Anthropogenic forcing and feedback of the Earth system

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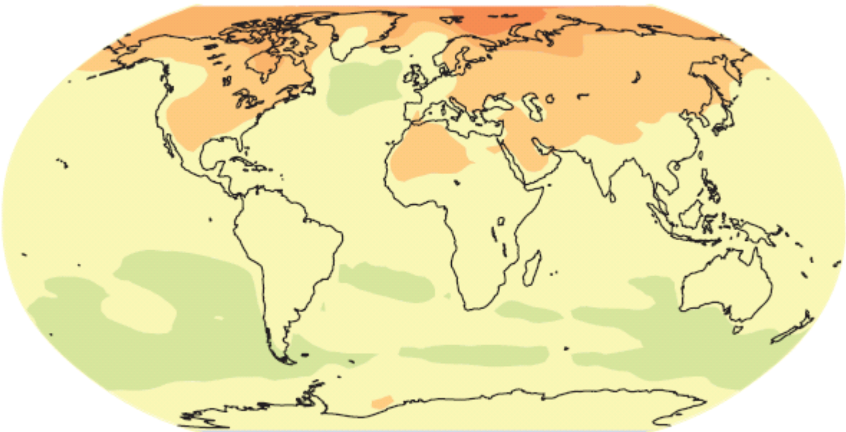
Why do we care about global average SAT change (ΔT)?

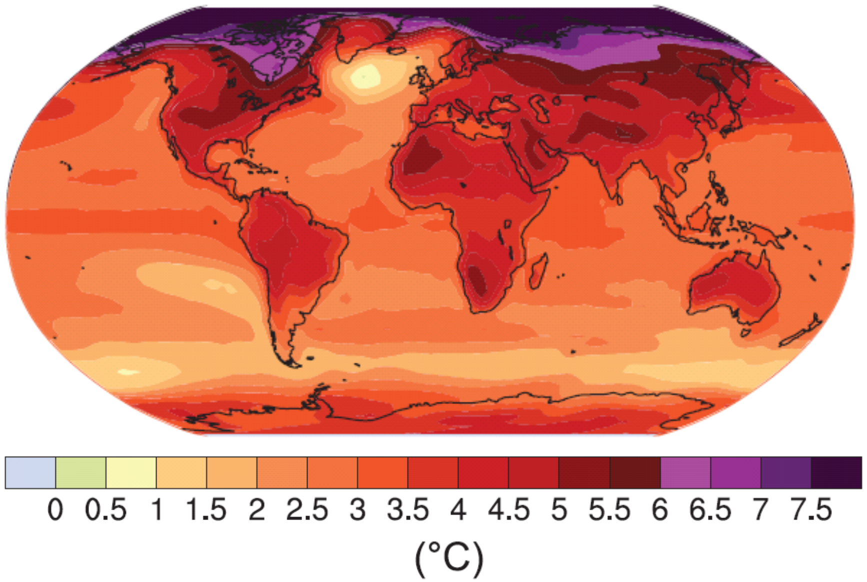
- It has the longest instrumental record, with good signal/noise.
- It is a useful indicator of the magnitude of global climate change.

Why do we care about global average SAT change (ΔT)?

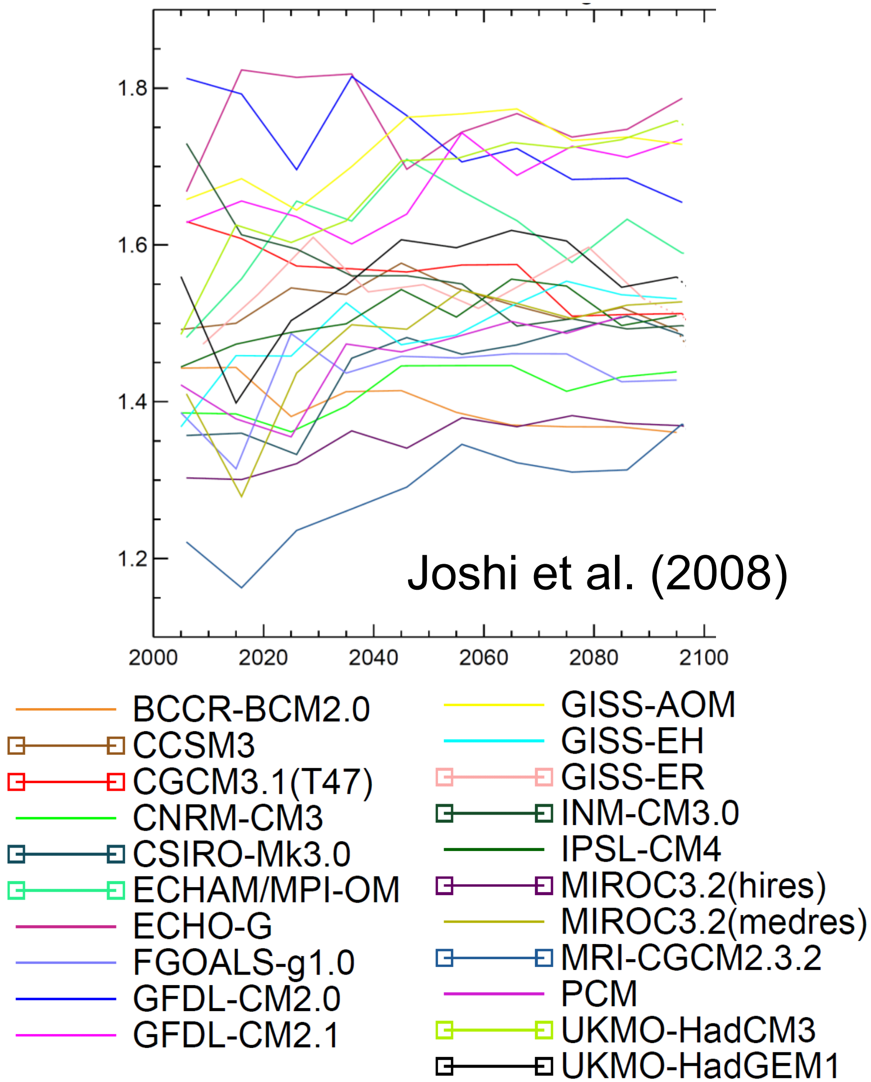
SAT change in SRES B1 2020-2029



SAT change in SRES A2 2090-2099



SAT change land/sea in SRES A1B



Climate sensitivity, forcing and feedback

Equilibrium climate sensitivity (ECS) measures the steady-state climate response for a particular forcing ($2{\times}CO_2$).

It is useful in predicting ΔT because of the separation of forcing and "feedback":

$$F = \alpha\,\Delta T \text{ or } \Delta T = F/\alpha$$

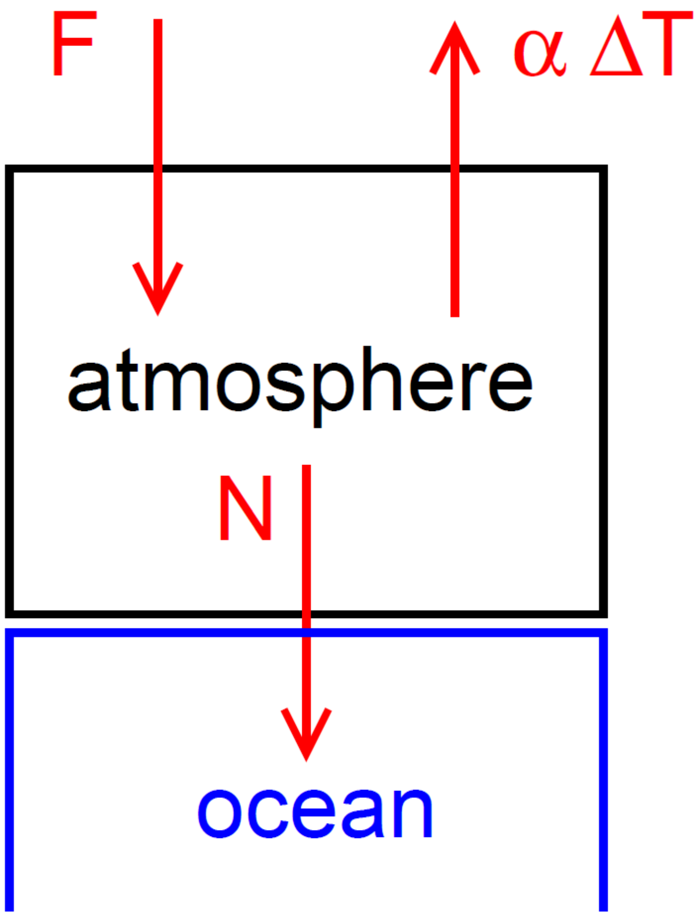
radiative forcing
F ($\mathrm{W\,m^{-2}}$)
depends on the forcing agent

climate feedback parameter
α ($\mathrm{W\,m^{-2}\,K^{-1}}$)
is a property of the climate system

How should we define forcing and feedback?

Heat budget of the global climate system

$$N = F - \alpha\,\Delta T$$



N is the net heat flux into the climate system. In the unperturbed steady state $N = F = 0$ and $\Delta T = 0$.

While the climate is changing, $N \neq 0$. In the perturbed steady state $N = 0$ and $F = \alpha\,\Delta T$.

We can define *F* as equal to *N* in the presence of the forcing agent, but in the absence of climate change, so that *N* = *F*.

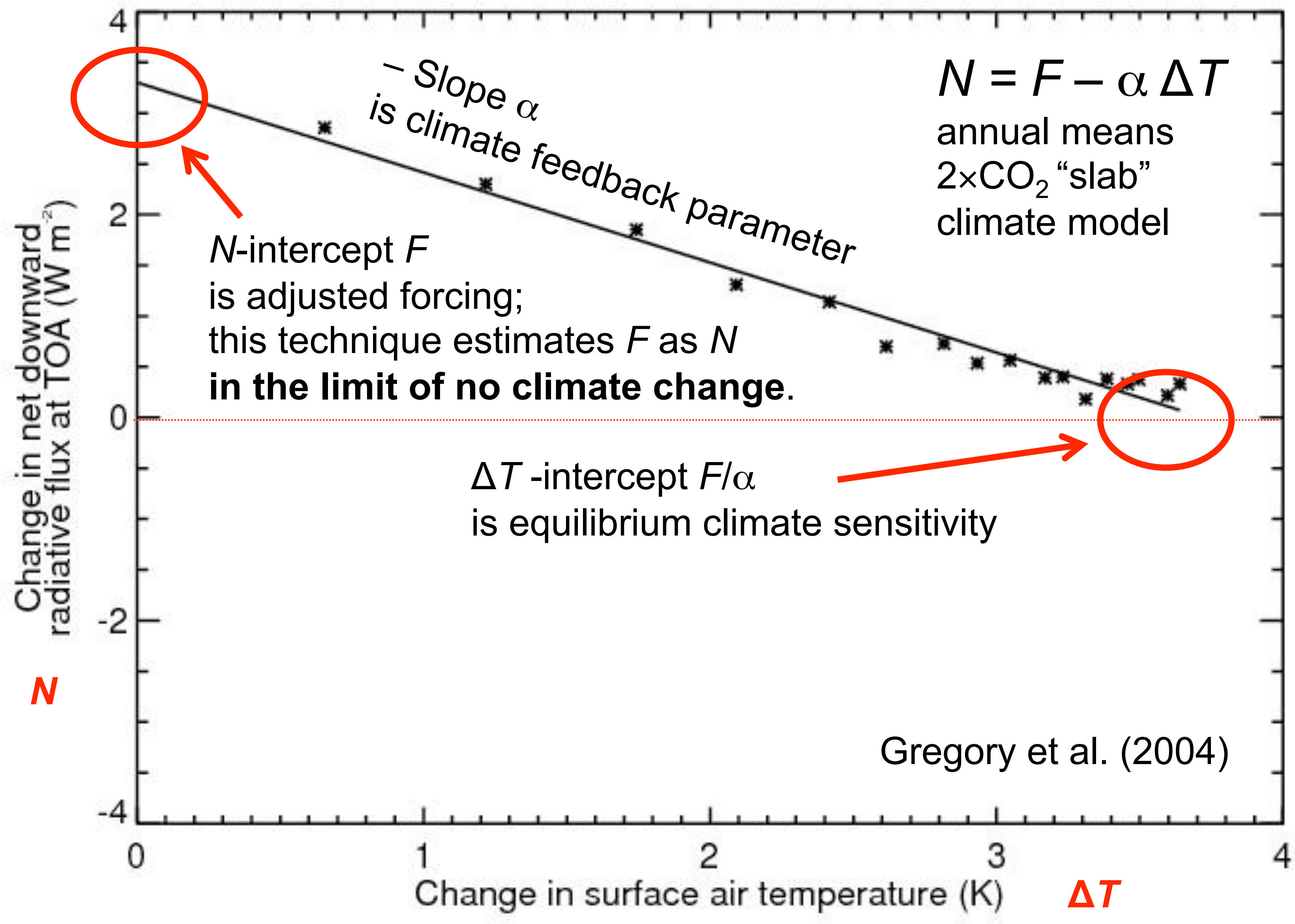
Experiments with fixed surface temperature

This technique **inhibits climate change**, so that $N = F$.

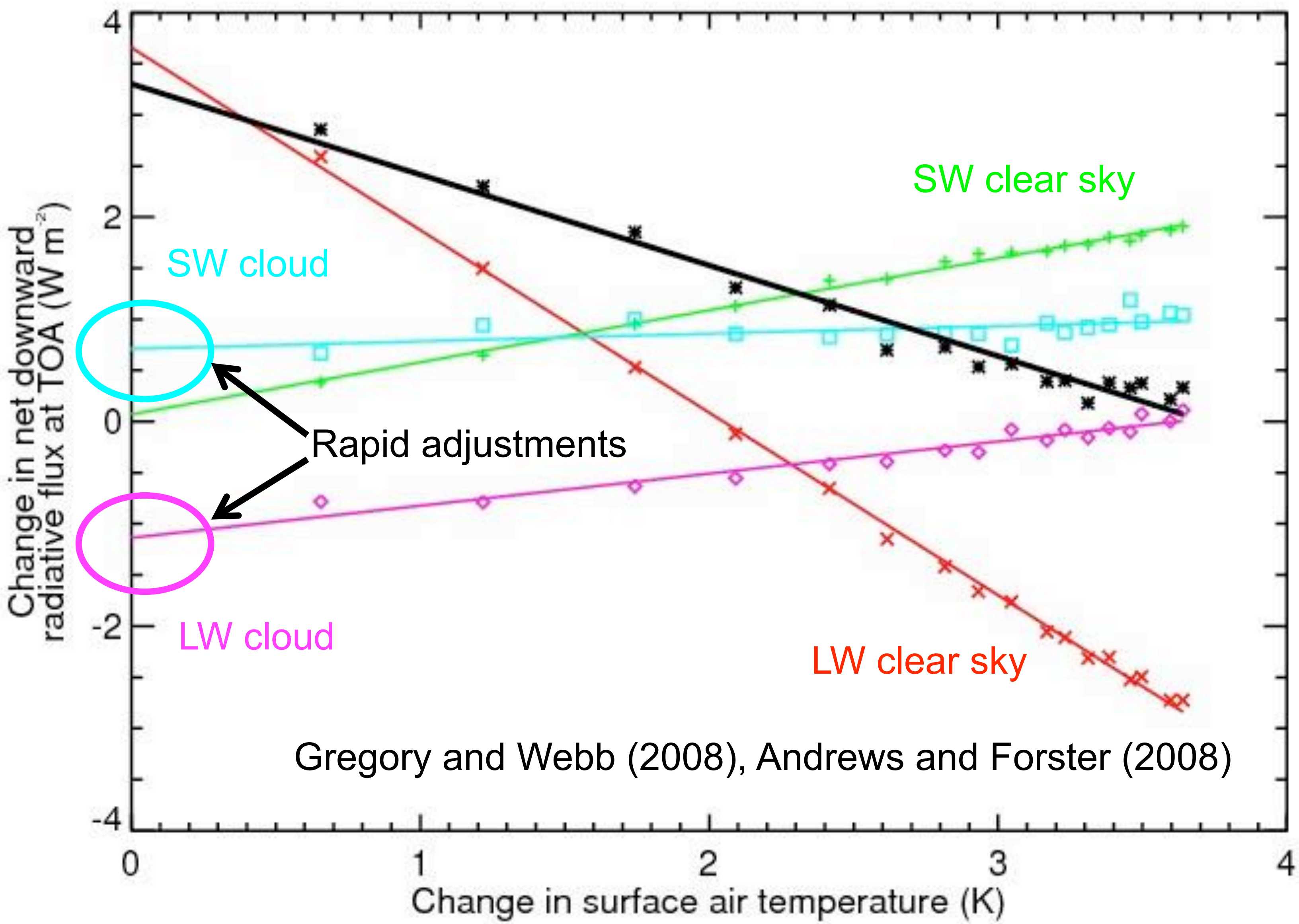
		stratosphere-adjusted		**fixed SAT**	
Forcing	ΔT	F	α	F	α
$2\times CO_2$	1.9	3.8	2.0	4.3	2.3
Aerosol ω = 1.0	–1.7	–4.6	2.7	–4.1	2.4
Aerosol ω = 0.8	2.9	1.6	0.7	6.8	2.3

Shine et al. (2003)

Experiments with fixed forcing agent

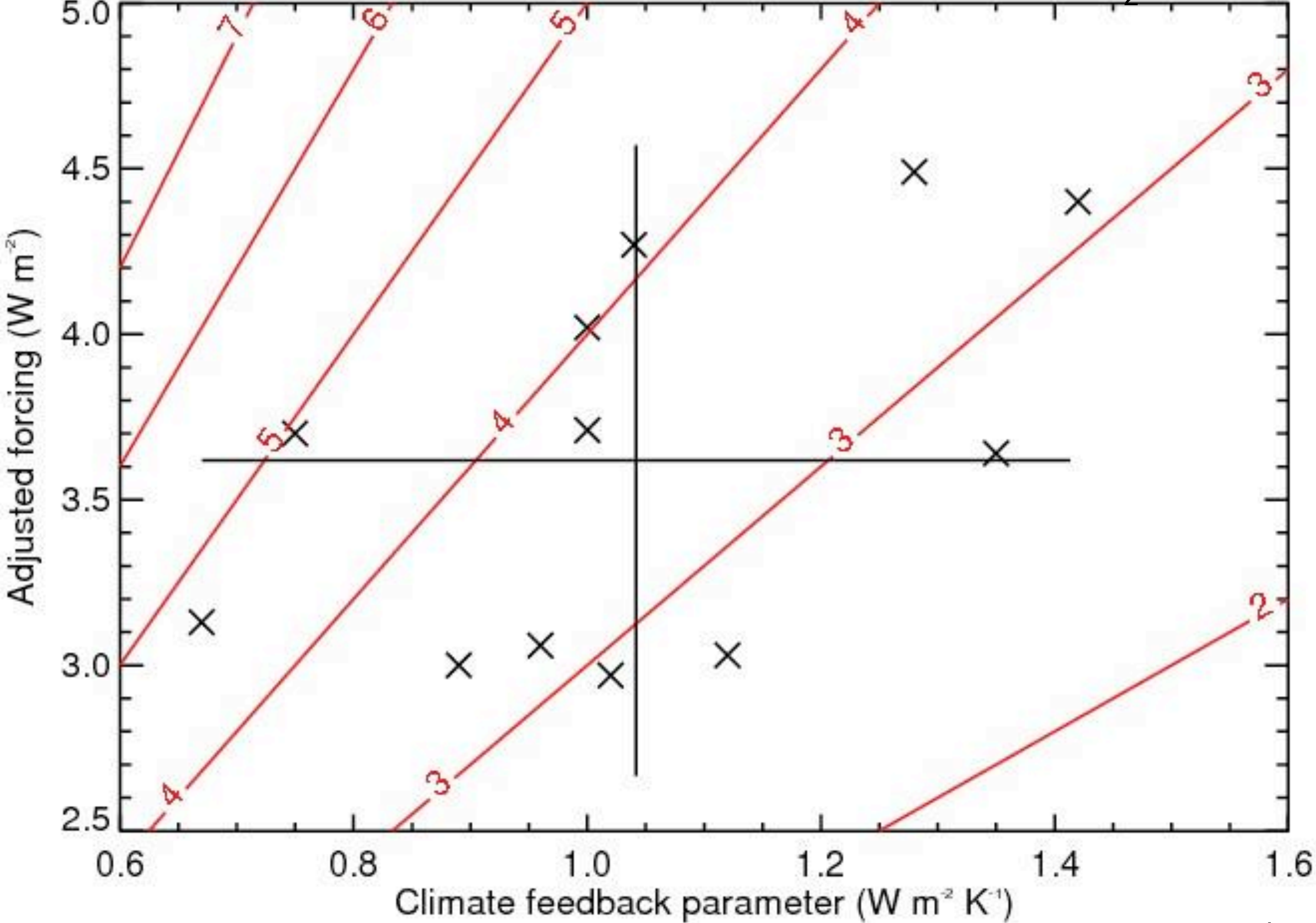


Components of forcing and feedback



Uncertainty in ECS arises from forcing as well as feedback

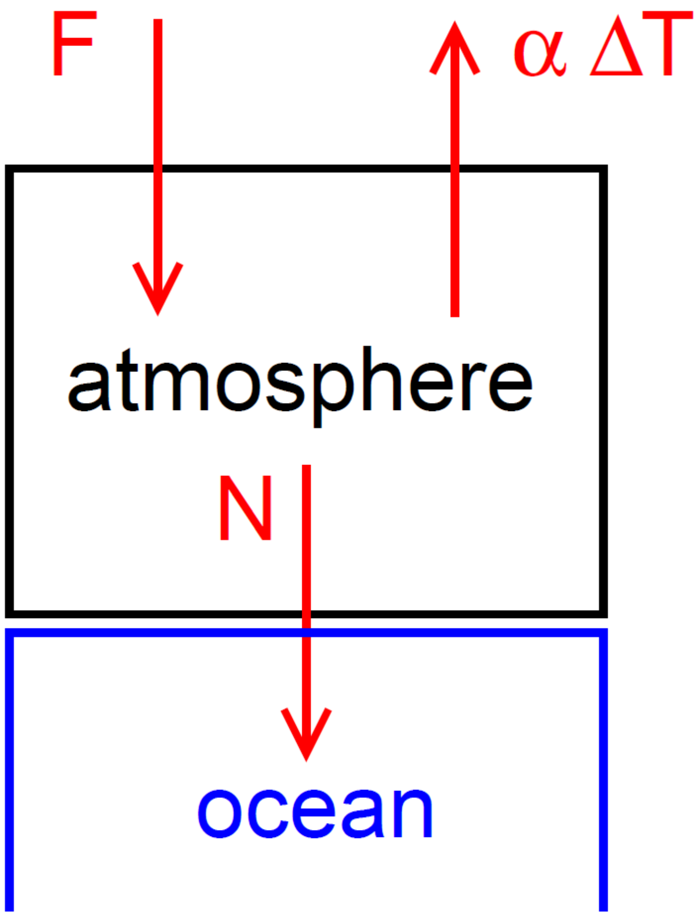
CMIP3 and CFMIP2 slab models under $2\times CO_2$



Webb et al. (in prep)

Heat budget of the global climate system

$$N = F - \alpha\, \Delta T$$

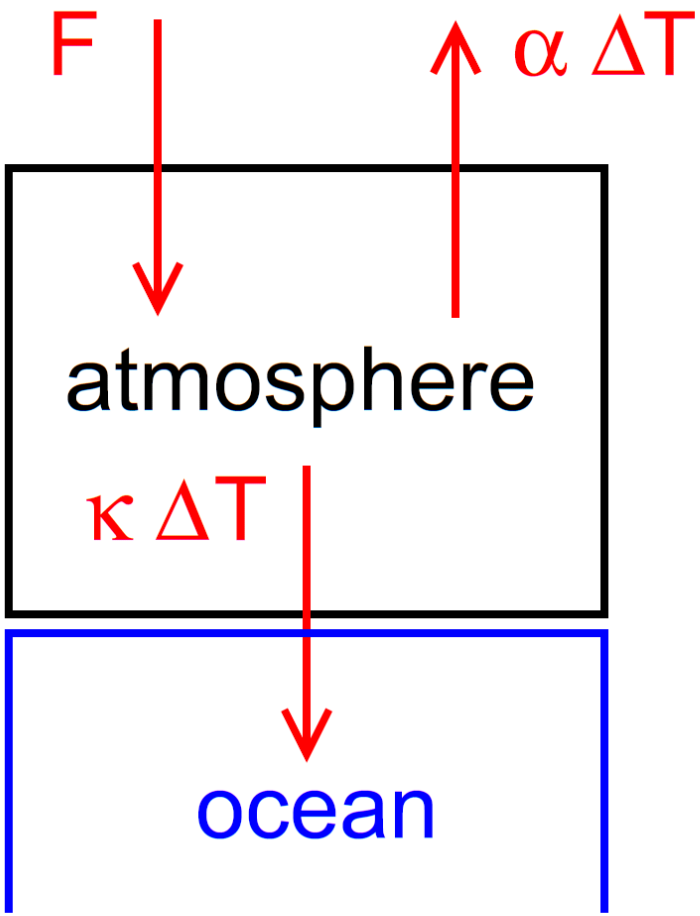


Two alternative approximate models for *N*

- $N = C\, d\Delta T/dt$
- $N = \kappa\, \Delta T$

Heat budget of the global climate system

$$\kappa\,\Delta T = F - \alpha\,\Delta T$$



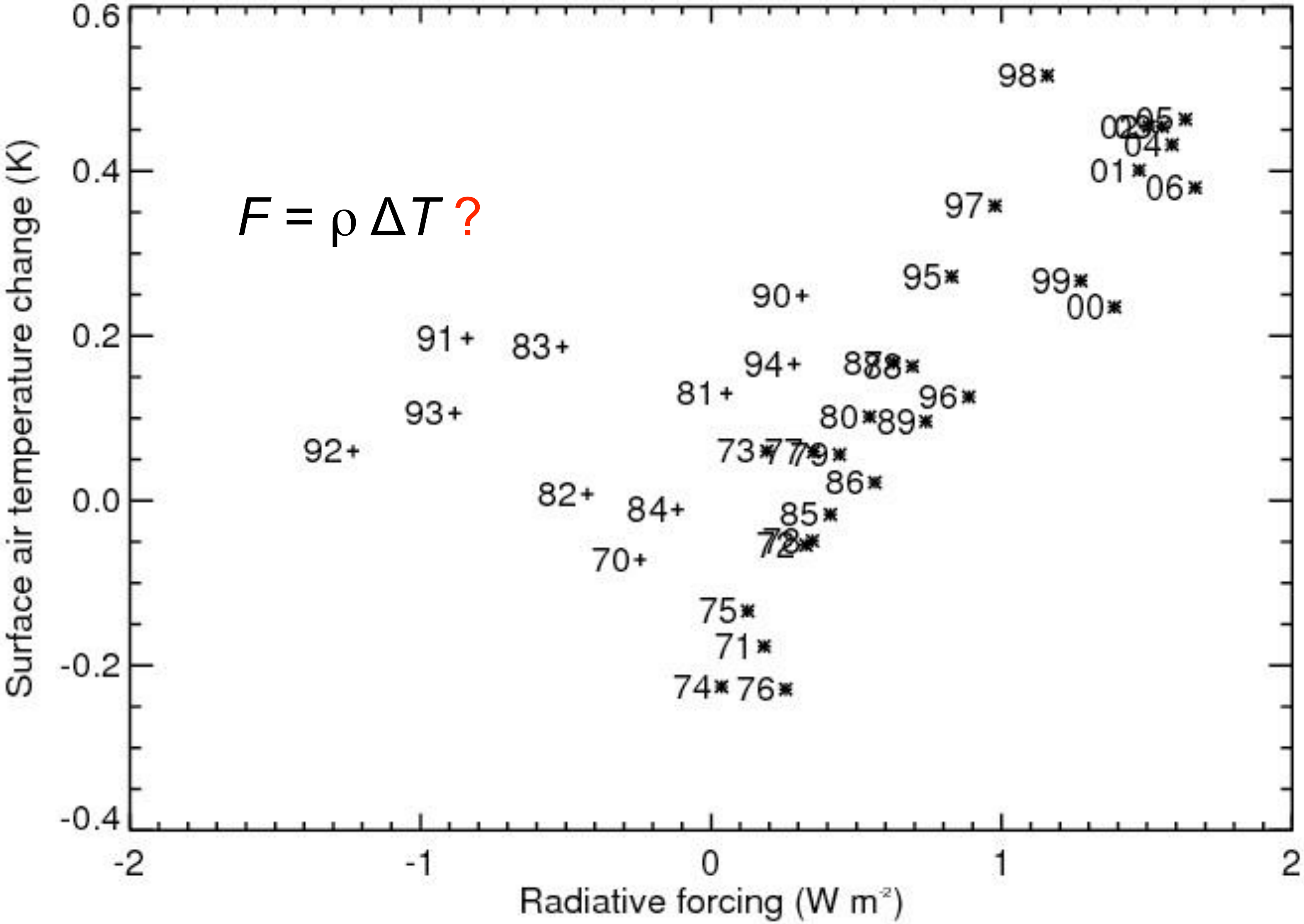
$$F = \alpha\,\Delta T + \kappa\,\Delta T = \rho\,\Delta T$$

The **ocean heat uptake efficiency** κ is formally like a climate feedback parameter.

Equilibrium climate sensitivity ECS = $F_{2\times}/\alpha$
Climate sensitivity parameter $1/\alpha$

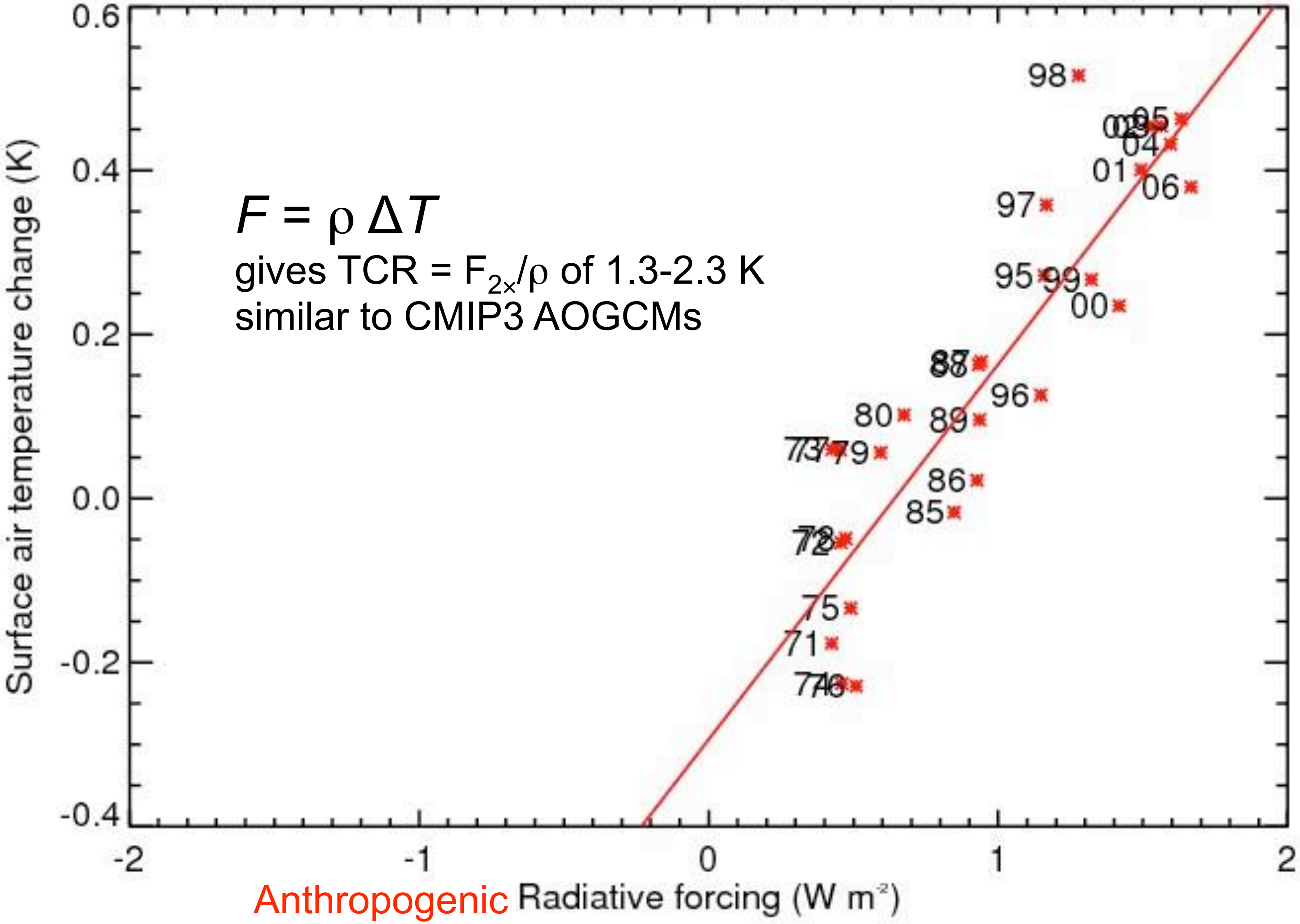
Transient climate response TCR = $F_{2\times}/\rho$
Climate resistance $\rho = \alpha + \kappa$
(Gregory and Forster, 2008)
Transient climate sensitivity TCS = $1/\rho$
(Held et al., 2010)

TCR evaluated from recent decades (1970-2006)

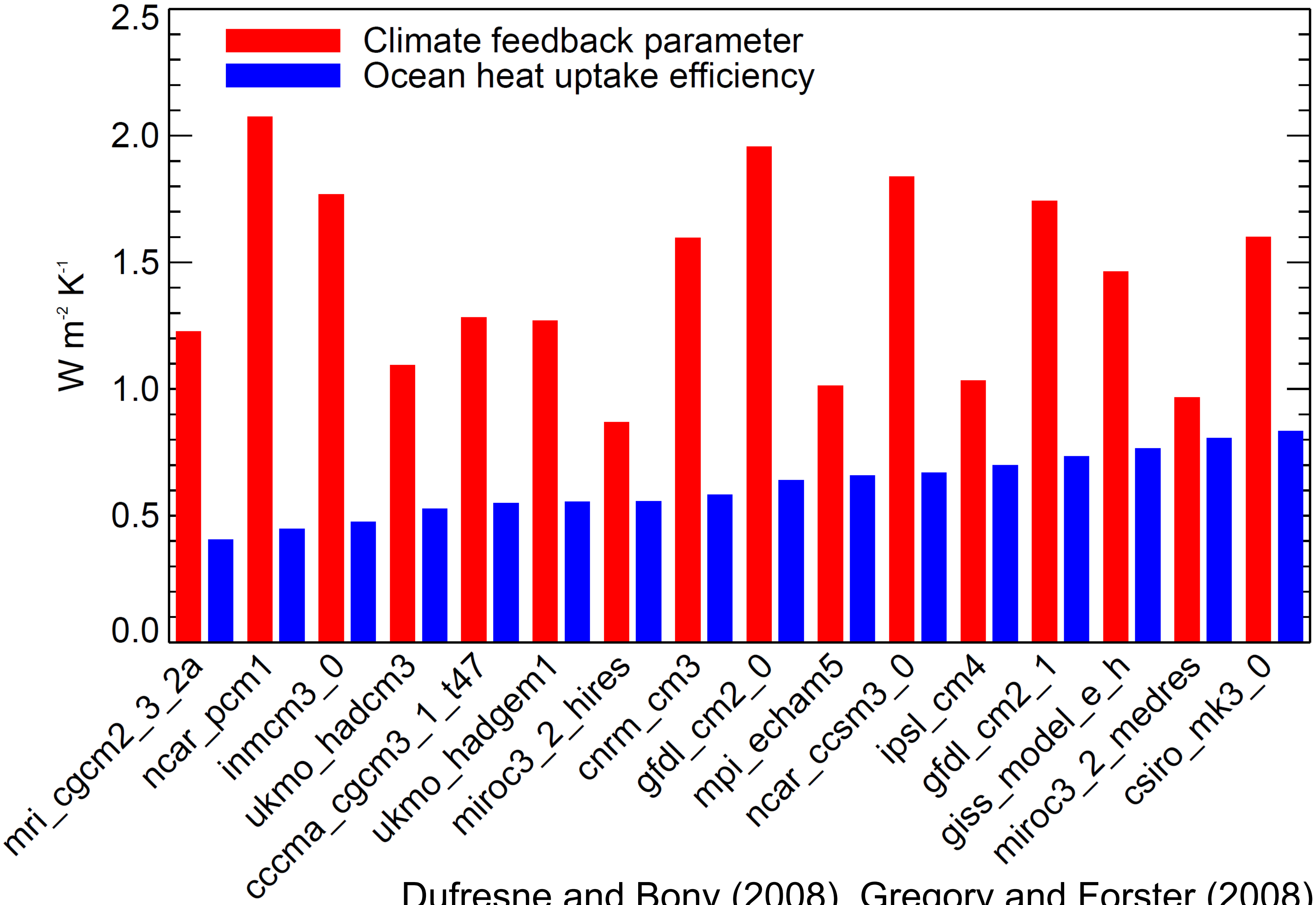


TCR evaluated from recent decades (1970-2006)

excluding years strongly affected by volcanoes

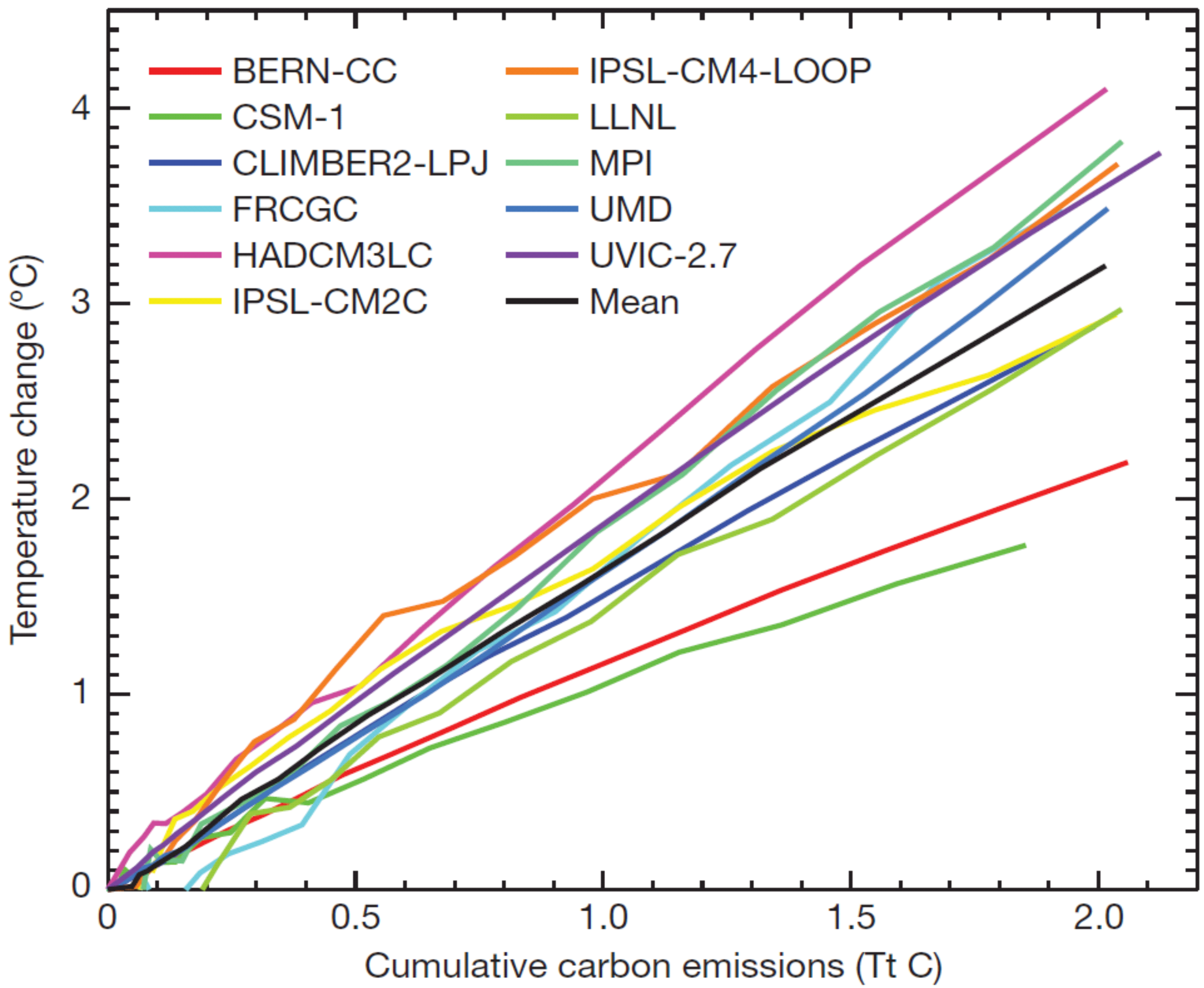


Comparing climate feedback and ocean heat uptake



Dufresne and Bony (2008), Gregory and Forster (2008)

ΔT proportional to cumulative carbon emissions C_E



C4MIP results analysed by Matthews et al. (2009)

ΔT proportional to cumulative carbon emissions C_E

$$C_E = \Delta C + \beta\,\Delta C + \gamma\,\Delta T$$

airborne GtC

concentration-carbon feedback GtC GtC^{-1}

climate-carbon feedback GtC K^{-1}

W m^{-2} GtC^{-1}

$$F = \varphi\,\Delta C \text{ and } F = \rho\,\Delta T \Rightarrow \varphi\,\Delta C = \rho\,\Delta T$$

Transient climate sensitivity to emissions (TCSE, K GtC^{-1}, carbon-climate response of Matthews et al.) is

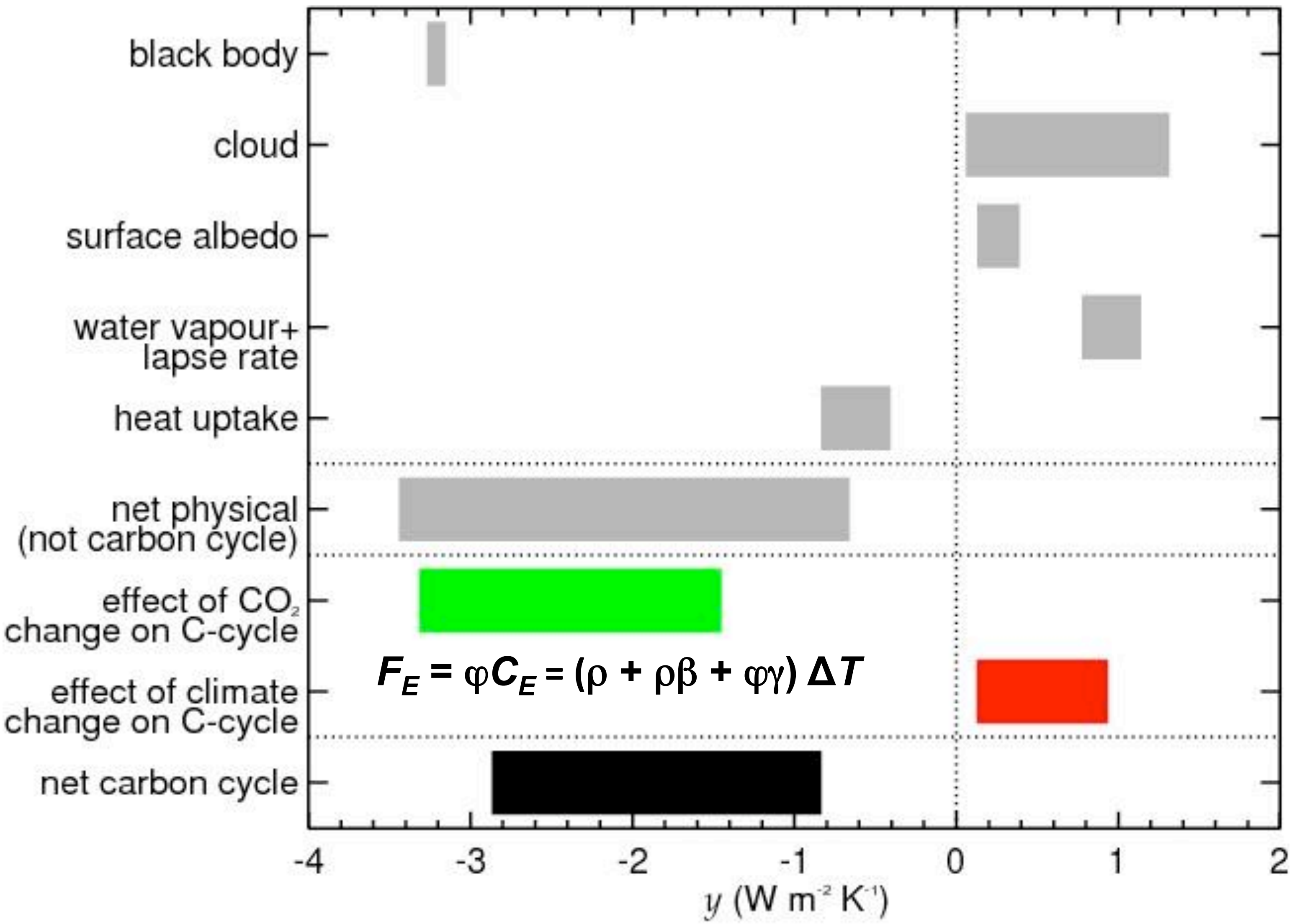
$$\mathrm{TCSE} = \varphi \times A \times \mathrm{TCS}$$

airborne fraction $\Delta C/C_E$

transient climate sensitivity $1/\rho$

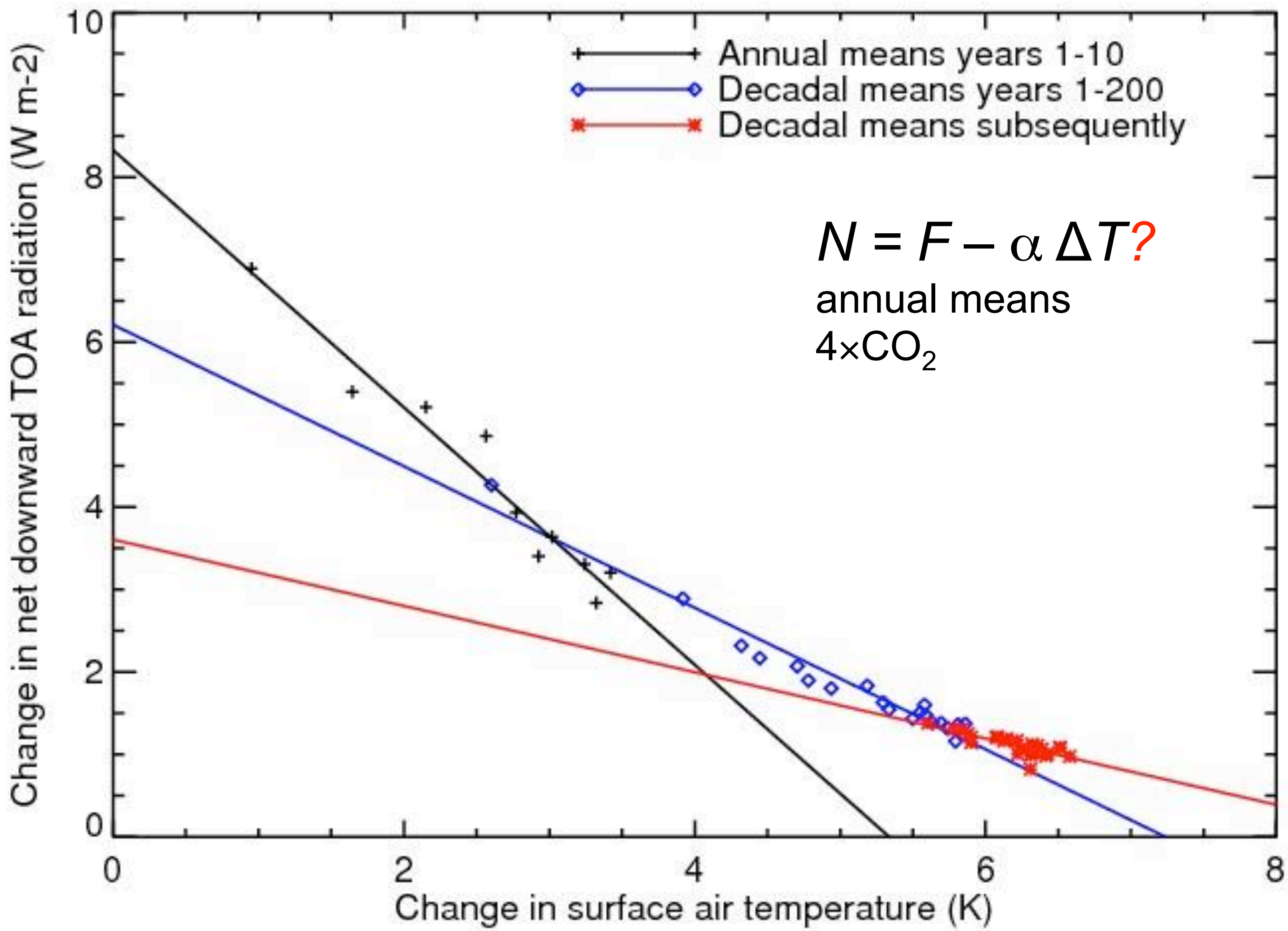
Gregory et al. (2009)

Physical and carbon-cycle feedbacks in radiative terms



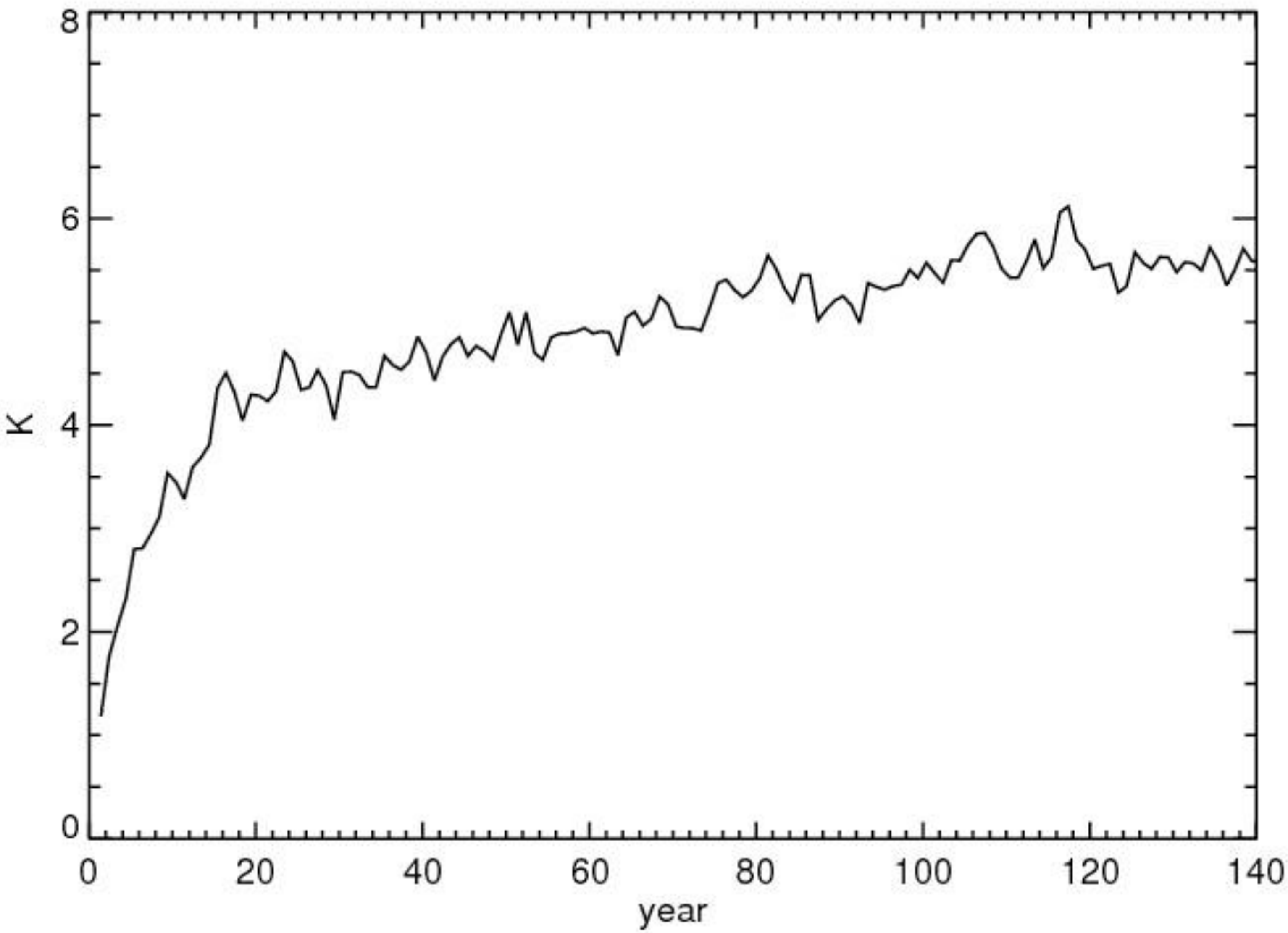
Gregory et al. (2009)

Non-linearity shown by AOGCMs under fixed forcing

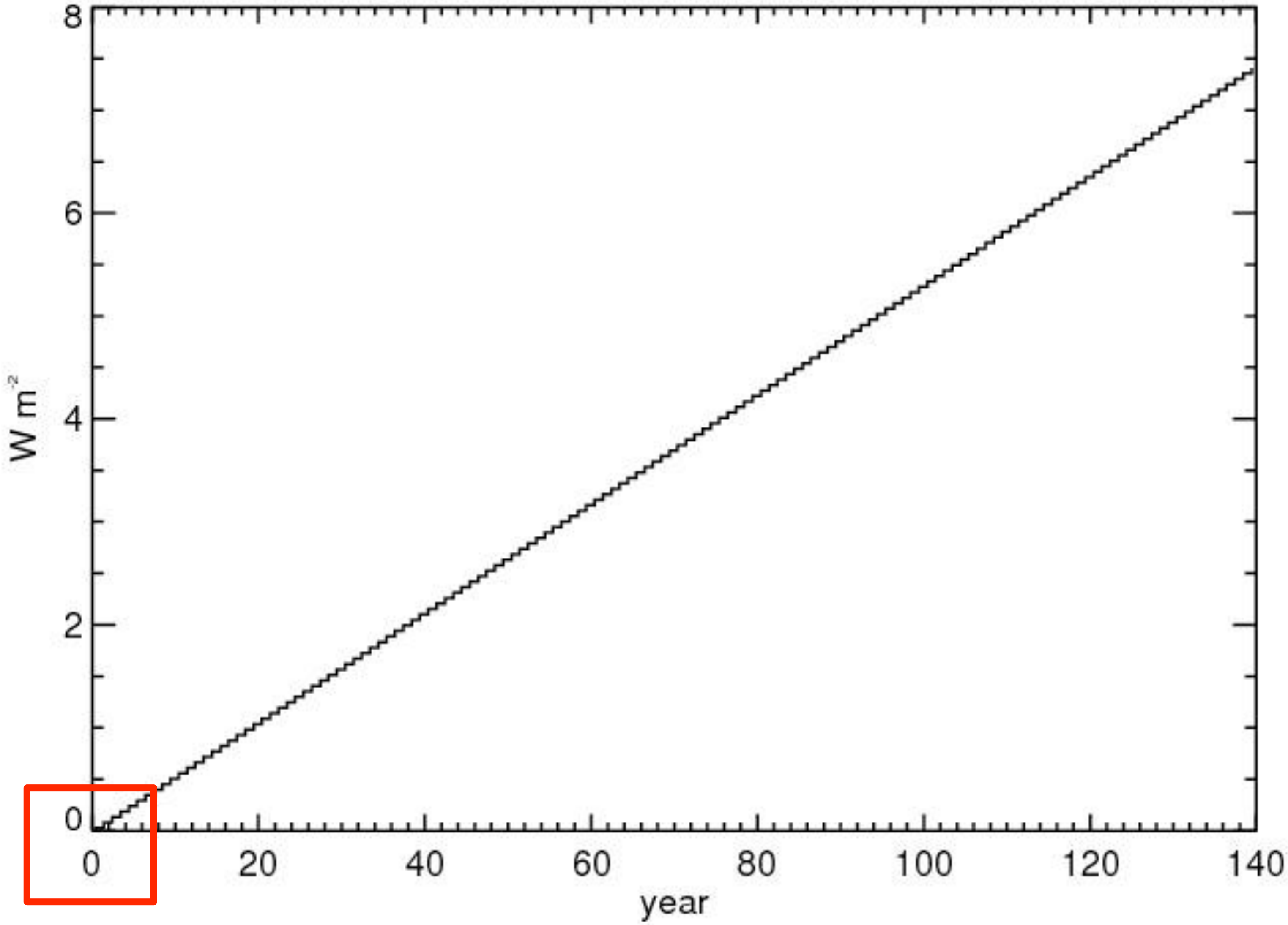


Gregory et al. (2004), Williams et al. (2008)

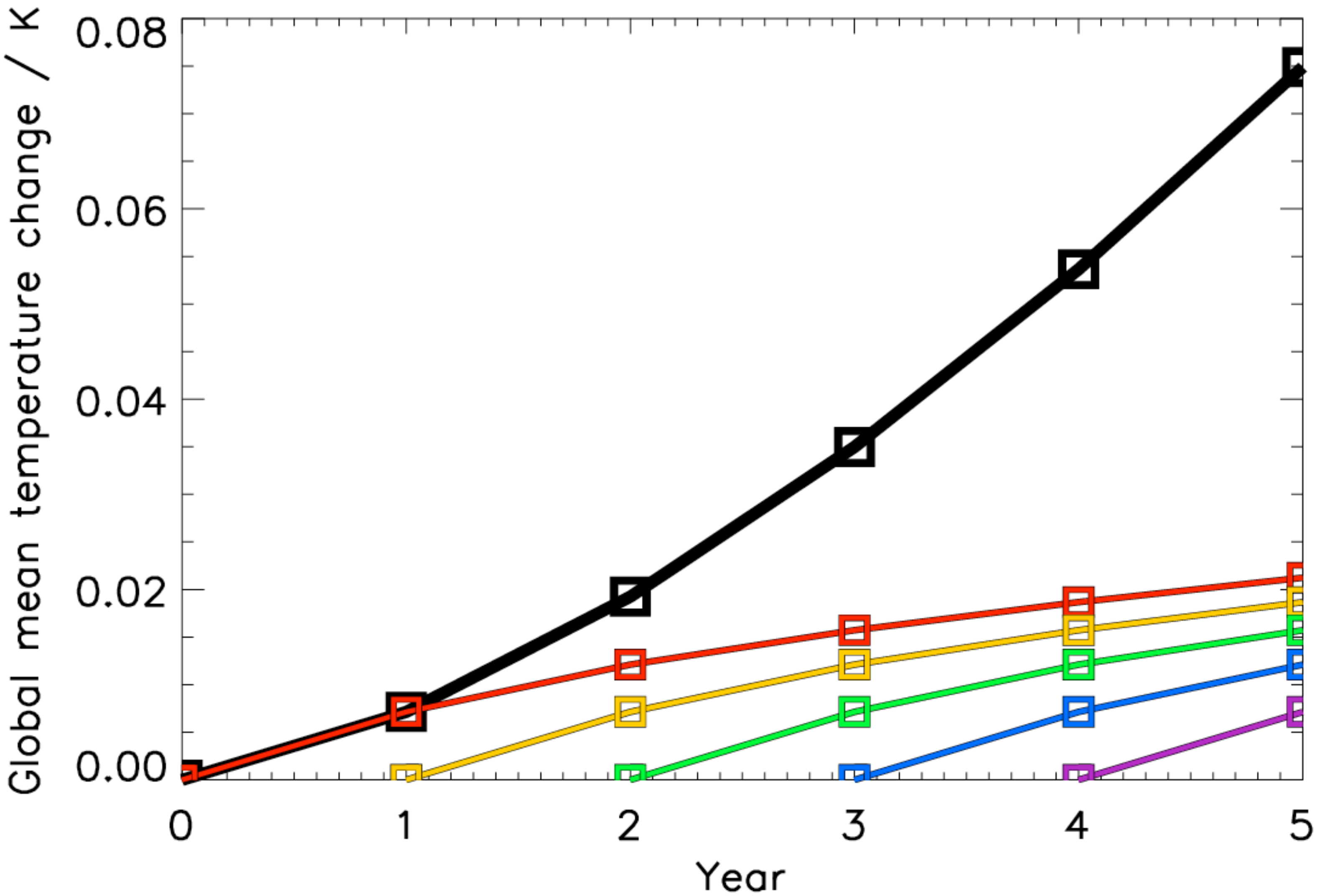
$\Delta T(t)$ in response to fixed forcing ($4\times CO_2$)



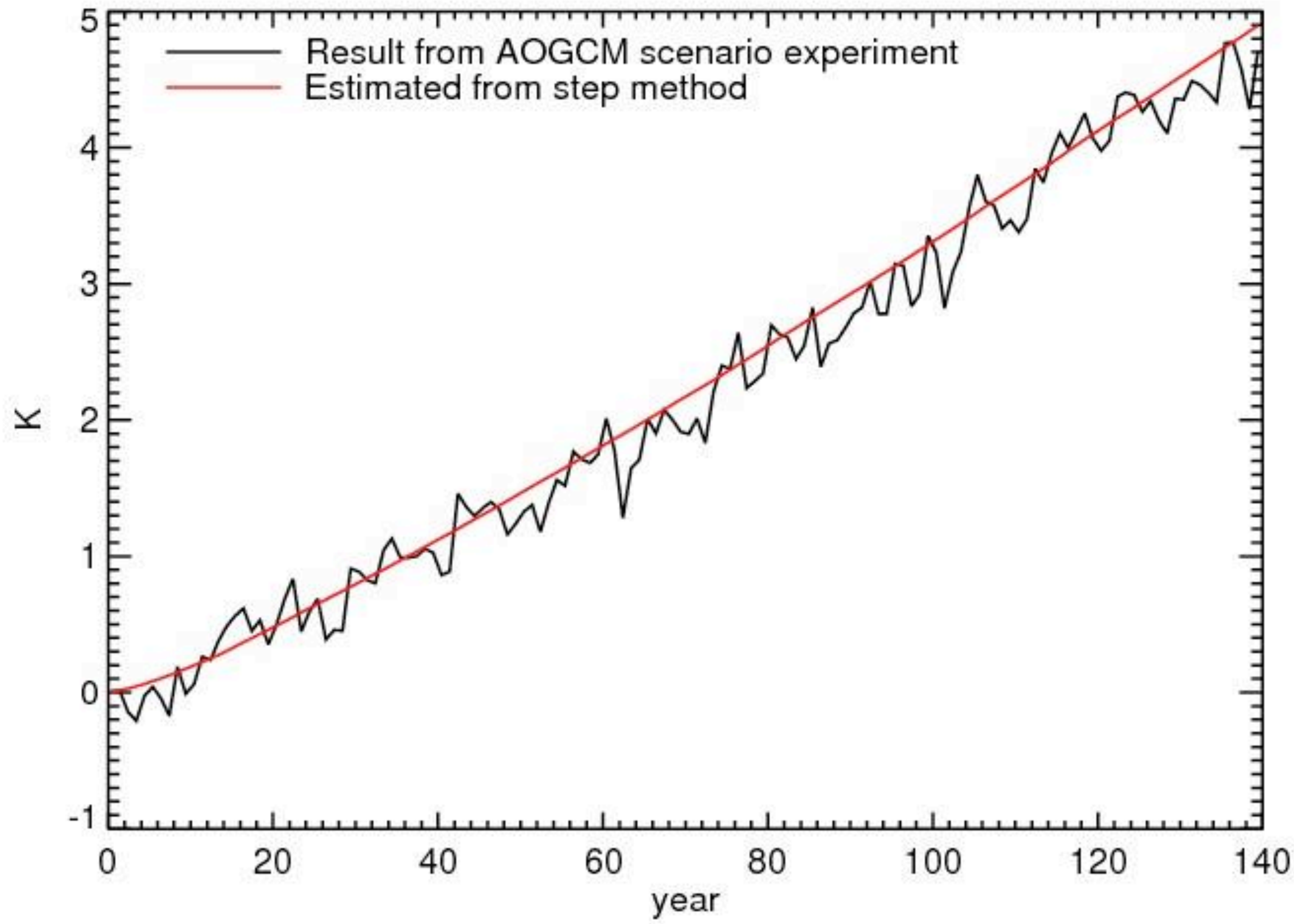
Regard $F(t)$ (e.g. 1% CO_2) as a succession of annual steps



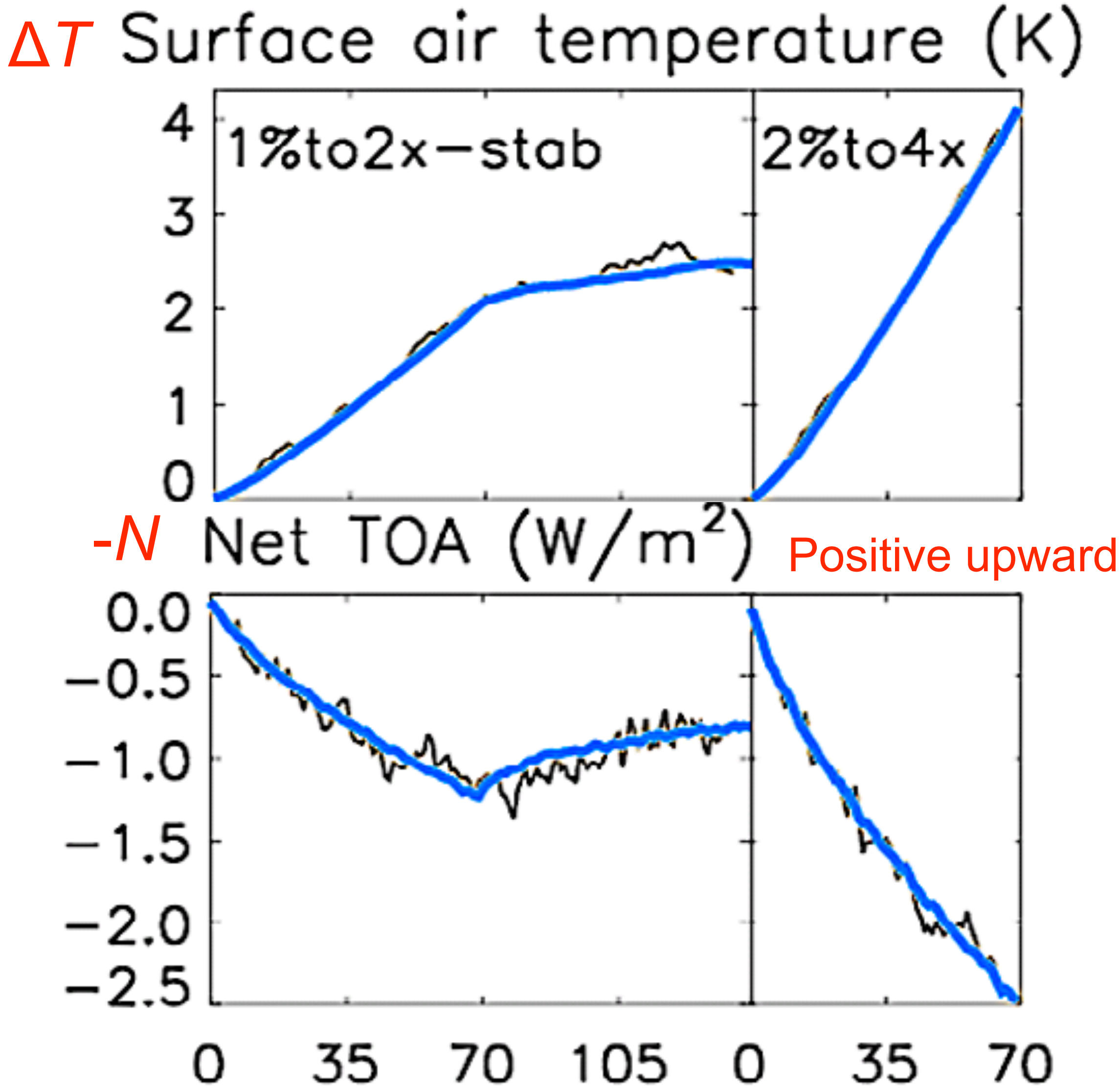
Calculate the responses $\Delta T(t)$ to the individual steps



Add them up to get $\Delta T(t)$ for $F(t)$



Examples for other scenarios and quantities



Good et al. (2011)

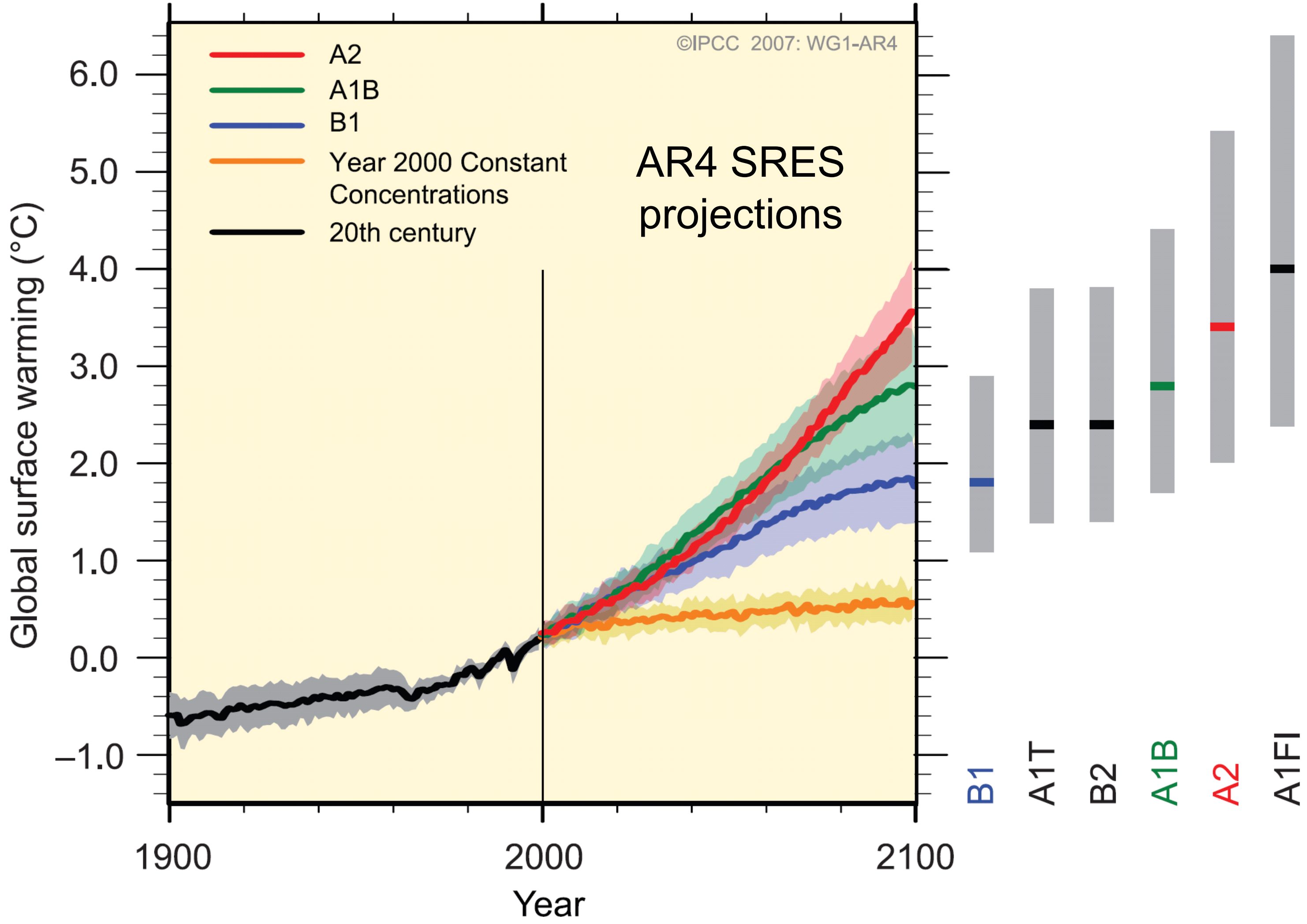
Summary

ΔT is useful as an indicator of the magnitude of global climate change.
A framework of metrics has been developed to account for ΔT.

	ΔT metric	**Forcing and feedback**	**Linear with many timescales**	**Non-linear**
Fixed CO_2	ECS	Adjusted F, α	Time-dependent response	
Time-dependent forcing	TCR/TCS	κ	Combination of responses to steps	
CO_2 emissions	TCSE	C_E, β, γ, etc.		
Other emissions and forcings		Arneth et al., Raes et al.		

Our practical interest is in regional change in many quantities.

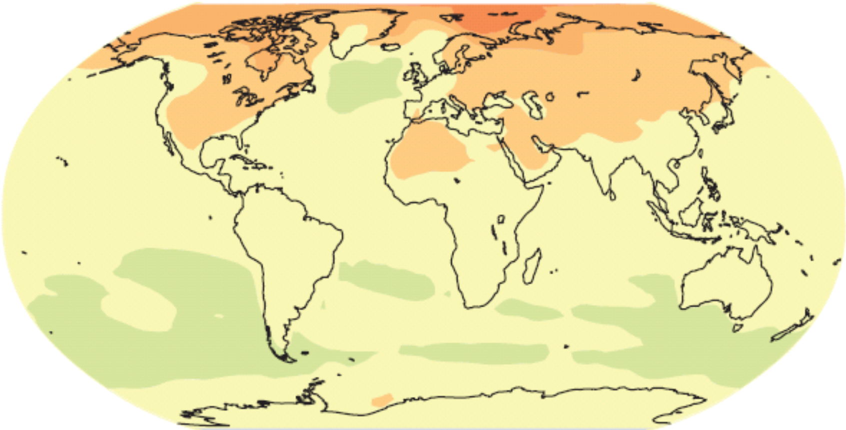
Global average surface air temperature change ΔT



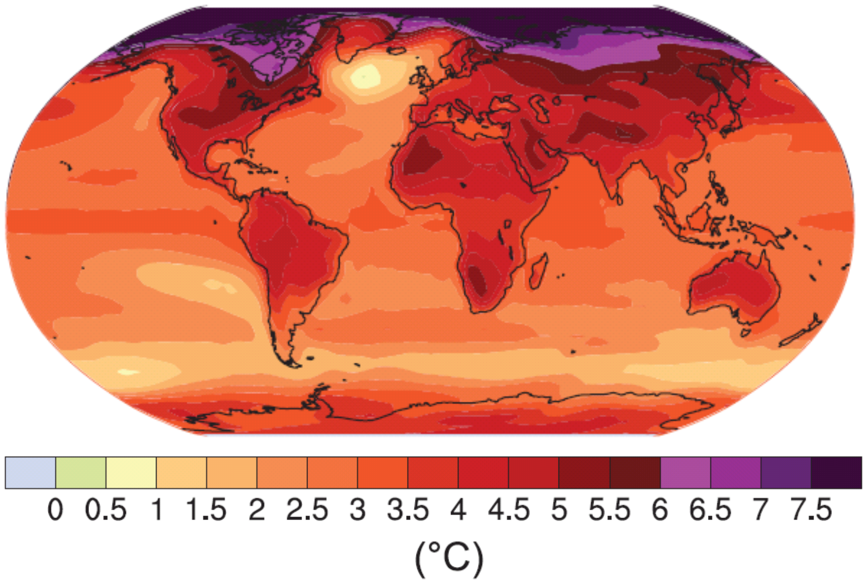
Why do we care about this quantity?

Why do we care about global average SAT change (ΔT)?

SAT change in SRES B1 2020-2029



SAT change in SRES A2 2090-2099



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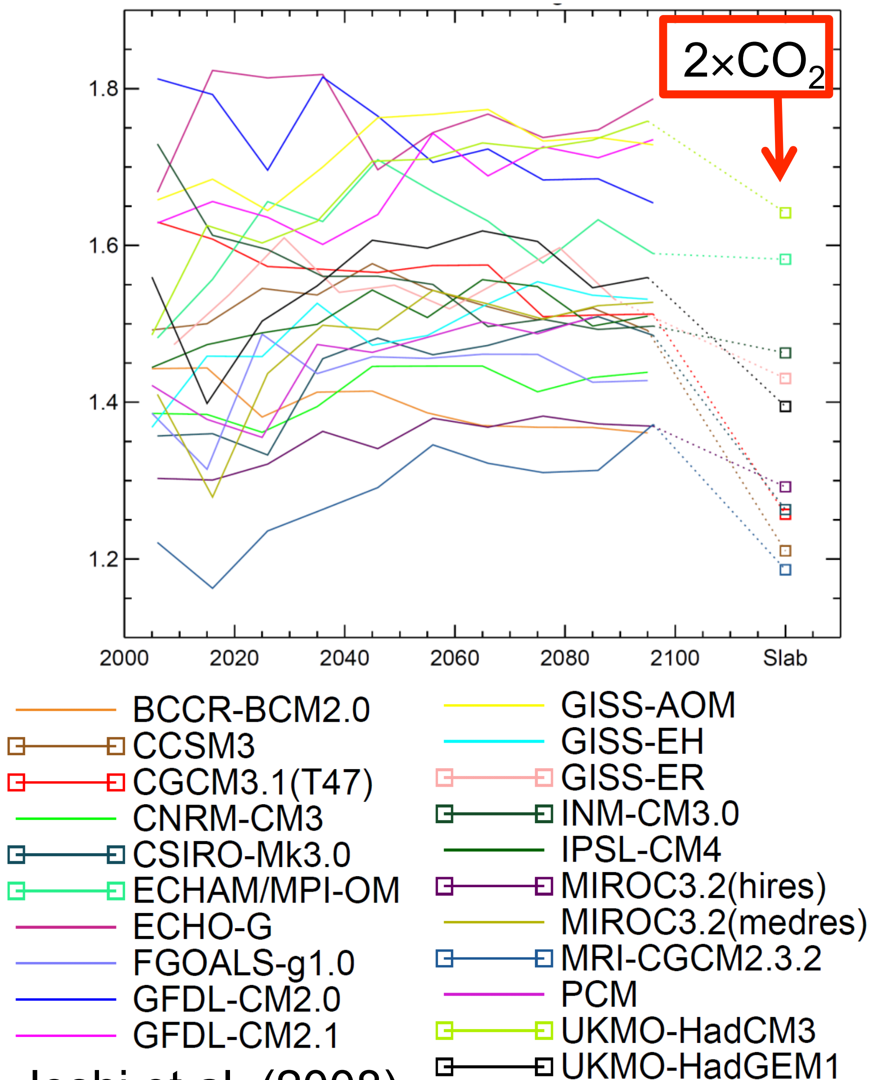
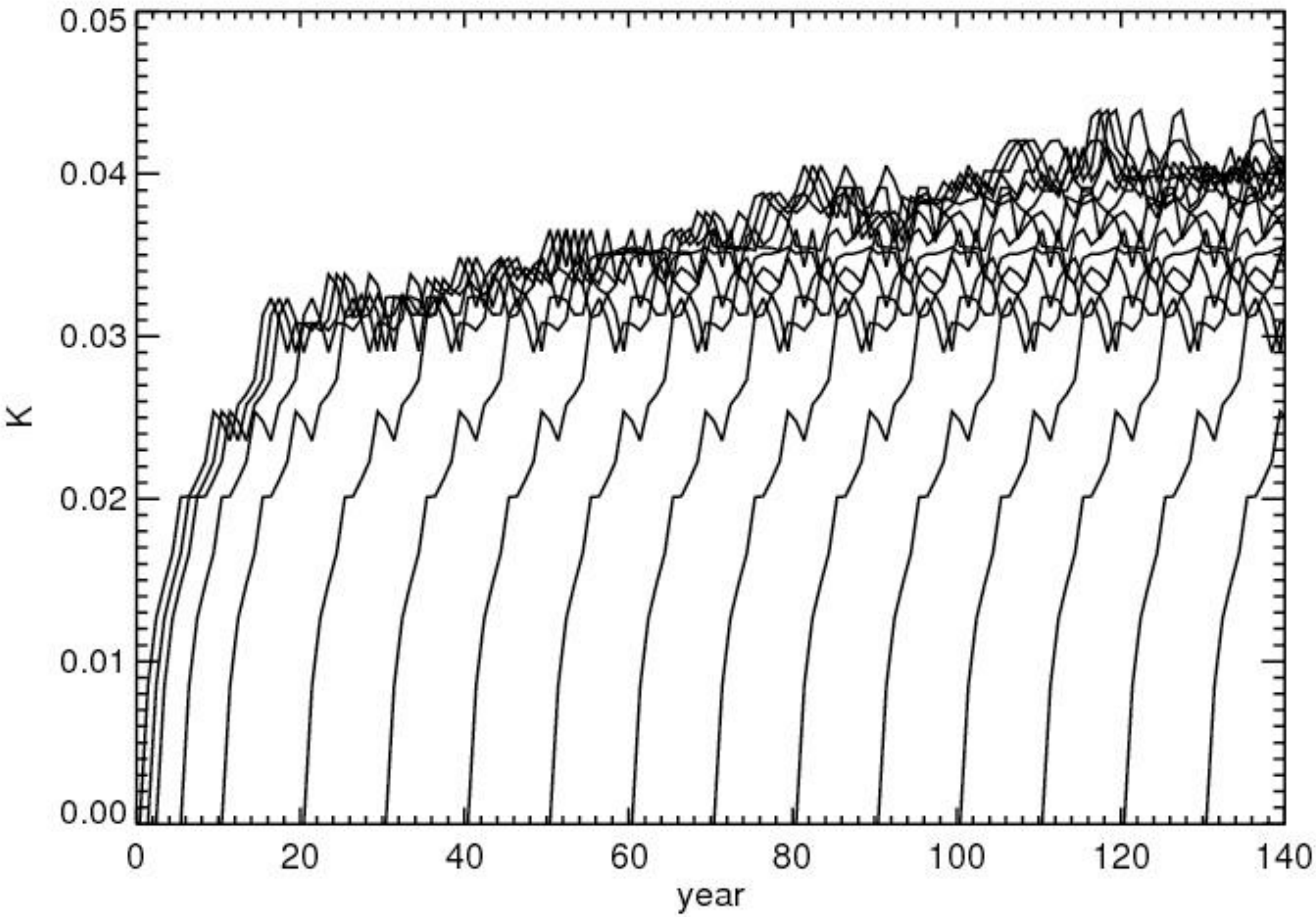
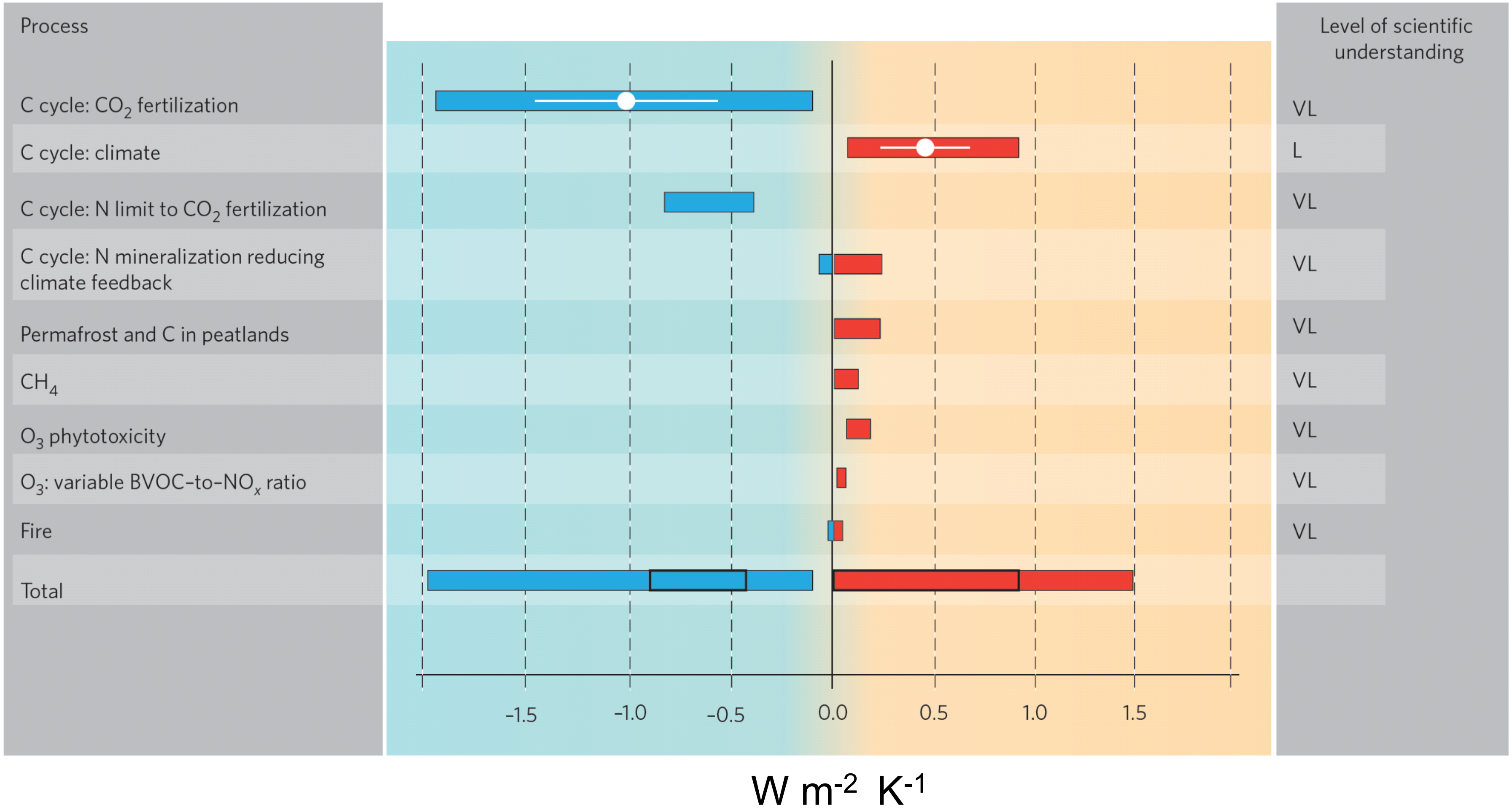


Joshi et al. (2008)

Calculate the responses $\Delta T(t)$ to the individual steps



Terrestrial feedbacks in radiative terms



Arneth et al. (2010)