EMPIRICAL DETERMINATION OF EARTH'S CLIMATE SENSITIVITY AND IMPLICATIONS OF PRESENT UNCERTAINTIES

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Workshop on Accounting for Uncertainty:
A Conversation with Climate Scientists and Economists

New Haven, CT

November 21, 2013

GLOBAL ENERGY BUDGET

$$\frac{dH}{dt} \equiv N$$

$$\frac{dH}{dt} \equiv N = J_{\text{abs}} - J_{\text{emit}}$$

For unperturbed climate system (***steady state***),

$$\frac{dH}{dt} \equiv N = J_{\text{abs}} - J_{\text{emit}} = 0$$

Apply a forcing: $\frac{dH}{dt} \equiv N = F$

Climate system responds: $\frac{dH}{dt} \equiv N = F - R$

Linear response *ansatz*: $R = \lambda \Delta T$

"EQUILIBRIUM" CLIMATE SENSITIVITY

$$N = F - \lambda \Delta T$$

$$\lambda \Delta T = F - N$$

$$\Delta T = \frac{F - N}{\lambda}$$

At new ***steady state*** following response to ***constant forcing*** F, $N \rightarrow 0$ and

$$\Delta T \rightarrow \frac{F}{\lambda} = \Delta T_{\mathrm{eq}} = S_{\mathrm{eq}} F \,,$$

from which, "equilibrium" climate sensitivity $S_{\mathrm{eq}} \equiv \dfrac{\Delta T_{\mathrm{eq}}}{F} = \lambda^{-1}$.

Units: $\mathrm{K} / (\mathrm{W\ m^{-2}})$ or $\mathrm{K} / (3.7\ \mathrm{W\ m^{-2}})$ as $F_{2\times \mathrm{CO_2}} \approx 3.7\ \mathrm{W\ m^{-2}}$

DETERMINATION OF "EQUILIBRIUM" CLIMATE SENSITIVITY

$$S_{\mathrm{eq}}\left[\mathrm{K}/(\mathrm{W\ m^{-2}})\right]=\frac{\Delta T}{F-N};\quad S_{\mathrm{eq}}\left[\mathrm{K}/(3.7\ \mathrm{W\ m^{-2}})\right]=3.7\frac{\Delta T}{F-N}$$

ΔT, late 19th century to present, from observation: 0.78 K.

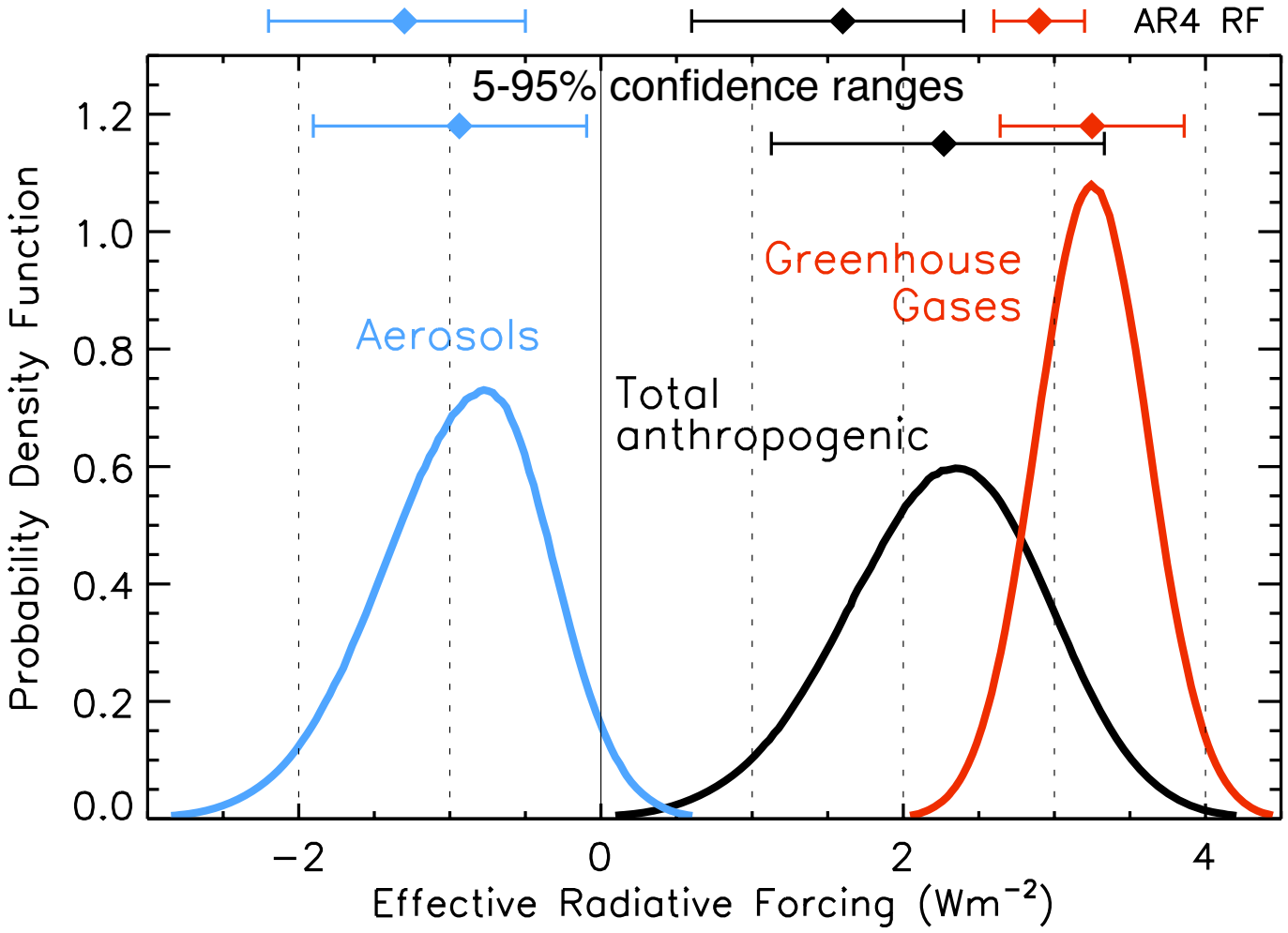
N from present observed rate of increase of ocean heat content: 0.35 W m^{-2}.

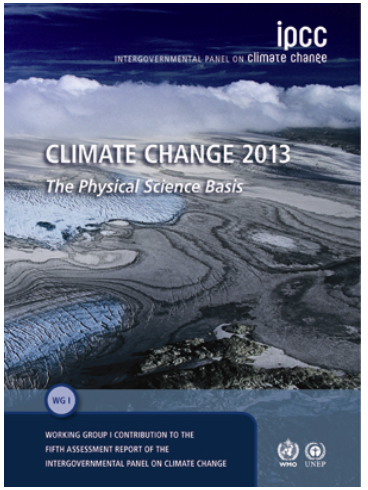
Forcing not well known.

Evaluate as function of forcing for assumed range of forcing.

RADIATIVE FORCING OF CLIMATE CHANGE

Probability density functions for anthropogenic forcing, 1750-2011



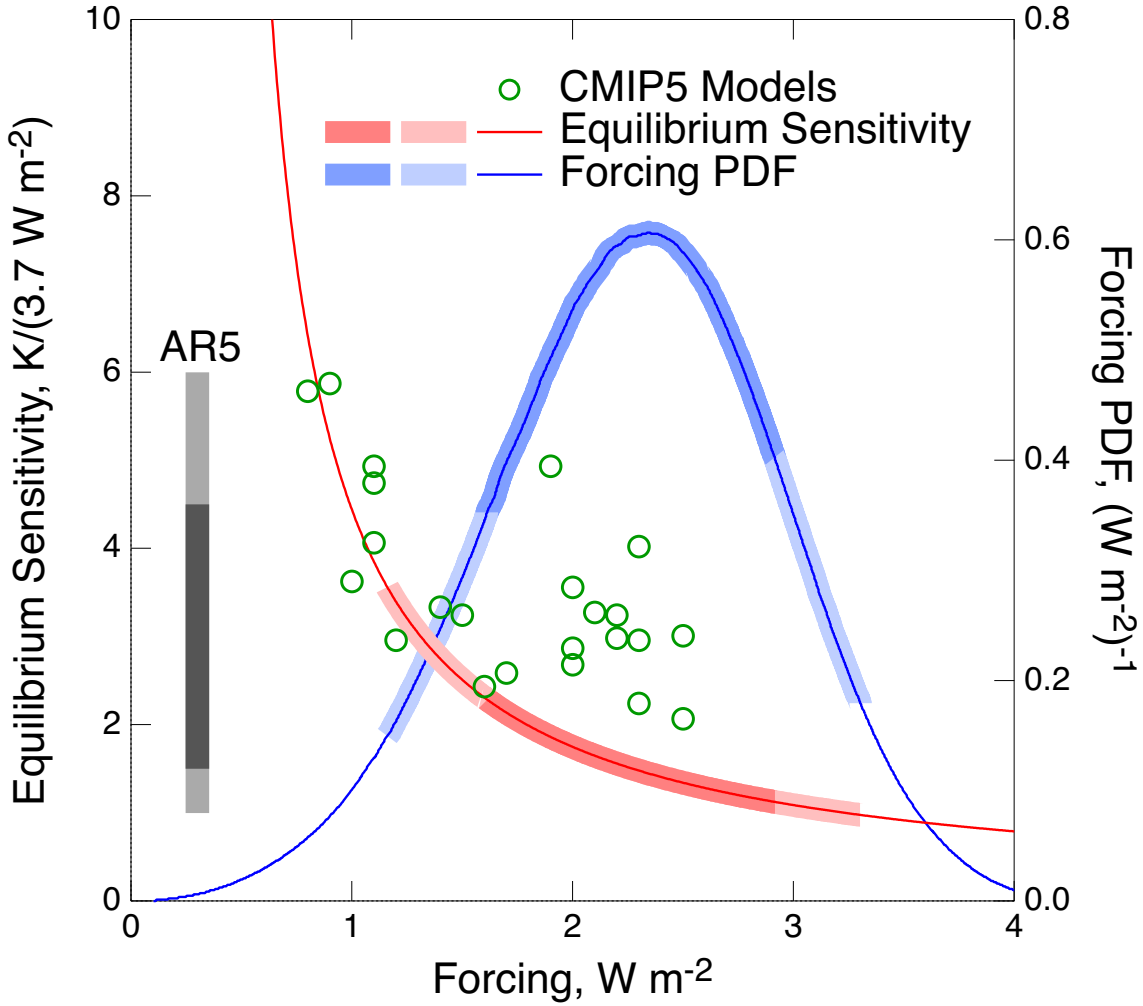


IPCC, AR5, 2013, Fig. 8.16

Total forcing is sum of greenhouse gas plus (negative) aerosol forcing.
Effective forcing accounts for rapid atmospheric response to perturbations.
Uncertainty in total forcing is due largely to uncertainty in aerosol forcing.

EMPIRICAL DETERMINATION OF "EQUILIBRIUM" CLIMATE SENSITIVITY

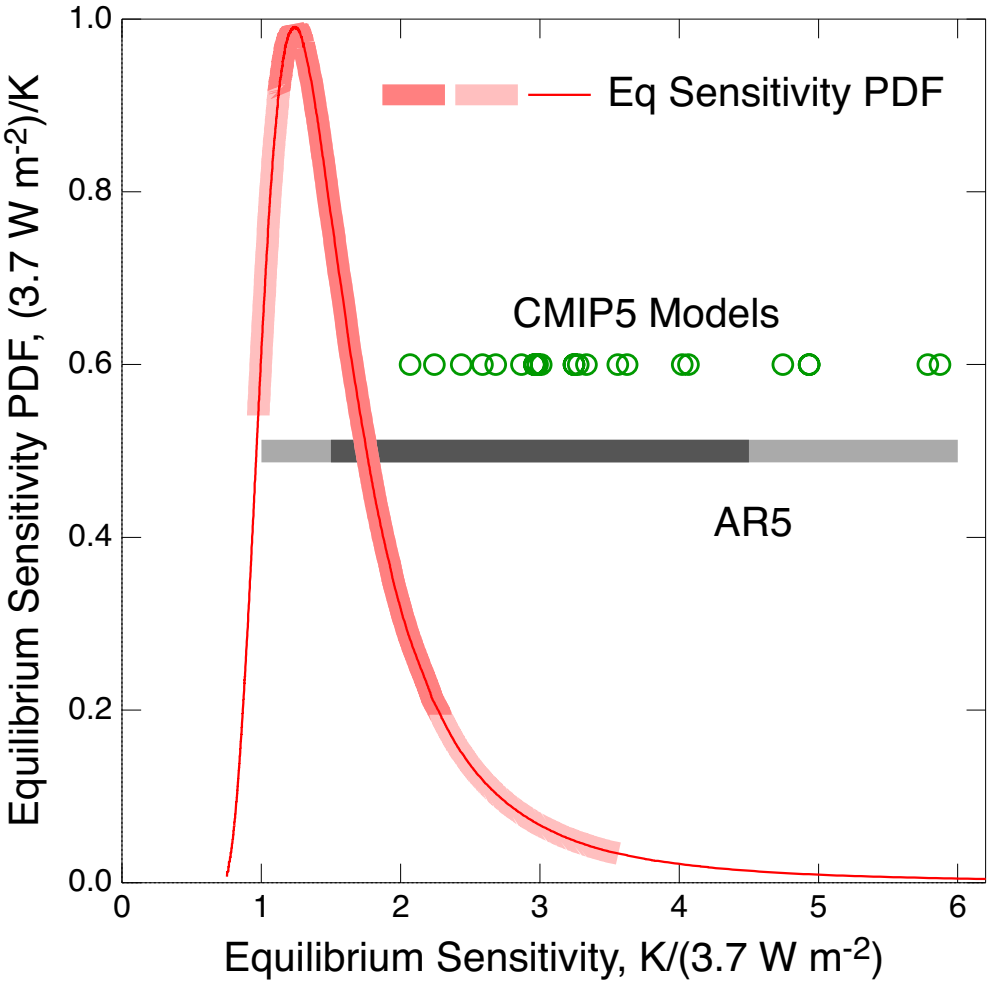
Dependence on assumed forcing for $\Delta T = 0.78$ K and $N = 0.35$ W m^{-2}



"Likely" and "very likely" sensitivity ranges corresponding to forcing ranges are much lower than sensitivity ranges in AR5 and CMIP5 models.

EMPIRICAL DETERMINATION OF "EQUILIBRIUM" CLIMATE SENSITIVITY

PDF of equilibrium sensitivity determined from PDF of AR5 forcing



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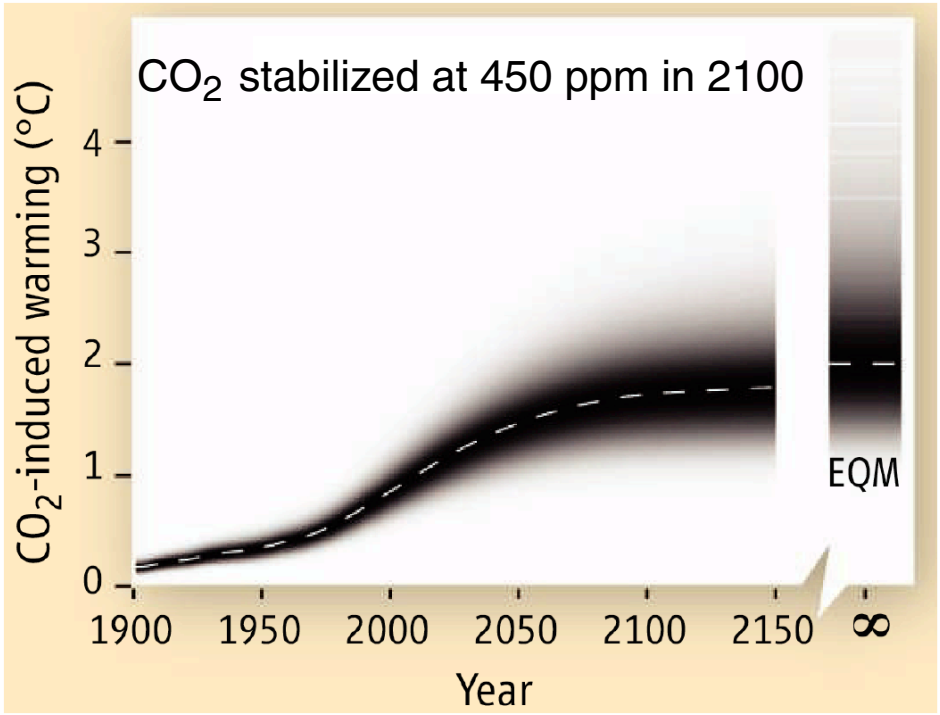
26 OCTOBER 2007 VOL 318 **SCIENCE** www.sciencemag.org

ATMOSPHERE

Call Off the Quest

Myles R. Allen and David J. Frame

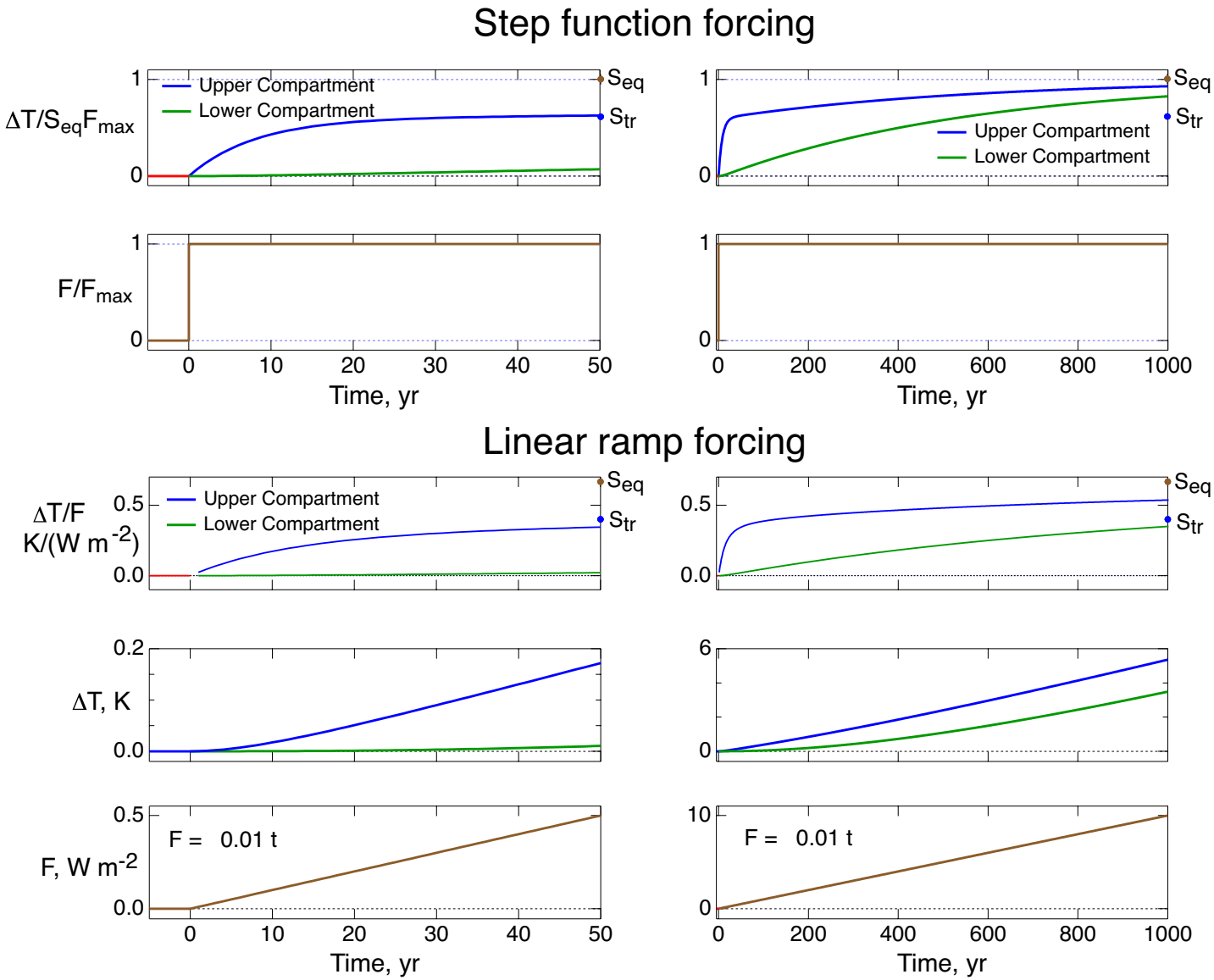
Knowledge of the long-term response of Earth's climate to a doubling of atmospheric carbon doixide may be less useful for policy-makers than commonly assumed.



“ An upper bound on the climate sensitivity has become the holy grail of climate research.... It is inherently hard to find. It promises lasting fame and happiness to the finder, but it may not exist and turns out not to be very useful if you do find it. Time to call off the quest.

FORCING AND RESPONSE IN TWO-COMPARTMENT SYSTEM

Realistic analog for Earth climate system



Modified from Schwartz, Surv. Geophys. 2012

Transient sensitivity represents temperature change on multi-decadal scale.

DETERMINATION OF "EQUILIBRIUM" CLIMATE SENSITIVITY

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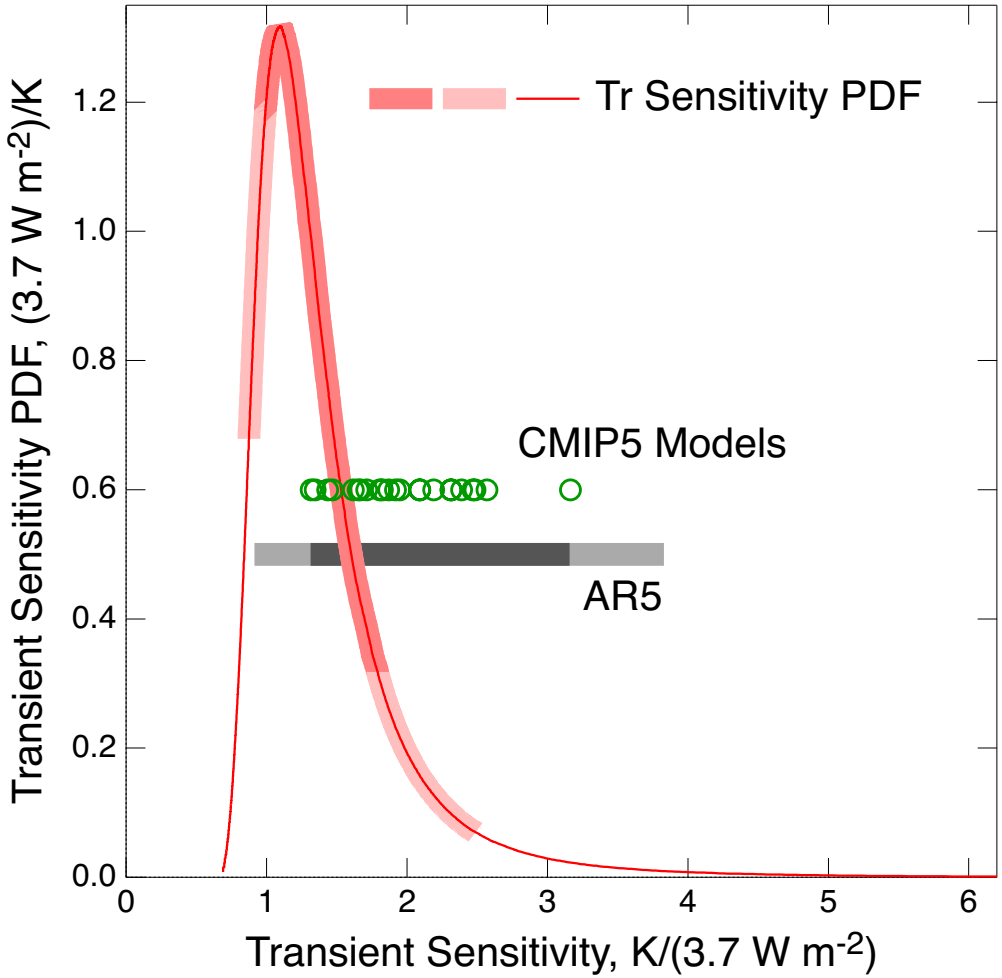
TRANSIENT CLIMATE SENSITIVITY

$$S_{\mathrm{tr}}\left[\mathrm{K}/(\mathrm{W\ m^{-2}})\right]=\frac{\Delta T}{F};\quad S_{\mathrm{tr}}\left[\mathrm{K}/(3.7\ \mathrm{W\ m^{-2}})\right]=3.7\frac{\Delta T}{F}$$

EMPIRICAL DETERMINATION OF TRANSIENT CLIMATE SENSITIVITY

PDF of ***transient*** sensitivity determined from PDF of AR5 forcing



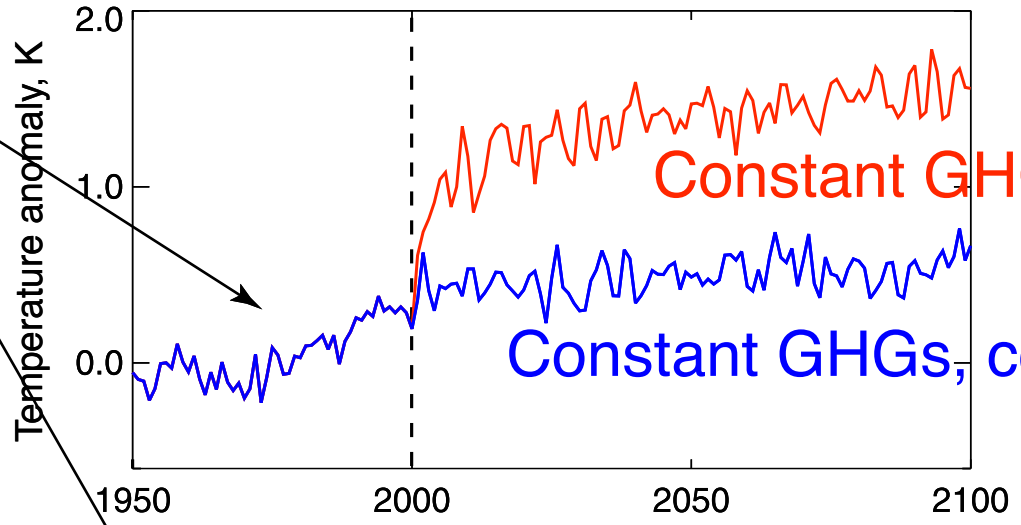
"Likely" and "very likely" sensitivity ranges corresponding to forcing ranges are much lower than sensitivity ranges in AR5 and CMIP5 models.

USING CLIMATE MODELS TO ANSWER "WHAT IF" QUESTIONS

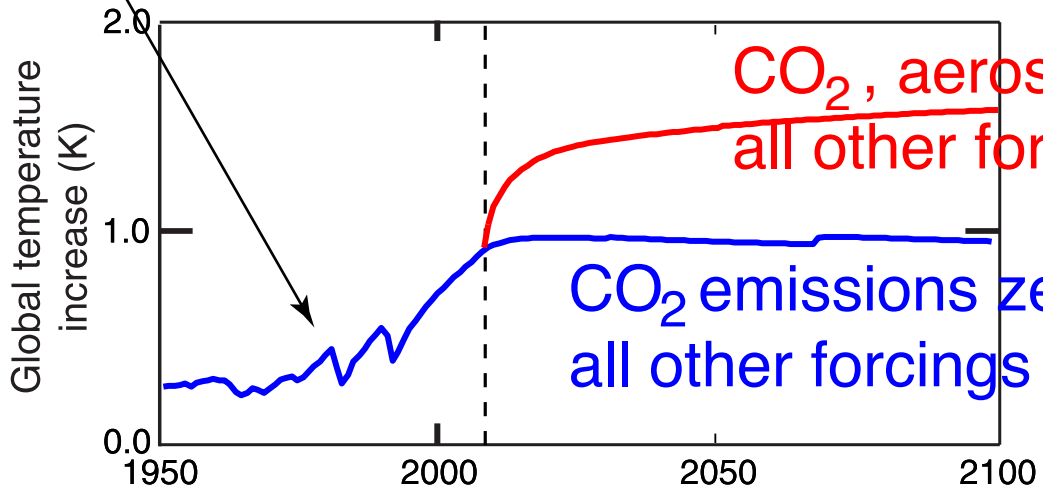
Turn off CO_2 emissions ***and aerosol forcing***

Increasing GHGs and aerosols

Hamburg ECHAM-5 coupled ocean-atmosphere model
Brasseur & Roeckner GRL, 2007



Bern 2D intermediate complexity carbon cycle–climate model
Knutti & Plattner J Climate, 2012



Global temperature ***rapidly increases*** when aerosol forcing is halted.

COMMITTED WARMING

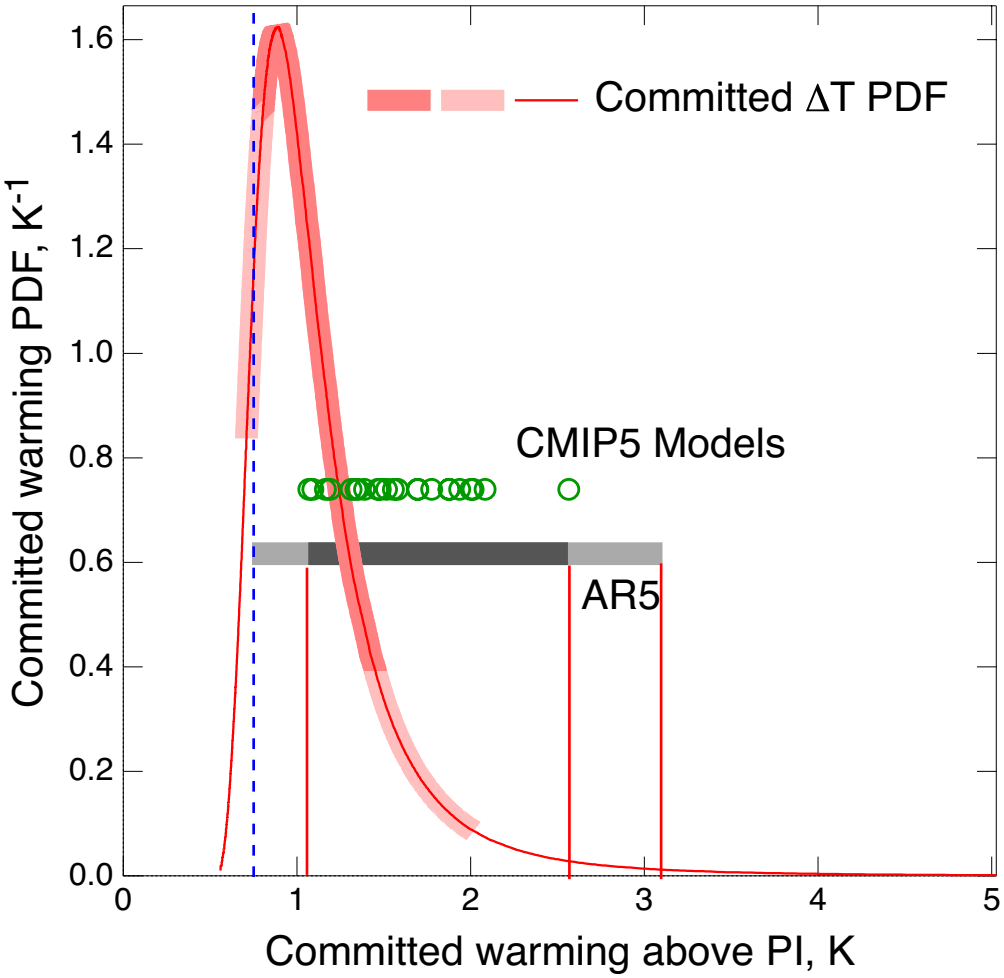
Calculate committed warming from forcing by long-lived greenhouse gases only, maintained at present mixing ratio.

Assumes forcings by short-lived species (importantly aerosols) will rapidly decrease to zero.

$$\Delta T_{\mathrm{cmt}} = S_{\mathrm{tr}} F_{\mathrm{ghg}} = \frac{F_{\mathrm{ghg}} \Delta T}{F}$$

EMPIRICAL DETERMINATION OF COMMITTED WARMING RELATIVE TO PI

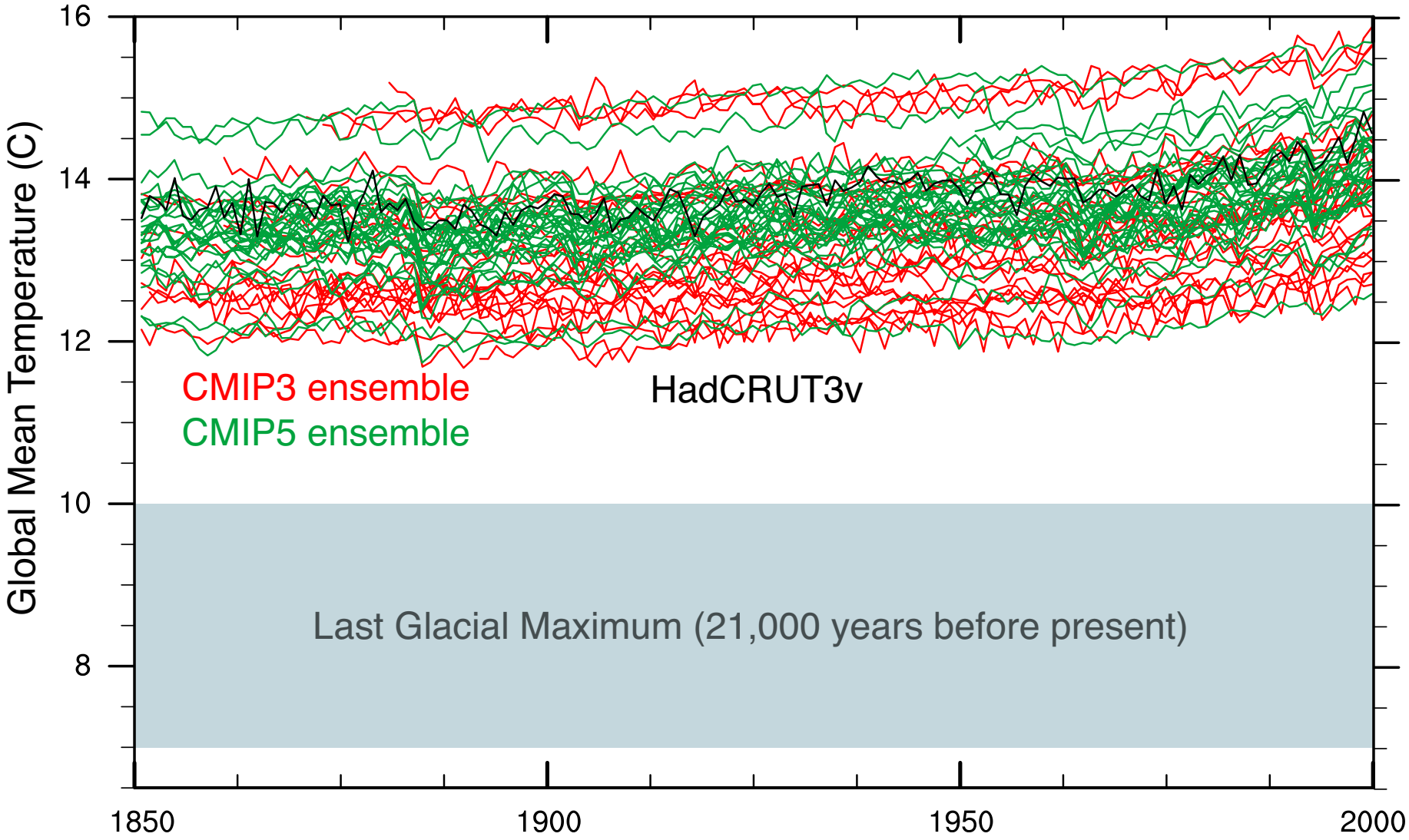
PDF of ***committed warming*** determined from PDF of AR5 forcing



"Likely" and "very likely" ranges corresponding to forcing ranges are much lower than sensitivity ranges for AR5 sensitivity and CMIP5 models.

GLOBAL MEAN SURFACE TEMPERATURE 1850-2000

Measurements and Coupled Atmosphere Ocean Models



Mauritsen, Stevens, Roeckner, et al. 2012

Some improvement in CMIP-5 models, but spread is still substantial relative to observed warming and to warming since last LGM.

FOR DISCUSSION

Is global mean surface temperature (GMST) an appropriate measure of climate change? ***Is it sufficient?***

Do other indices of climate change scale with GMST?

How much increase of GMST above preindustrial is ***acceptable***?

Is equilibrium sensitivity important? Is ***transient sensitivity*** more relevant?

What is the ***magnitude of climate forcing?*** Is it at the high end or current estimates or the low end?

How much of a ***bump in temperature*** can be expected if we stop emitting aerosols/precursors?

Can we afford to reduce carbon emissions? Can we afford not to?

Are current ***global climate models reliable enough*** for planning emissions and energy futures? If not, what can we rely on?