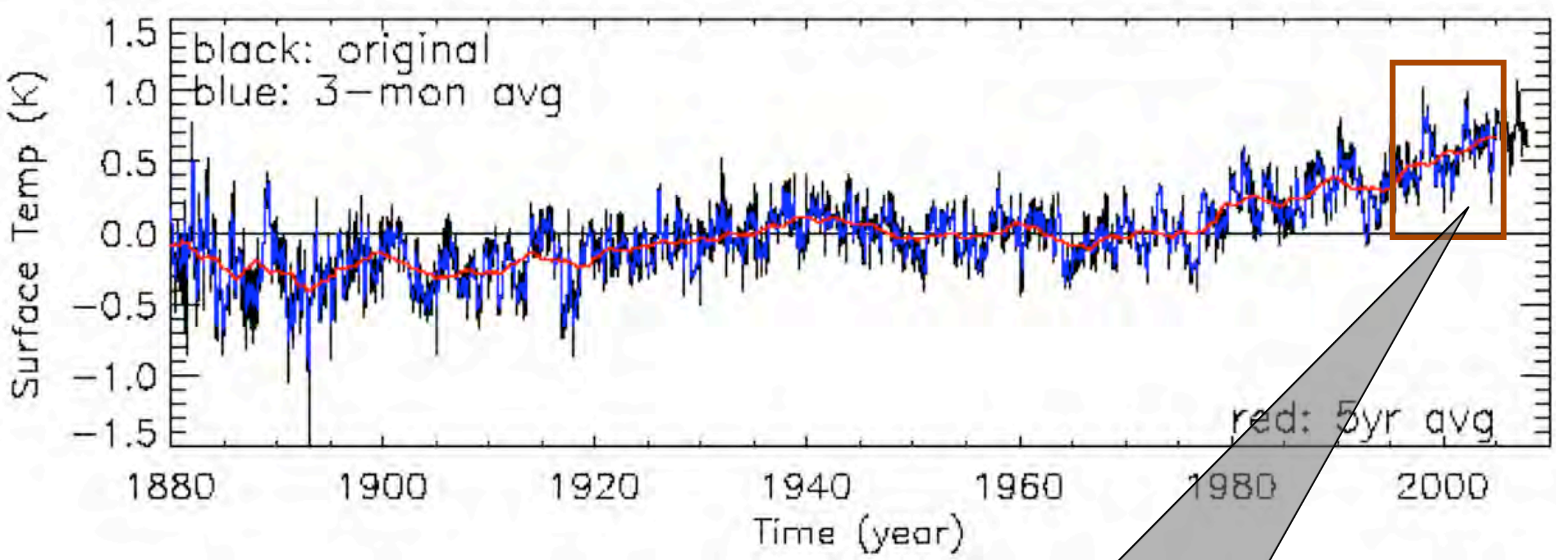
Current Approach

Current Approach



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

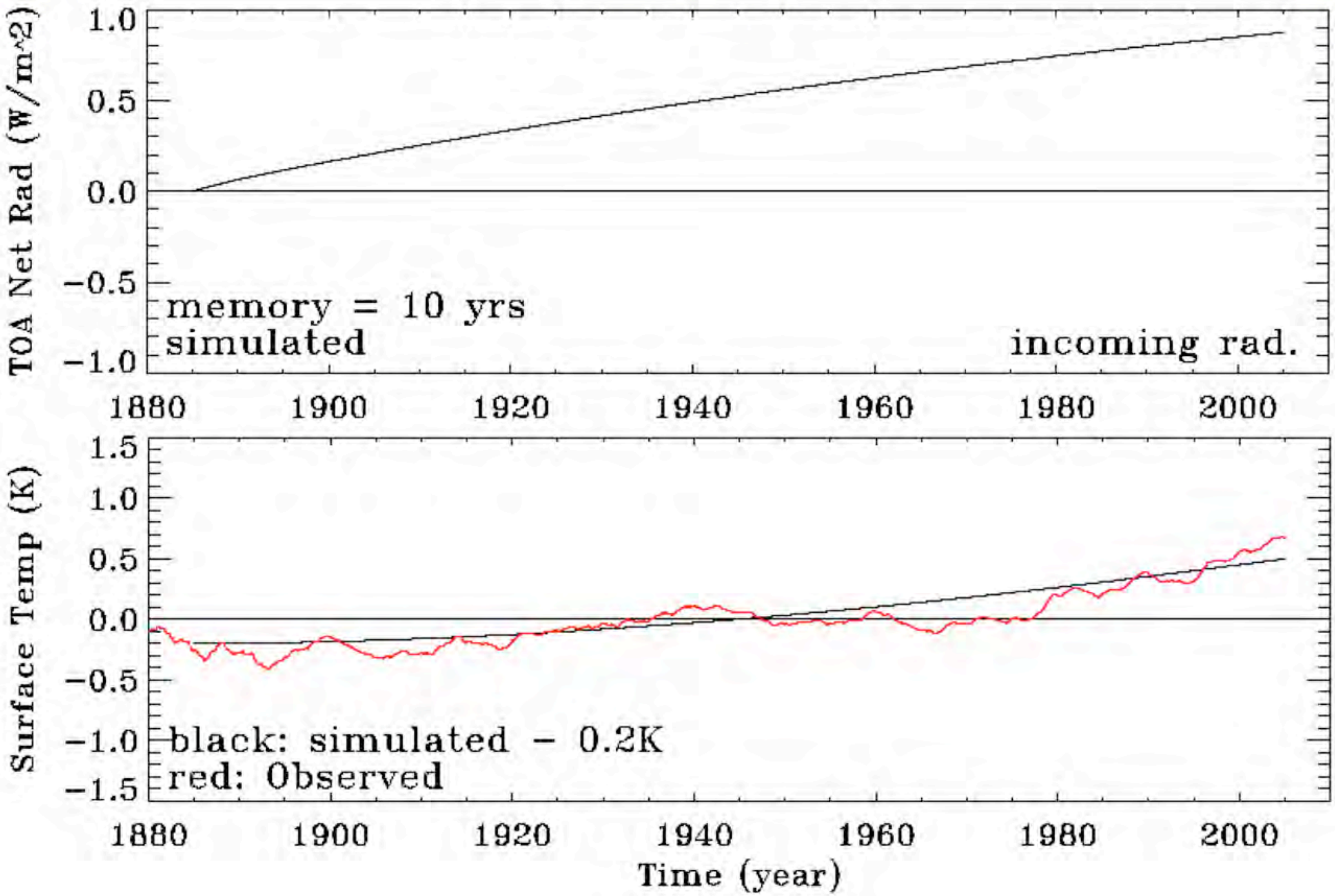
Current Approach



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

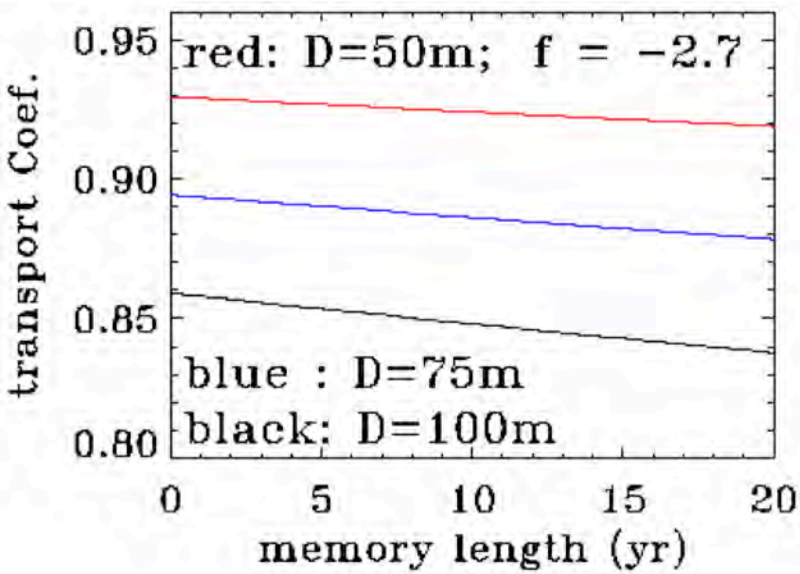
- √ **Numerical solution of f_m and η (or μ): easier**
- ☐ **Analytic solution is also available (not discussed here) (solving transcendental equations; more math)**

Results

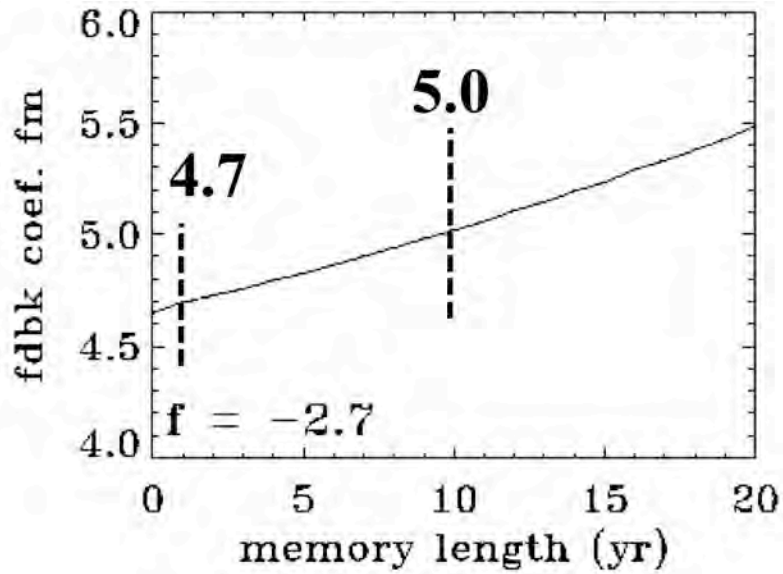


TOA Net Rad (W/m^2)
1.0
0.5
0.0
−0.5
−1.0
memory = 10 yrs
simulated
incoming rad.
1880 1900 1920 1940 1960 1980 2000
Surface Temp (K)
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
black: simulated − 0.2K
red: Observed
1880 1900 1920 1940 1960 1980 2000
Time (year)

Results

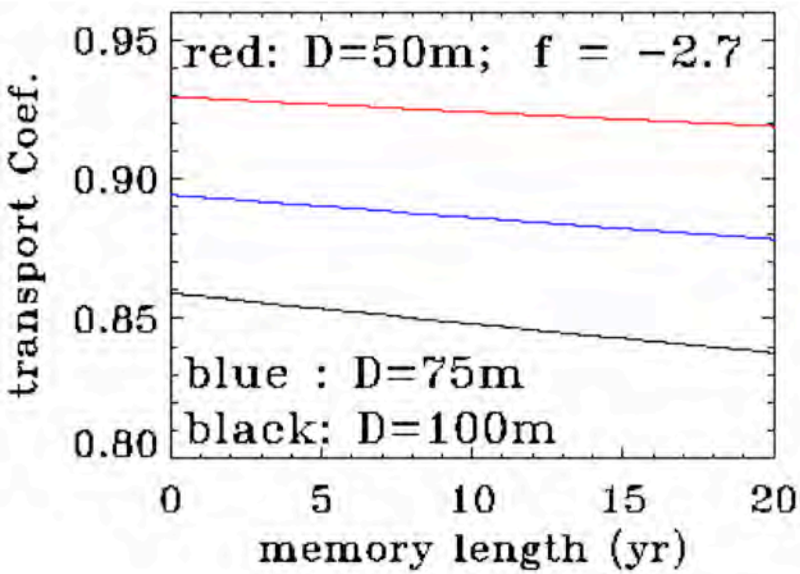


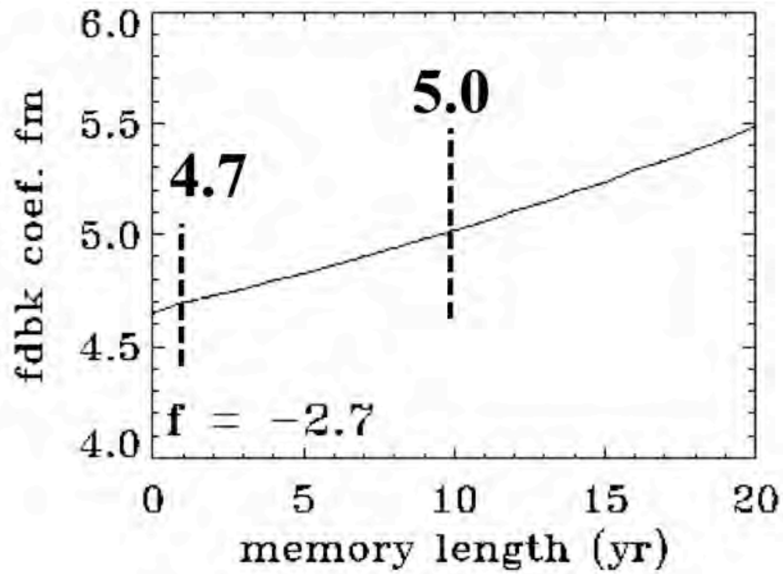
red: D=50m; f = -2.7
blue : D=75m
black: D=100m
transport Coef.
memory length (yr)
0.95
0.90
0.85
0.80
0
5
10
15
20



5.0
4.7
f = -2.7
fdbk coef. fm
memory length (yr)
6.0
5.5
5.0
4.5
4.0
0
5
10
15
20

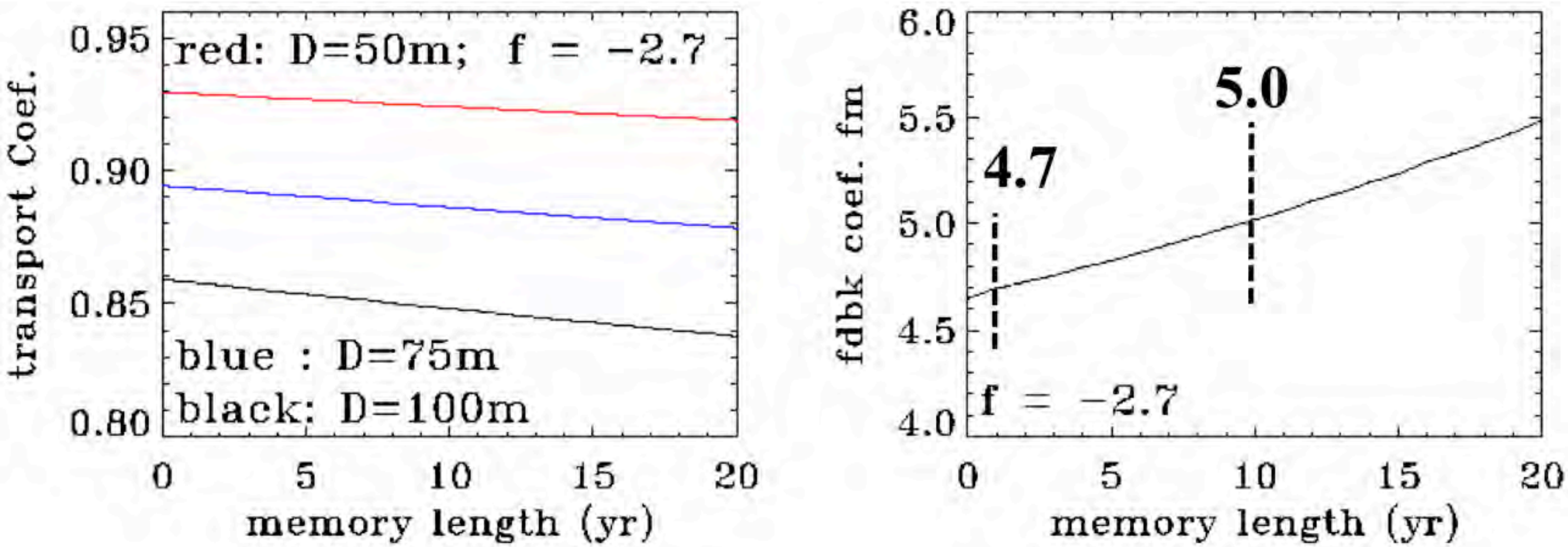
Results





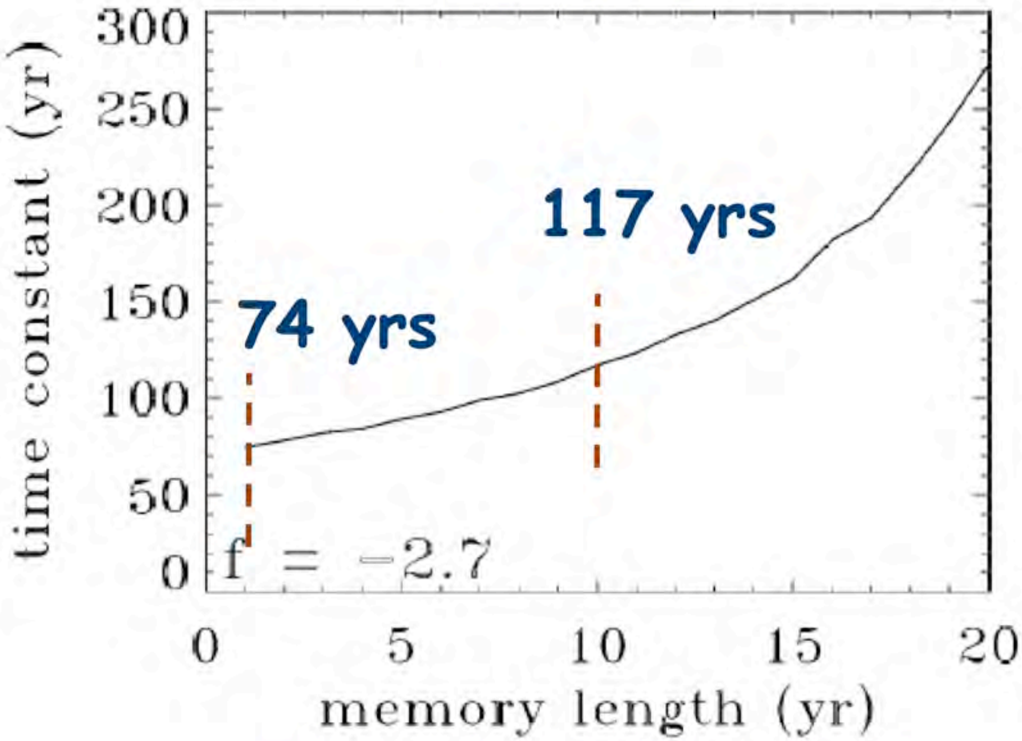
1. **Most heat is transported to deep ocean (μ > 80%).**

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: $fc = 4.7 - 2.7 = 2.0$
   $fc = 5.0 - 2.7 = 2.3$

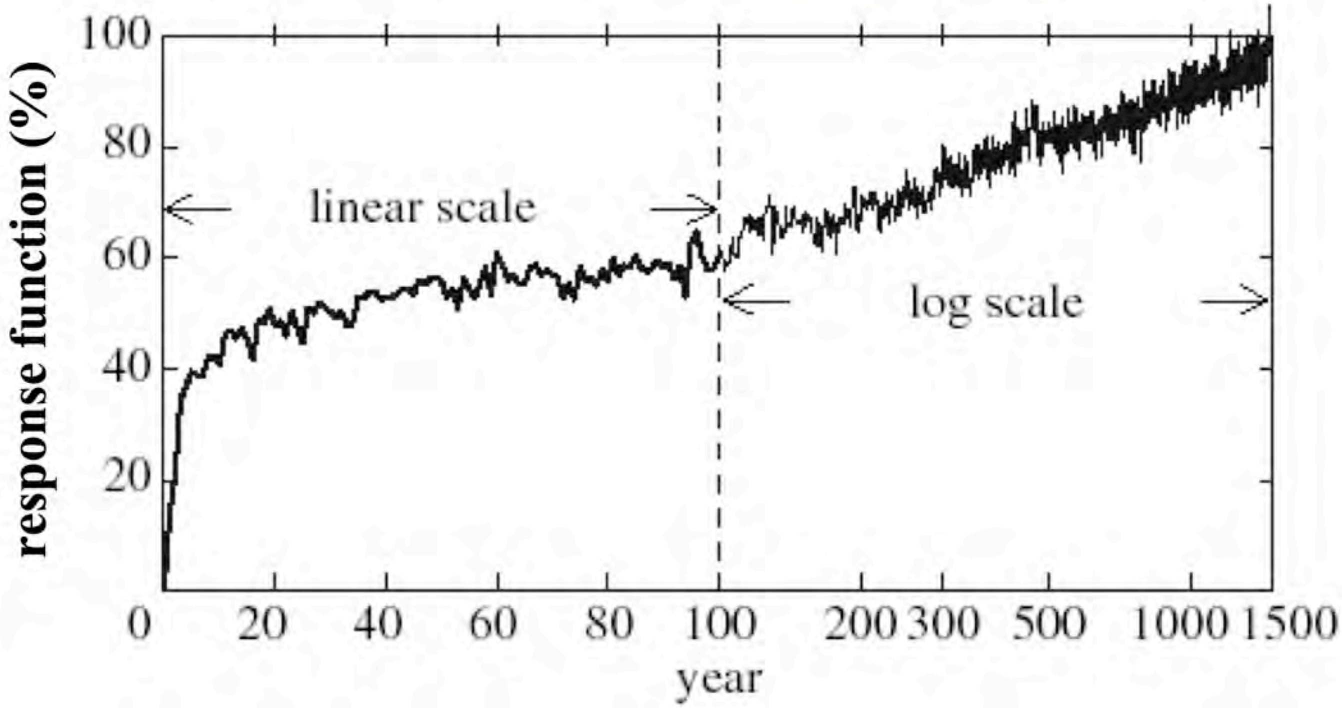
Results



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.

GISS AOGCM



60% in 100 yrs **90% after 1000 yrs**

Time const.: 109 yrs 434 yrs

Hansen et al. (2007, PTRS)

Results: asymptote

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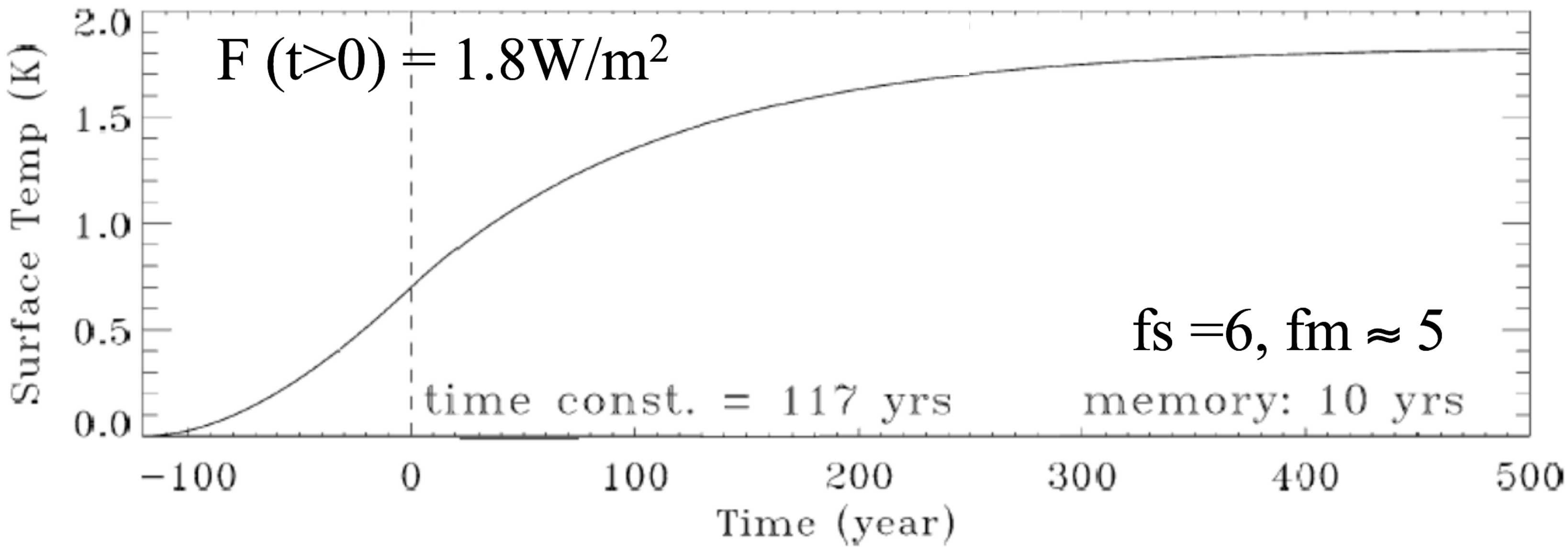
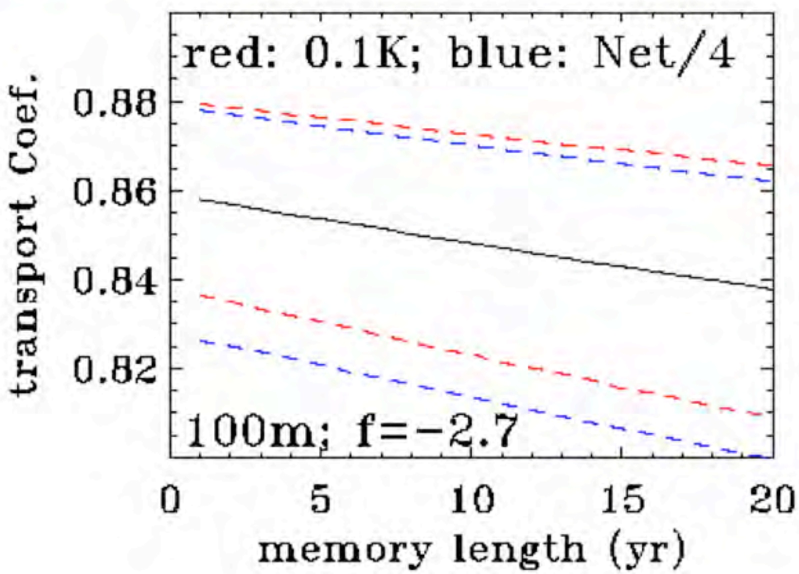
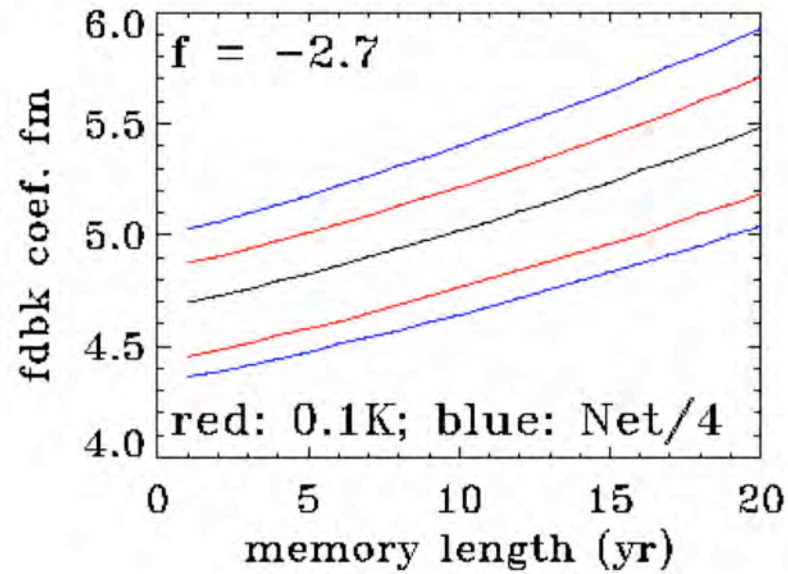


$$0 = F - fsT + \frac{fm}{t_0} Tt_0 = F - fsT + fmT$$

$$T = F/(fs - fm) = 1.8K$$

Results: sensitivity on Q and T





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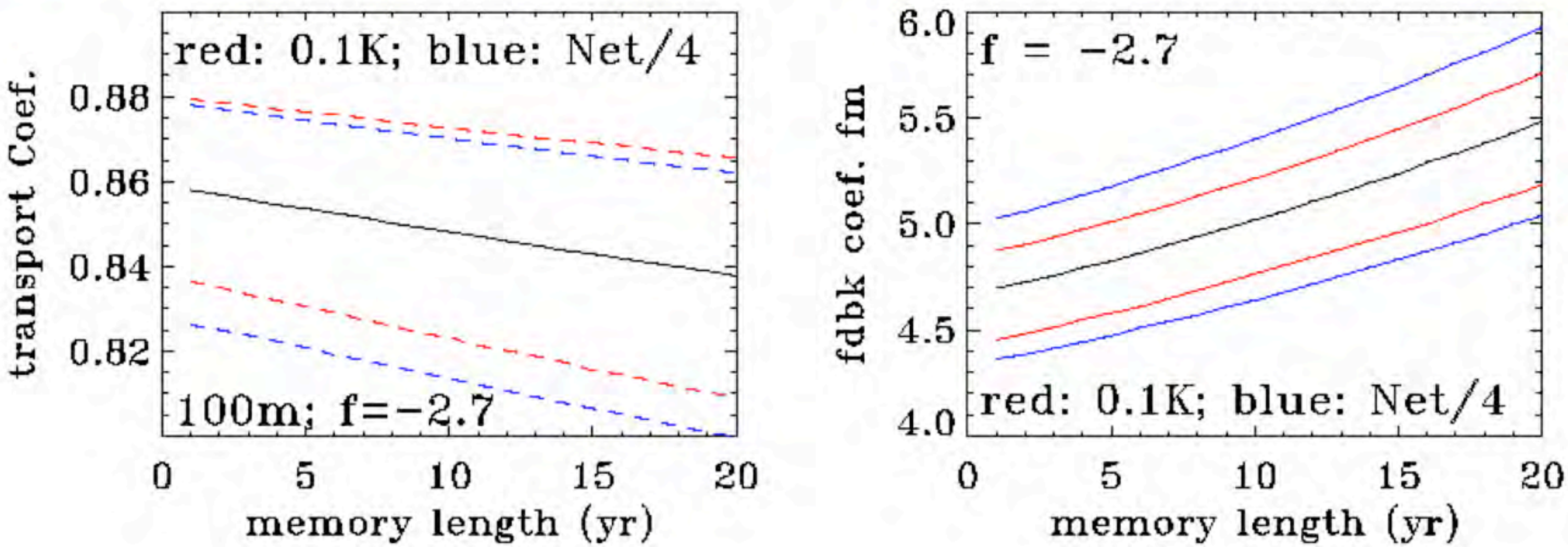

Surface T uncertainty 0.1K → not very sensitive

Q_{net} uncertainty (25% or ~0.2W/m^2) → sensitive

Actual error in TOA net or ocean heat storage change measurements may be larger or smaller than 0.2 W/m^2. Current the best error estimate is about 0.13 W/m^2 (1-σ).

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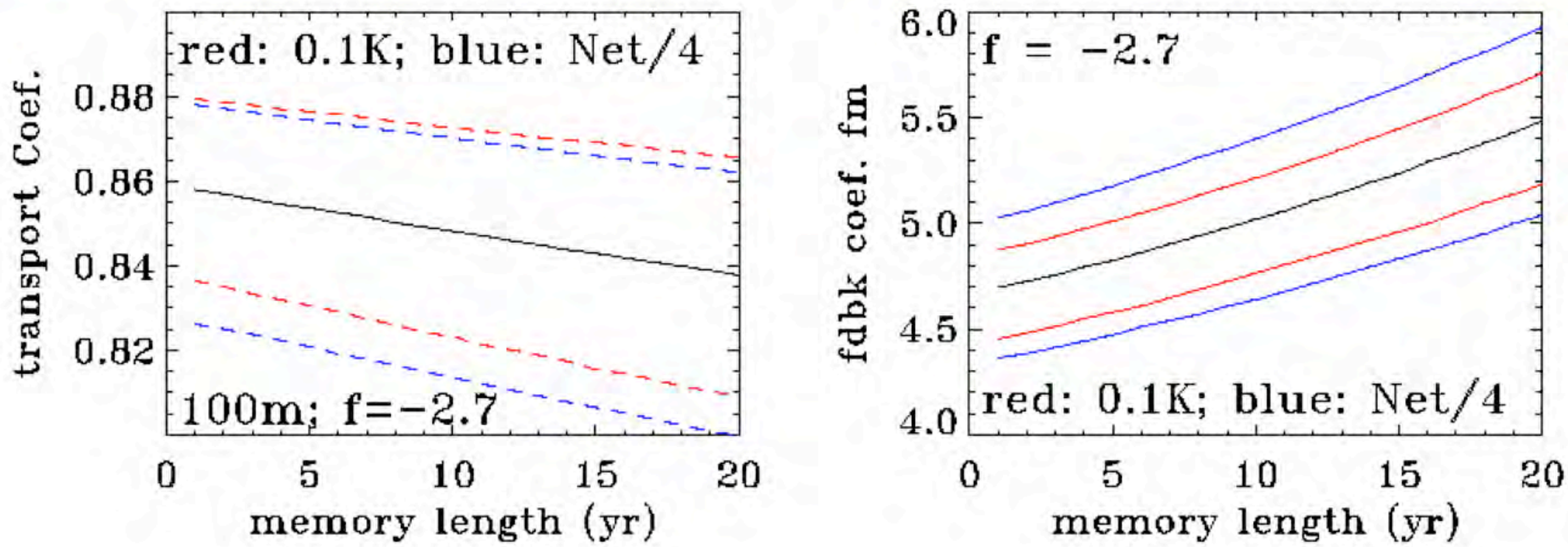

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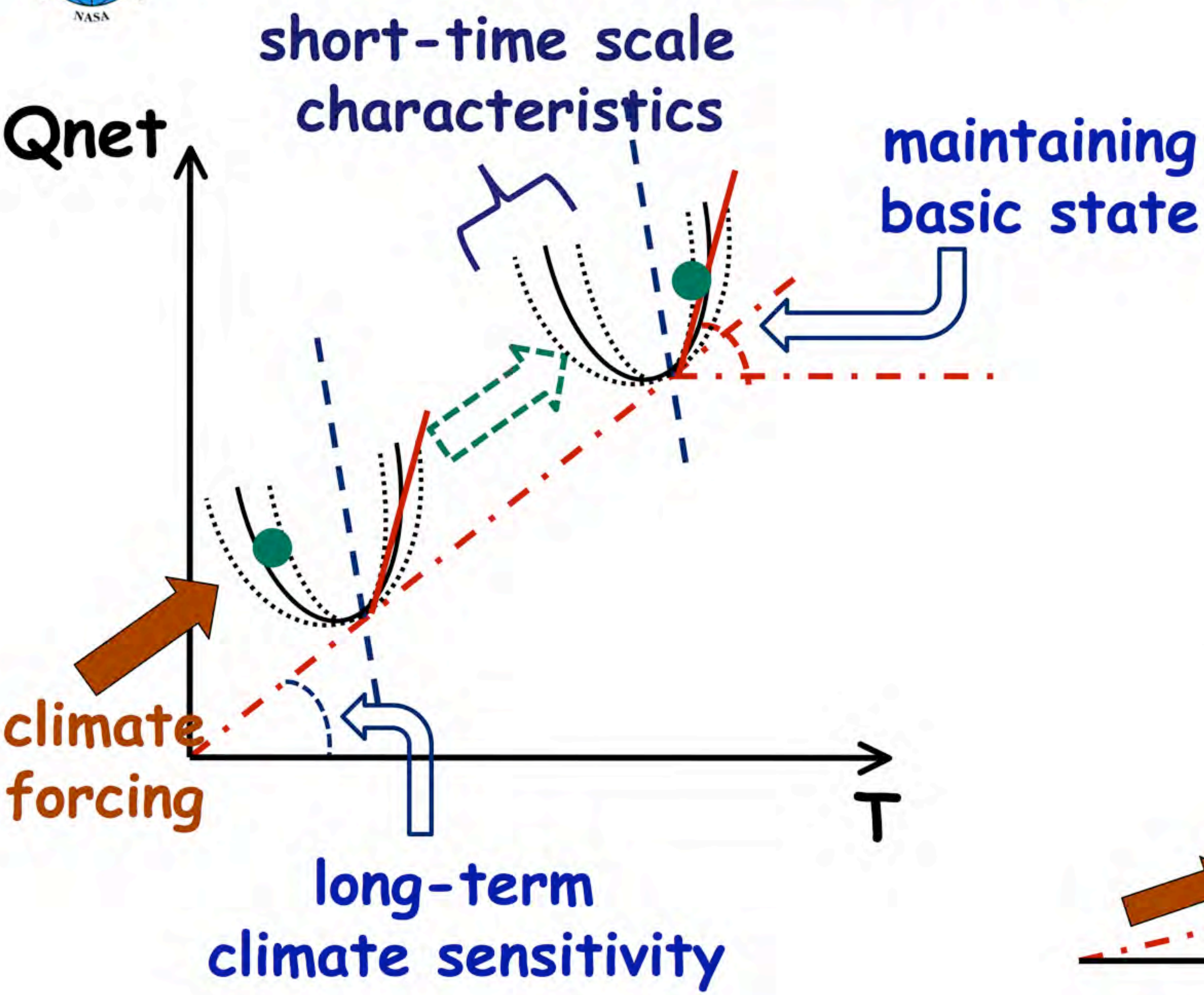
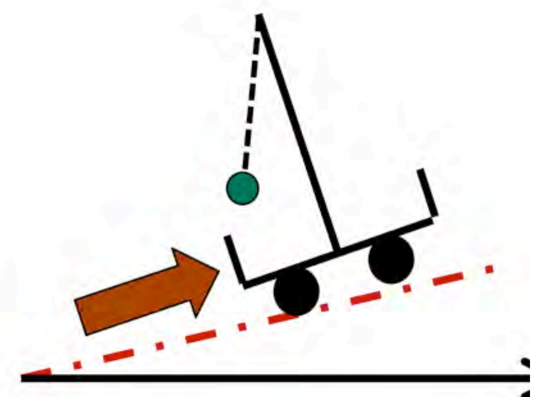
fm: 4.7 ~ 5.0 ± 0.26 (f_{tot} = 1.0 ~ 1.3 ± 0.26)

T = 2.85 ~ 3.7 K (-0.48K & +1.3K; 2×CO_2 = 3.7 W/m^2)

climate sensitivity





Summary

- Energy balance model 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.
- Targeted at boundary condition problem instead of classic initial condition solutions. Thus, it is really modeling the climate.
- Cannot use short-time scale climate system adjustment (or relaxation) to mimic climate change: different scales, different physics

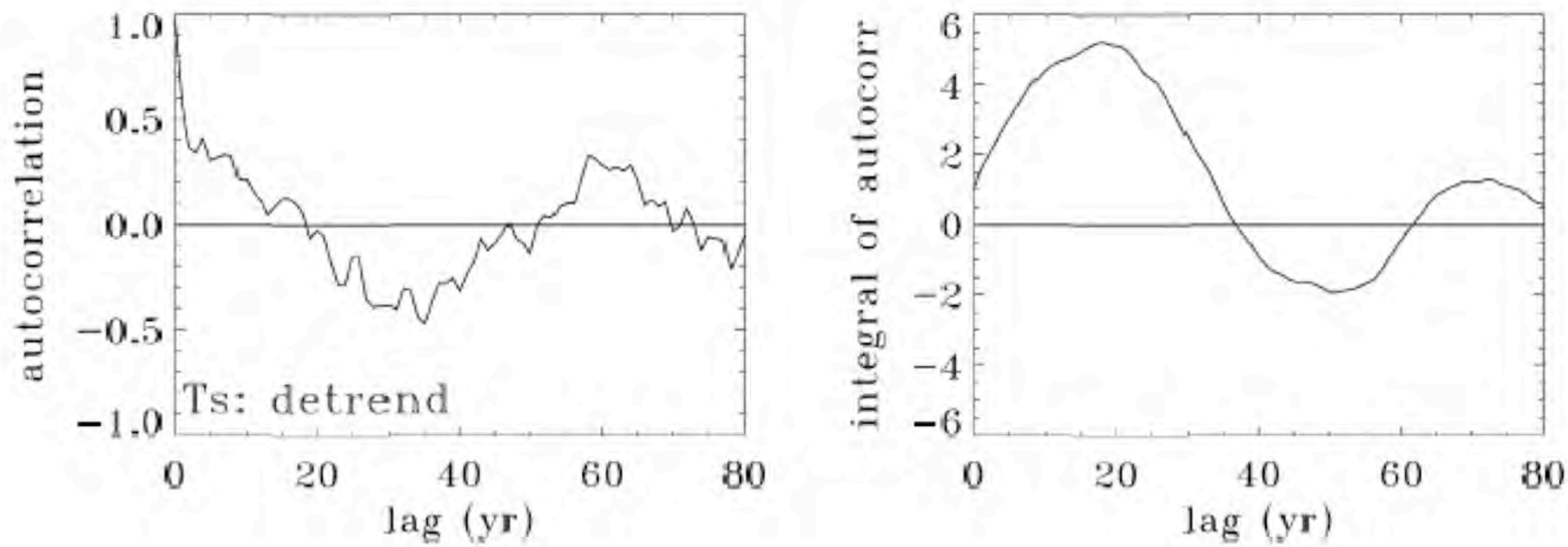
Summary

- fm about 4.7 ~ 5.0 (± 0.26), positive feedback factor 2.0 ~ 2.3. Or, equivalent 2×CO_2 (or 3.7 W/m^2) global warming 2.85 ~ 3.7 K with low & high ends 2.4 & 5.0 K, respectively.
- Time scale much longer than what Schwartz obtained and the system is not in equilibrium (or steady) state
- Key TOA Qnet = 0.85 W/m^2
- Results: sensitive to Qnet values, but not GISS T and short-time scale feedbacks.
- Strong desire for long-term radiation missions with accurate absolute calibrations, such as proposed CLARREO & CERES.

Acknowledgement

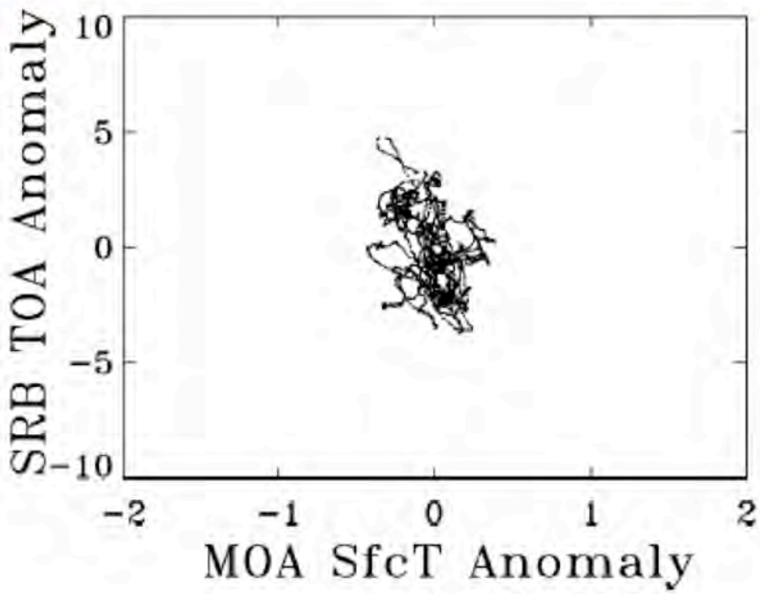
Many people, especially David Young, Gary Gibson, and Don Garber, have significant supports for this study.

Results

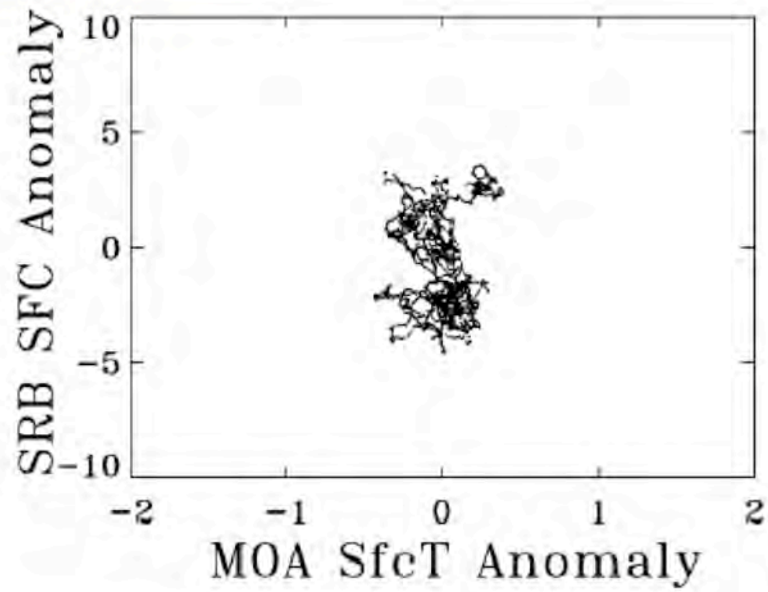


autocorrelation
1.0
0.5
0.0
−0.5
−1.0
Ts: detrend
0
20
40
60
80
lag (yr)
integral of autocorr
6
4
2
0
−2
−4
−6
0
20
40
60
80
lag (yr)

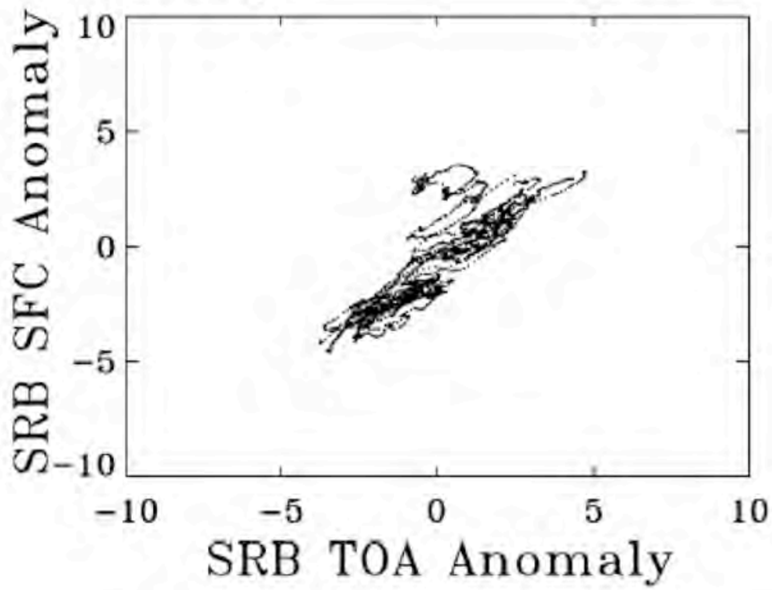
Results



SRB TOA Anomaly
10
5
0
−5
−10
−2
−1
0
1
2
MOA SfcT Anomaly

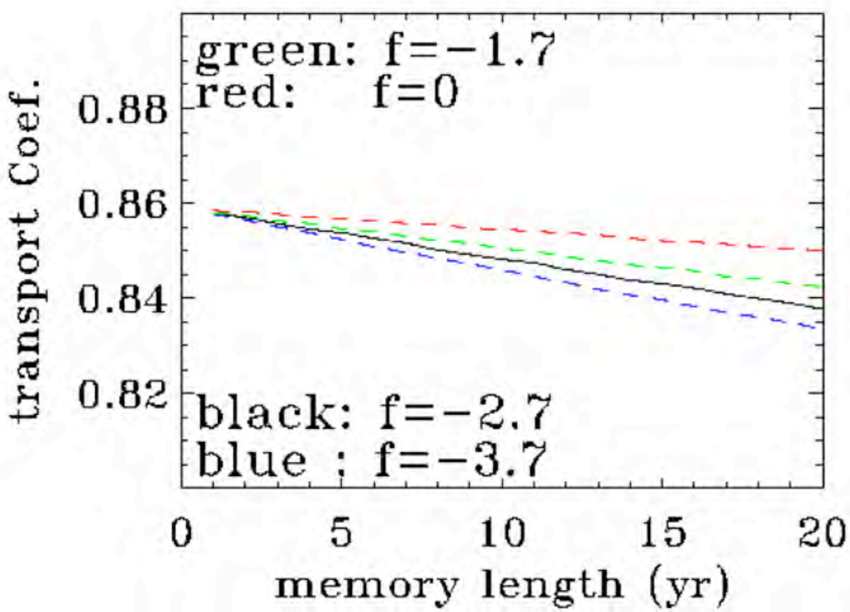


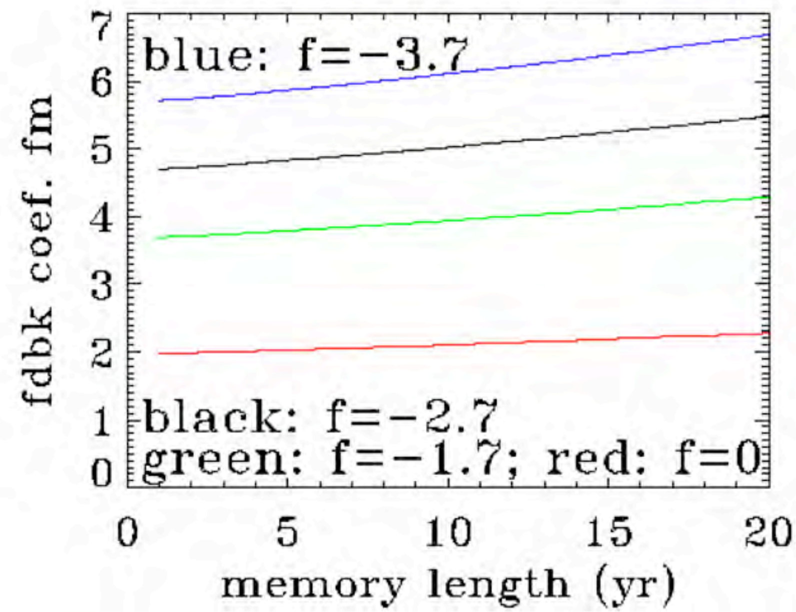
SRB SFC Anomaly
10
5
0
−5
−10
−2
−1
0
1
2
MOA SfcT Anomaly



SRB SFC Anomaly
10
5
0
−5
−10
−10
−5
0
5
10
SRB TOA Anomaly

Results: sensitivity on f





These fm values are parallel each other, i.e., total feedback coefficients are almost the same when memory length is fixed.

Thus, final results are not sensitive to short-term f values used.