Some issues related to feedback analyses of climate sensitivity

CERES Workshop, GFDL, Oct 2012

Isaac Held

The simplest linear model for global mean temperature

forcing

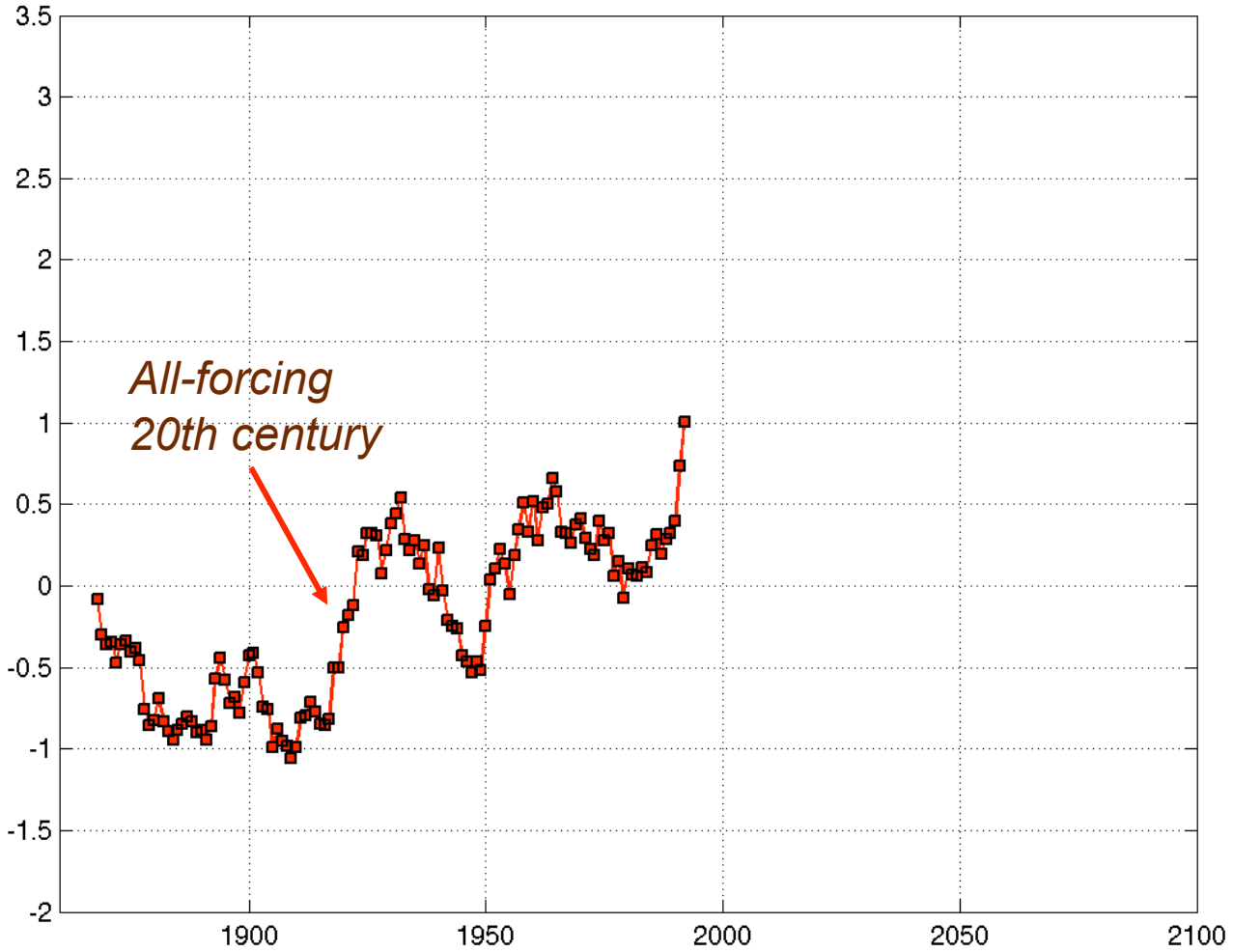
Heat uptake

$$C\frac{dT}{dt} = F - \beta T \equiv N$$

$$T_{EQ} = F/\beta$$

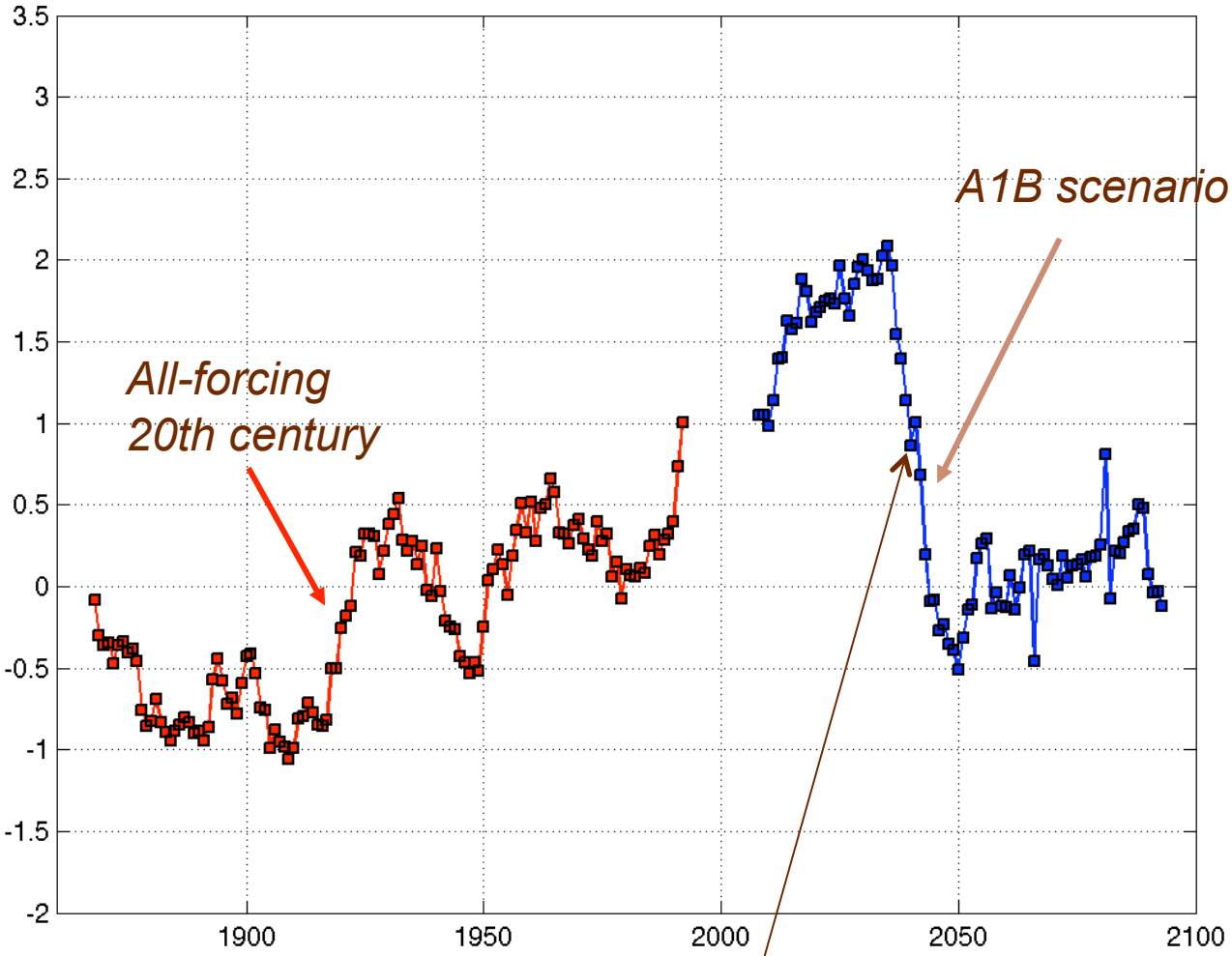
Shortwave regression across ensemble,
following K. Swanson 2008

$Wm^{-2}K^{-1}$



Following an idea of K. Swanson,
take a set of realizations of the 20th century from one model,
and correlate global mean TOA with surface temperature across the ensemble

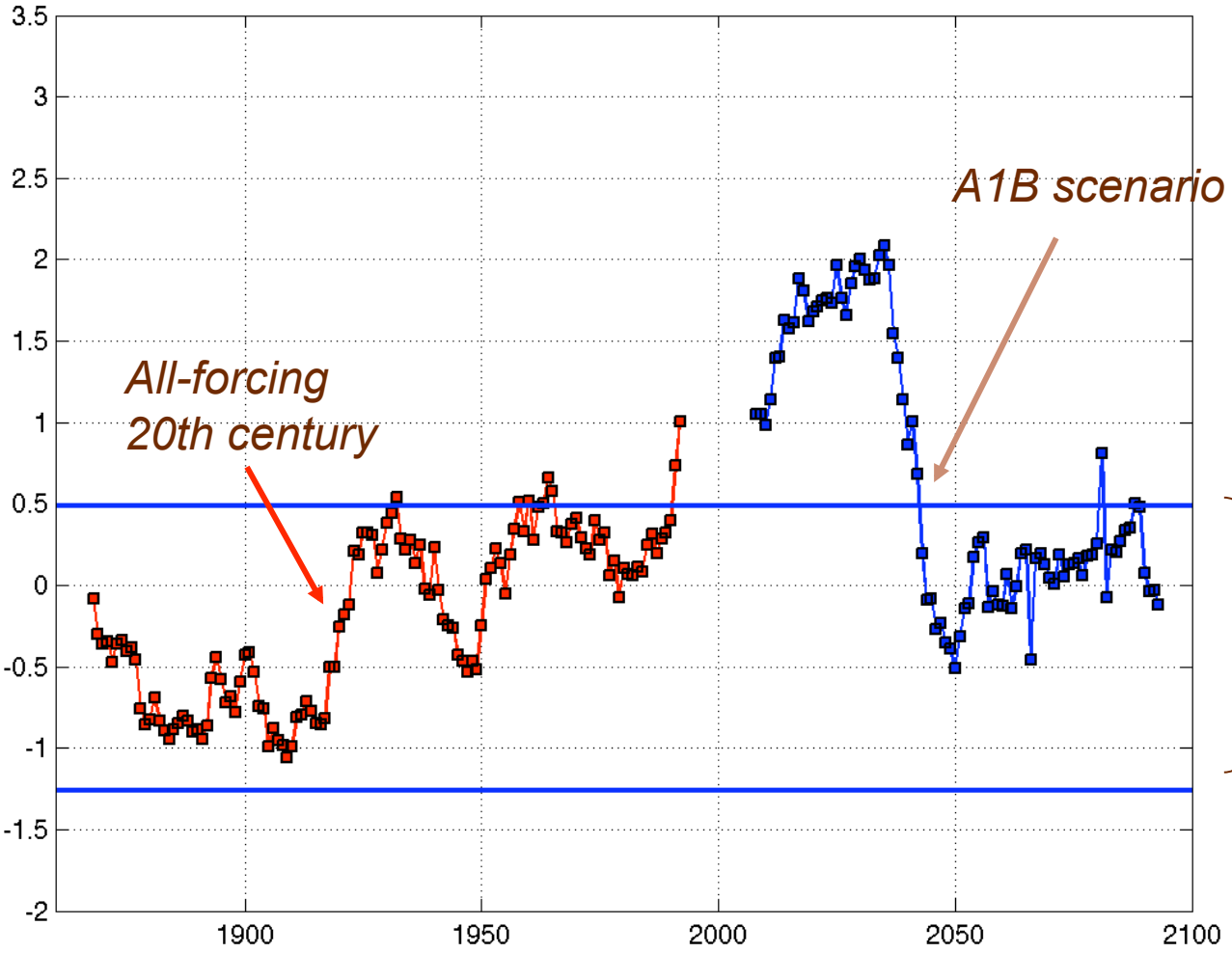
Shortwave regression across ensemble, following K. Swanson 2008



$Wm^{-2}K^{-1}$

Is this a sign of non-linearity? What is this?

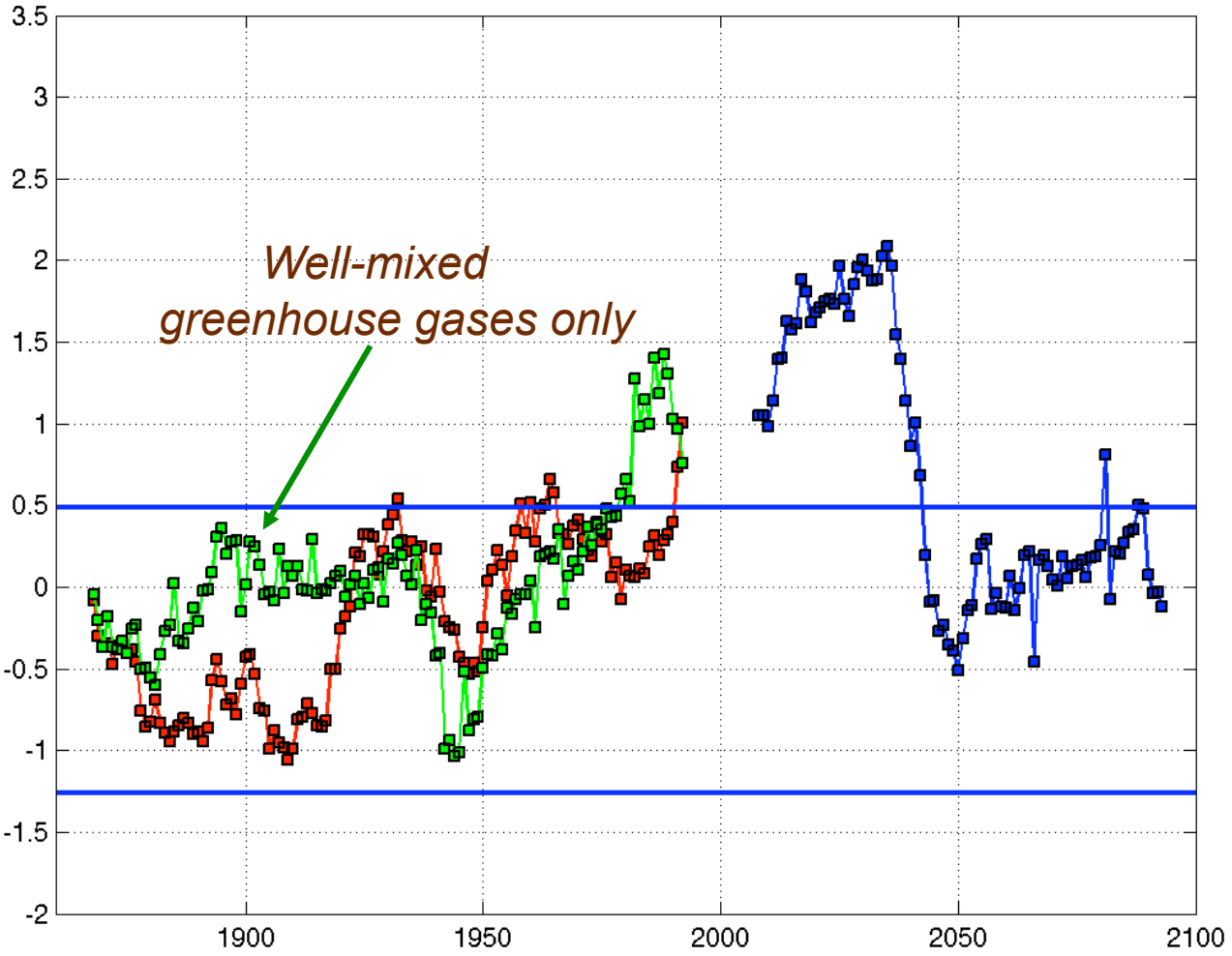
Shortwave regression across ensemble, following K. Swanson 2008



$Wm^{-2}K^{-1}$

Estimate of noise in this statistic from 2000yr control run

Shortwave regression across ensemble, following K. Swanson 2008



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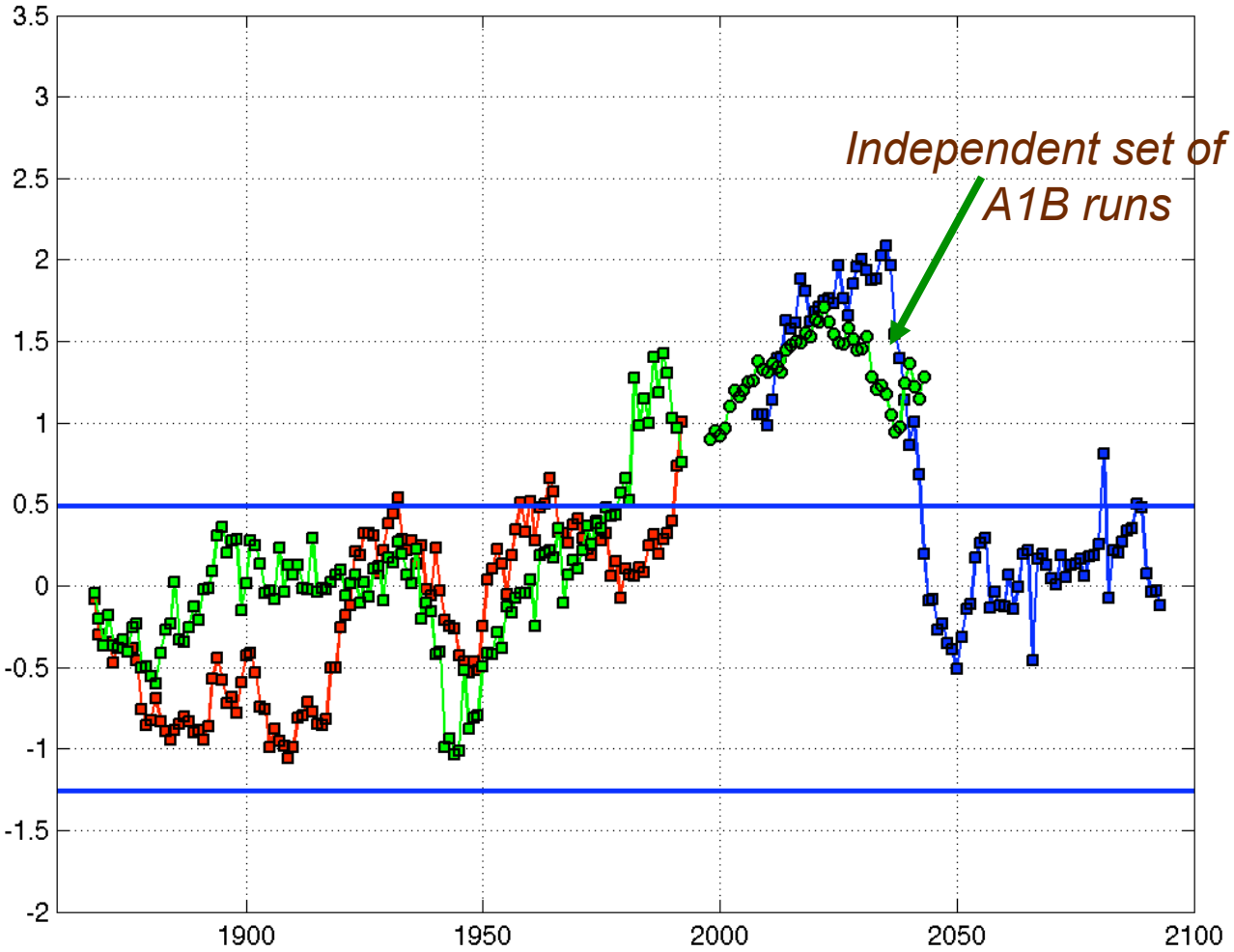
Shortwave regression across ensemble, following K. Swanson 2008



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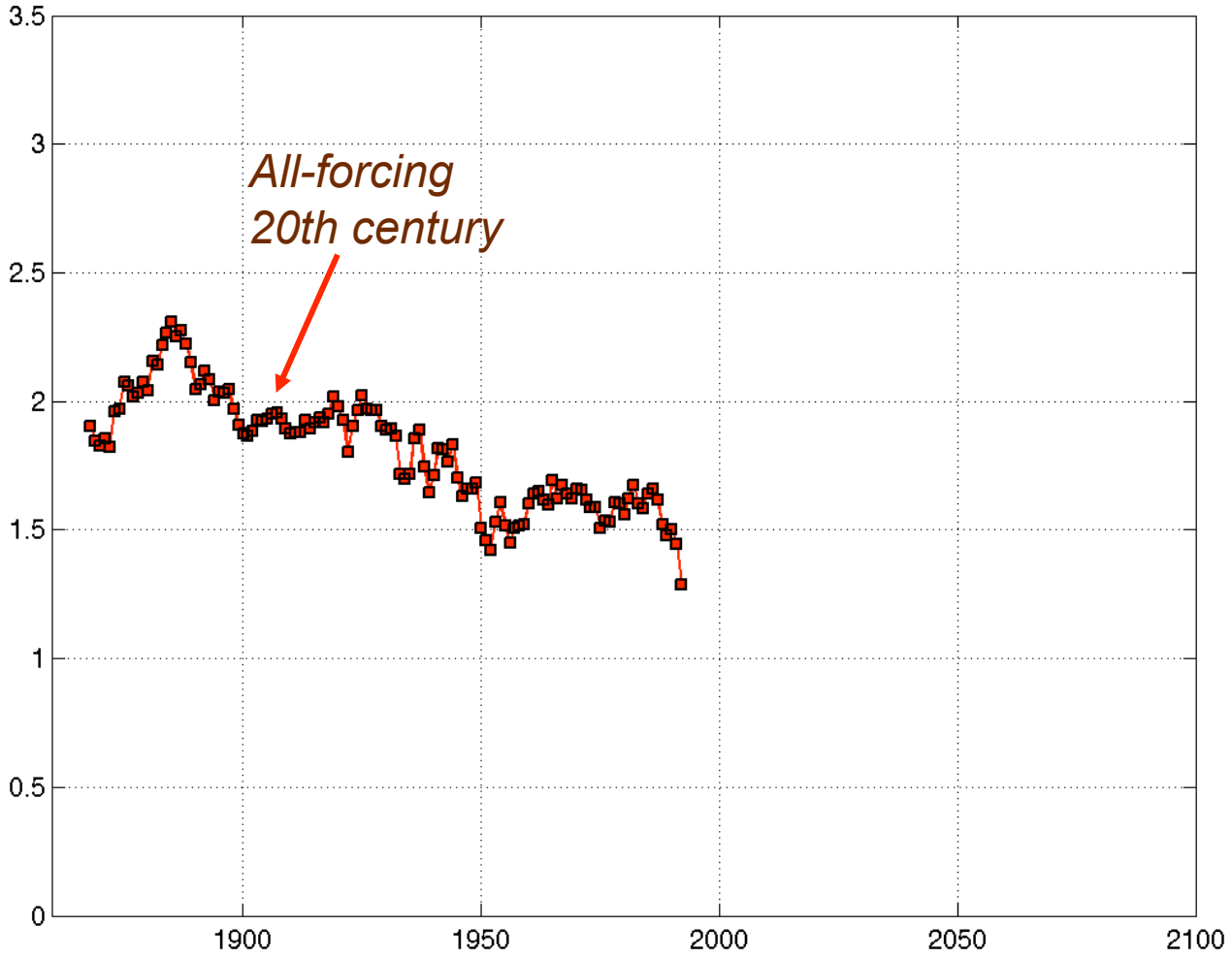
Longwave regression across ensemble, following K. Swanson 2008



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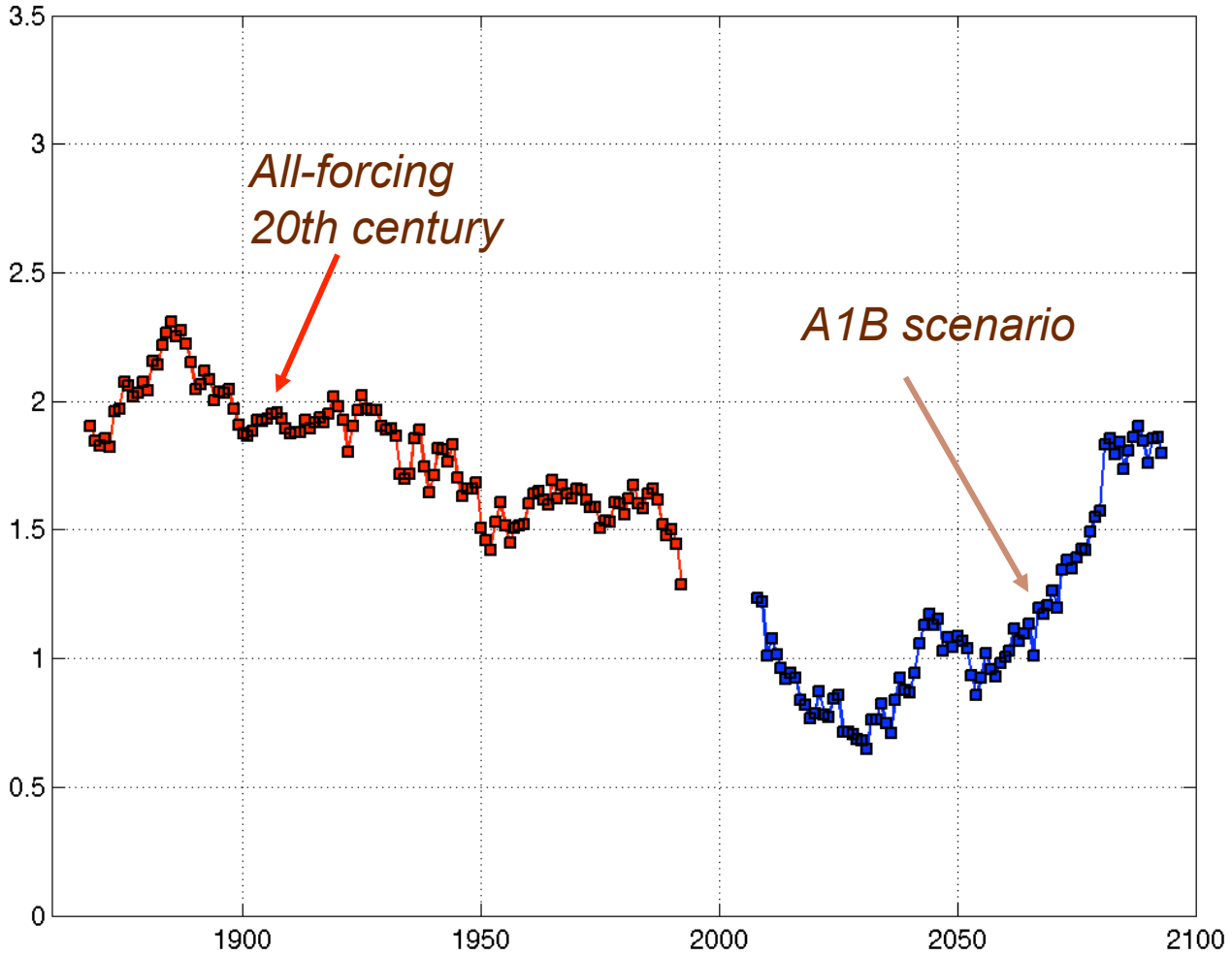
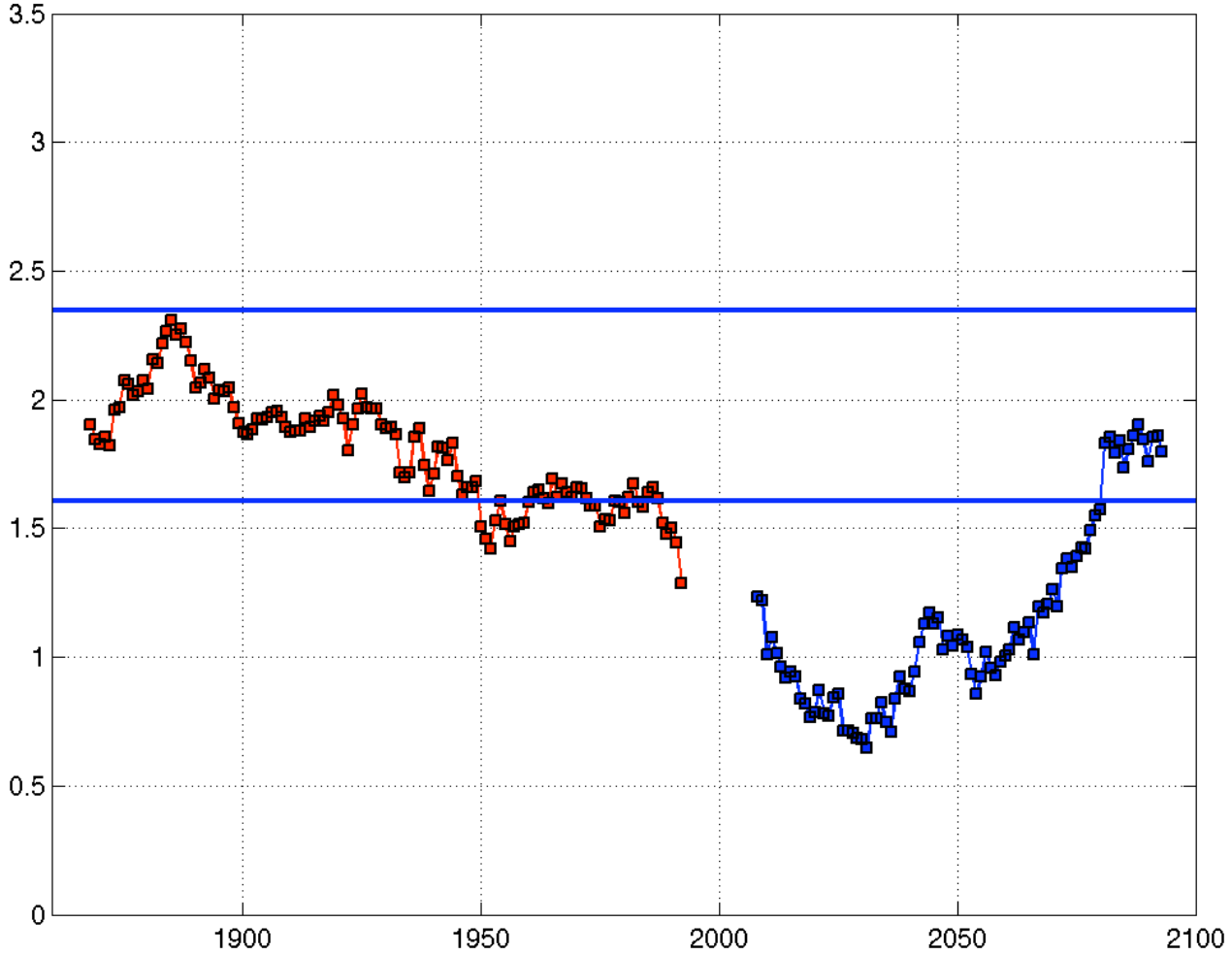


$Wm^{-2}K^{-1}$

Longwave regression across ensemble, following K. Swanson 2008

$Wm^{-2}K^{-1}$



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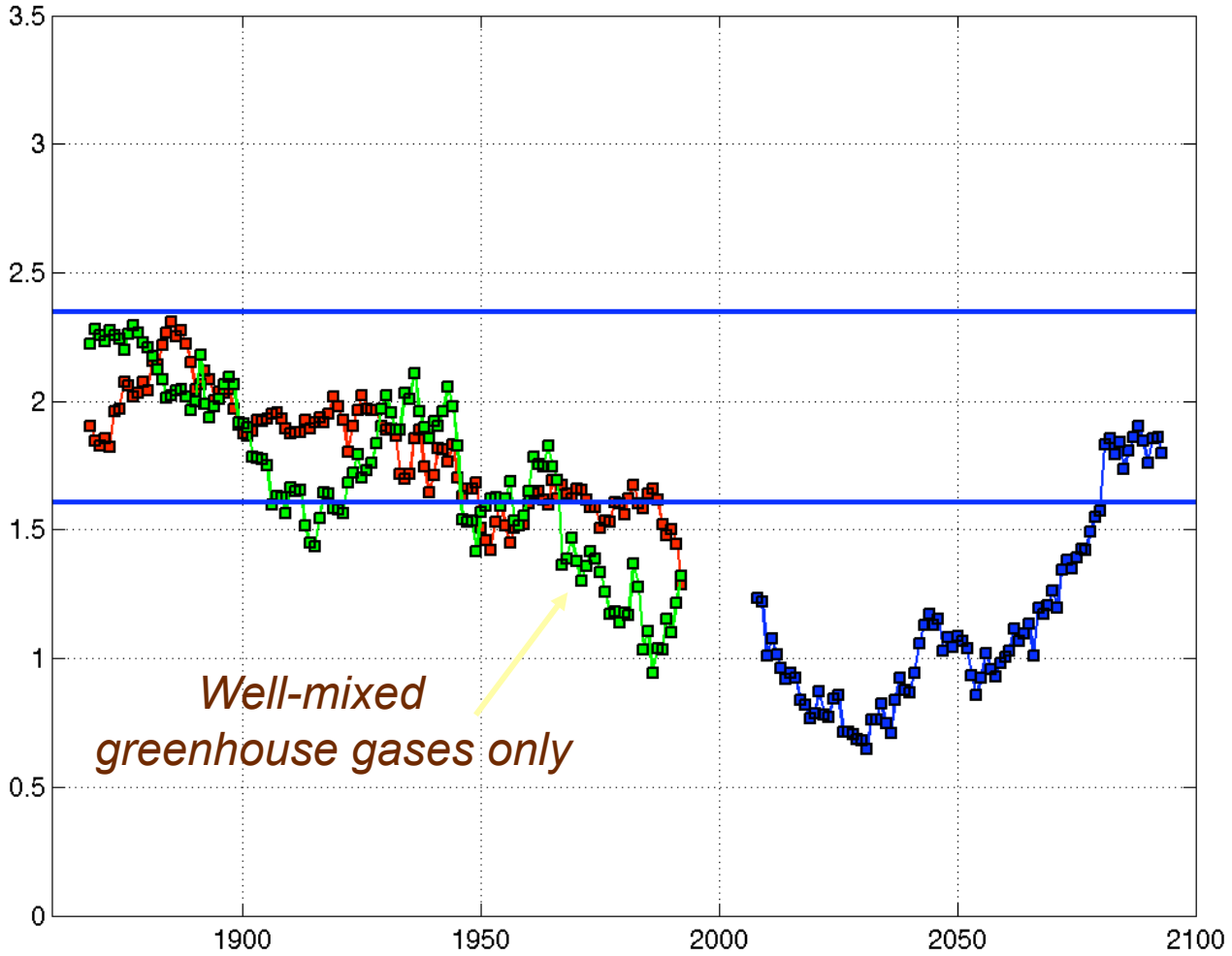
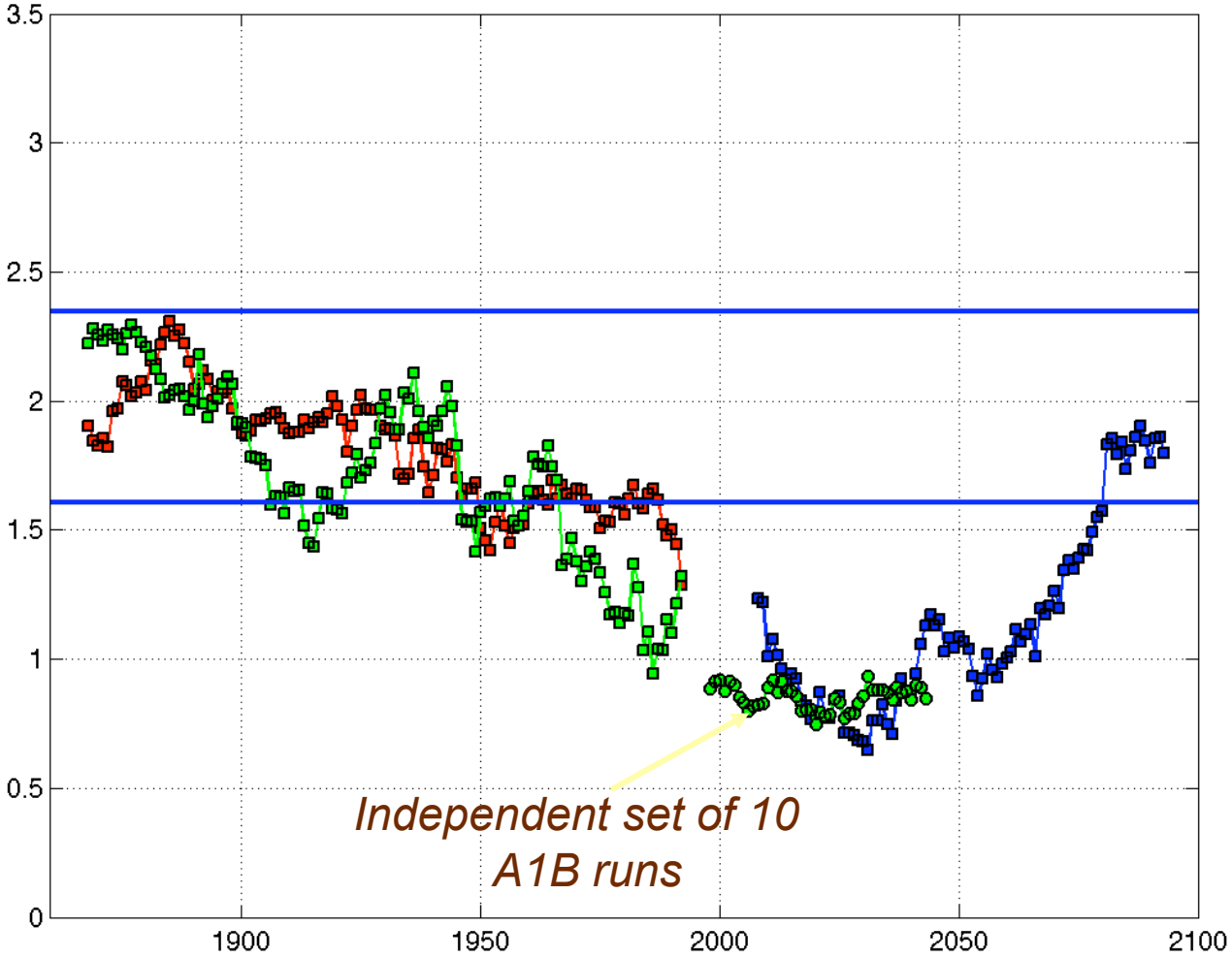
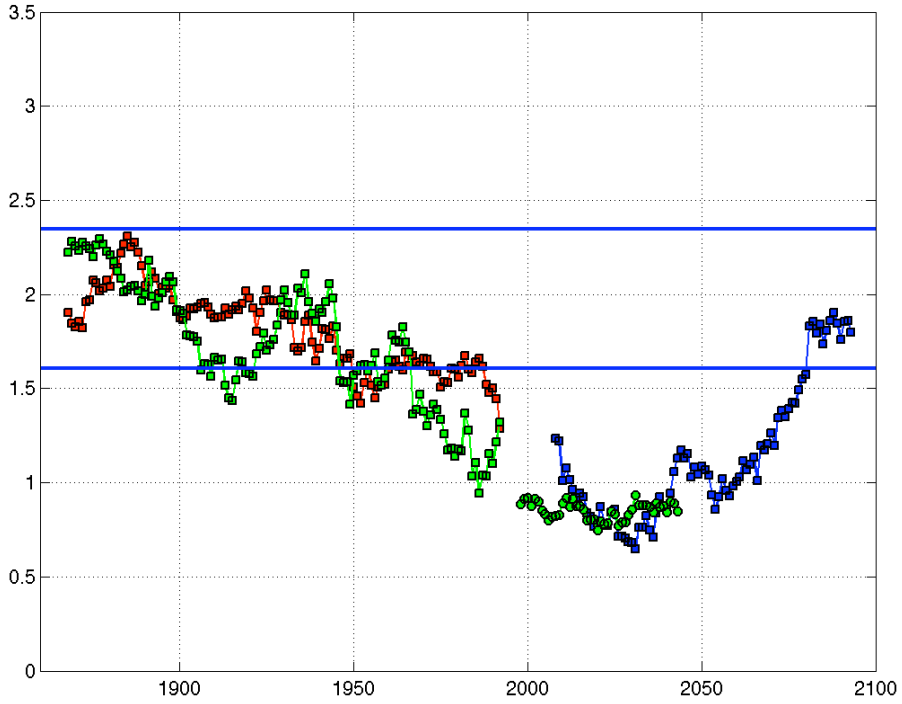


Longwave regression across ensemble, following K. Swanson 2008



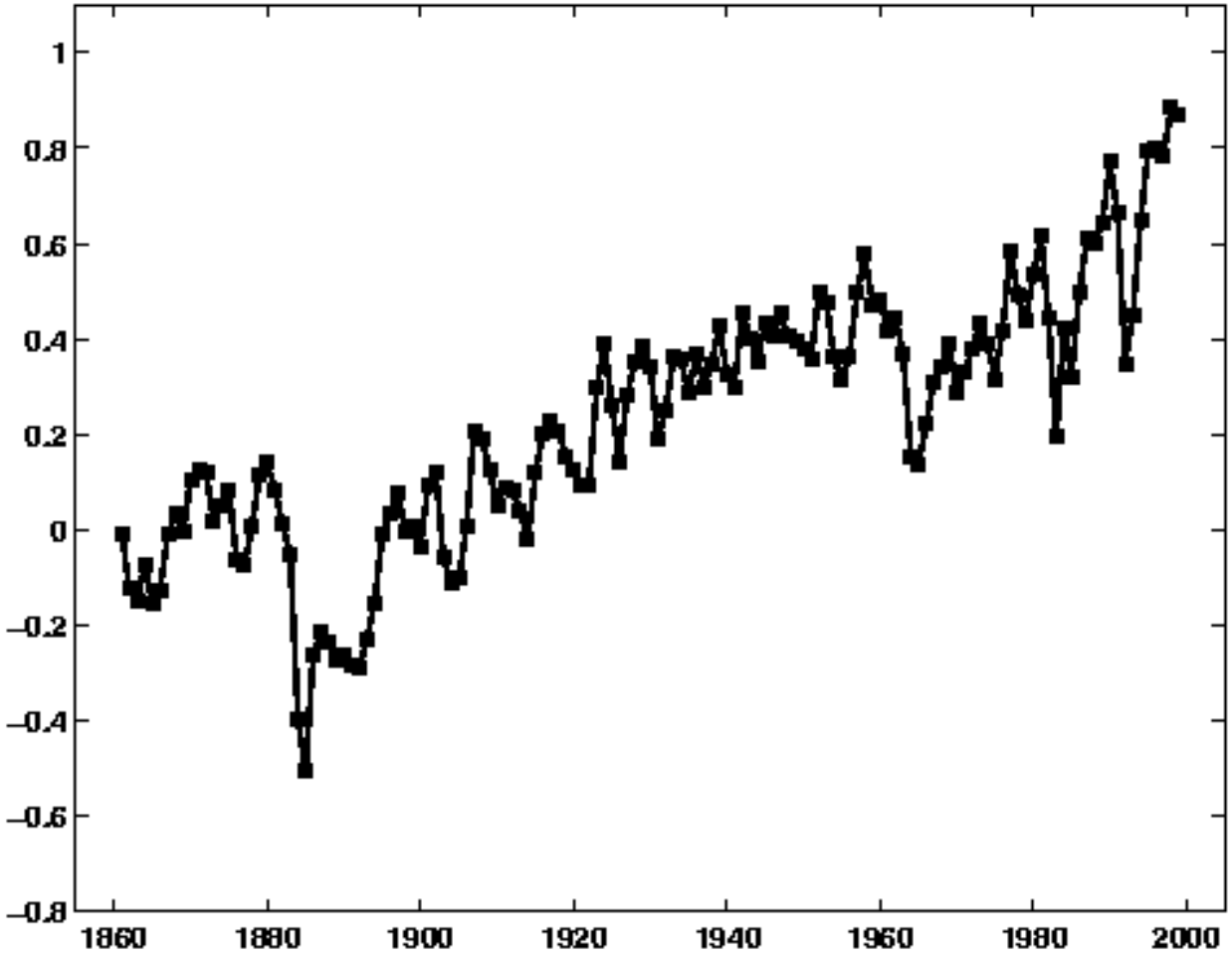
Longwave regression across ensemble, following K. Swanson 2008

But we can fit the models 20th century simulations without time-dependence in OLR-temperature relationship!



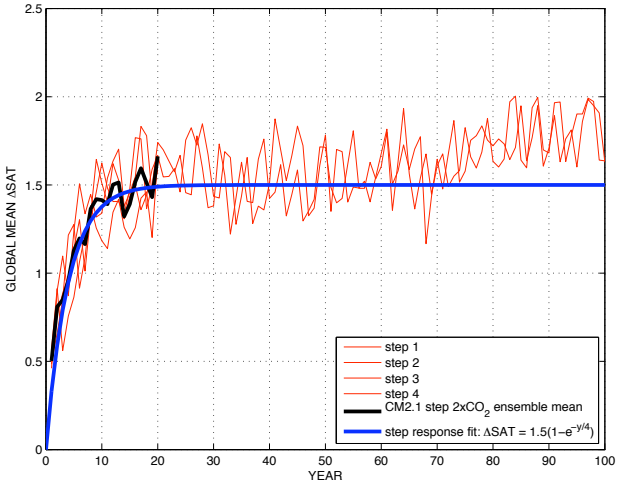
ENSO is changing in subtle ways, but with no obvious connection to global sensitivity

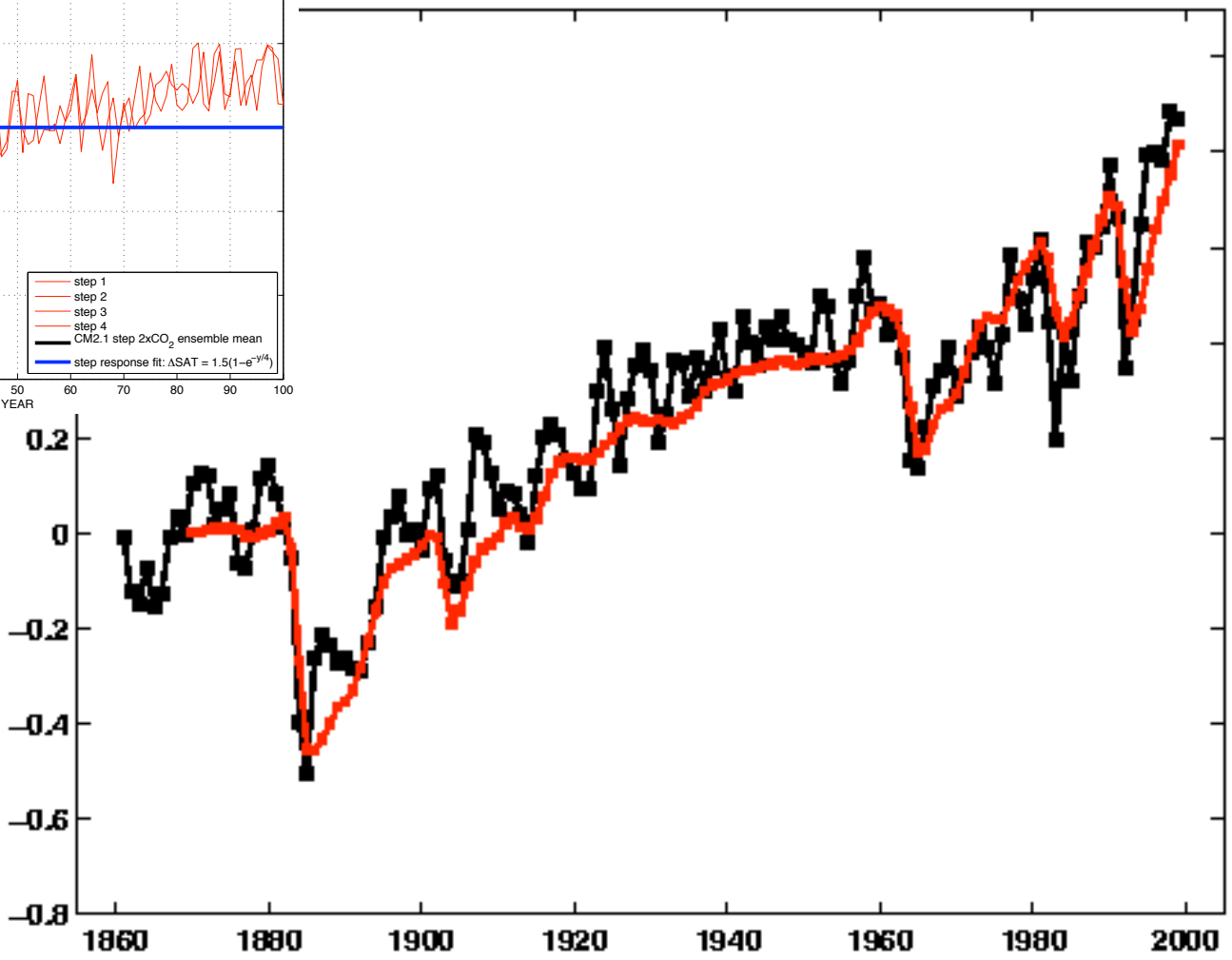
Temperature change averaged over 5 realizations of 20th century in CM2.1 coupled model



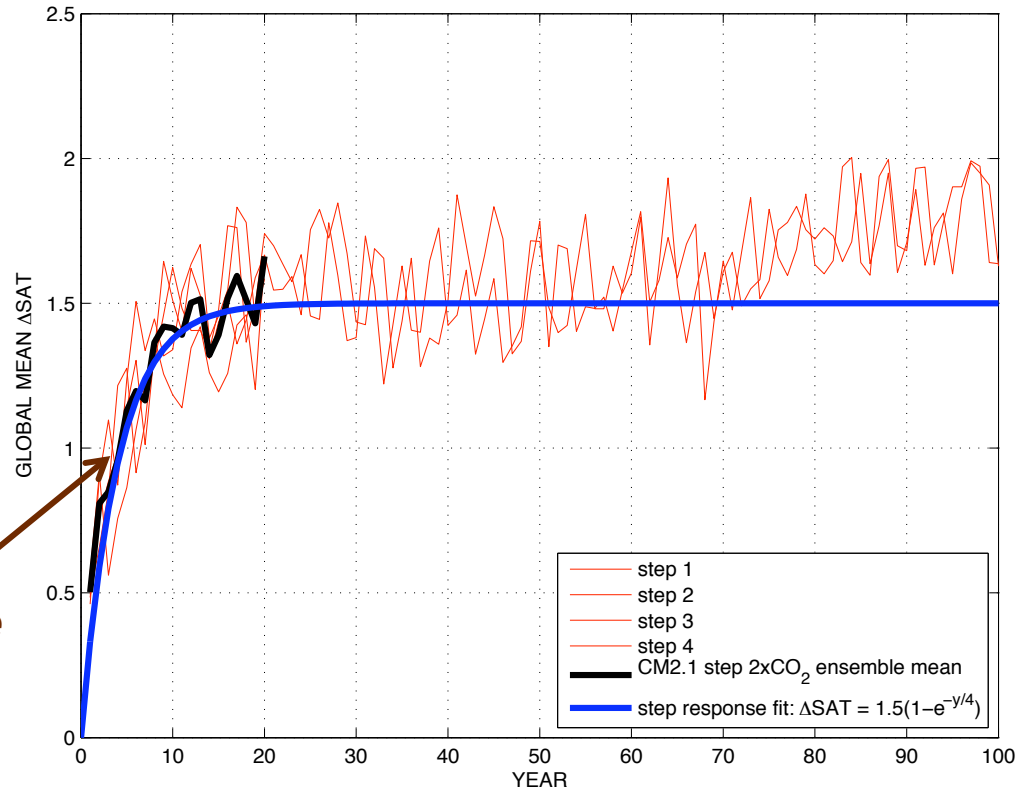
Fit with

$$C\frac{dT}{dt} = F - \beta T;\ \ \beta = 2.3\,Wm^{-2}\,/\,K; \qquad \frac{C}{\beta} = 4\,years$$





Response of global mean temperature in CM2.1 to instantaneous doubling of CO2
Equilibrium sensitivity >3K
Transient response ~1.6K



Fast response

$$T = (1.6K)e^{-t/(4\,yrs)}$$

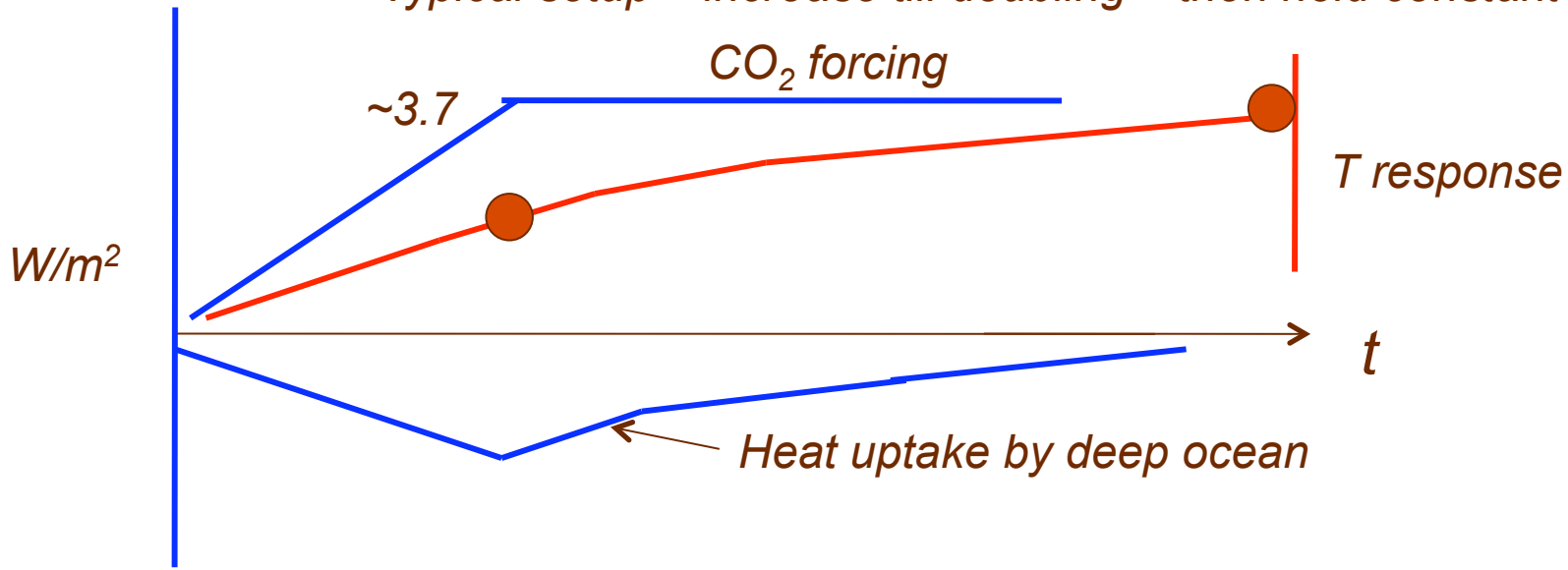
Slow response evident only after ~100 yrs and seems irrelevant for transient sensitivity

Equilibrium climate sensitivity:
Double the CO_2 and wait for the system to equilibrate

But what is the "system"?
glaciers? "natural" vegetation?

Transient climate sensitivity:
Increase CO_2 1%/yr and examine climate at the time of doubling

Typical setup – increase till doubling – then hold constant



After CO2 stabilized, warming of near surface can be thought of as due to reduction in heat uptake

$$c_F \frac{dT}{dt} = -\beta T - \gamma(T - T_D) + F$$

$$c_D \frac{dT_D}{dt} = \gamma(T - T_D)$$

Mixed layer Heat capacity

Deep ocean heat capacity

forcing

Heat exchange between mixed layer and deep ocean

$$T = T_D = \frac{F}{\beta}$$ *in equilibrium*

If

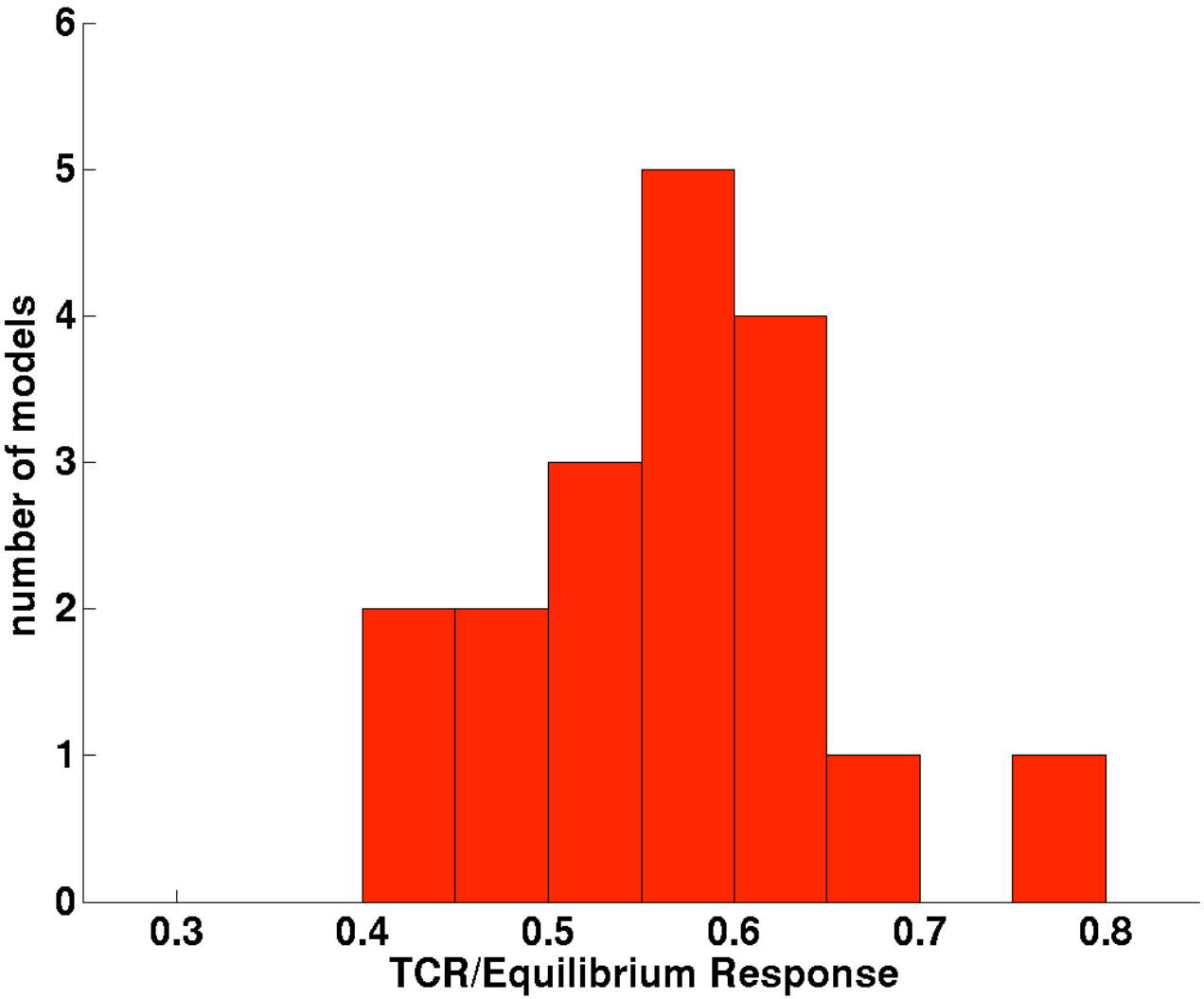
Forcing varies on time scales that are longer than
Equilibration time for shallow ocean

but shorter than time required for deep ocean to warm significantly

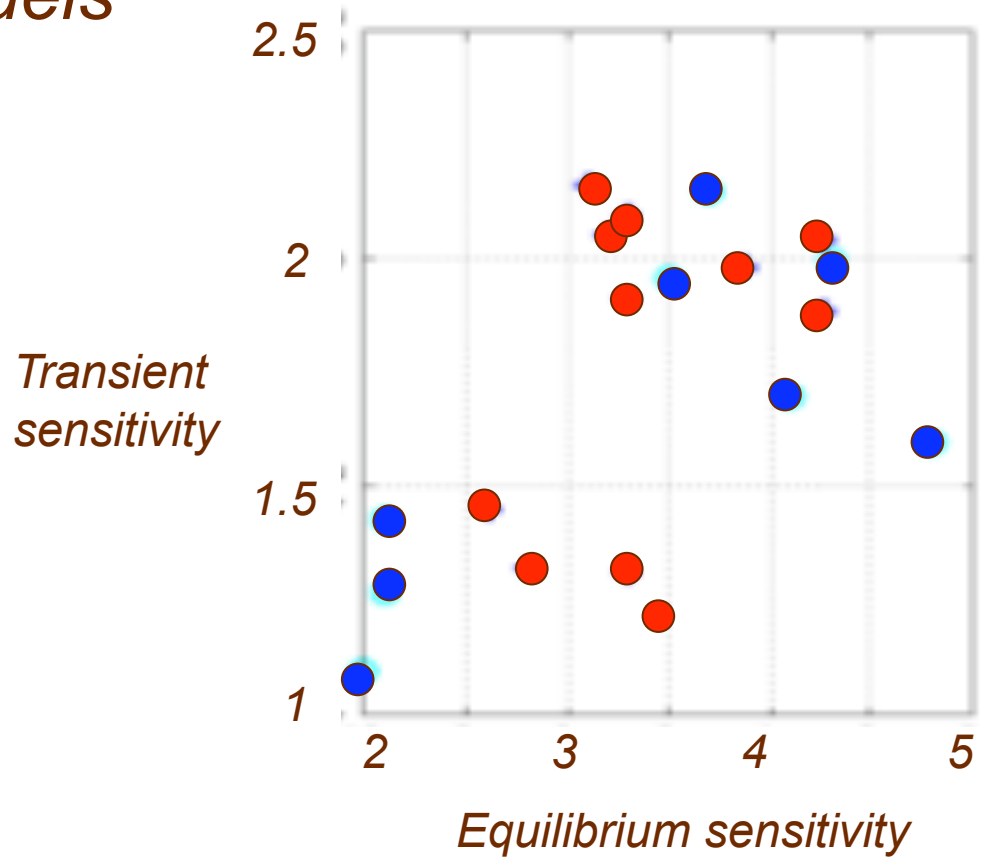
Then we are in "Intermediate regime"

$$\Rightarrow \quad T_D \approx 0 \qquad T \approx \frac{F}{\beta + \gamma}$$

$$TCR / T_{EQ} \approx \frac{\beta}{\beta + \gamma}$$


number of models
0
1
2
3
4
5
6
0.3
0.4
0.5
0.6
0.7
0.8
TCR/Equilibrium Response

AR4 models



Not well correlated across models – equiilbrium response brings into play feedbacks/dynamics in subpolar oceans that are surpressed in transient response

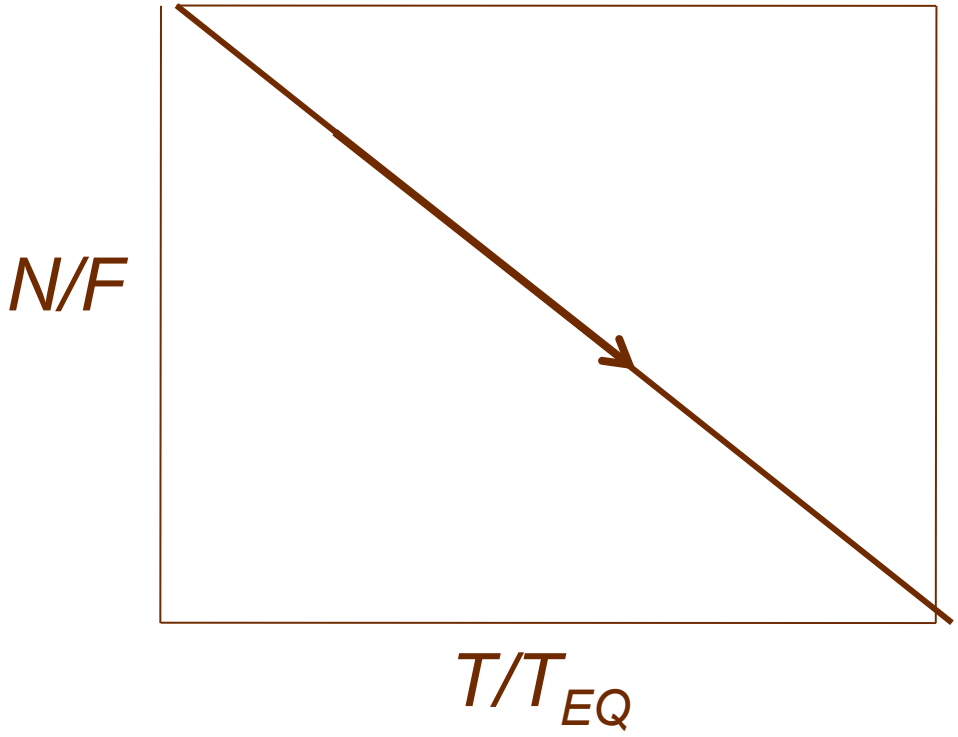
The simplest linear model

$$C\frac{dT}{dt} = F - \beta T \equiv N$$

$$T_{EQ} = F/\beta$$

$$N/F = 1 - T/T_{EQ}$$

If correct, evolution should be along the diagonal



$$C\frac{dT}{dt} = F - \beta T \equiv N$$

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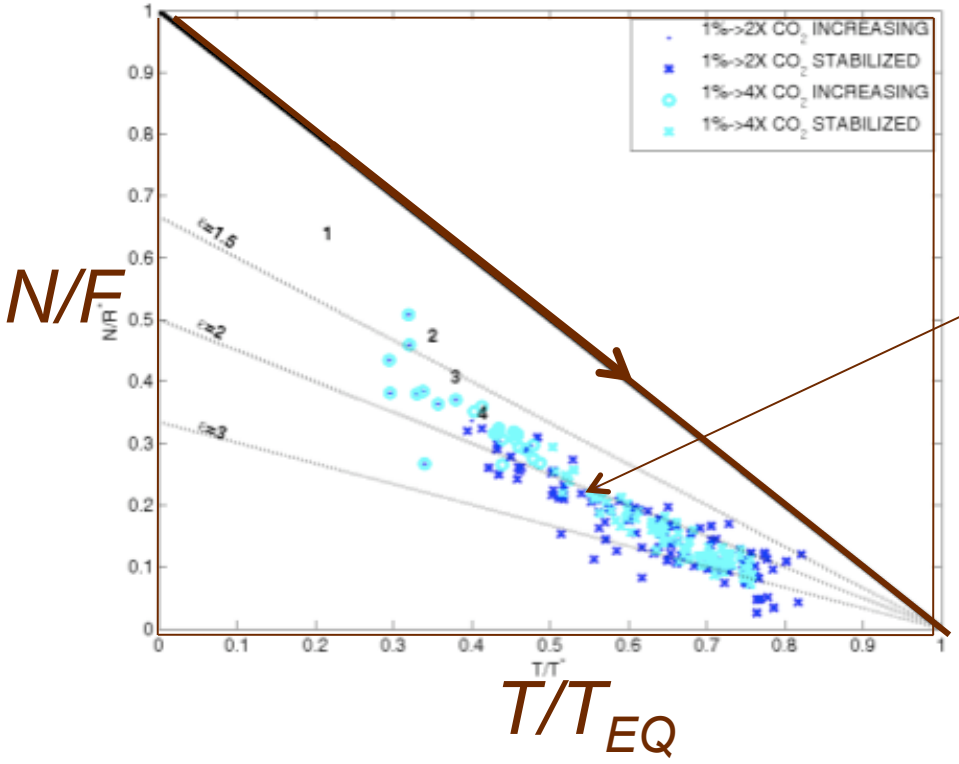
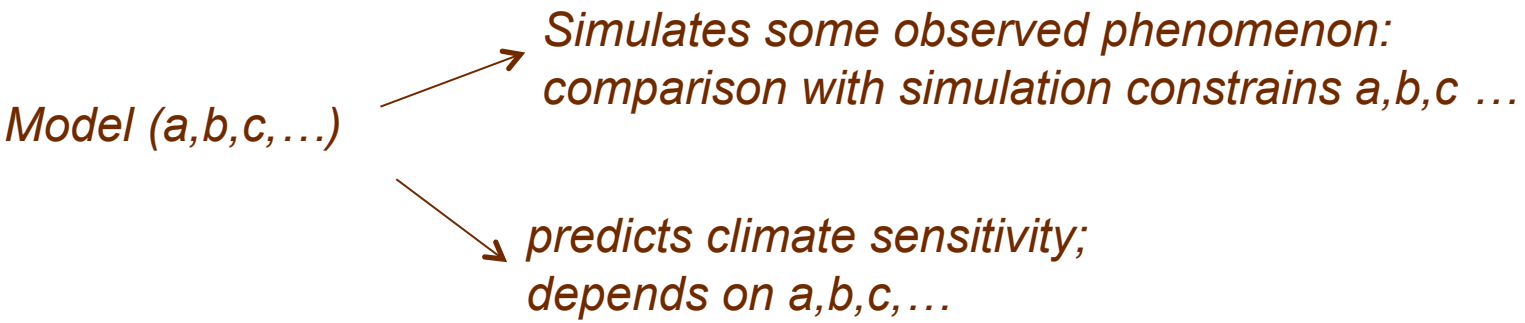
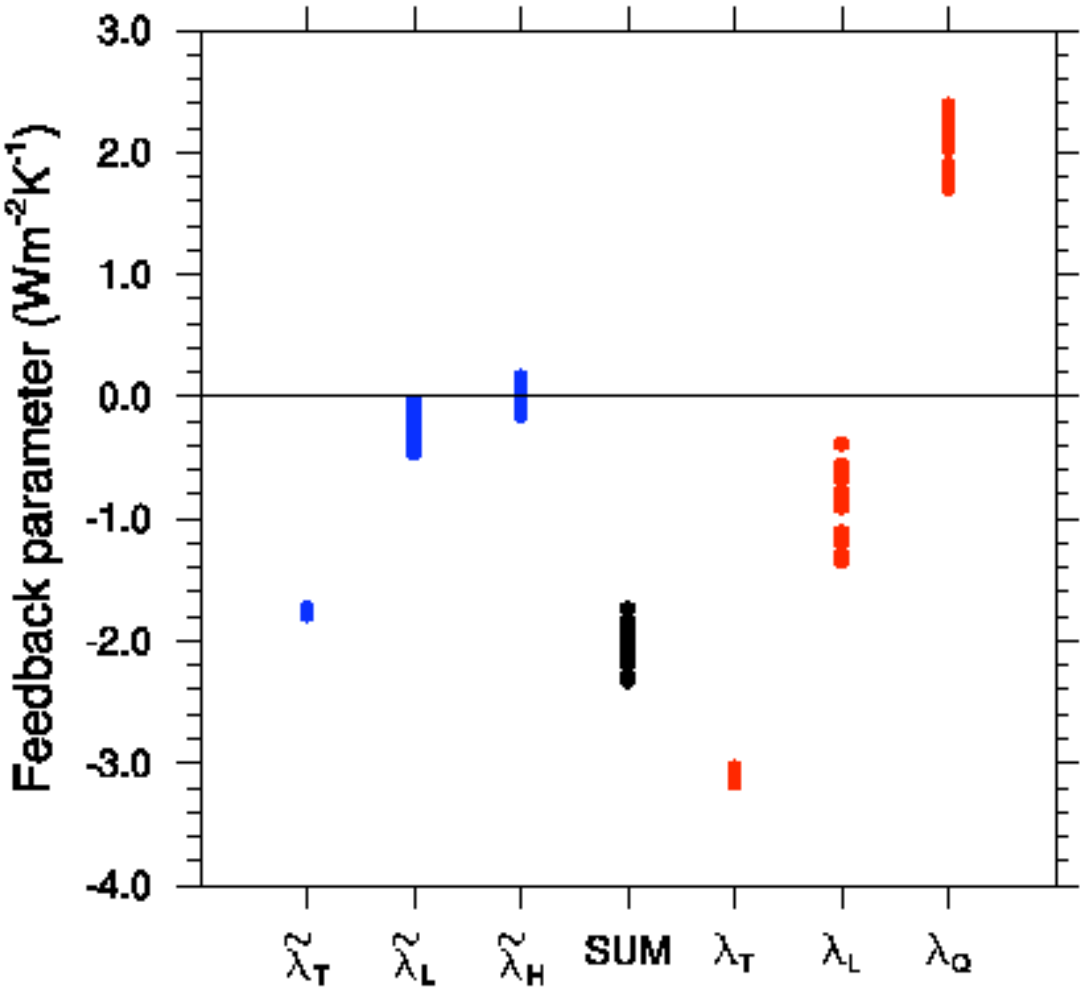


Evolution in a particular GCM (GFDL's CM2.1) for 1/% till doubling + stabilization

"Observational constraints" on climate sensitivity



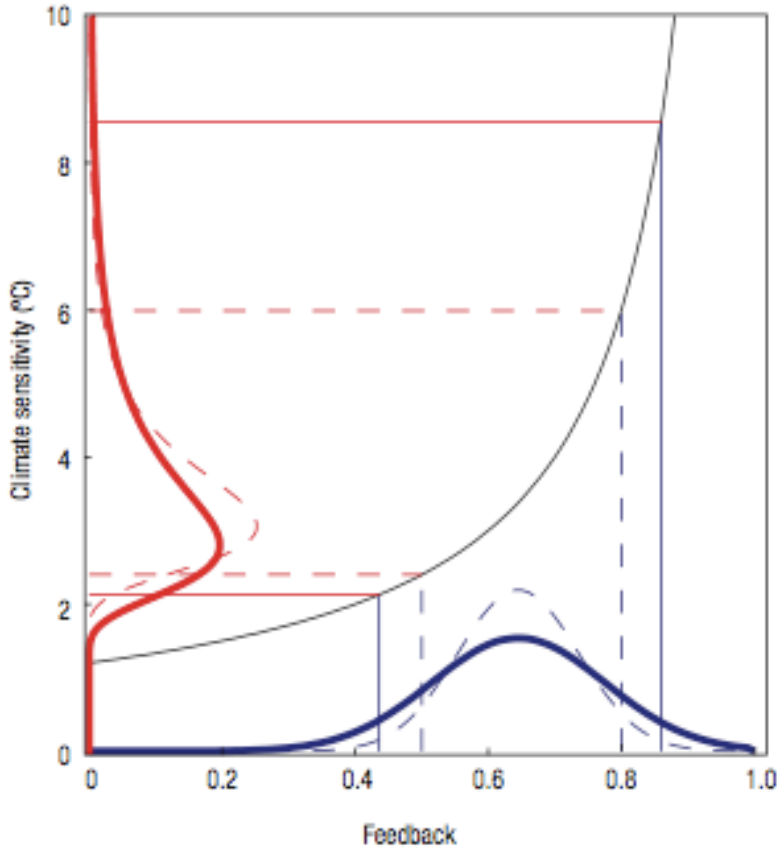
Model can be GCM – in which case constraint can be rather indirect (constraining processes of special relevance to climate sensitivity)
Or it can be simple model in which climate sensitivity is determined by 1 or 2 parameters.



Fixed lapse rate,
fixed relative humidity
reference

Fixed lapse rate,
fixed specific humidity
reference

Gaussian distribution of f => skewed distribution of Response = (Reference response) x 1/(1-f)



Roe-Baker

Final Thoughts:

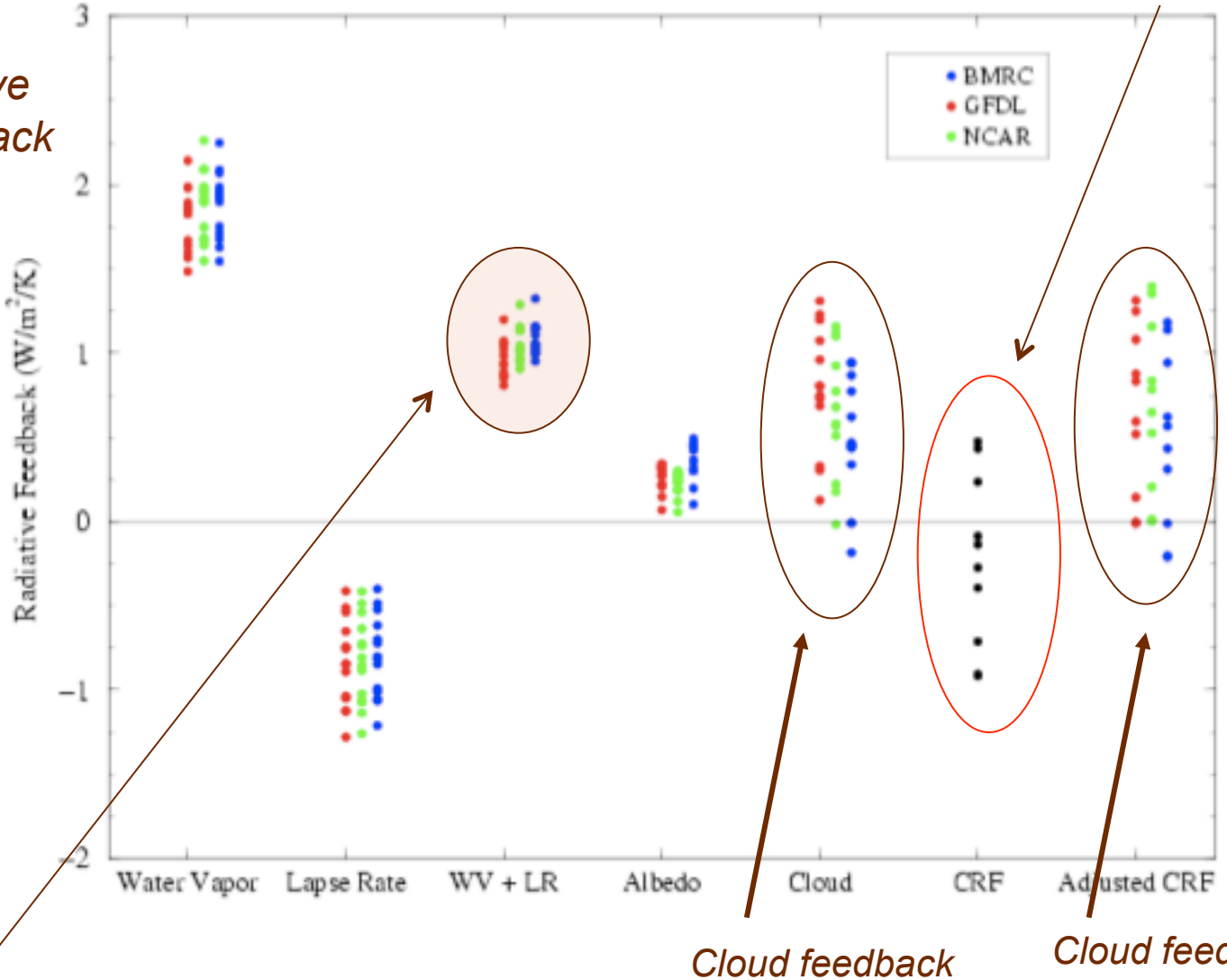
Focus on constraining transient climate sensitivity

"observational constraints on climate sensitivity"
(equilibrium or transient)
are always based on simple models
These simple models may very well be inadequate

Think in terms of (tropospheric) relative humidity feedback
rather than water vapor feedback
i.e, think of fixed relative humidity as the
reference (no-feedback) response

Rough feedback analysis for AR4 models

"Cloud forcing"



Positive feedback

Lapse rate cancels water vapor in part and reduces spread

Cloud feedback as residual

Cloud feedback by adjusting cloud forcing for masking effects