WHY HASN'T THE EARTH CLIMATE WARMED AS MUCH AS EXPECTED?

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FROM FORCING BY LONG-LIVED GREENHOUSE GASES?

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Why Hasn't Earth Warmed as Much as Expected?

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HOW MUCH WARMING IS EXPECTED?

$$\begin{array}{c}\text{Equilibrium change}\\ \text{in global mean}\\ \text{surface temperature}\end{array} = \begin{array}{c}\text{Climate}\\ \text{sensitivity}\end{array} \times \text{Forcing}$$

$$\Delta T = S \times F$$

S is ***equilibrium*** sensitivity. Units: K/(W m^{-2})

Sensitivity is commonly expressed as "CO_2 doubling temperature"

$$\Delta T_{2\times} \equiv S \times F_{2\times}$$

where $F_{2\times}$ is the "CO_2 doubling forcing" *ca.* 3.7 W m^{-2}.

THE WARMING DISCREPANCY

For increases in CO_2, CH_4, N_2O, and CFCs over the industrial period

$$F = 2.6 \text{ W m}^{-2}$$

IPCC, 2007
Best Estimate

Expected temperature increase:

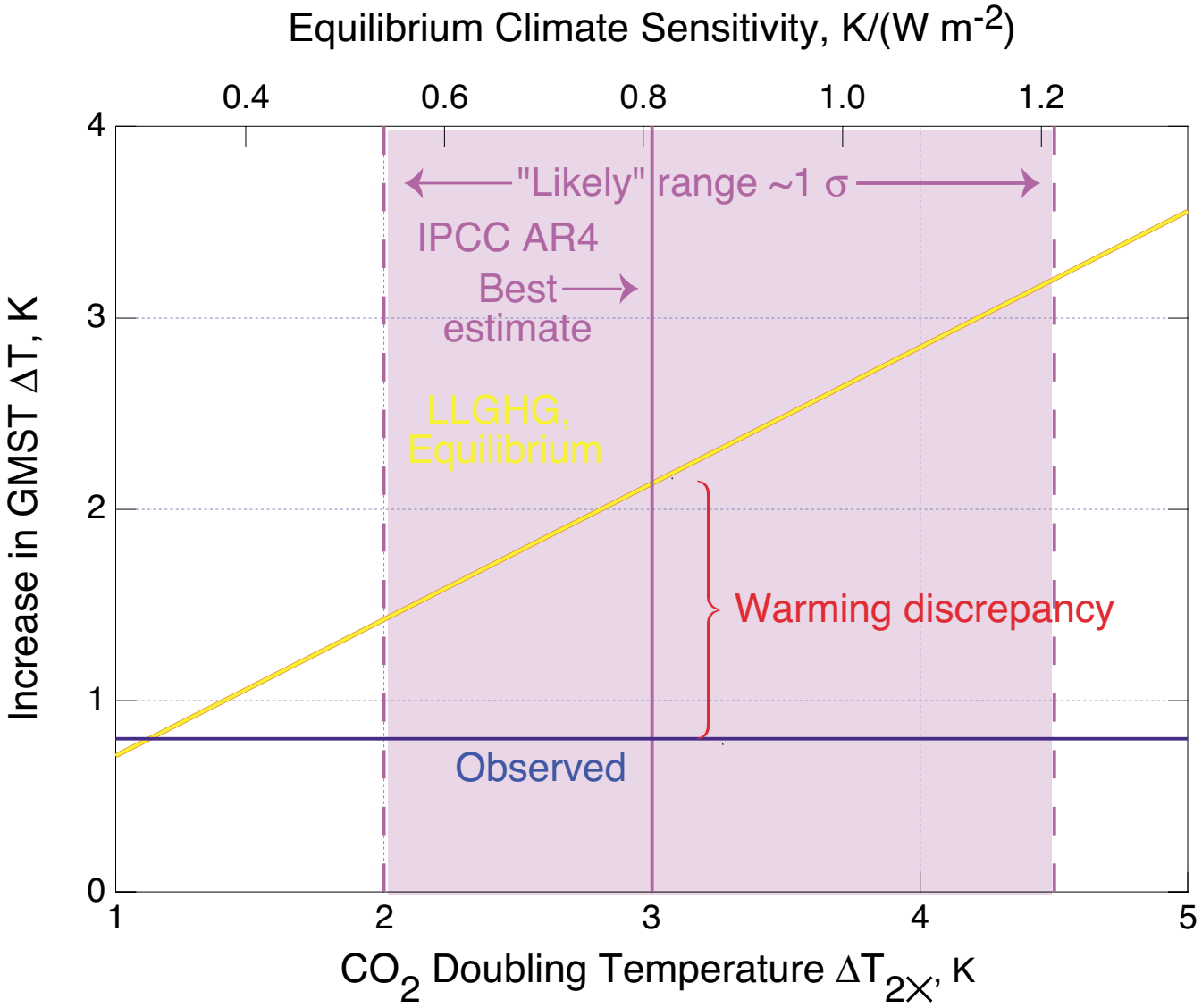
$$\Delta T_{\text{exp}} = \frac{F}{F_{2\times}} \times \Delta T_{2\times} = \frac{2.6}{3.7} \times 3 \text{ K} = 2.1 \text{ K}$$

Observed temperature increase:

$$\Delta T_{\text{obs}} = 0.8 \text{ K}$$

EXPECTED INCREASE IN GLOBAL TEMPERATURE

Long-lived GHGs only – Dependence on climate sensitivity



This discrepancy holds throughout the IPCC AR4 “likely” range for climate sensitivity.

WHY HASN'T THE EARTH CLIMATE WARMED AS MUCH AS EXPECTED?

FROM FORCING BY LONG-LIVED GREENHOUSE GASES?

- ~~Uncertainty in greenhouse gas forcing.~~
- ~~Countervailing natural cooling over the industrial period.~~
- Lag in reaching thermal equilibrium. ~0.4 W m^{-2} – 15%
- Countervailing cooling forcing by aerosols.
- Climate sensitivity lower than current estimates.

AEROSOL FORCING UNCERTAINTY AND ITS IMPLICATIONS

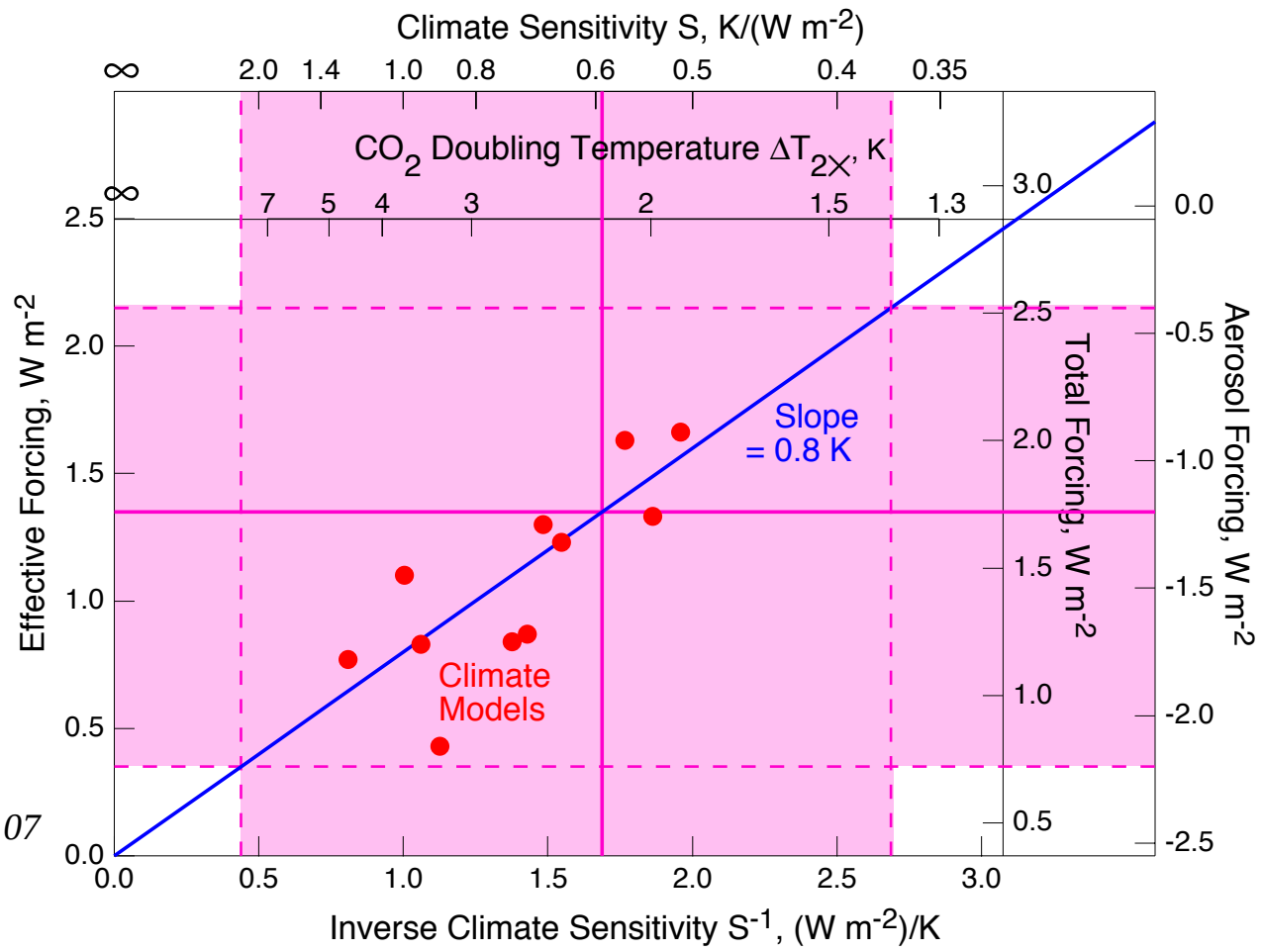
CLIMATE MODEL DETERMINATION OF CLIMATE SENSITIVITY

Effect of uncertainty in forcing

$$F_{\text{eff}} = F - H$$

$$\Delta T = SF_{\text{eff}}$$

$$F_{\text{eff}} = \Delta T S^{-1}$$

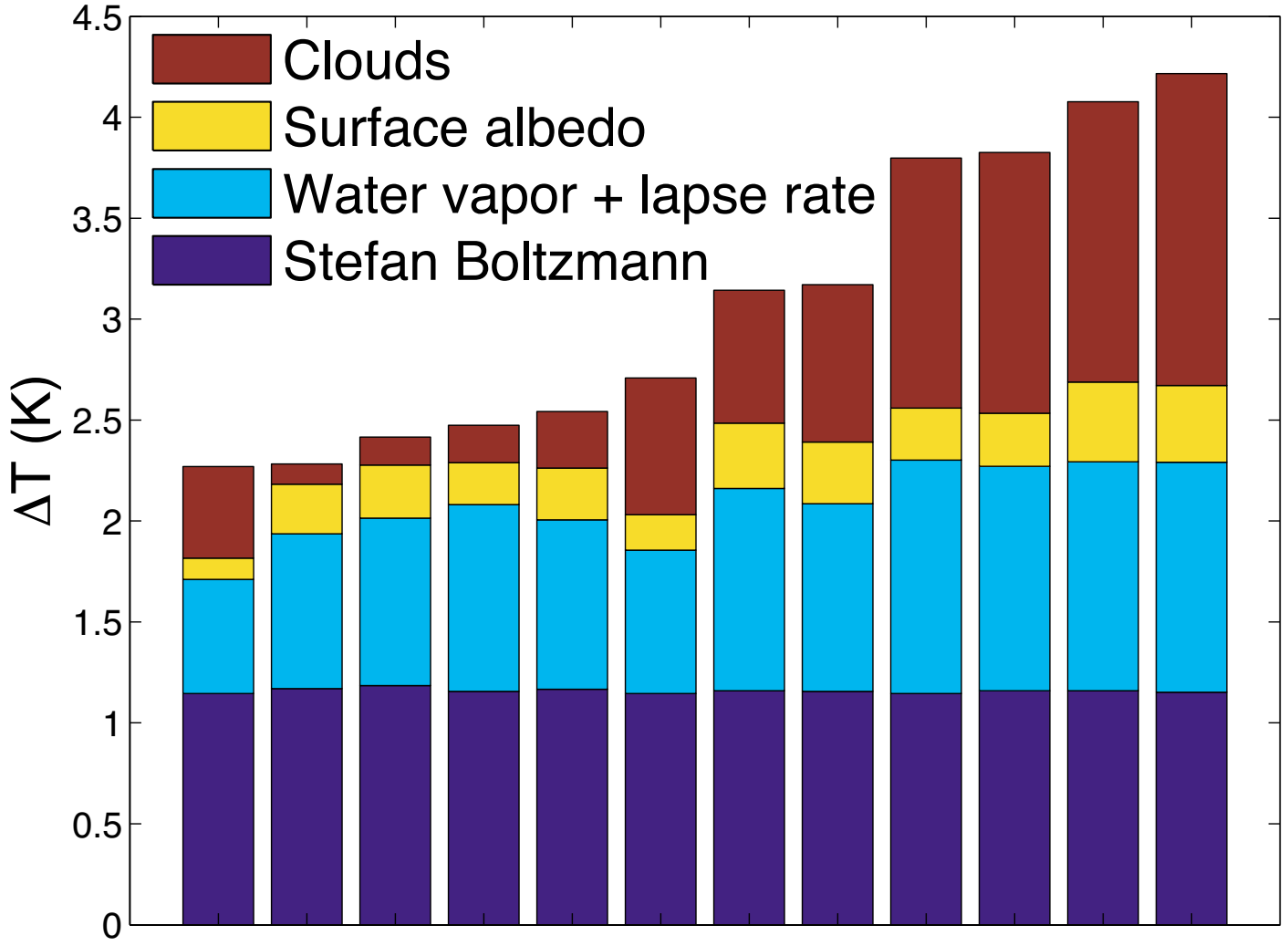


Model sensitivities and forcings from Kiehl, GRL, 07

Uncertainty in aerosol forcing allows climate models with widely differing sensitivities to reproduce temperature increase over industrial period.

CLIMATE SENSITIVITY IN AR4 MODELS

Attribution to feedback mechanisms



Dufresne & Bony, J. Clim. 2008

Equilibrium temperature increase to $2 \times CO_2$ in 12 AOGCMs.

Variation in sensitivity is due mainly to difference in cloud feedback.

U.S. DEPARTMENT OF ENERGY

Program Announcement To DOE National Laboratories LAB 10-04

Climate Uncertainties at Regional and Global Scales

The Office of Biological and Environmental Research (BER) of the Office of Science (SC), U.S. Department of Energy (DOE), hereby announces its interest in receiving peer-reviewable Field Work Proposals (FWPs) on the topic of ***Climate Uncertainties at Regional and Global Scales*** under the Regional and Global Climate Modeling (RGCM) program.

Characterization of Climate Feedbacks and their Uncertainties

Feedback processes play a crucial role in amplifying or dampening the climate response of the earth system to both anthropogenic forcing and natural variability.

Cloud-Climate Feedbacks

Cloud feedback has been identified as a particularly important process responsible for the ***spread among projections in general circulation models.***

Inter-model differences in cloud feedbacks are largely attributable to ***short-wave cloud feedback*** components.

Moreover responses to both ***deep convective and low-level clouds*** differ markedly among climate models with ***marine stratus clouds*** contributing the most to cloud feedbacks.

This Announcement encourages studies that examine ***cloud-related feedback processes*** in coupled global and/or regional models:

Use of the results of Coupled Model Intercomparison Project Phase 5 (***CMIP5***) models are encouraged.

Proposals should address ***physical processes*** in the current and future climate.

BNL PROPOSAL IN PREPARATION

Cloud Feedbacks and Climate Sensitivity in Climate Models And Observations

$$S = S_{SB} f = S_{SB} \frac{1}{\left(1 - \frac{1}{4}\frac{\partial \ln \gamma}{\partial \ln T_s} + \frac{1}{4}\frac{\partial \ln \varepsilon}{\partial \ln T_s}\right)}$$

S_{SB} = Sensitivity of Stefan-Boltzmann planet = 0.30 K/(W m^{-2}); $\Delta T_{2\times}$ = 1.1 K

f = feedback factor

T_s = global mean surface temperature

γ = planetary coalbedo (complement of albedo)

ε = effective emissivity = $\langle \mathrm{OLR} \rangle / \sigma T_s^4$; OLR = outgoing longwave radiation; σ = Stefan-Boltzmann radiation constant.

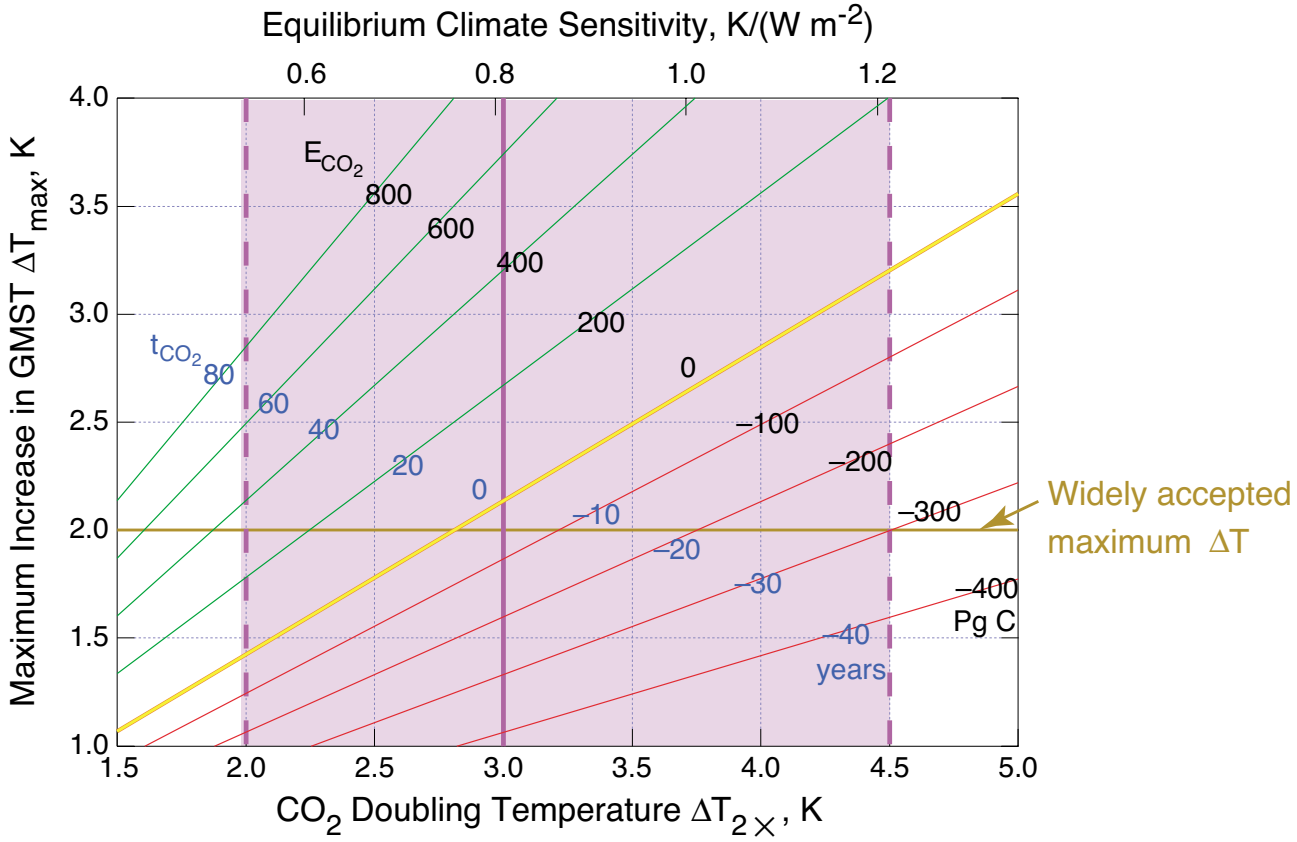
Approach: Examine feedbacks in satellite observations; compare with models.

IMPLICATIONS OF PRESENT UNCERTAINTY IN CLIMATE SENSITIVITY:

ALLOWABLE FUTURE CO_2 EMISSIONS

ALLOWABLE FUTURE CO_2 EMISSIONS

Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial



For $\Delta T_{max} = 2$ K . . .

If sensitivity $\Delta T_{2\times}$ is 3 K, ***no more emissions***.

If sensitivity $\Delta T_{2\times}$ is 2 K, ~ ***30 more years of emissions at present rate***.

If sensitivity $\Delta T_{2\times}$ is 4.5 K, ***threshold is exceeded by ~30 years***.