The inconstancy of transient climate response

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Results mostly from Gregory, Andrews and Good (2015)
and Gregory and Andrews (2016)

Climate sensitivity, forcing and feedback

Equilibrium climate sensitivity applies to a particular forcing ($2\times CO_2$).

It is more generally useful because of the separation of forcing and feedback:

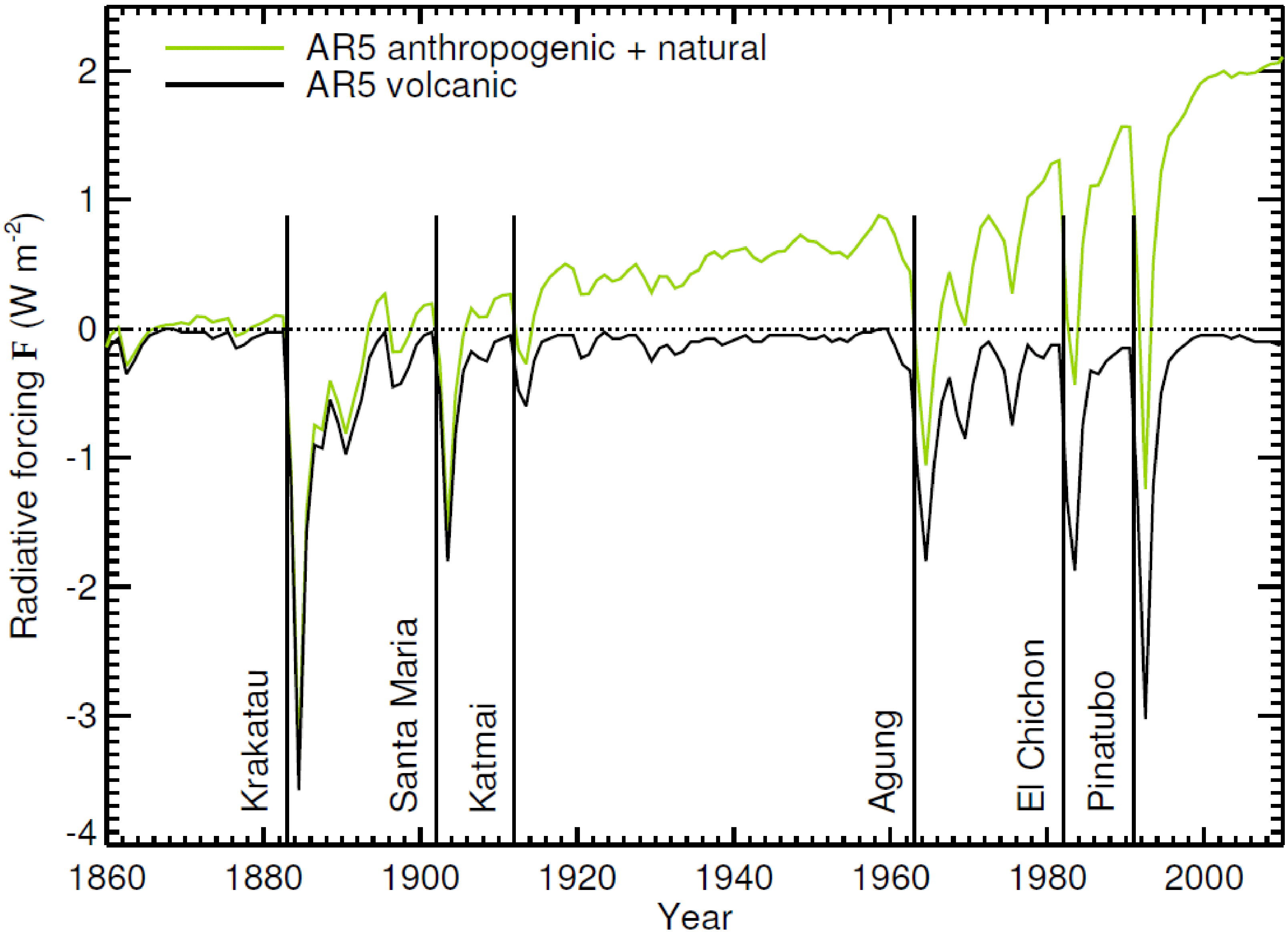
$$T \propto F \text{ or } F = \alpha T$$

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

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

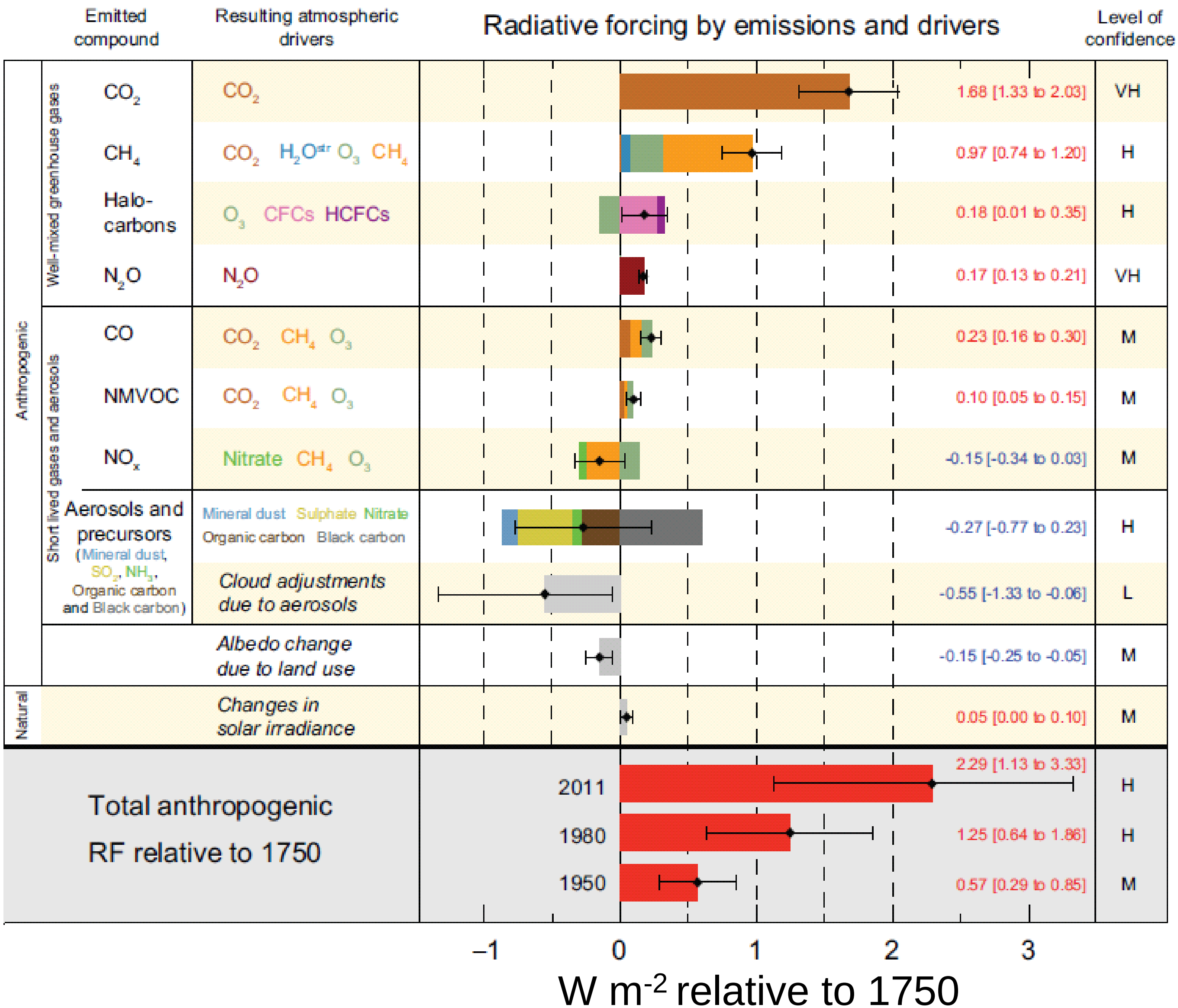
Radiative forcing is the net heat flux into the climate system in the presence of the forcing agent, before climate change has occurred.

Radiative forcing is time-dependent

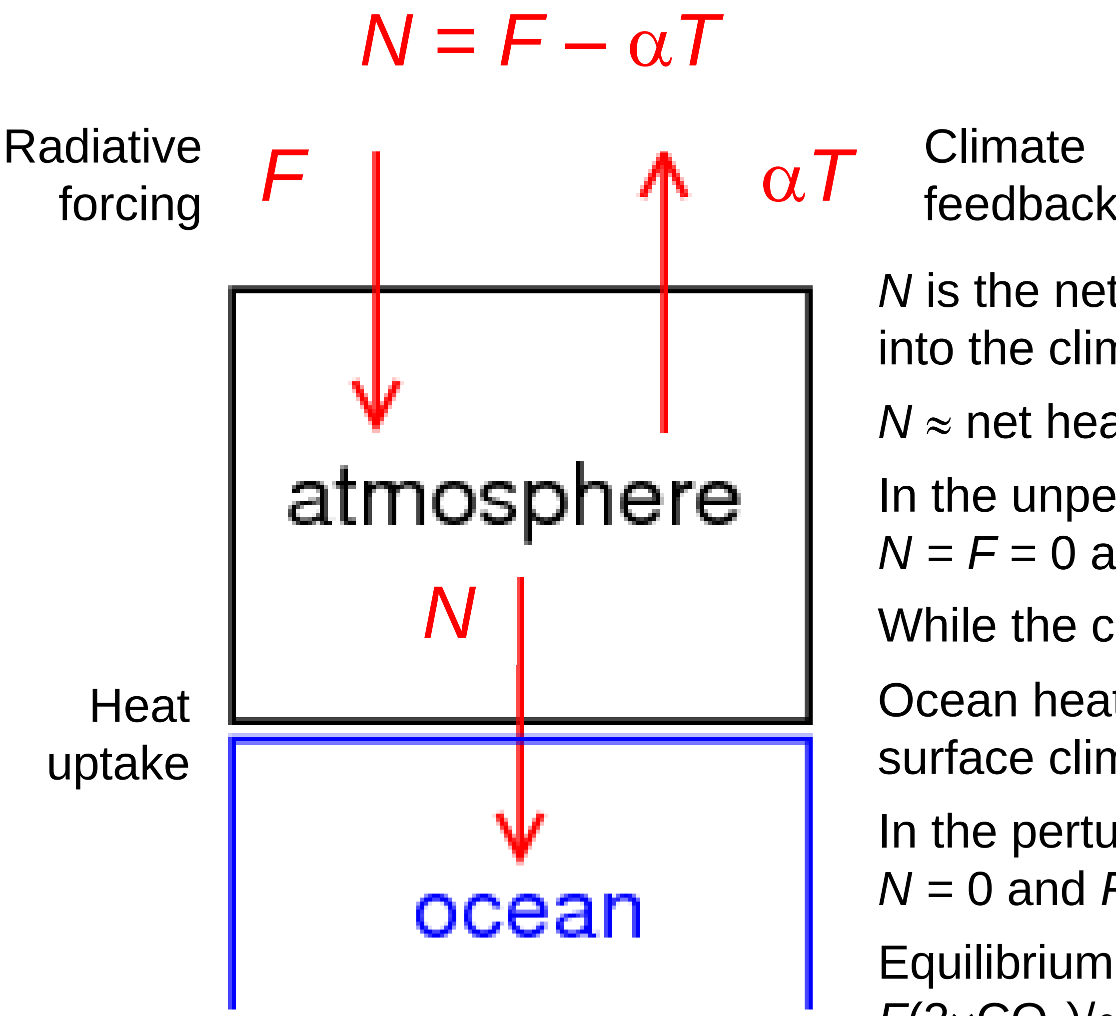


CO_2 is the largest contributor to the net radiative forcing

IPCC AR5 Fig SPM5



Earth energy budget



N is the net heat flux at the TOA i.e. into the climate system.

$N \approx$ net heat flux into the ocean.

In the unperturbed steady state $N = F = 0$ and $T = 0$.

While the climate is changing, $N \neq 0$.

Ocean heat uptake mitigates the rate of surface climate change, $T = (F - N)/\alpha$.

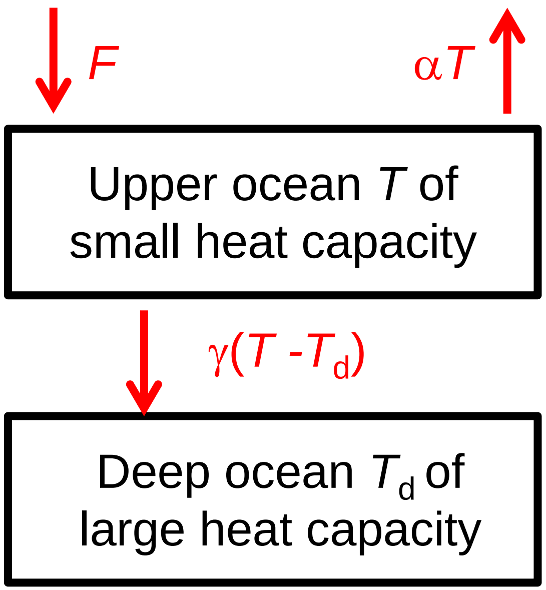
In the perturbed steady state $N = 0$ and $F = \alpha T$.

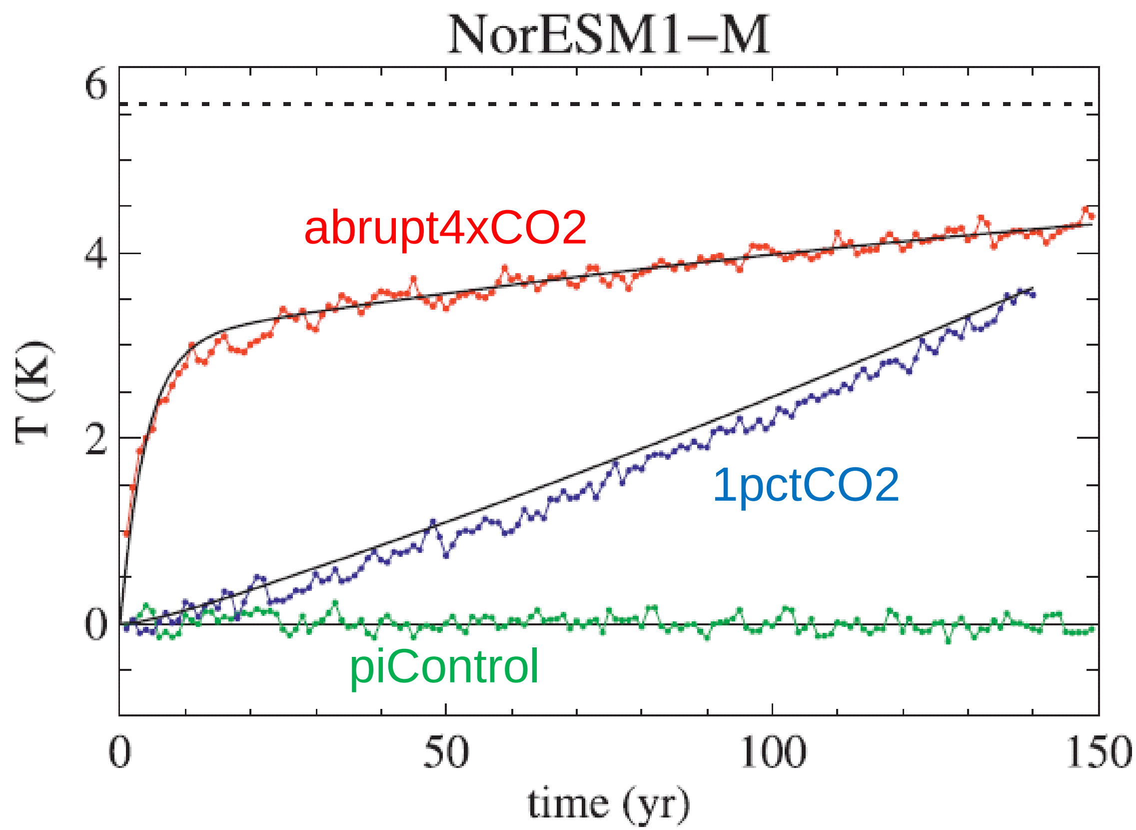
Equilibrium climate sensitivity ECS = $F(2\times CO_2)/\alpha$ is likely within 1.5 to 4.5 K.

Two-layer model for transient climate response

$N = F - \alpha T$

$N = C_u \, dT/dt + \gamma(T - T_d)$





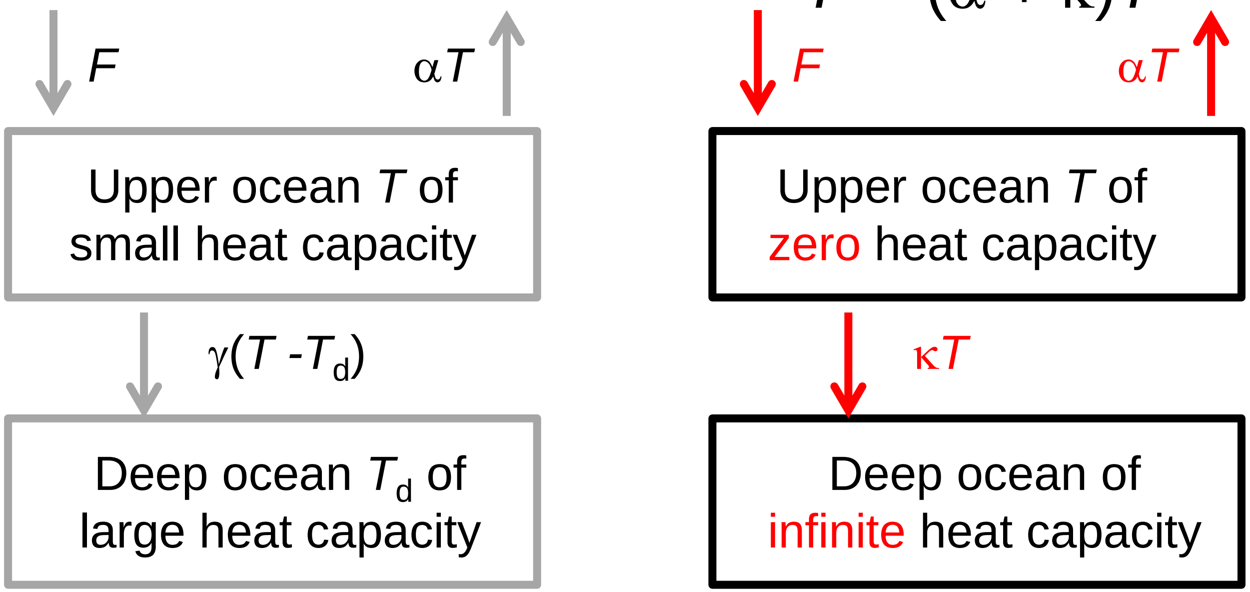
Gregory et al. (2000)
Held et al. (2010)

Geoffroy et al. (2013)

Simpler model for transient climate response

$$N = C_u\,dT/dt + \gamma(T - T_d) \qquad N = \kappa T = F - \alpha T$$

$$F = (\alpha + \kappa)T$$



Two-layer model **Zero-layer model**

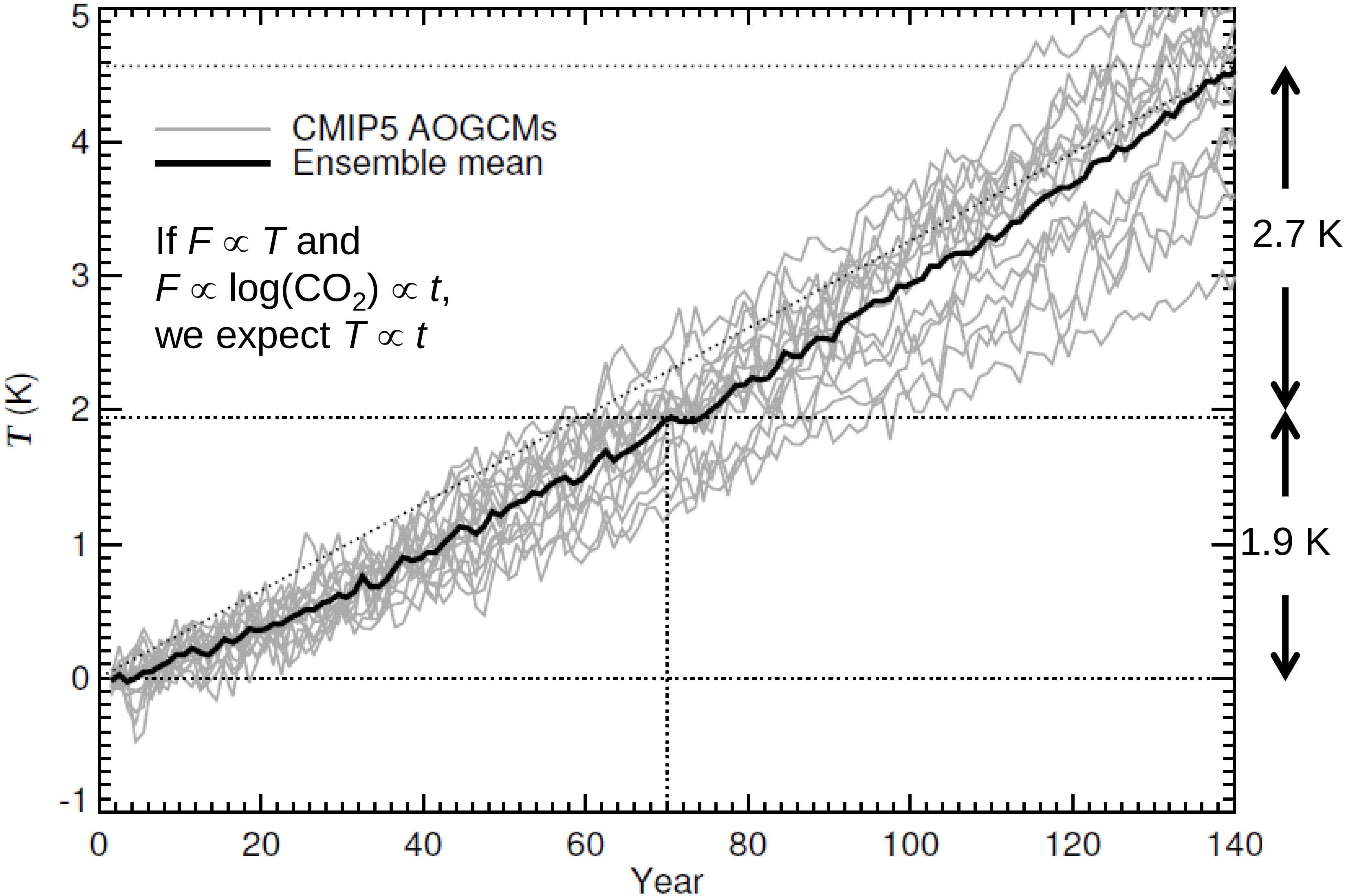
Transient climate response TCR = $F(2\times CO_2)/(\alpha + \kappa)$

The transient climate response (TCR) is likely in the range 1.0 to 2.5 K.

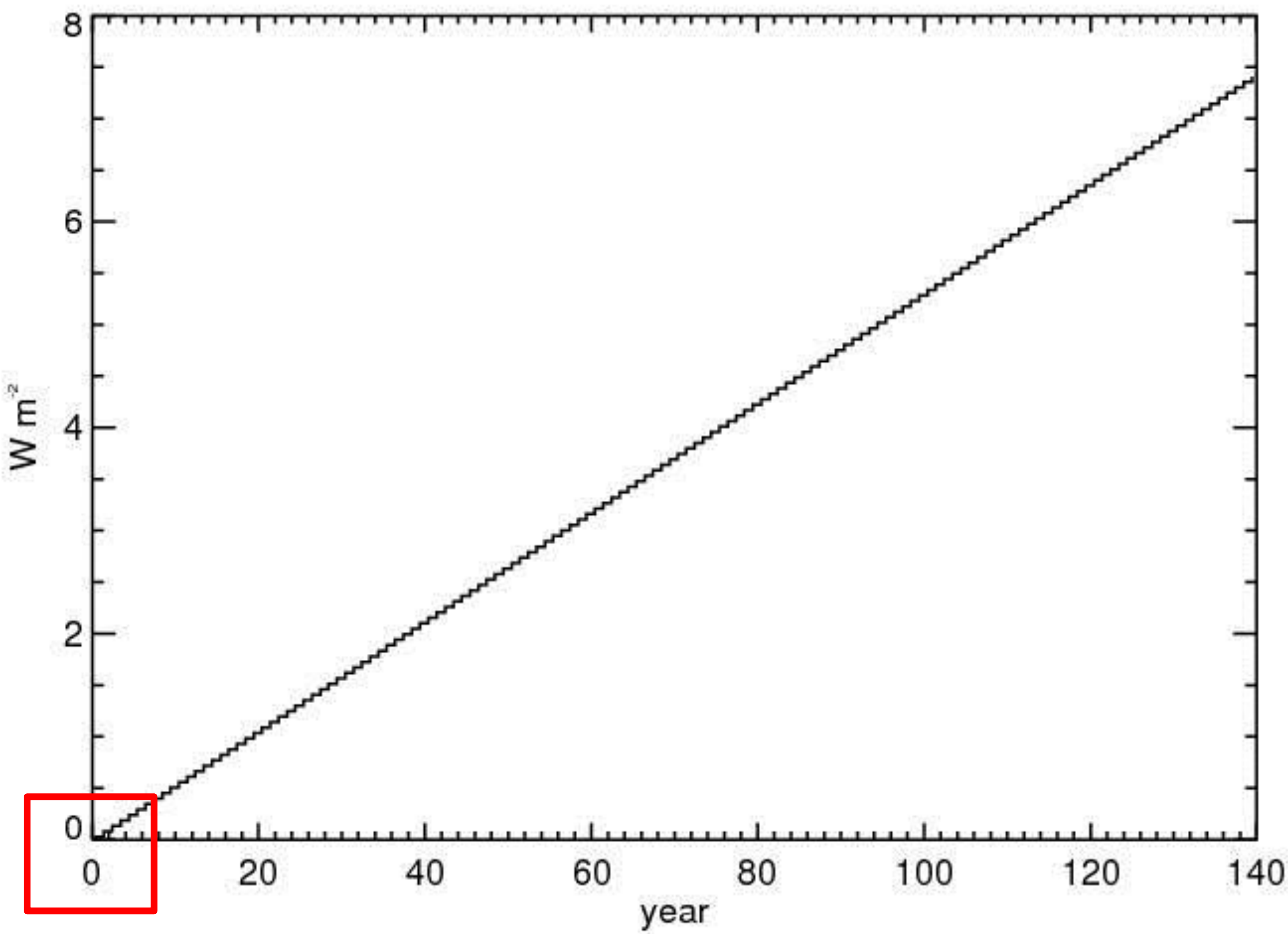
Transient climate response parameter TCRP=$1/(\alpha + \kappa)$ in K $(W\ m^{-2})^{-1}$

(Held et al., 2010; Gregory et al., 2015)

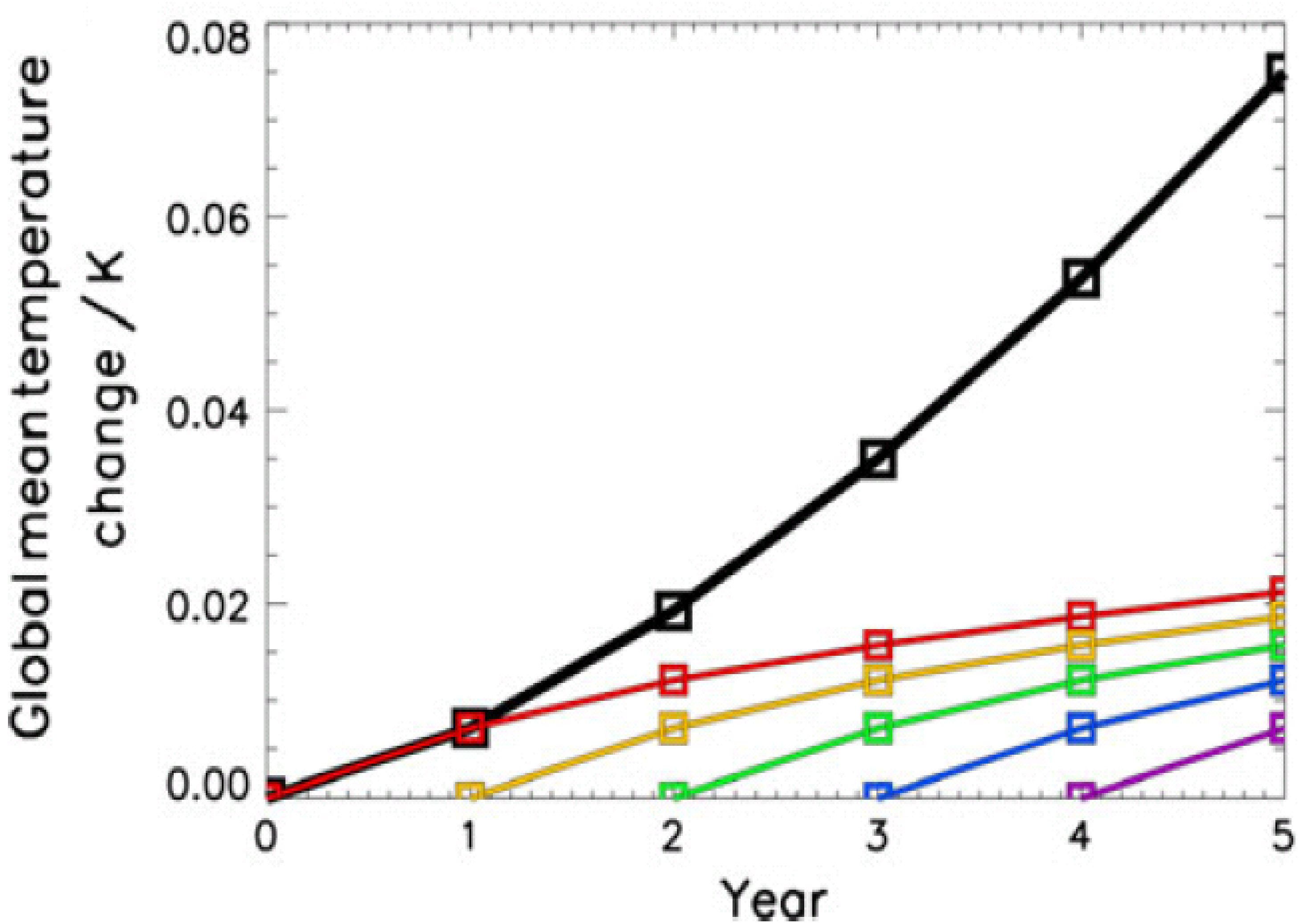
TCRP increases under 1pctCO2



Treat *F*(*t*) for 1pctCO2 as a succession of steps

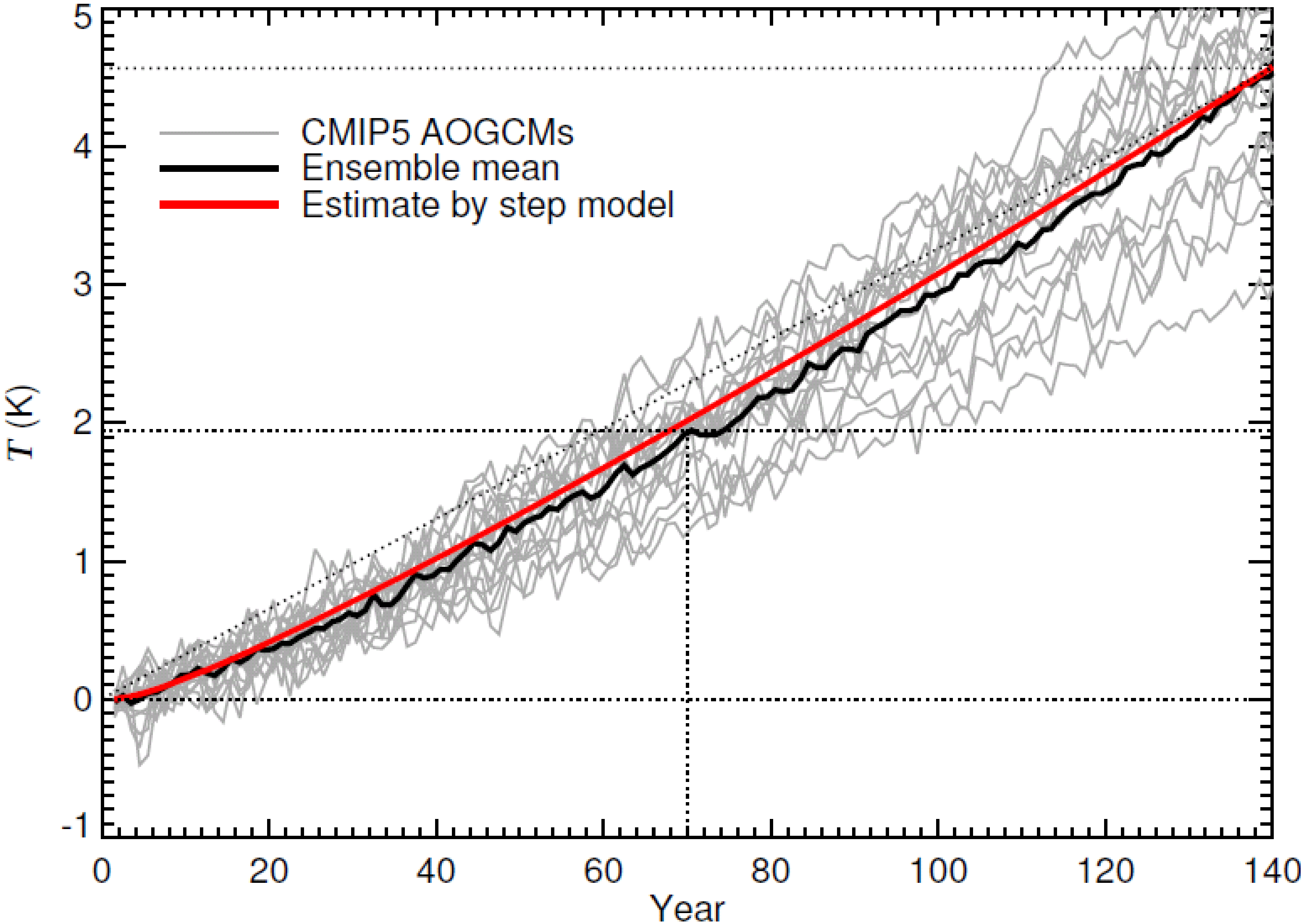


Step (Good et al., 2011) model

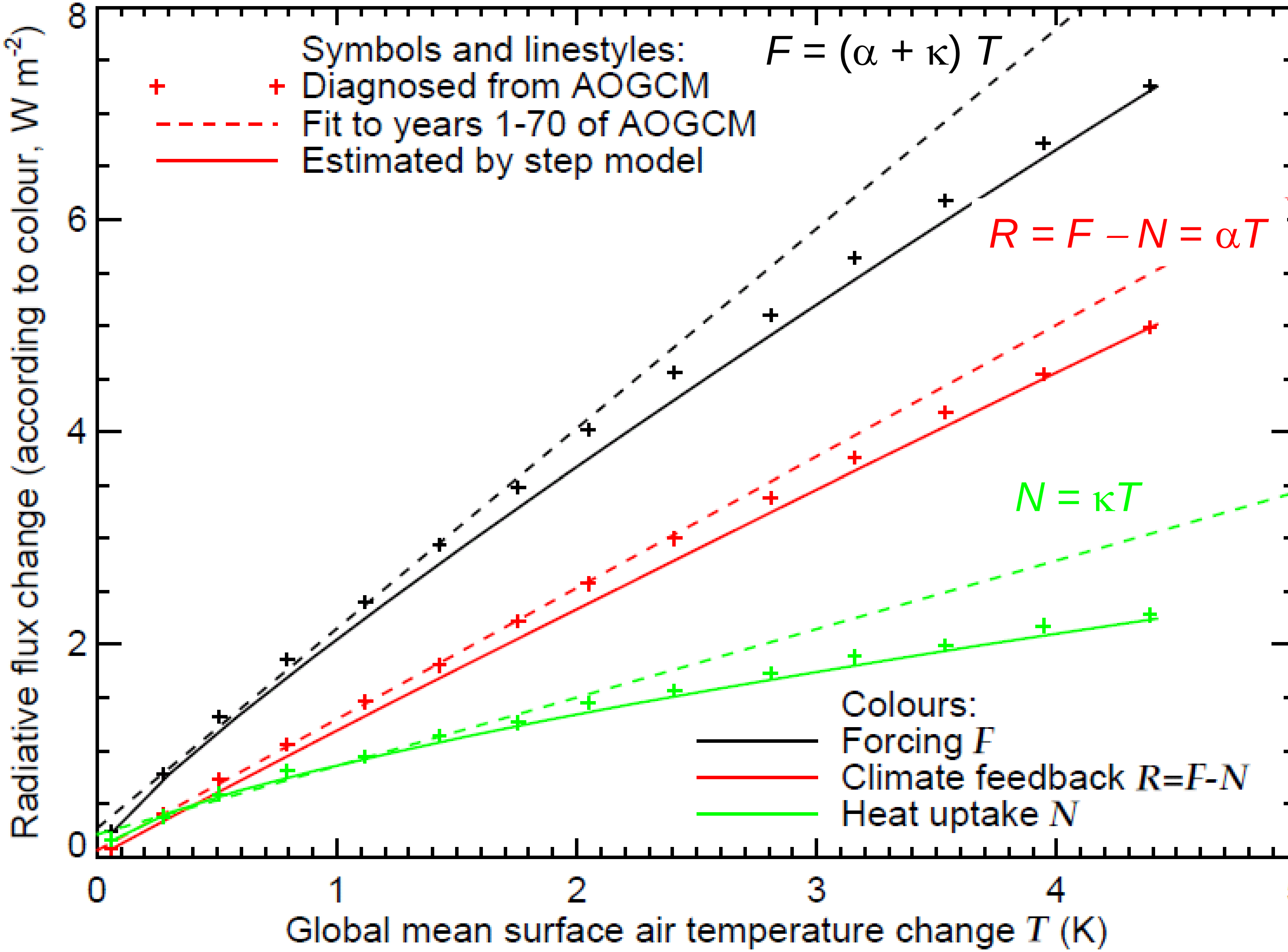


Good et al. (2013)

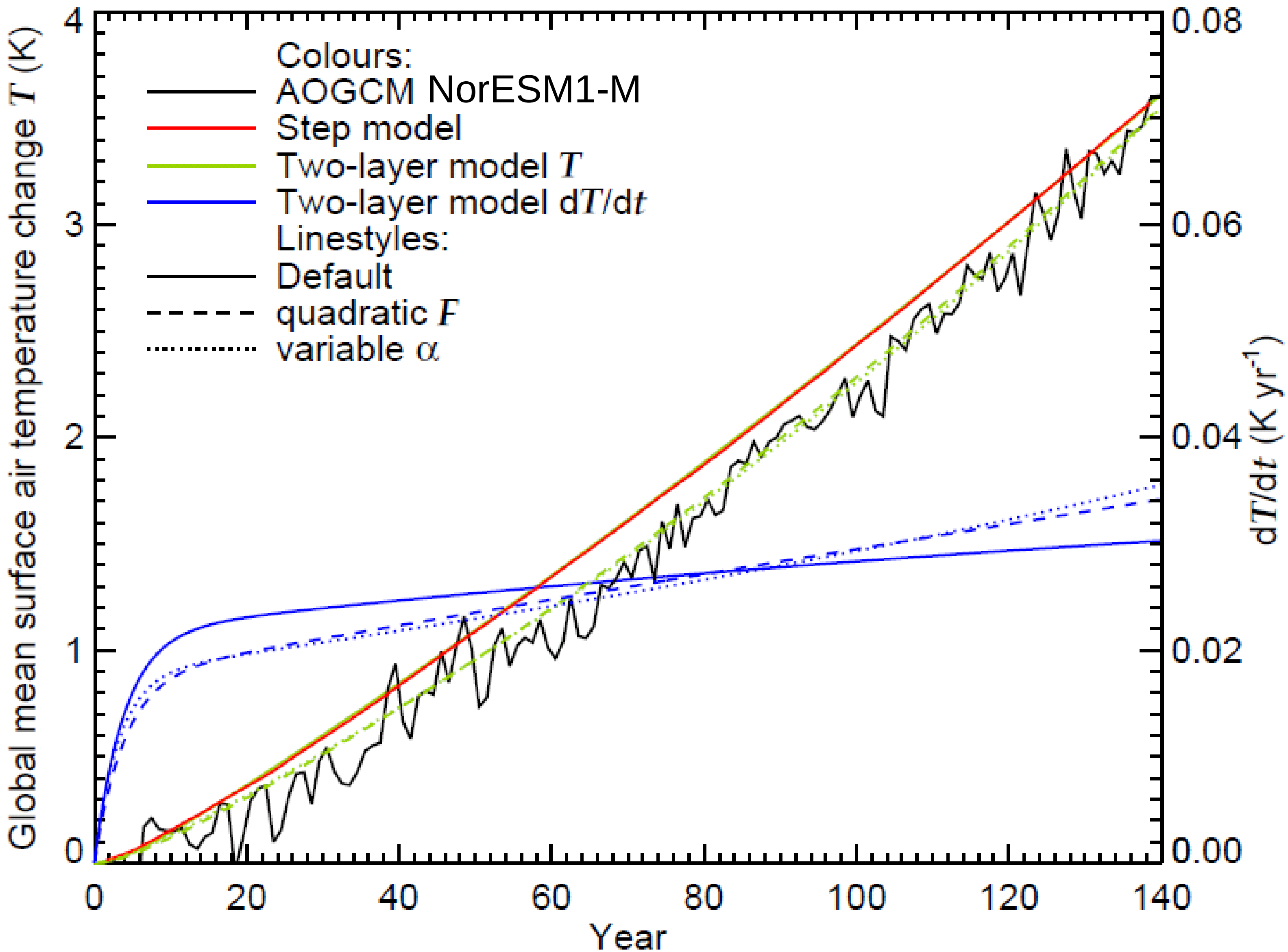
Inconstancy of TCRP partly predicted by step model



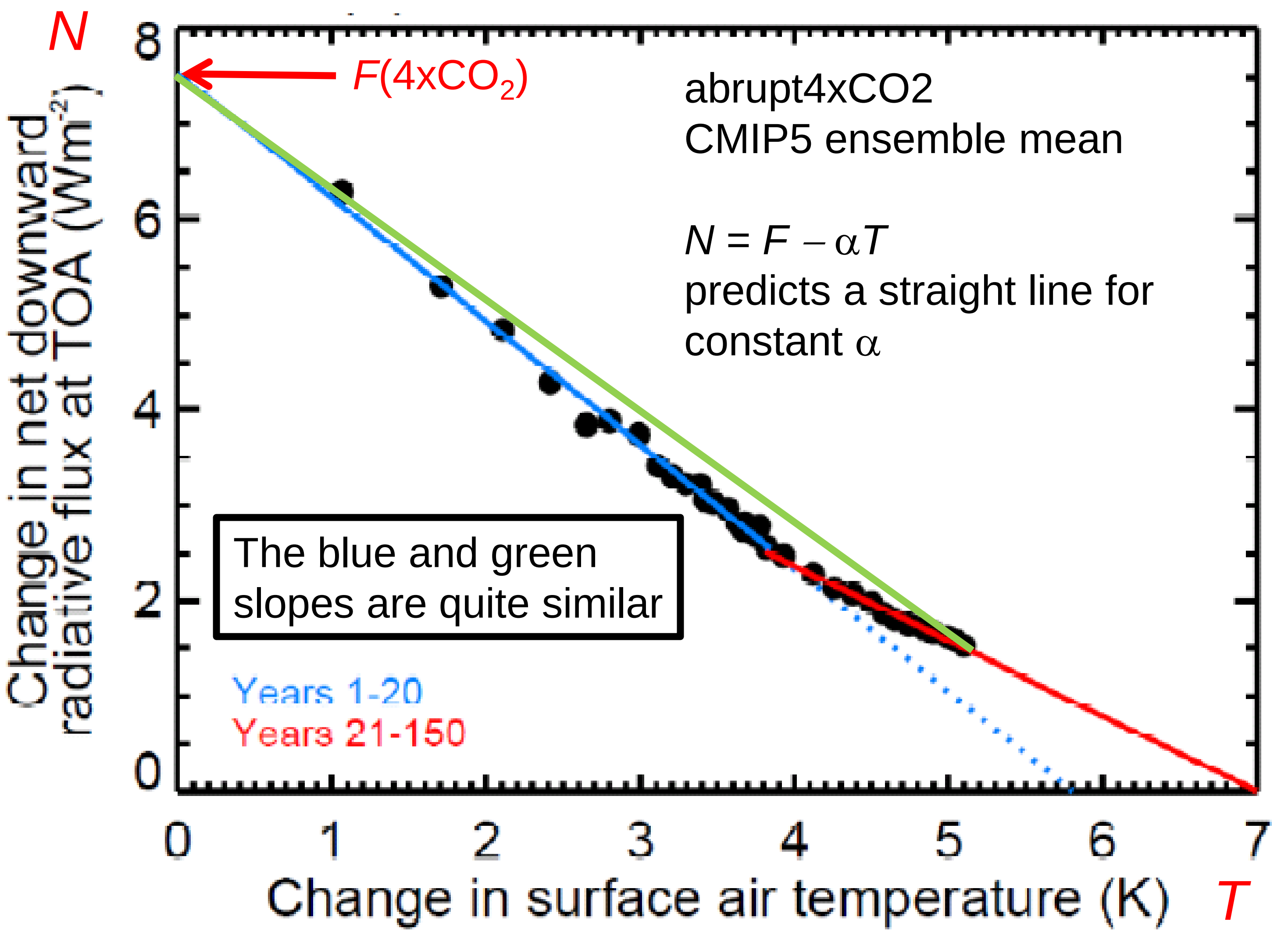
Inconstancy of TCRP partly predicted by step model



Inconstant d*R*/d*T* in 1pctCO2

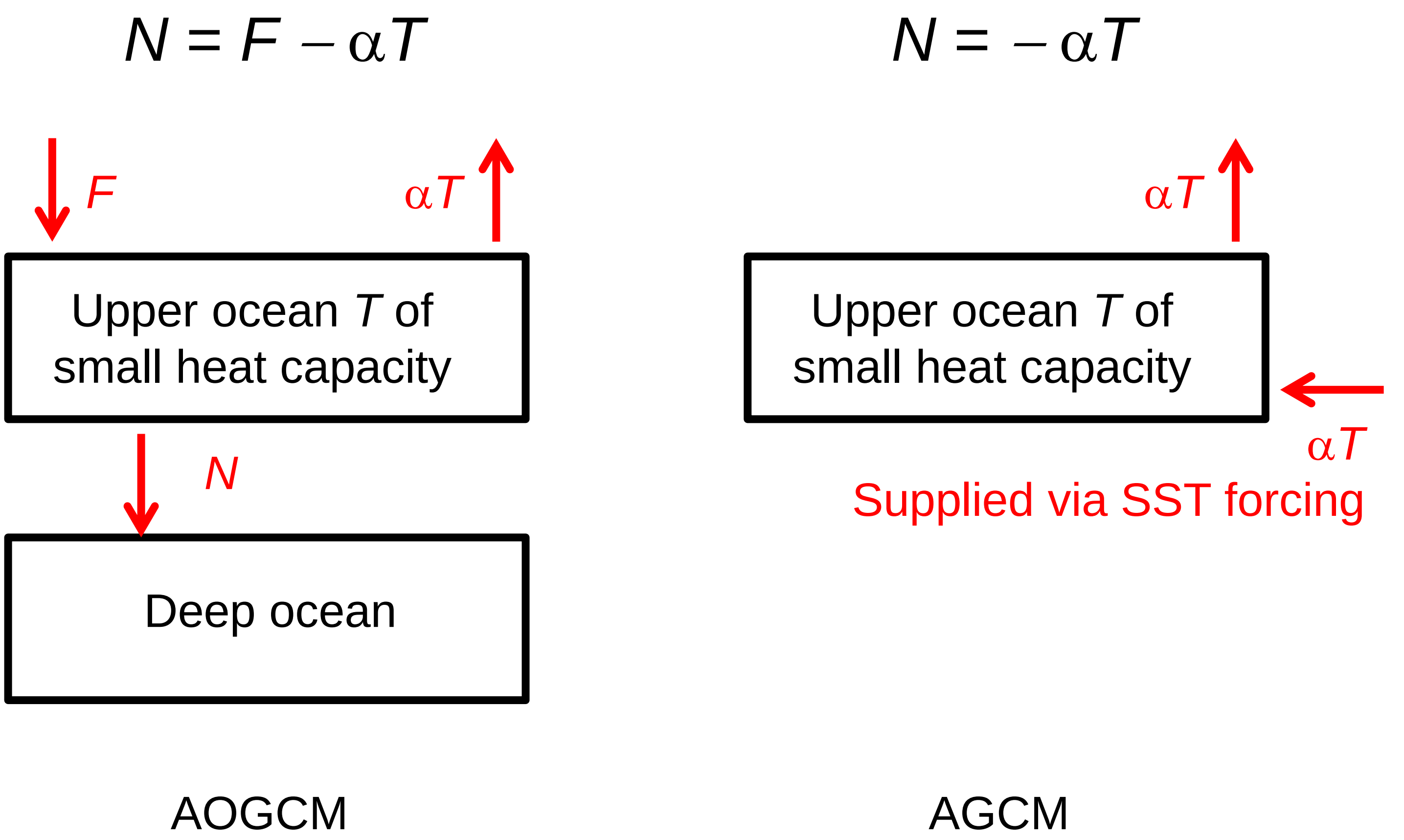


Climate feedback may vary under constant *F*



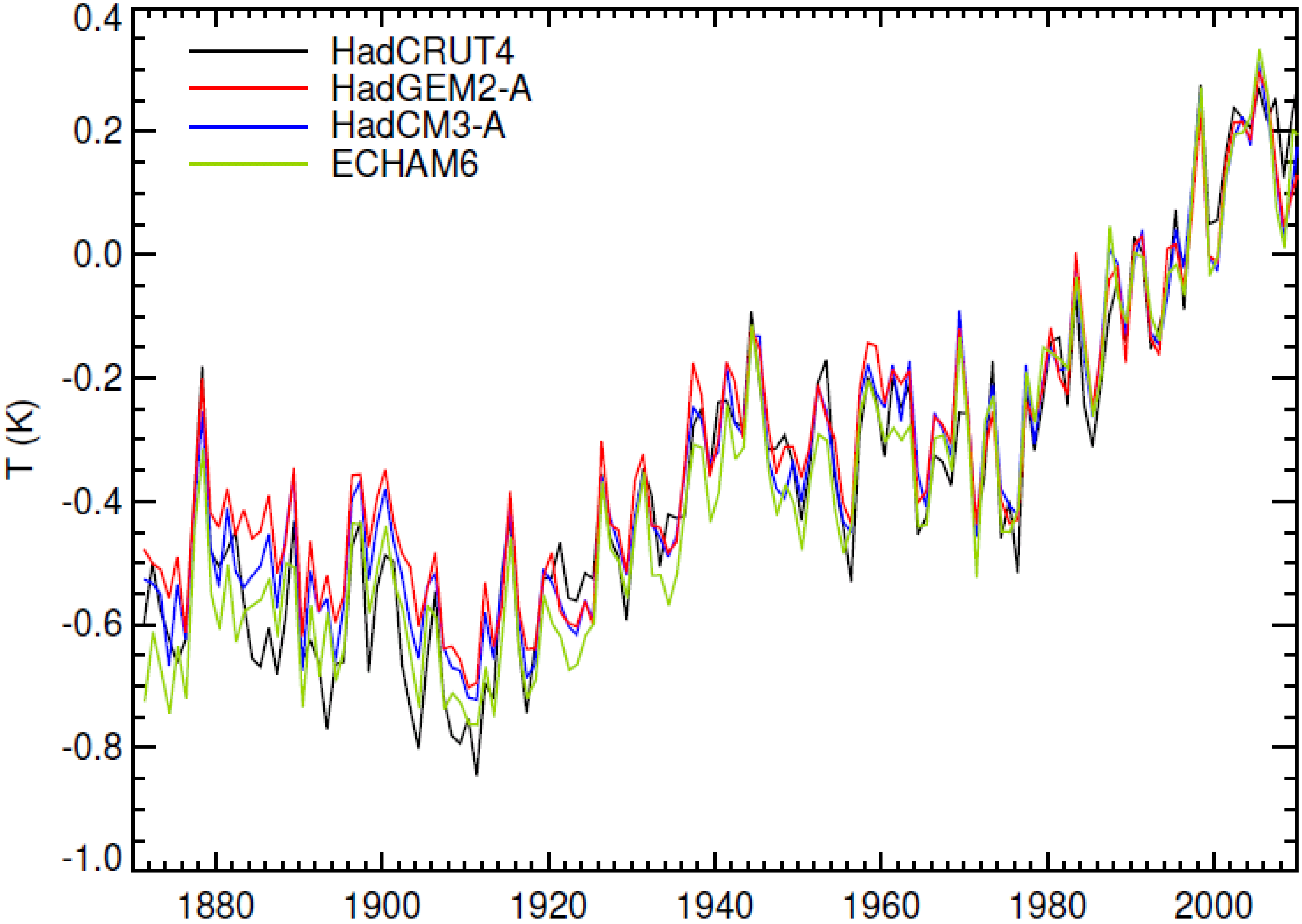
Andrews et al. (2015)

Historical α from SST-forced AGCM experiments

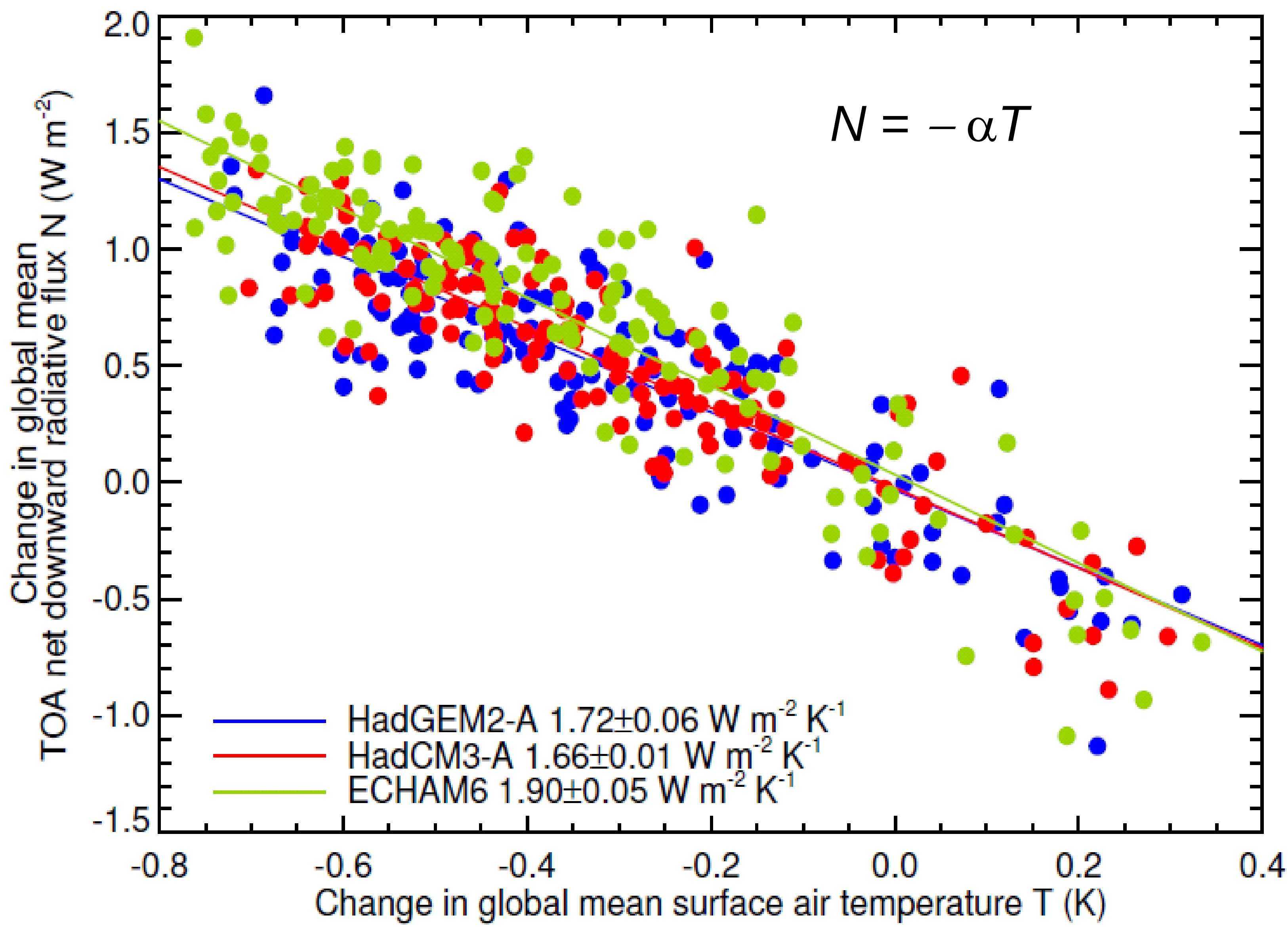


amip-piForcing is an AGCM experiment for CFMIP3/CMIP6 (coordinated by Tim) with AMIP sea-surface BCs for 1870-present and constant pre-industrial forcing.

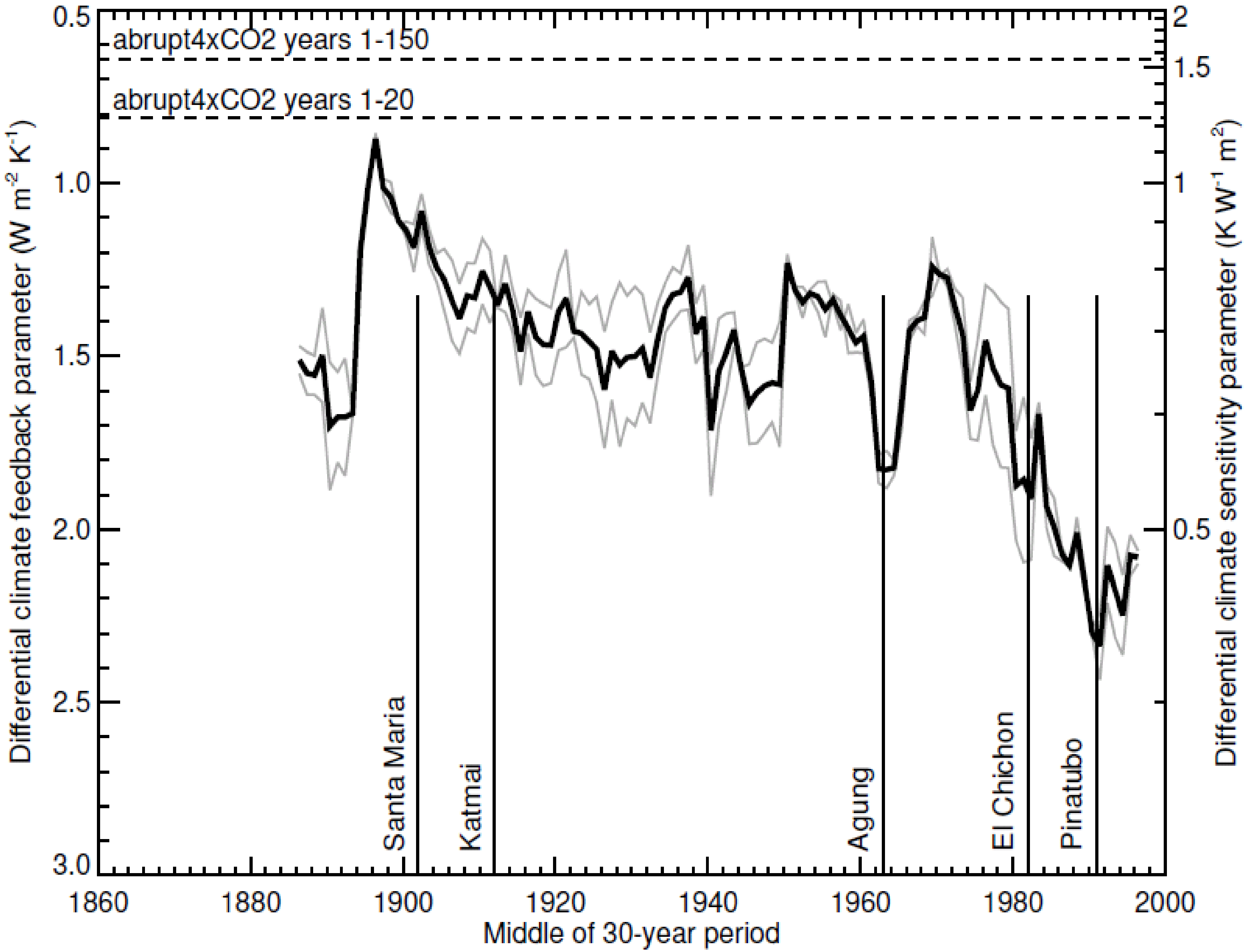
Historical *T*(*t*) from obs and amipPiForcing expts



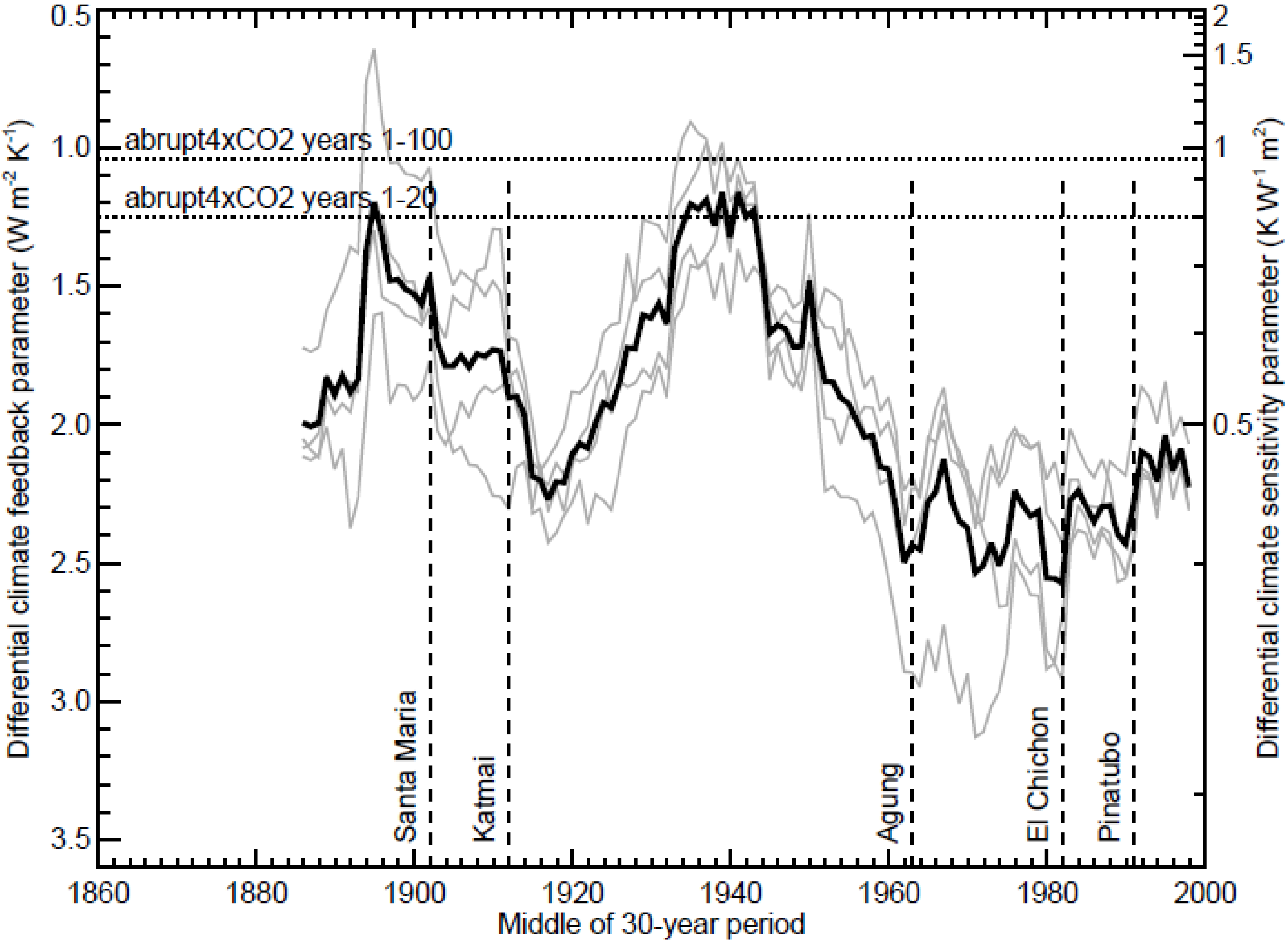
Climate feedback from amipPiForcing expts



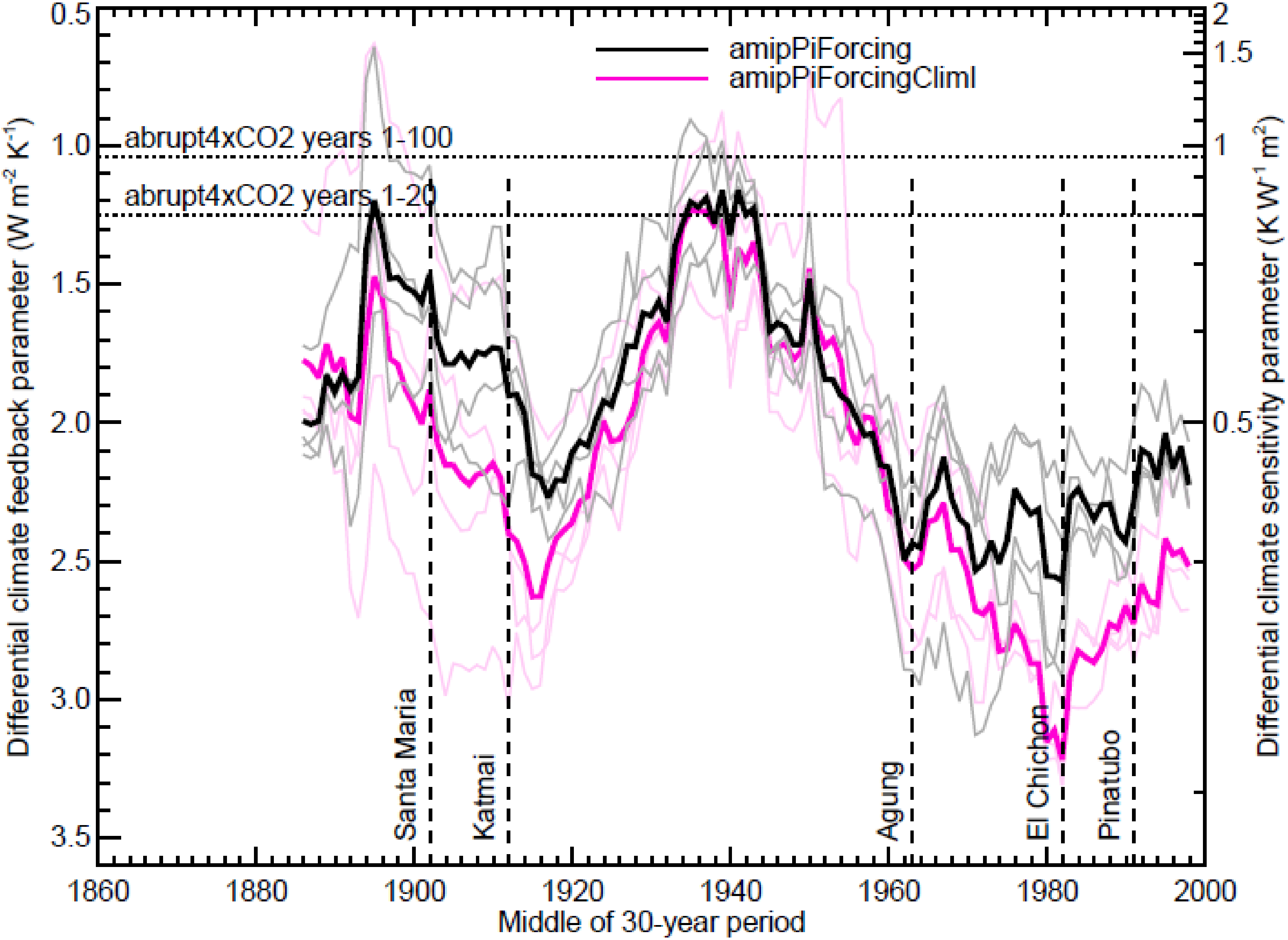
–dN/dT from HadGEM2-A amipPiForcing



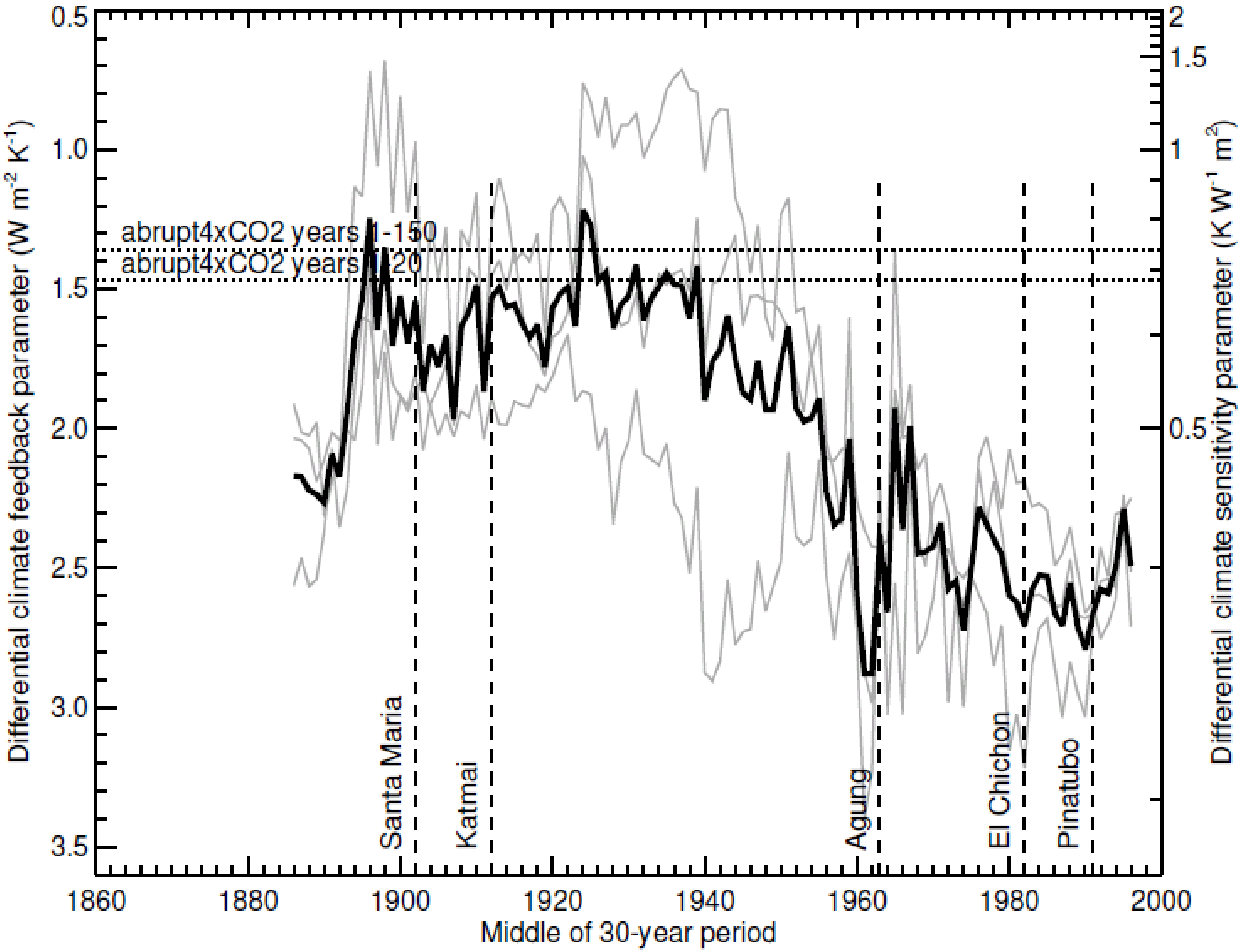
–dN/dT from HadCM3-A amipPiForcing



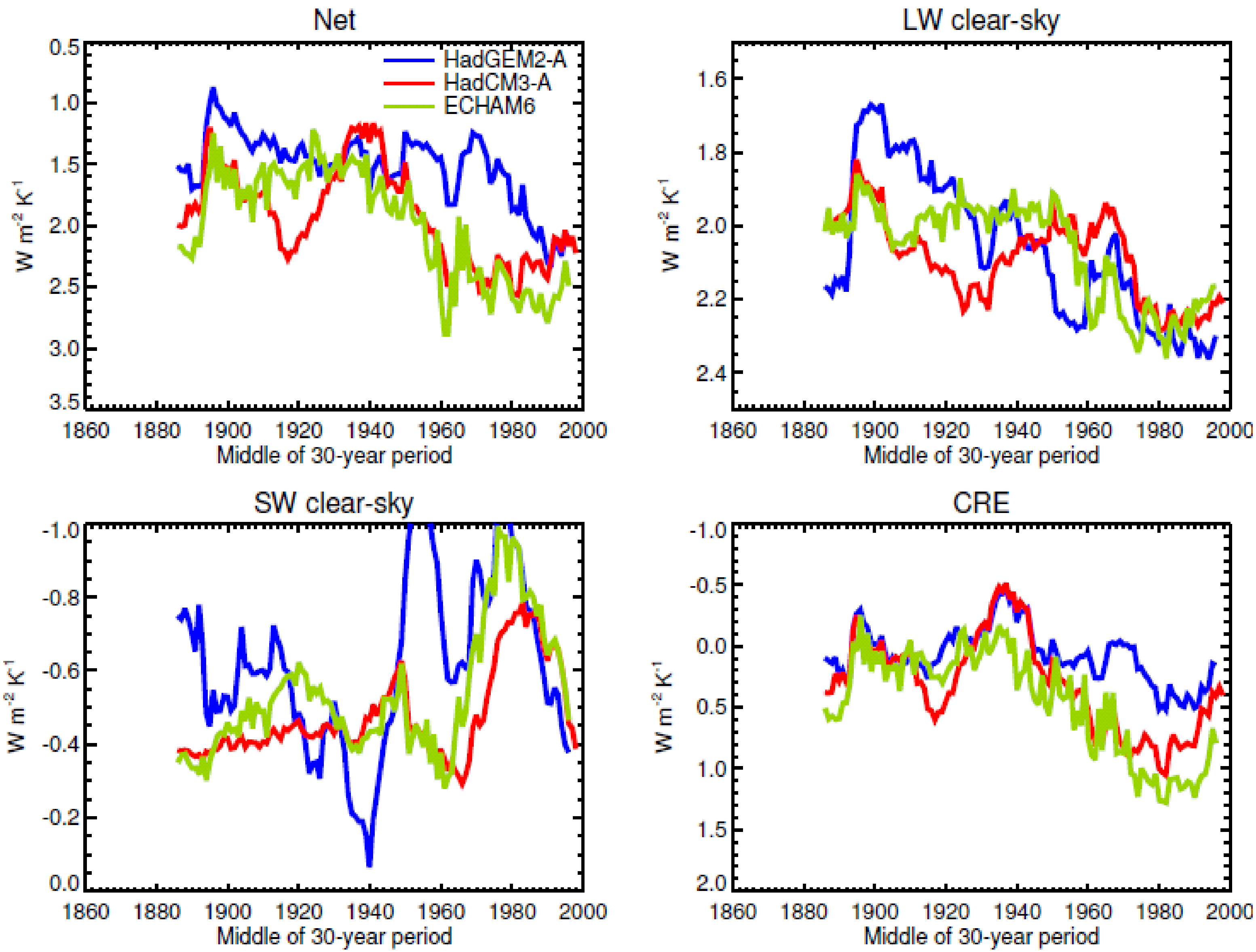
–dN/dT from HadCM3-A amipPiForcing



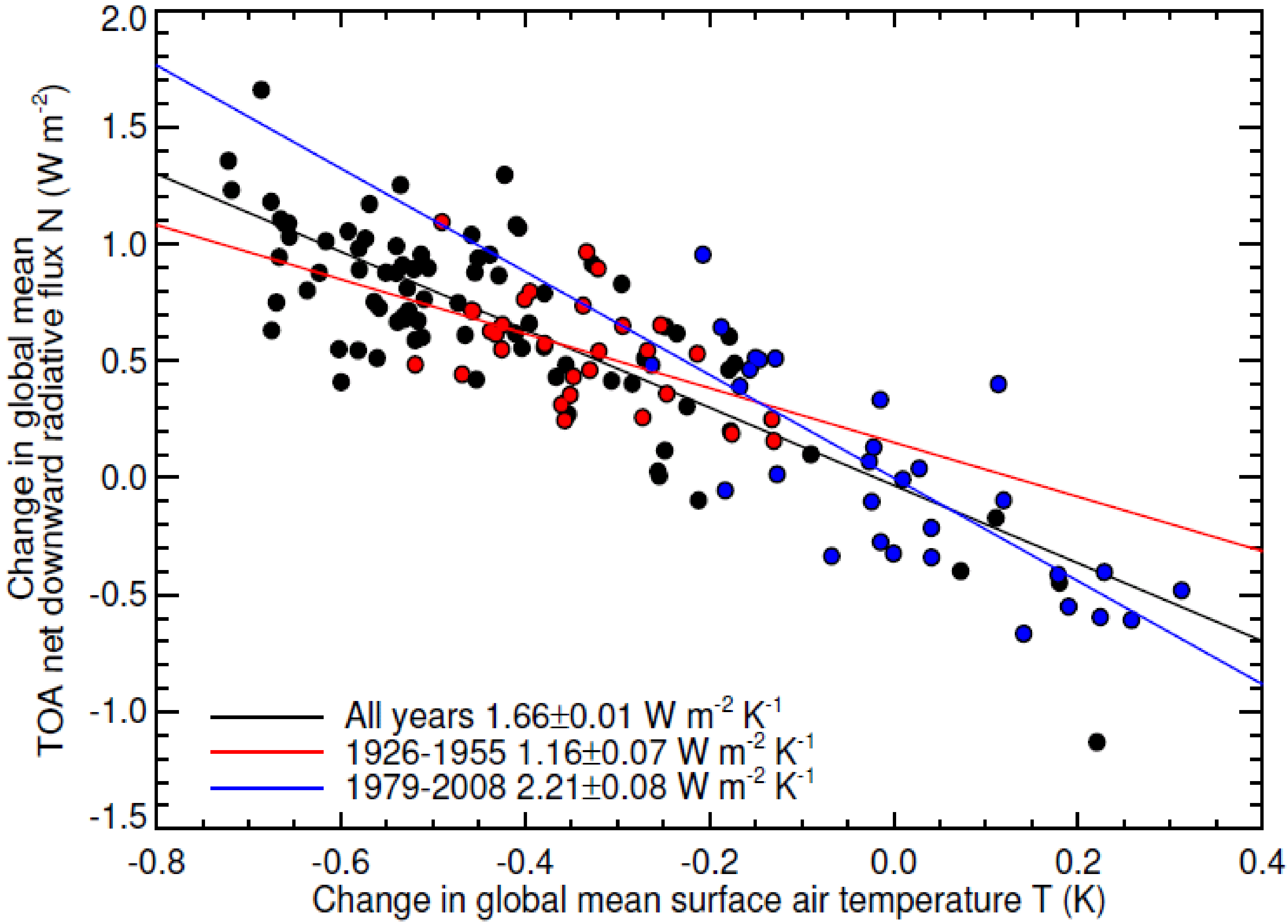
–dN/dT from ECHAM6 amipPiForcing



Components of –dN/dT for amipPiForcing

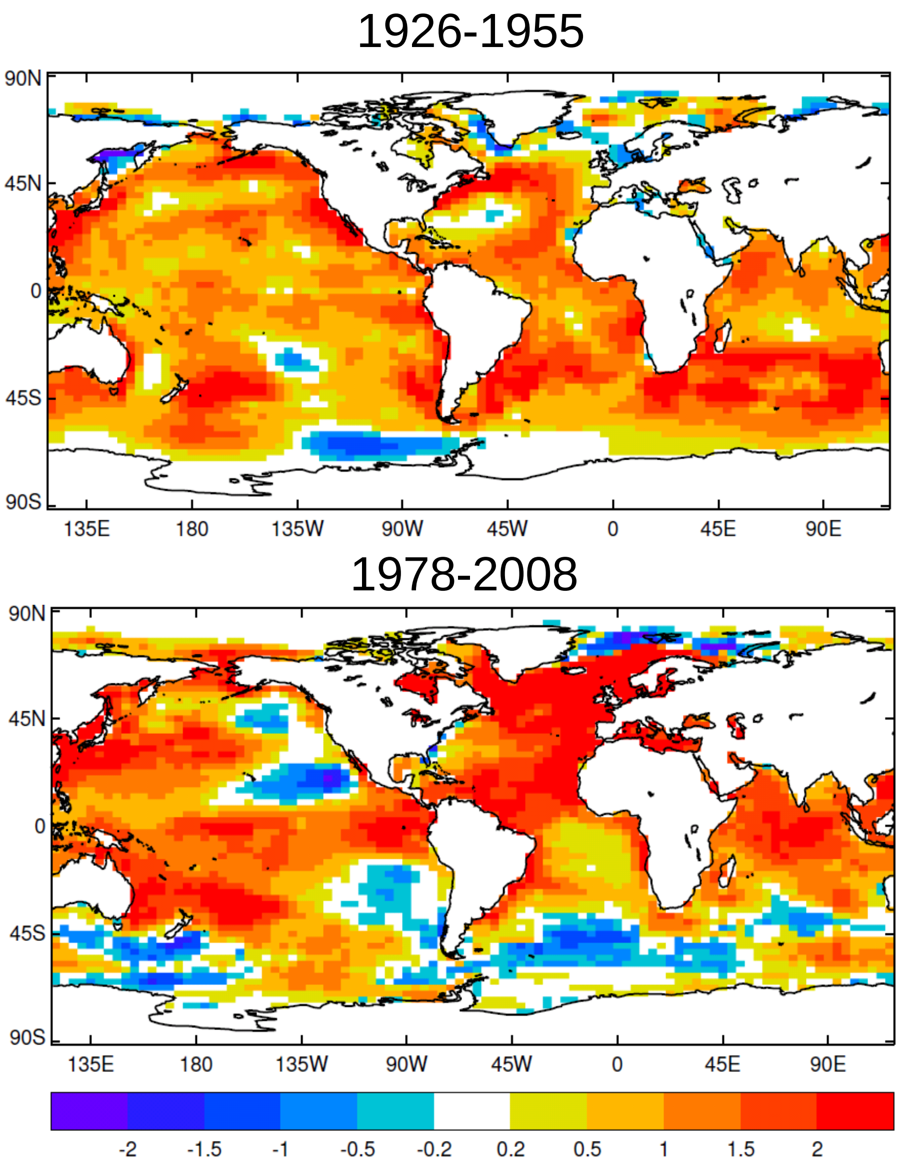


Climate feedback from HadCM3-A amipPiForcing

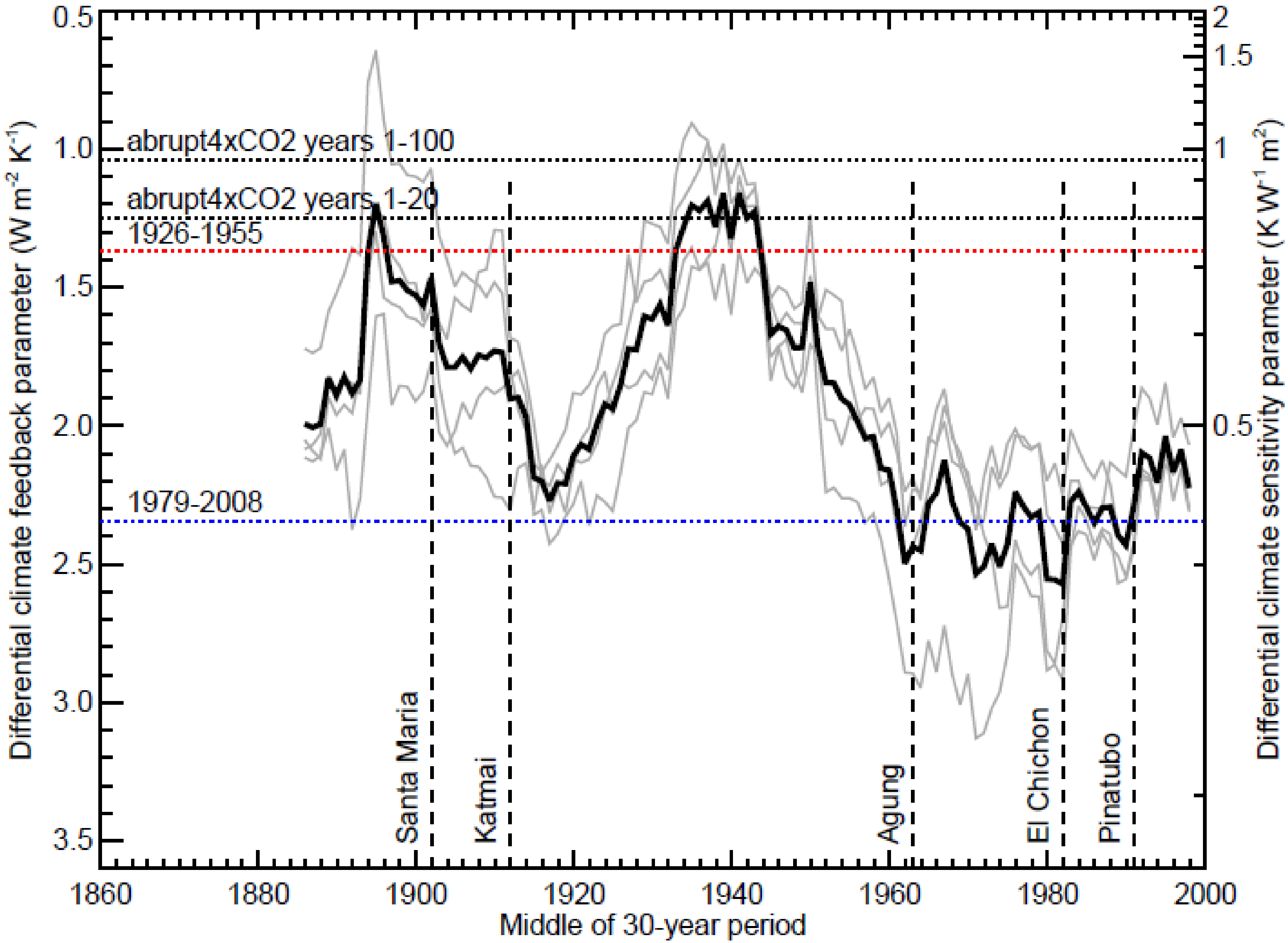


Regression slope of local T versus global T (K K^{-1})

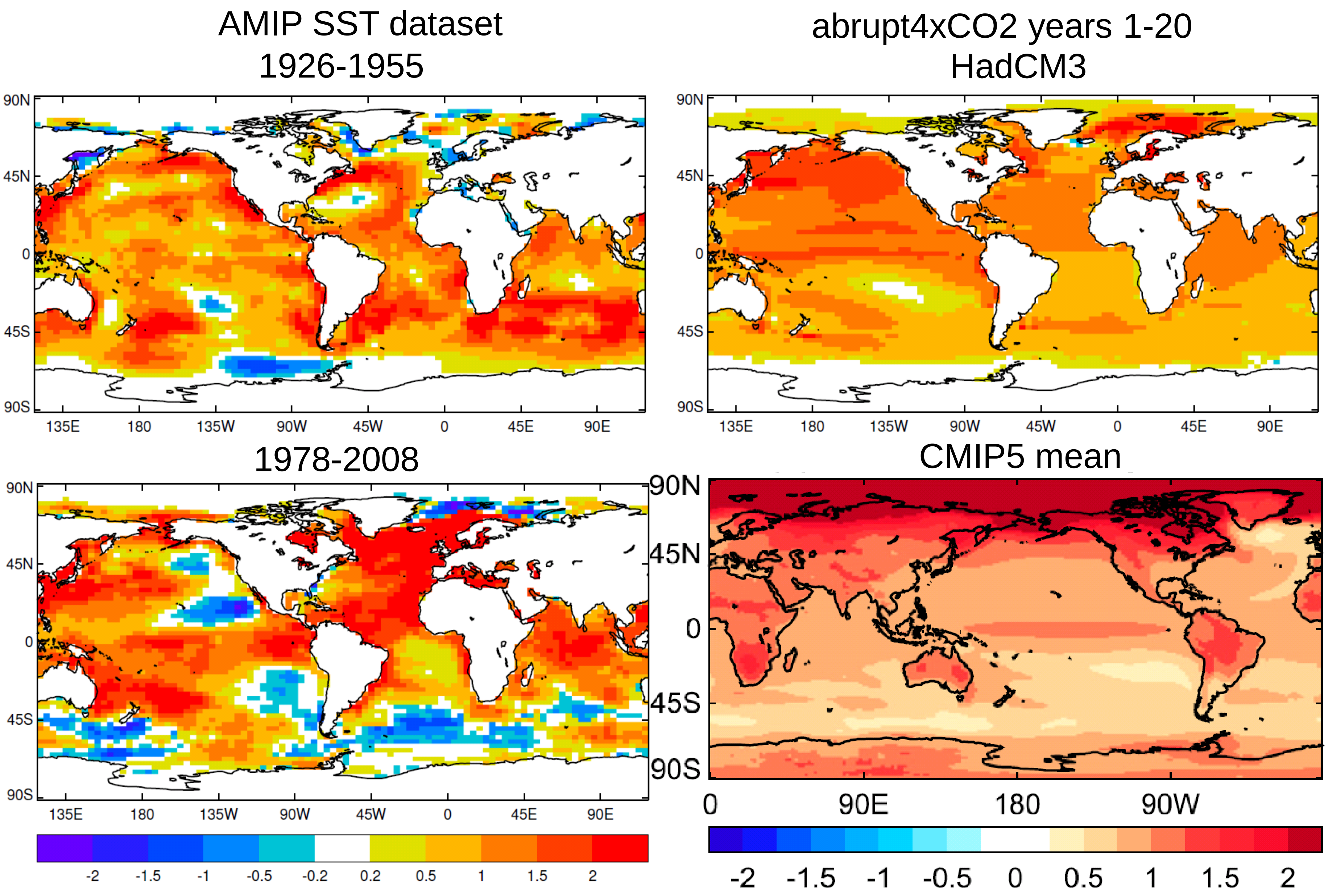
AMIP SST dataset



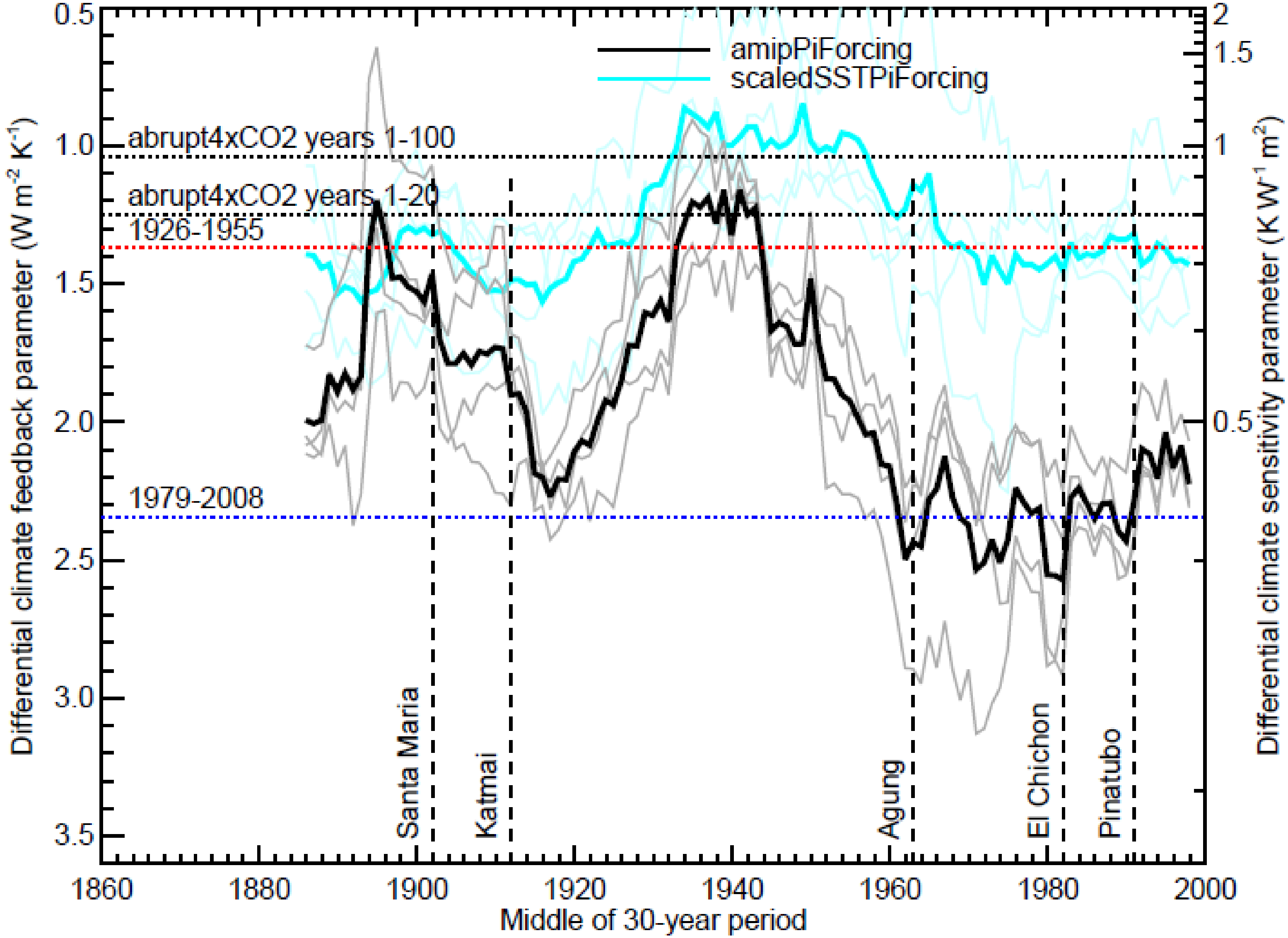
–d*N*/d*T* from HadCM3-A amipPiForcing



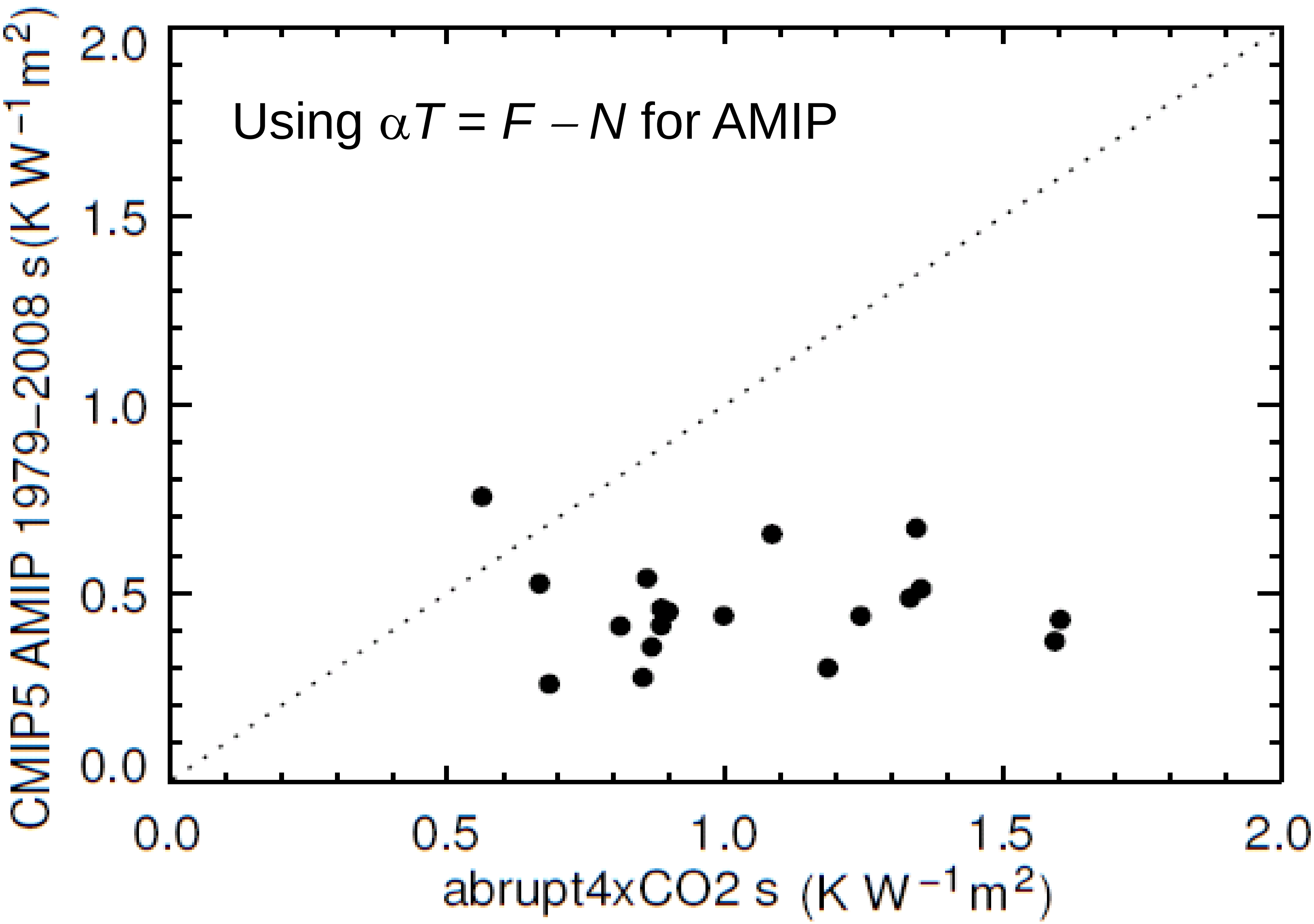
Regression slope of local T versus global T (K K^{-1})



–dN/dT from HadCM3-A amipPiForcing



Climate feedback from AMIP and abrupt4xCO2



Conclusions

Under 1pctCO2, The transient climate response parameter (TCRP increases), by about 20% over 140 years, because

- ocean heat uptake efficiency declines as time passes.
- climate feedback decreases, or forcing rises more rapidly than logarithmically, as CO_2 increases.

Consequently scaling the TCR gives an underestimate of projected *T*.

Under abrupt4xCO2, climate feedback decreases (climate sensitivity increases) as *T* rises and time passes, due mostly to the effect of changing SST patterns on SW cloud feedback, but this is a small effect for TCRP.

Time-dependent historical SSTs produce an effective climate sensitivity of ~2 K in three AGCMs, having large decadal variation that is partly model-dependent, explanations not yet clear (perhaps varying forcing or unforced variability).

These and other AMIP AGCMs give a historically unusually low effective climate sensitivity of ~1.5 K for 1979-2008, considerably less than for abrupt4xCO2.

These results may help to relieve the apparent contradiction in the AR5 between the larger values of effective climate sensitivity diagnosed from AOGCMs and the smaller values inferred from historical climate change.