CLIMATE SENSITIVITY

HOW MUCH WILL GLOBAL TEMPERATURE INCREASE FOR A GIVEN CONCENTRATION OF CO_2 AND OTHER CLIMATE FORCERS?

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KEY QUESTIONS FOR THIS WORKSHOP

How has the new IPCC report influenced our understanding of current and future climate change?

What are the most important remaining uncertainties?

The outcome of the discussions will . . . [lead] to an updated version of the 2009 Academy statement on the scientific basis for climate change.

Session 1: Climate sensitivity

How much will global temperature increase for a given concentration of CO_2 and other climate forcers?

THE 2009 ACADEMY STATEMENT

KUNGL. VETENSKAPS-AKADEMIEN

THE ROYAL SWEDISH ACADEMY OF SCIENCES

Kungl. Vetenskapsakademien har till uppgift att främja vetenskaperna och stärka deras inflytande i samhället.
The Royal Swedish Academy of Sciences has as its aim to promote the sciences and strengthen their influence in society.

THE SCIENTIFIC BASIS FOR CLIMATE CHANGE

Statement by the Royal Swedish Academy of Sciences

22 September 2009

THE 2009 ACADEMY STATEMENT

A. We note the following

10. The relationship between climate forcing and the response to climate forcing is complex and can only be reliably identified for periods of several decades and for hemispheric and global domains.

This is supported by both empirical and modelling studies.

Trends of shorter periods are unreliable and masked by the chaotic behaviour of the climate system.

However, based on detailed theoretical and modelling studies, IPCC concludes that the observed warming of the climate from around 1970 is in broad agreement with the increase of greenhouse gases and aerosols and consequently considers this to be the most probable main cause of the present global warming.

THE 2009 ACADEMY STATEMENT

B. What might happen in the future?

5. Regrettably, we are not yet in a position to determine with any precision what is going to happen.

For the time being we cannot rule out that there are hitherto overlooked anthropogenic effects on the climate system, with consequences which either reduce or enhance the influence of increased concentrations of greenhouse gases.

One factor is the formation and dissipation of clouds. Increased low-level cloudiness lowers surface temperature, and reduced cloudiness promotes warming. Present indications are that the cloud effect is broadly neutral to climate change.

CHARGE TO INTRODUCTORY LECTURERS

As I see it

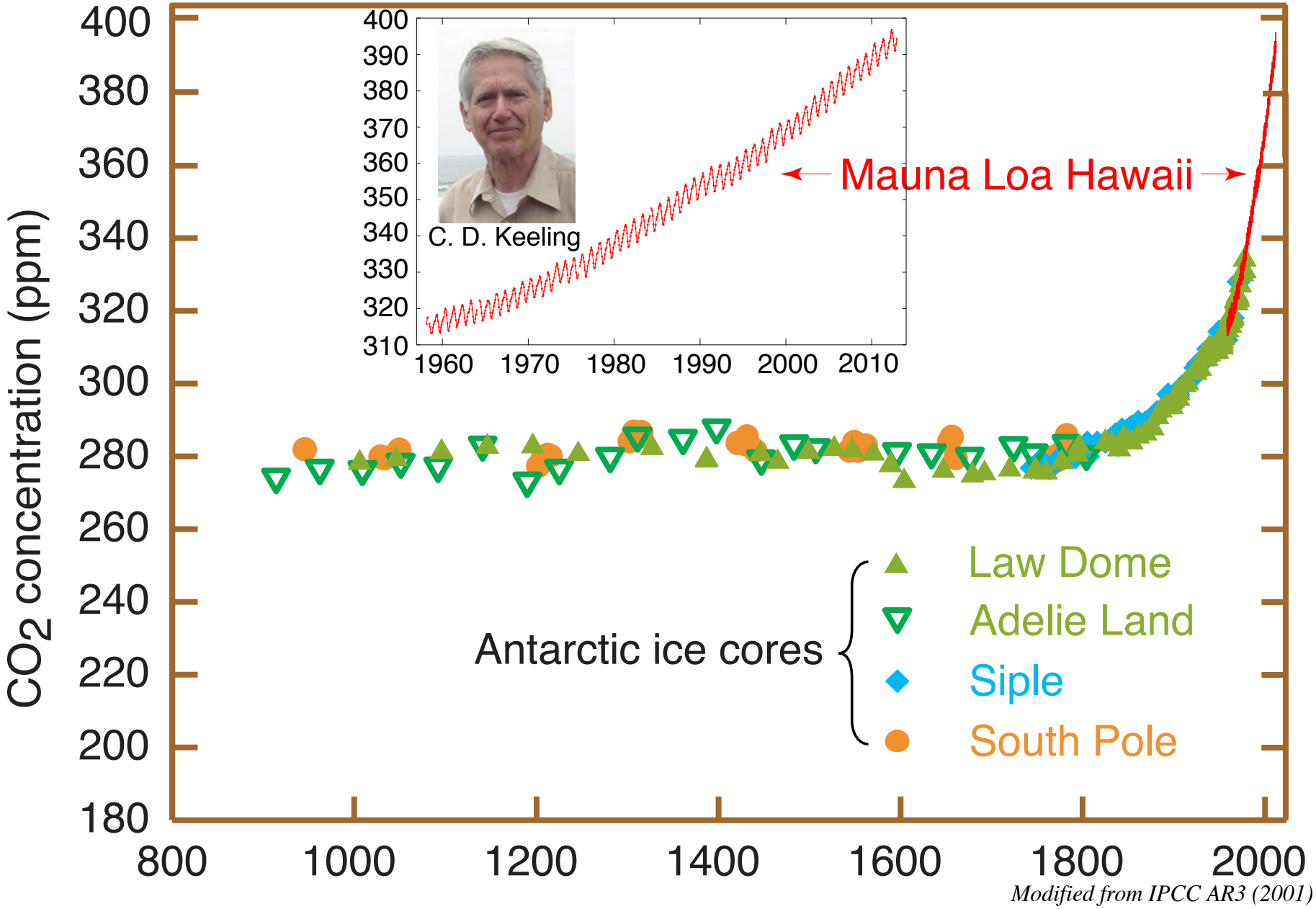
Define the issue.

Summarize the IPCC position.

Provide perspective on the IPCC position.

Identify the most important remaining uncertainties.

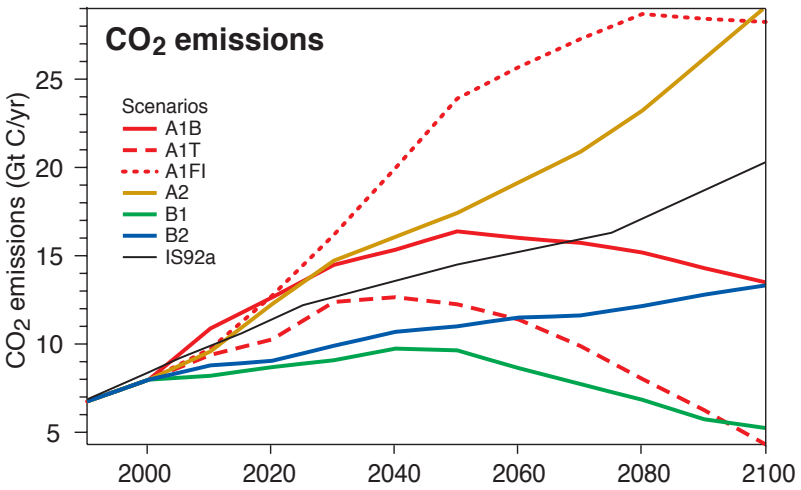
ATMOSPHERIC CARBON DIOXIDE IS INCREASING

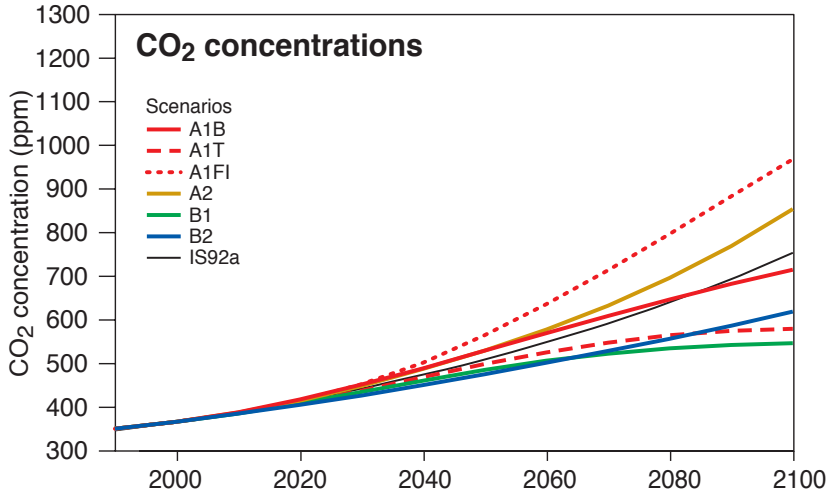


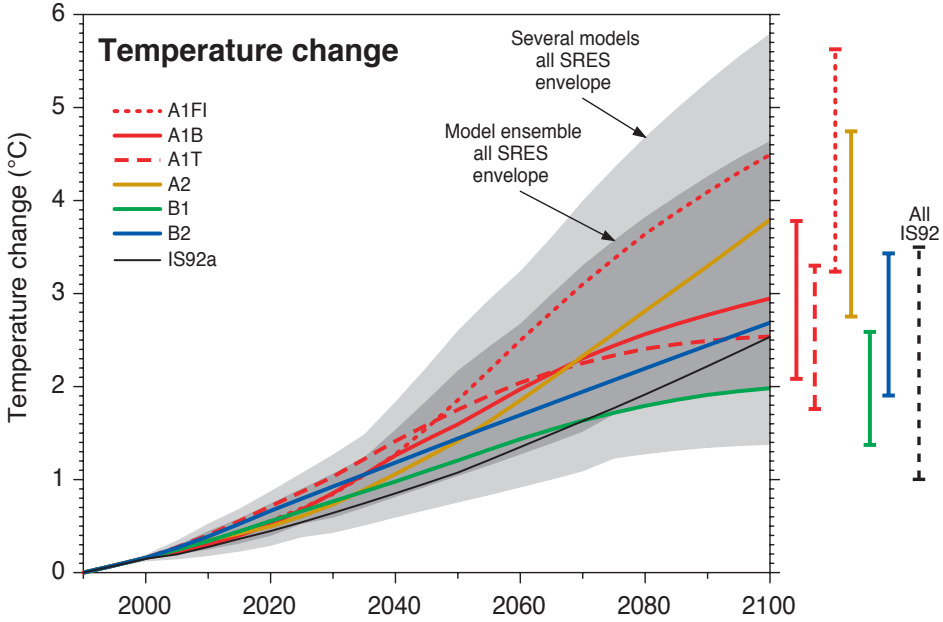
Global carbon dioxide concentration over the last thousand years

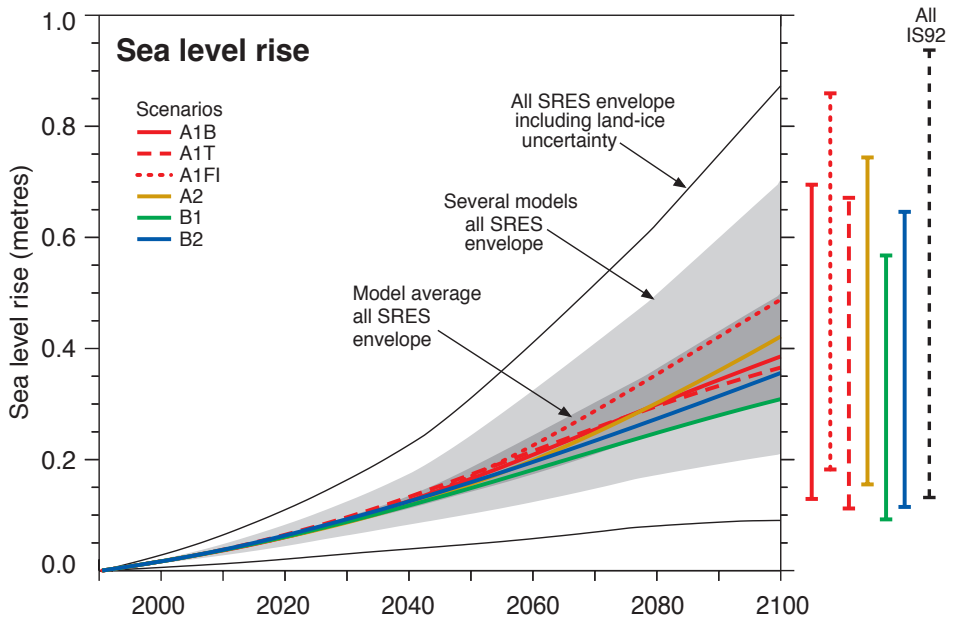
PROJECTIONS OF FUTURE CLIMATE CHANGE

Temperature change and sea level rise for different emissions scenarios









IPCC, AR3, 2001

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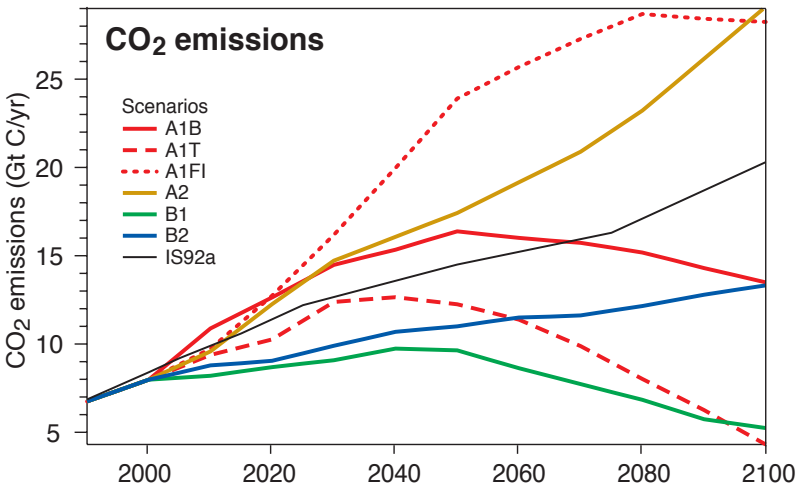
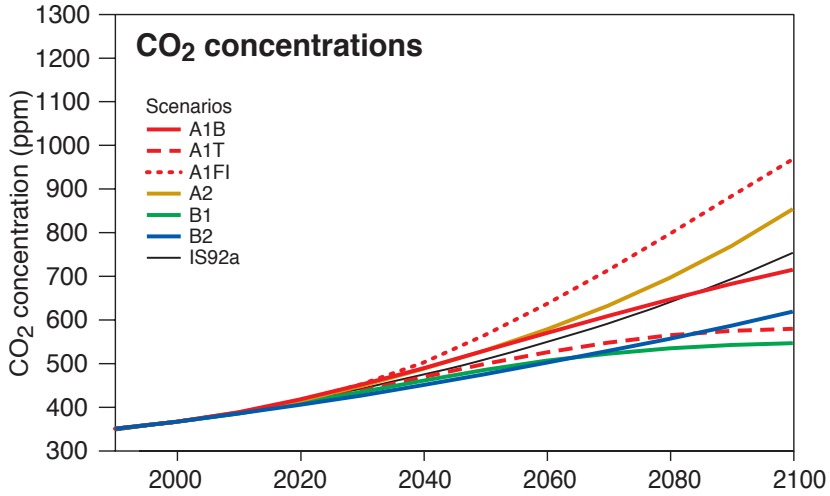
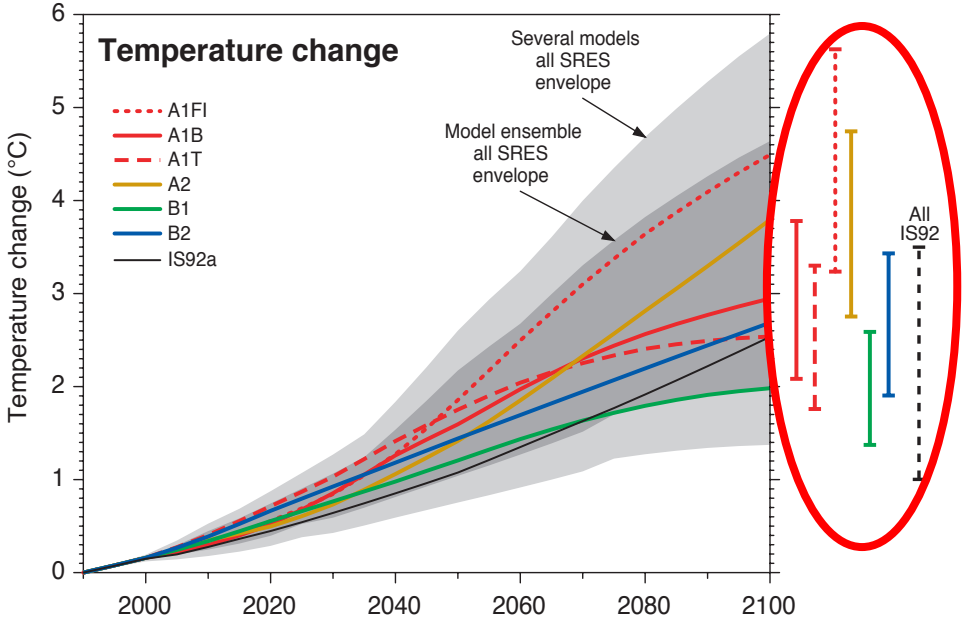
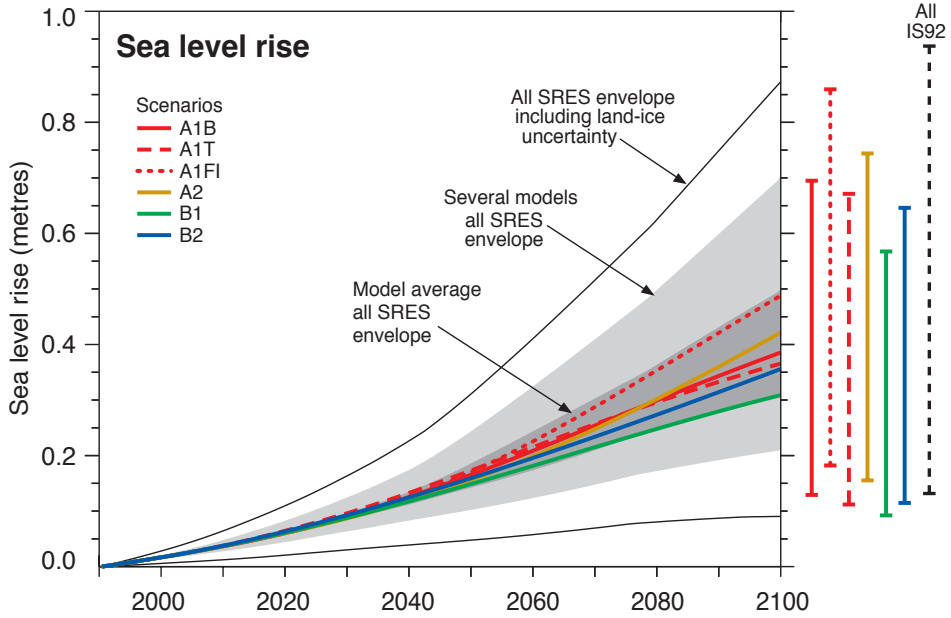








IPCC, AR3, 2001

EQUILIBRIUM CLIMATE SENSITIVITY ECS

The expected steady-state increase in global mean surface temperature ΔT_s in response to sustained forcing F is:

$$\Delta T_s(\infty) = S_{eq} F$$

S_{eq} is "equilibrium" sensitivity of Earth's climate system, $\mathrm{K}/(\mathrm{W\ m^{-2}})$.

Equilibrium climate sensitivity ECS (steady-state response to sustained $2 \times CO_2$ forcing) $\quad \mathrm{ECS}\ [\mathrm{K}/(3.7\ \mathrm{W\ m^{-2}})] \equiv S_{eq} \times (3.7\ \mathrm{W\ m^{-2}})$

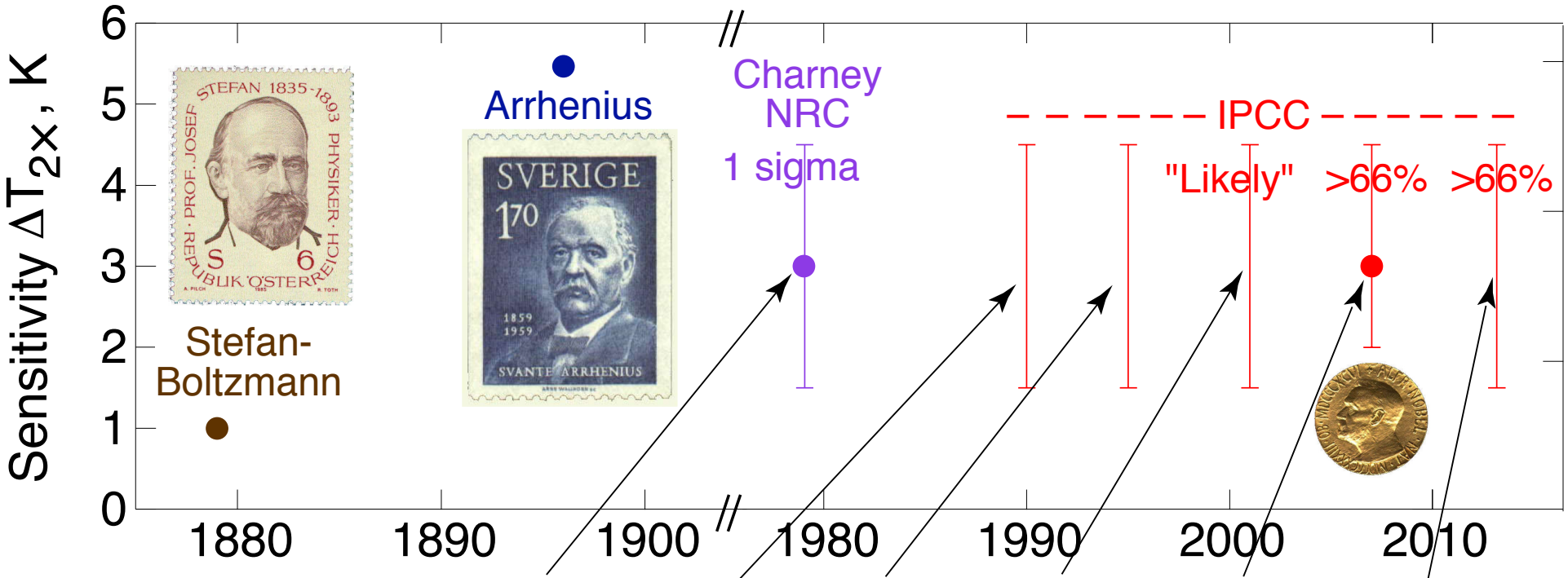
Synonyms: Equilibrium sensitivity, Climate sensitivity, Sensitivity, Doubling temperature $\Delta T_{2\times}$, all in units °C or K.

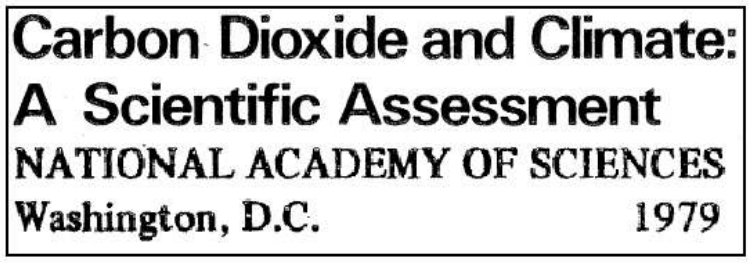
$$\mathrm{ECS} \overset{?}{=} 3\ \mathrm{K}/(3.7\ \mathrm{W\ m^{-2}})$$

It is essential to know the ***climate sensitivity*** and the ***forcing*** to interpret past change in Earth's temperature and to project future changes.

CLIMATE SENSITIVITY ESTIMATES THROUGH THE AGES

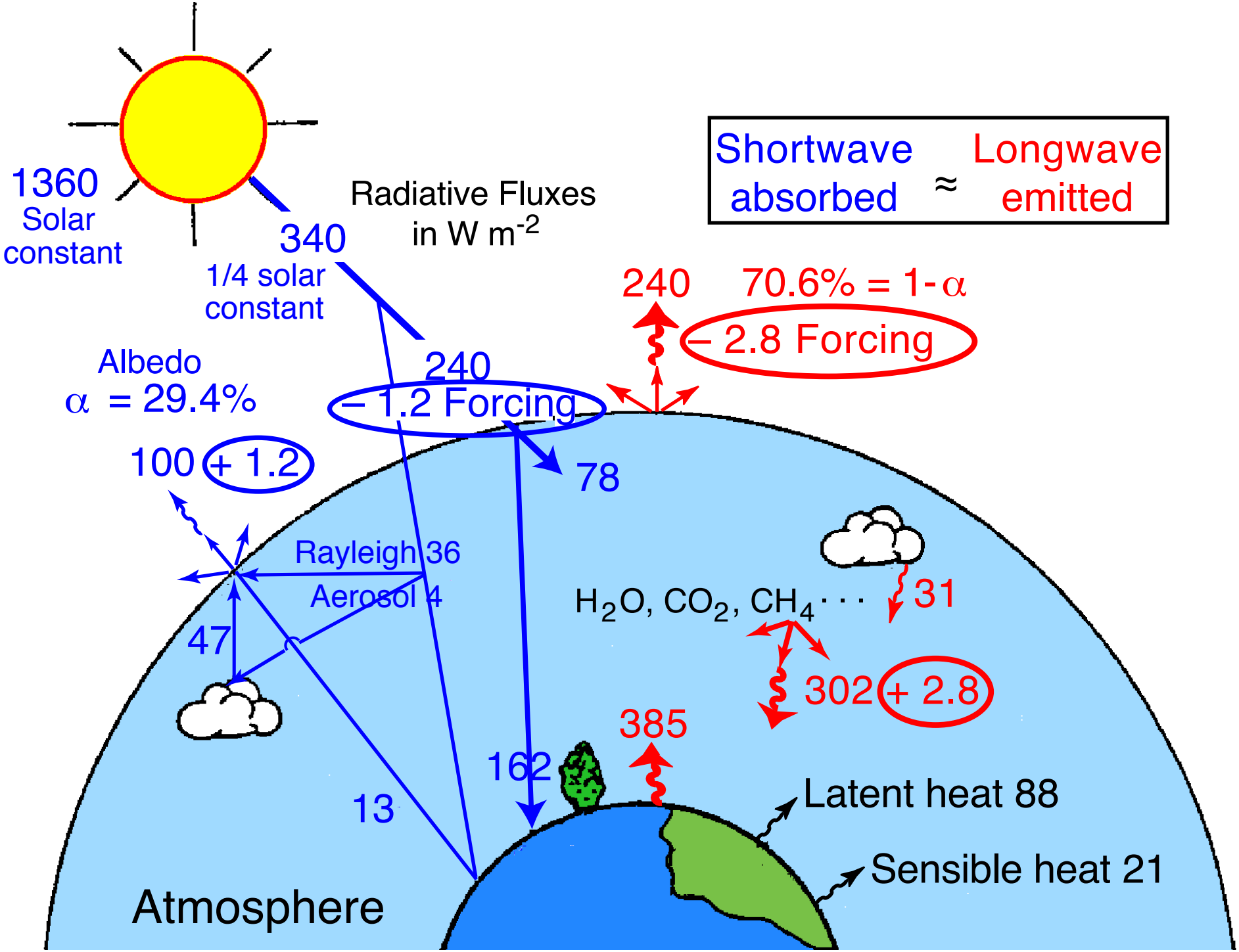
Estimates of central value and uncertainty range from major national and international assessments





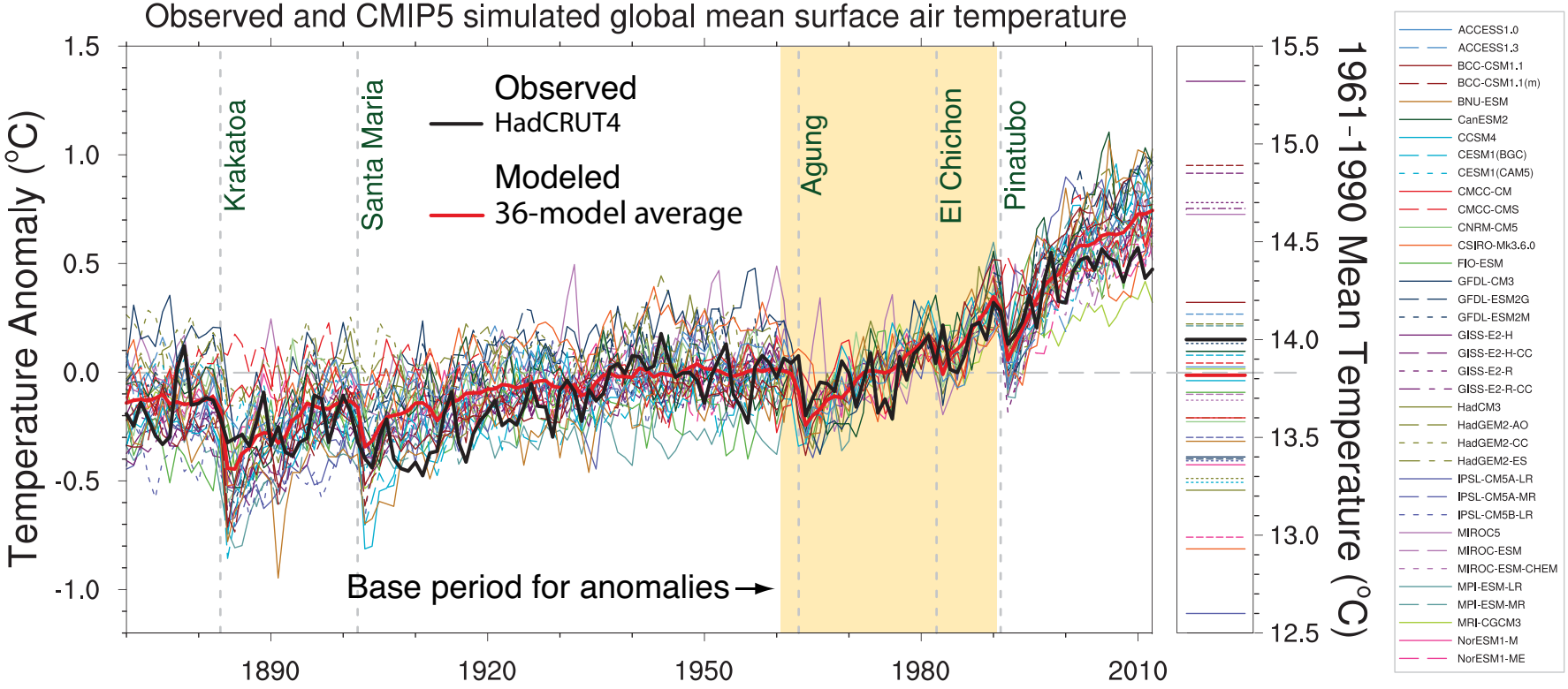
Despite extensive research, climate sensitivity remains ***highly uncertain***.

EARTH'S RADIATION BUDGET AND THE GREENHOUSE EFFECT



TEMPERATURE ANOMALY TREND OVER THE 20th CENTURY

Results from 36 climate models and observations, ***showing model offsets***

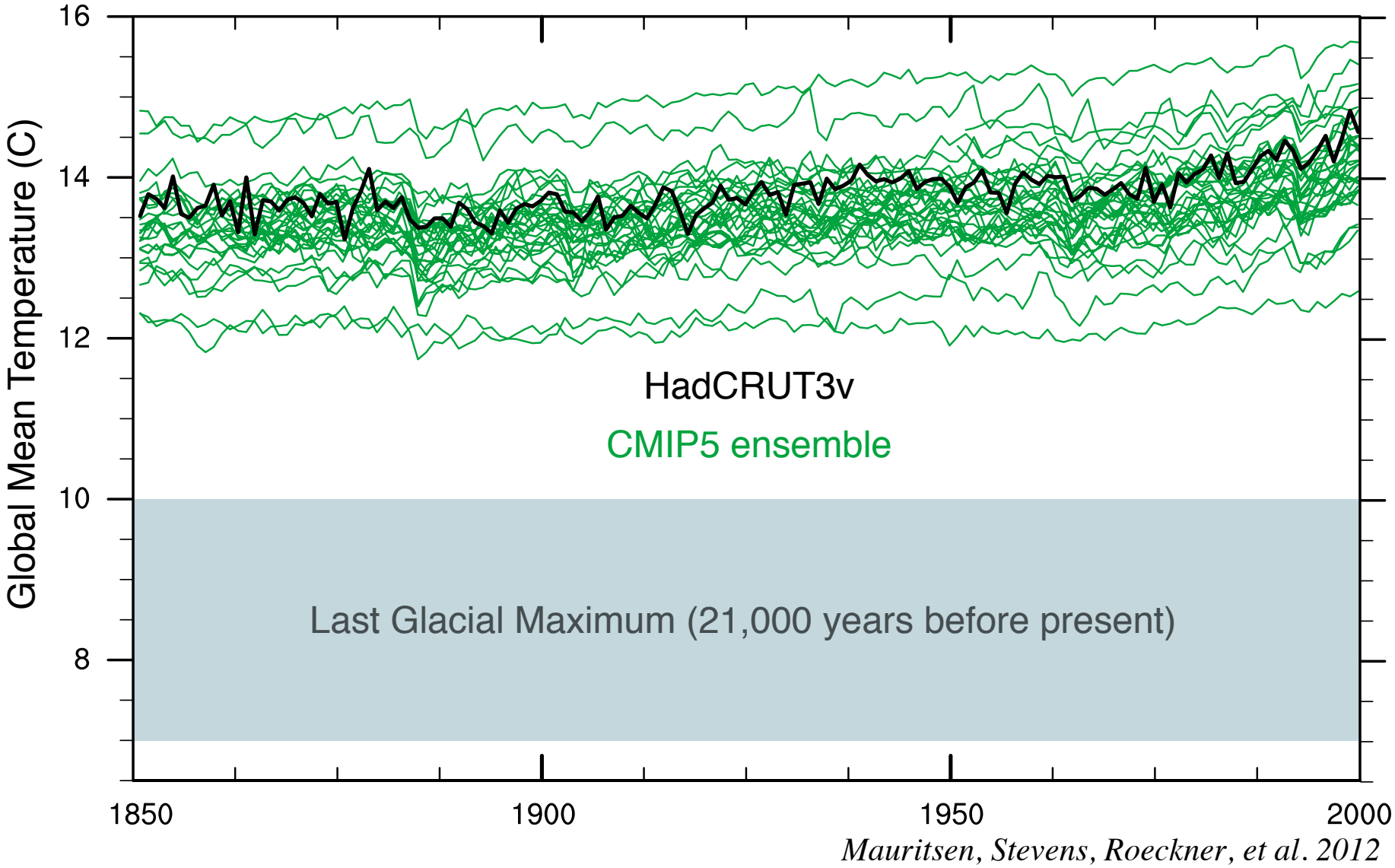


Modified from IPCC AR5 (2013)

"There is ***very high confidence*** that models reproduce the general features of the global-scale annual mean surface temperature increase over the historical period" ***despite model offsets spanning over 2 K, well greater than increase over the record, 0.8 K***.

GLOBAL MEAN SURFACE TEMPERATURE 1850-2000

Measurements and Coupled Atmosphere Ocean Models



Mauritsen, Stevens, Roeckner, et al. 2012

Spread is substantial relative to observed warming and to warming since last LGM.

SUMMARY OF IPCC POSITION

No best estimate of equilibrium climate sensitivity, because of “lack of agreement on values across assessed lines of evidence and studies.”

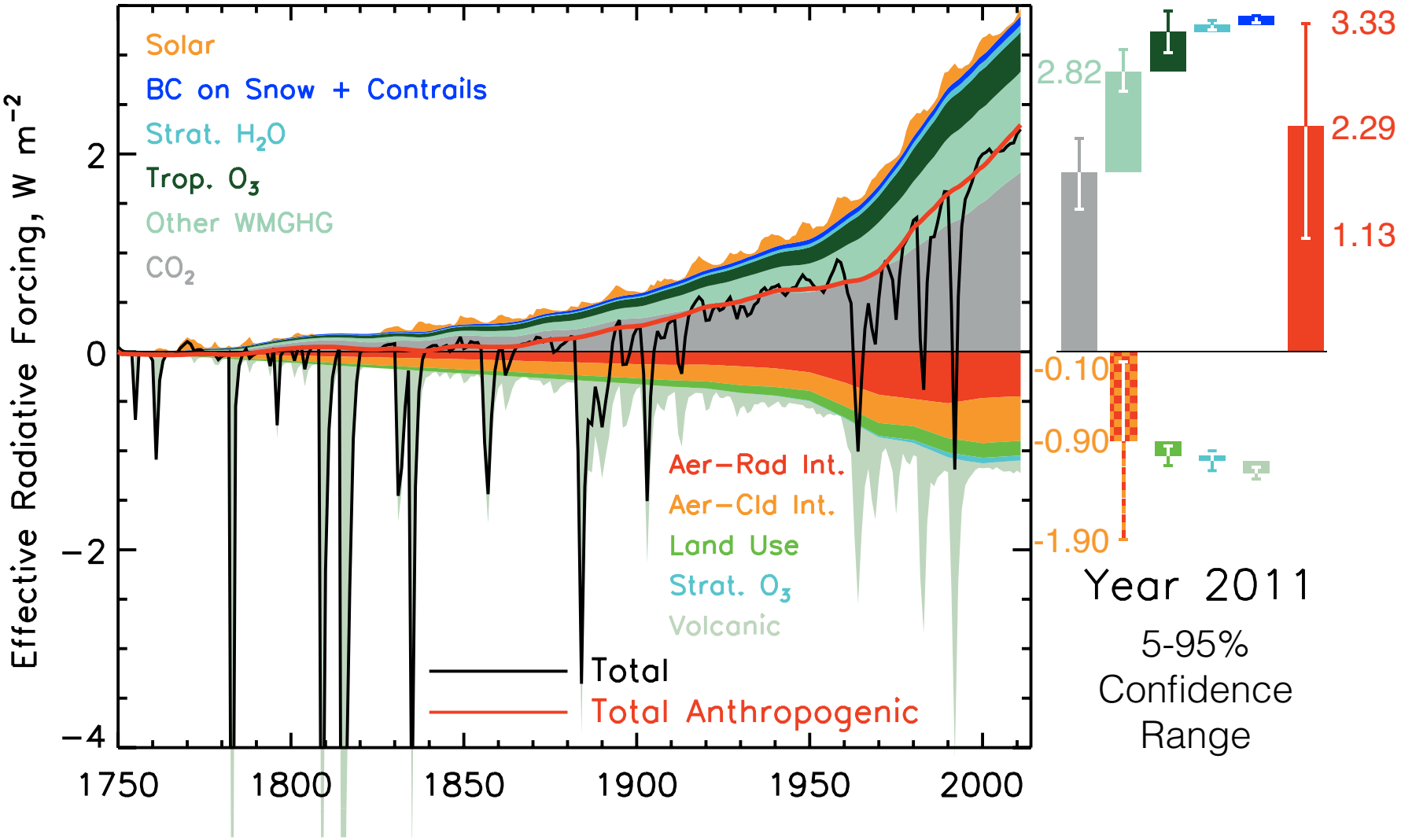
ECS is “likely” (66%) between 1.5 to 4.5 K.

ECS is “extremely unlikely” (5%) less than 1 K.

ECS is “very unlikely” (10%) greater than 6 K.

RADIATIVE FORCING IN ANTHROPOCENE

Total forcing



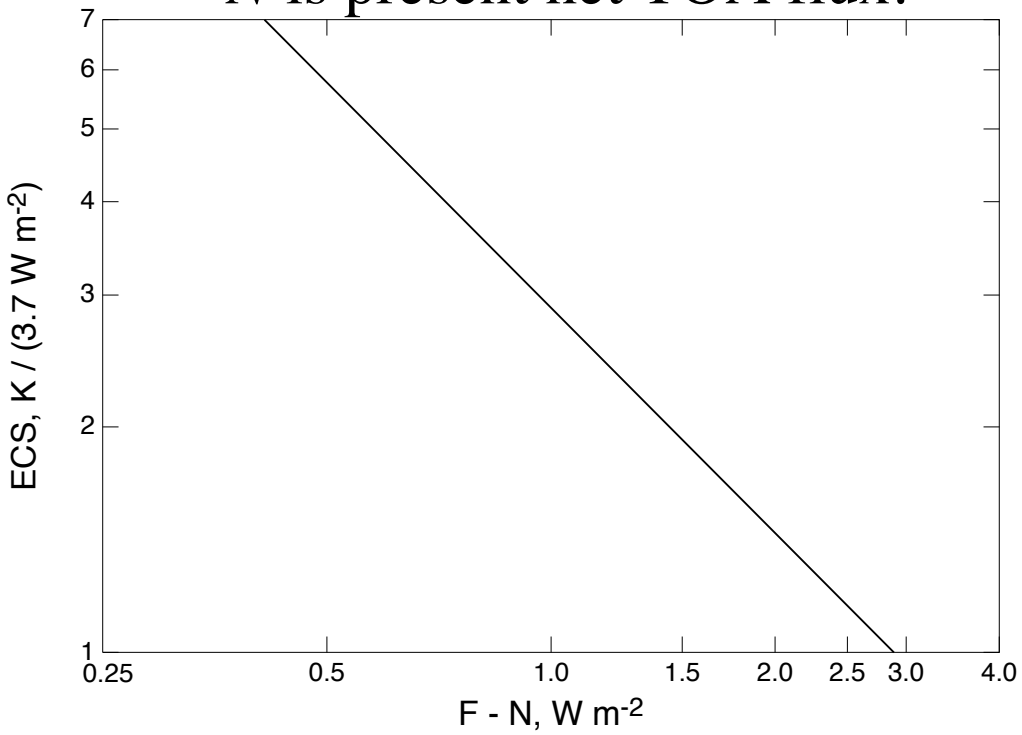
IPCC AR5 (2013)

Uncertainty in total forcing, about a factor of 3, is due largely to aerosols.

EXPECTED RELATION BETWEEN ECS AND FORCING

$$\mathrm{ECS} = (3.7\ \mathrm{W\ m^{-2}}) \times S_{\mathrm{eq}} = (3.7\ \mathrm{W\ m^{-2}}) \frac{\Delta T_{\mathrm{s}}}{F - N}$$

ΔT_{s} and F are temperature change and forcing over 20$^{\mathrm{th}}$century.
N is present net TOA flux.



ECS vs $F - N$ is straight line on log-log plot; slope = −1.

ΔT_{s} over 20$^{\mathrm{th}}$ century, 0.78 K; net TOA flux N, 0.44 W m^{-2} (*IPCC AR5*).

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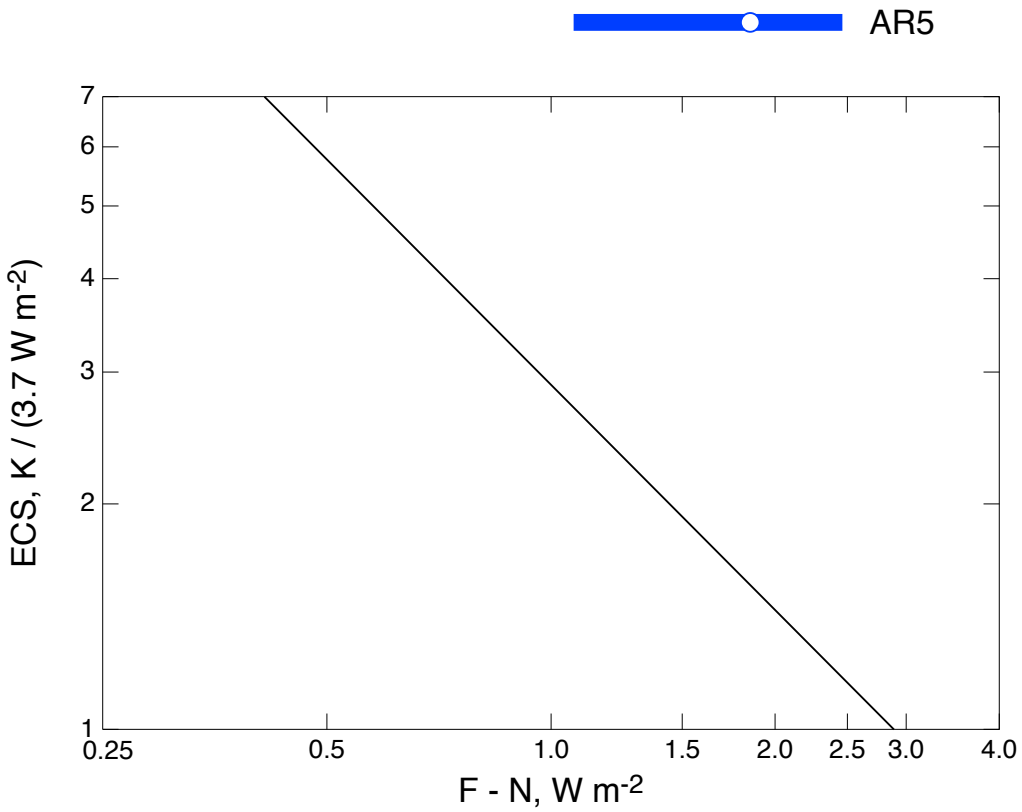

Forcing (best estimate and central 66% likelihood range) from IPCC Fifth Assessment Report (2013), AR5.

EXPECTED RELATION BETWEEN ECS AND FORCING

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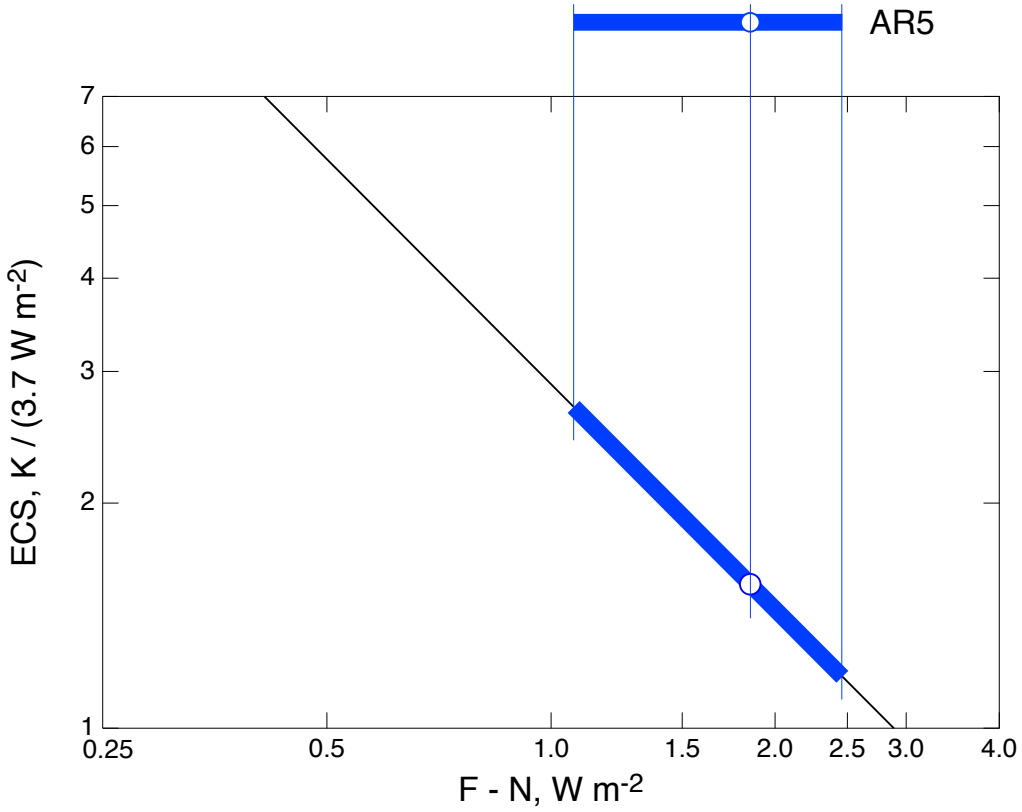
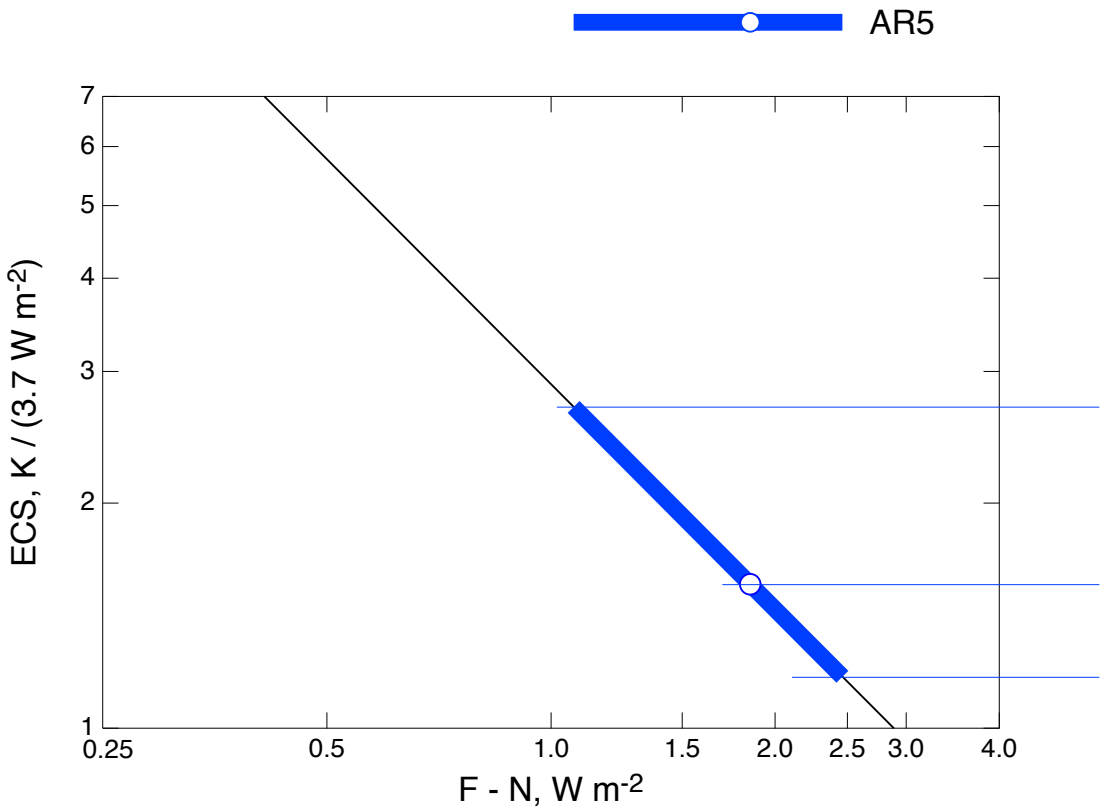


Project forcing onto ECS vs $F - N$ to obtain consistent ECS range.

EXPECTED RELATION BETWEEN ECS AND FORCING

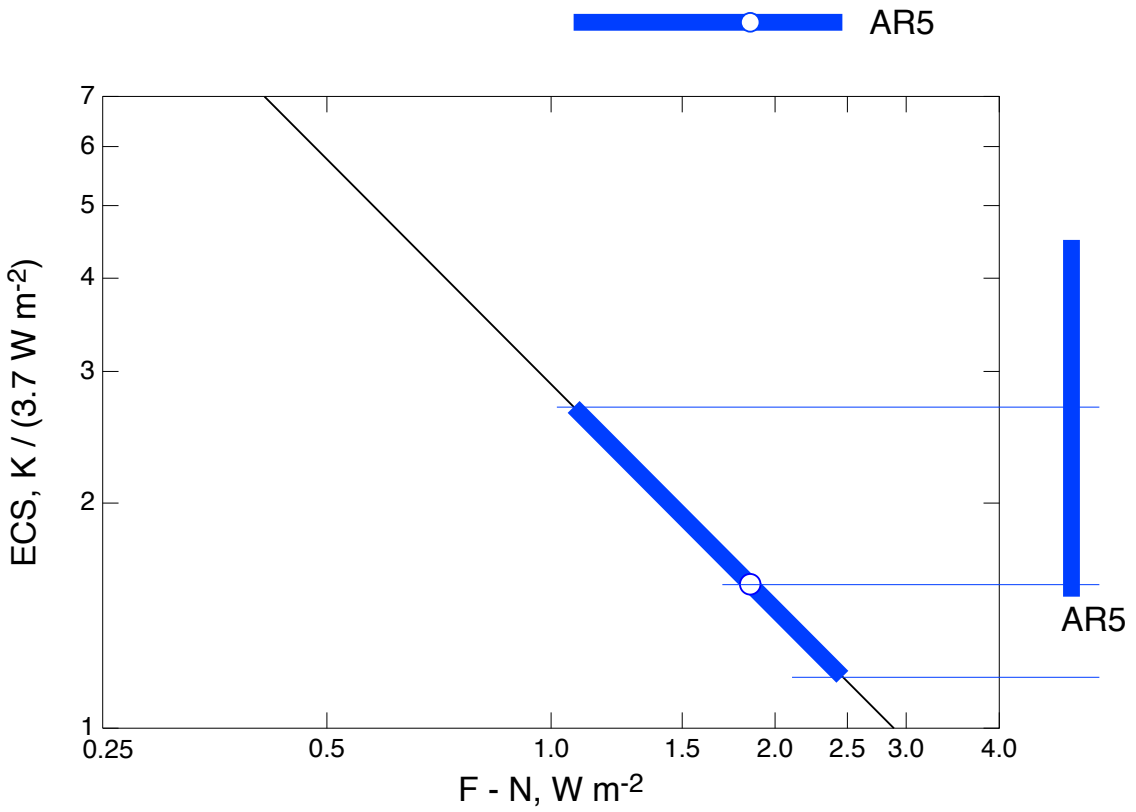
$$\mathrm{ECS} = (3.7\ \mathrm{W\ m^{-2}}) \times S_{\mathrm{eq}} = (3.7\ \mathrm{W\ m^{-2}}) \frac{\Delta T_{\mathrm{s}}}{F - N}$$



Transfer consistent ECS range to vertical scale.

EXPECTED RELATION BETWEEN ECS AND FORCING

$$\mathrm{ECS} = (3.7\ \mathrm{W\ m^{-2}}) \times S_{\mathrm{eq}} = (3.7\ \mathrm{W\ m^{-2}}) \frac{\Delta T_{\mathrm{s}}}{F - N}$$



ECS range consistent with "likely" forcing range, 1.2 – 2.7 K, is much lower than assessed "likely" ECS range, 1.5 – 4.5 K.

EXPECTED RELATION BETWEEN ECS AND FORCING

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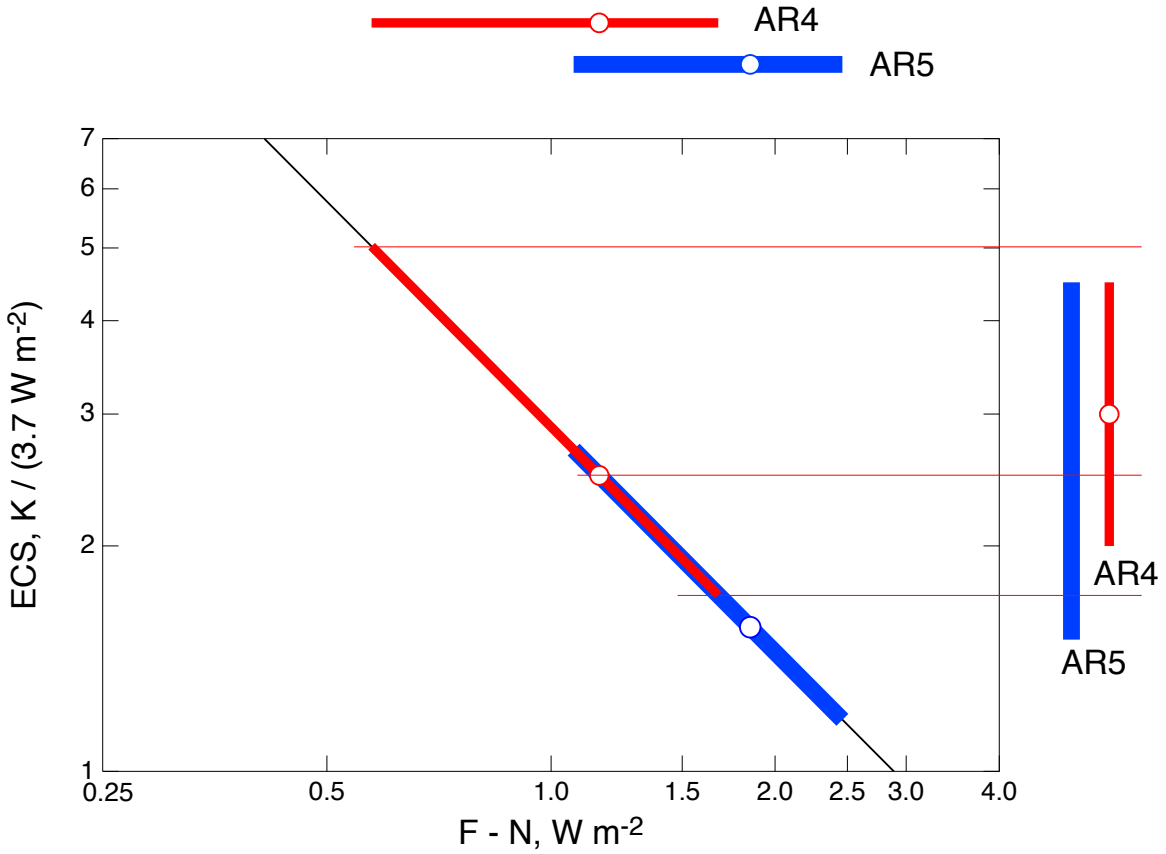

AR4 (2007) is more internally consistent than AR5.

Forcing in AR5 is much greater than in AR4.

EXPECTED RELATION BETWEEN ECS AND FORCING

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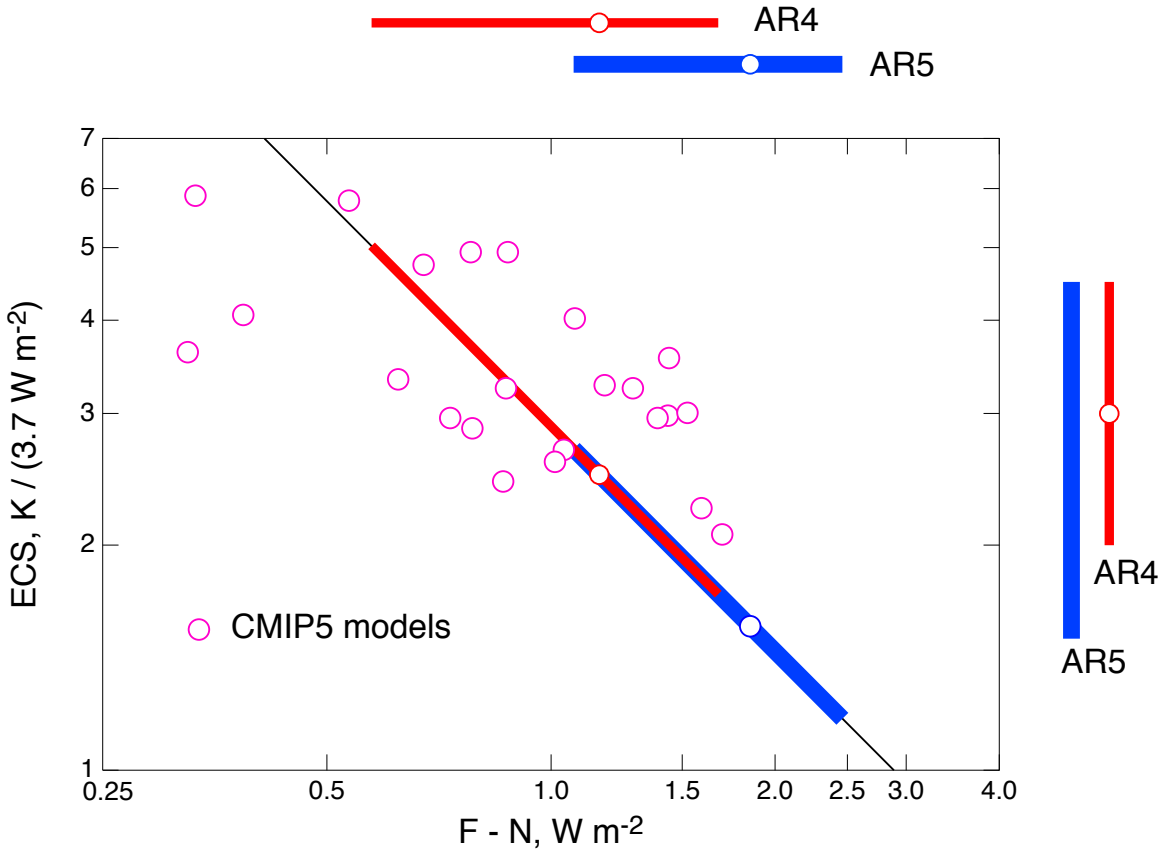

Forcings in CMIP5 models are lower than AR5 range and sensitivities higher. ***Forcings and sensitivities are anticorrelated across models***.

SUMMARY OF IPCC POSITION

No best estimate of equilibrium climate sensitivity, because of “lack of agreement on values across assessed lines of evidence and studies.”

ECS is “likely” (66%) between 1.5 to 4.5 K.

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PERSPECTIVE ON IPCC POSITION

The assessed magnitude of negative aerosol forcing over the industrial period is substantially reduced in AR5 vs. AR4, and total forcing correspondingly increased.

In contrast, the assessed sensitivities between the two reports shows little change.

The likely range of ECS, 1.5 to 4.5 K exhibits apparent inconsistency with that inferred from the likely range of forcing, 1.2 to 2.7 K.

The forcings employed in the CMIP5 model calculations of climate change over the twentieth century are systematically lower than those given in the AR5 assessment.

The anticorrelation between forcing and ECS suggests that the climate models may be overly sensitive, with implications on interpretation of past climate change and on projections of future climate change obtained with these models.

KEY UNCERTAINTIES

Equilibrium climate sensitivity remains uncertain to a factor of 3, 1.5 to 4.5 K “likely” range (central 66%).

Total forcing over the industrial period likewise remains highly uncertain, 1.1 to 3.3 W m^{-2} “very likely” range, also a factor of 3.

FINAL REMARK

Observational constraints between forcing and climate sensitivity point to the need to reduce uncertainty in forcing in order to constrain climate sensitivity.