ATMOSPHERIC CO_2 – A GLOBAL LIMITING RESOURCE

HOW MUCH FOSSIL CARBON CAN WE BURN?

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http://www.ecd.bnl.gov/steve

OVERVIEW

Increasing carbon dioxide over the industrial period

Target limits on climate change

Radiative forcing; climate sensitivity

Estimates of climate sensitivity

Approaches to determining climate sensitivity

Atmospheric aerosols – a confounding influence

Climate sensitivity from climate models

Uncertainty in current estimates of climate sensitivity and its implications

Carbon dioxide in a shared global atmosphere

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (1992)

- “ The ultimate objective of this Convention ... is to achieve ... ***stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system***.
- “ The Parties should take precautionary measures to ***anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects***.
- “ Where there are threats of serious or irreversible damage, ***lack of full scientific certainty should not be used as a reason for postponing such measures***.

EUROPEAN UNION STATEMENT (2004)

The Council of the European Union

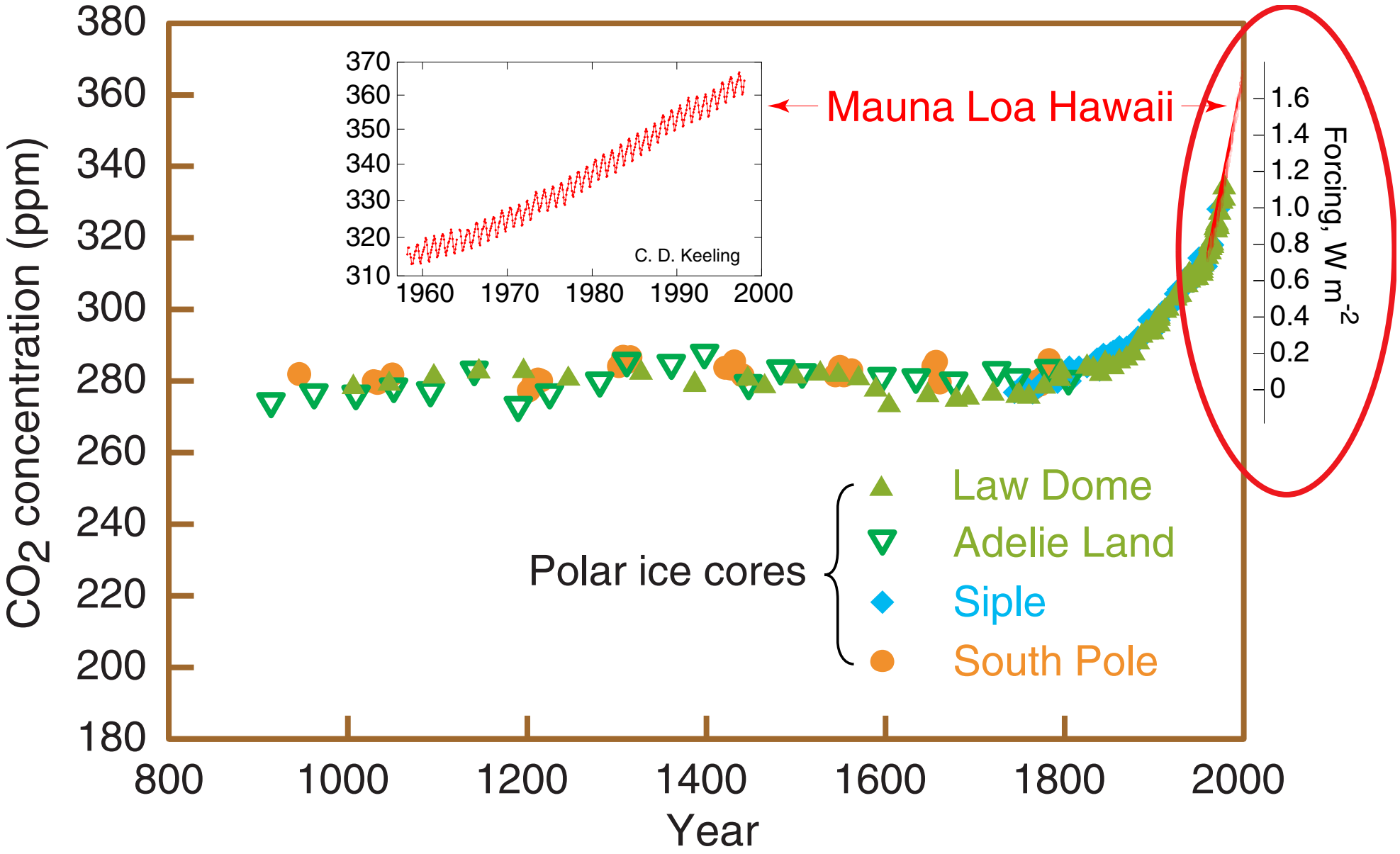
REAFFIRMS that, with a view to meeting the ultimate objective of the Unite Nations Framework Convention on Climate Change to prevent dangerous anthropogenic interference with the climate system, overall ***global annual mean surface temperature increase should not exceed 2ºC above preindustrial levels*** in order to limit high risks, including irreversible impacts of climate change;

RECOGNISES that 2°C would already imply ***significant impacts on ecosystems an water resources***;

EMPHASISES that the maximum global temperature increase of 2ºC over preindustrial levels should be considered as an overall long-term objective to ***guide global efforts to reduce climate change risks in accordance with the precautionary approach***;

RECOGNISES that long term decision-making by the business community requires a ***long term global policy perspective*** to inform investment and drive technology development and diffusion, including with regard to cost-effective measures.

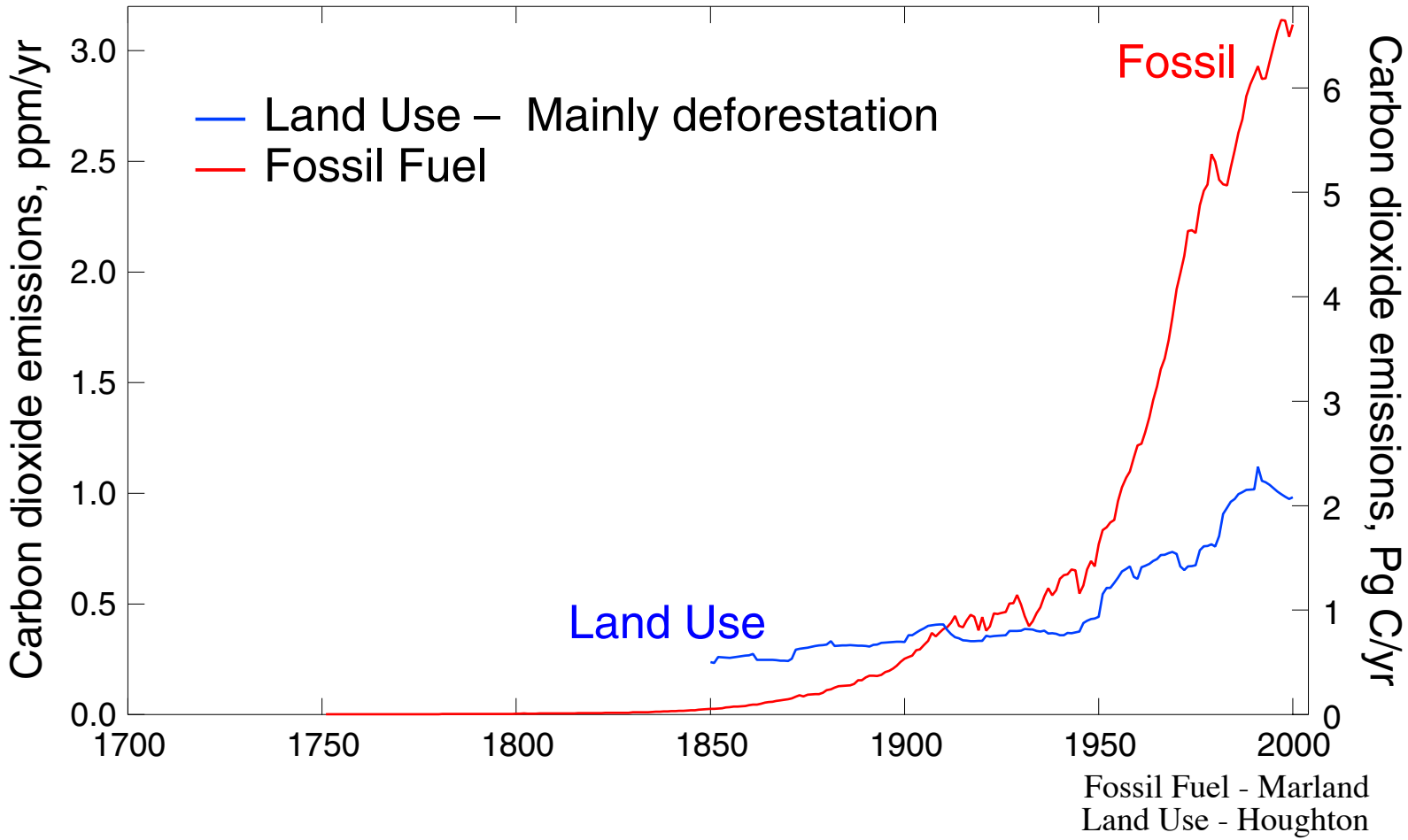
ATMOSPHERIC CARBON DIOXIDE IS INCREASING



Global carbon dioxide concentration and infrared radiative forcing over the last thousand years

ATMOSPHERIC CO_2 EMISSIONS

Time series 1700 - 2003

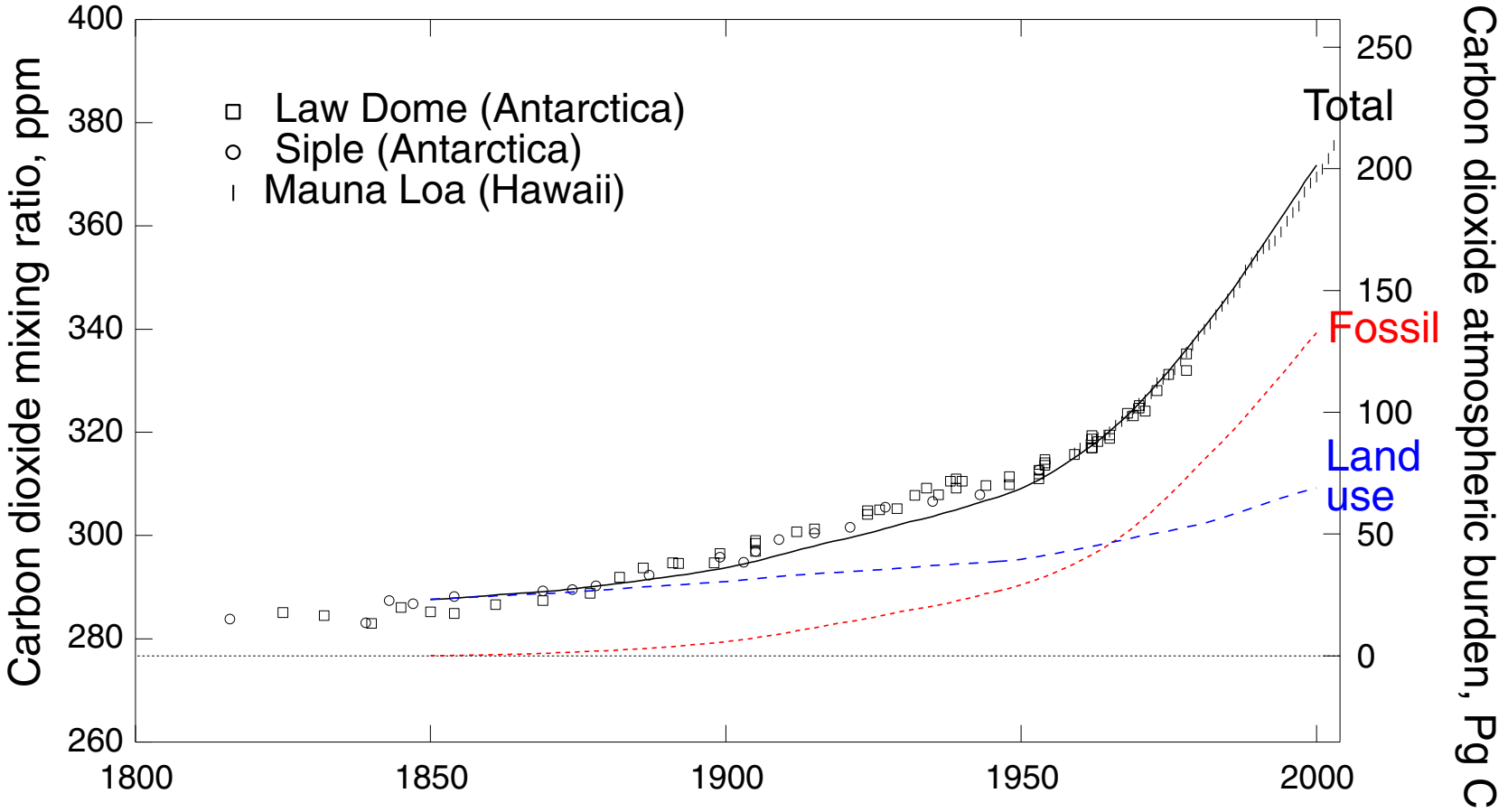


Prior to 1910 CO_2 emissions from land use changes were dominant.

Subsequently fossil fuel CO_2 has been dominant and rapidly increasing!

ATTRIBUTION OF ATMOSPHERIC CO_2

Comparison of CO_2 ***mixing ratio*** from fossil fuel combustion and land use changes



CO_2 from land use emissions – ***not fossil fuel combustion*** – was the dominant contribution to atmospheric CO_2 over the 20th century.

RADIATIVE FORCING

A ***change*** in a radiative flux term in Earth's radiation budget, ΔF, W m^{-2}.

Working hypothesis:

On a global basis radiative forcings are additive and fungible.

- This hypothesis is fundamental to the radiative forcing concept.
- This hypothesis underlies much of the assessment of climate change over the industrial period.

CLIMATE SENSITIVITY

The ***change*** in global and annual mean temperature per unit forcing, S, K/(W m^{-2}),

$$S = \Delta T/\Delta F.$$

Climate sensitivity is not known and is the objective of much current research on climate change.

Climate sensitivity is often expressed as the temperature for doubled CO_2 concentration $\Delta T_{2\times}$.

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

$$\Delta F_{2\times} \approx 3.7 \text{ W m}^{-2}$$

MAXIMUM FORCING FOR ONSET OF DANGEROUS GLOBAL WARMING

The threshold increase in global mean temperature above preindustrial ΔT_{max} is generally taken as about 2 K.

$$\Delta T_{max} = 2 \text{ K}$$

The corresponding maximum allowable forcing F_{max} depends on climate sensitivity S as:

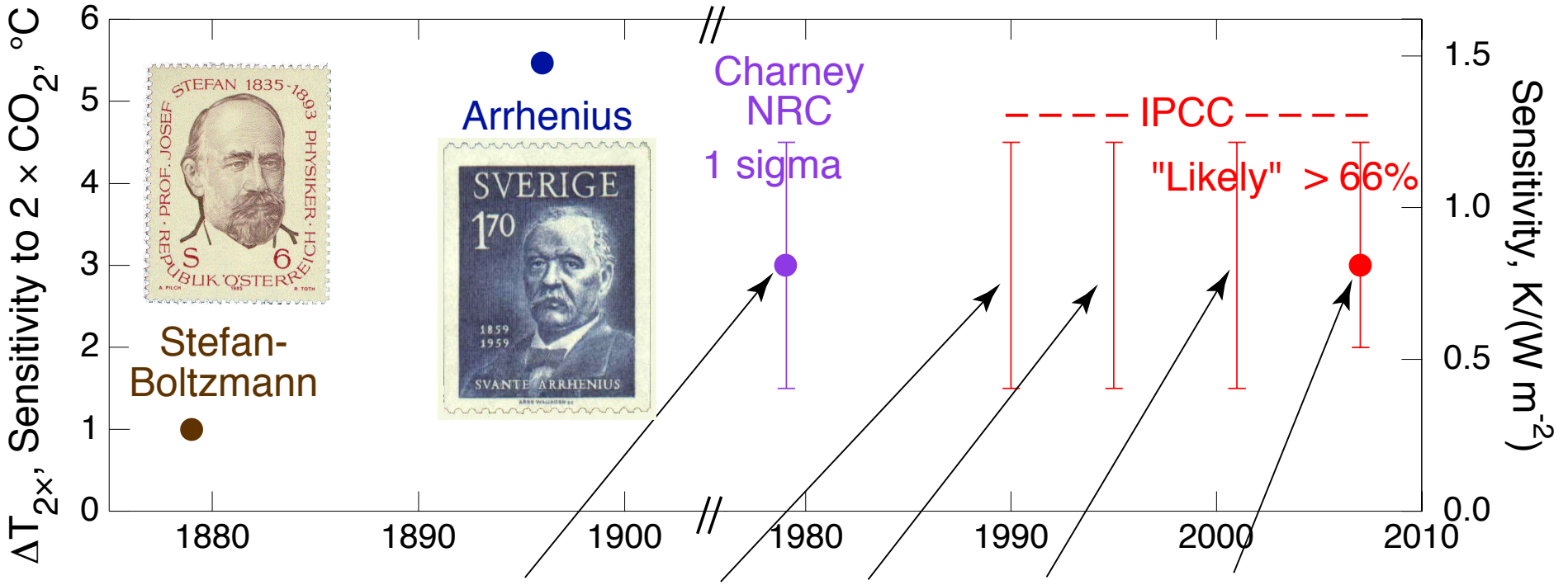
$$F_{max} = \Delta T_{max}/S$$

The greater the climate sensitivity, the lower the maximum allowable forcing.

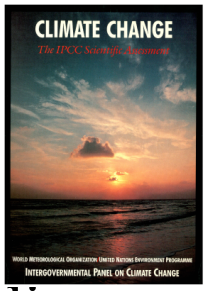
The lower the maximum allowable forcing, the lower the allowable CO_2 emissions.

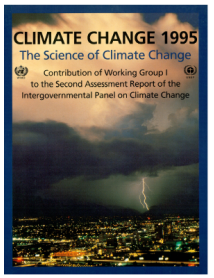
CLIMATE SENSITIVITY ESTIMATES THROUGH THE AGES

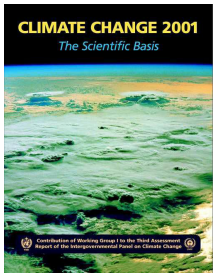
Estimates of central value and uncertainty range from major national and international assessments

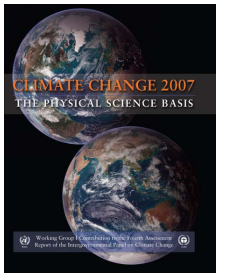


Carbon Dioxide and Climate:
A Scientific Assessment
NATIONAL ACADEMY OF SCIENCES
Washington, D.C. 1979









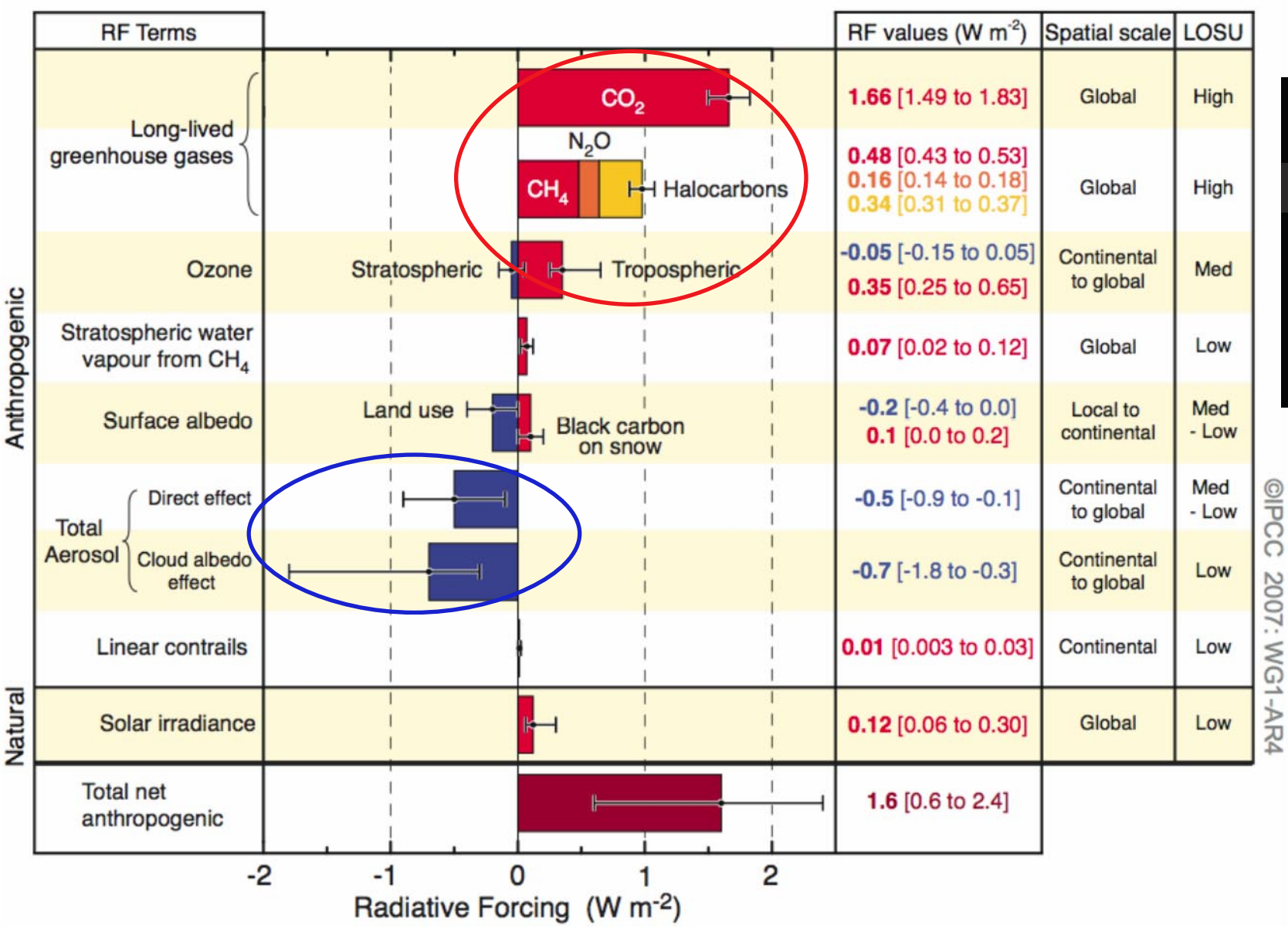
Despite extensive research, climate sensitivity remains ***highly uncertain***.

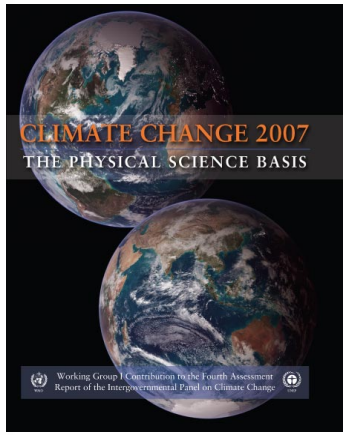
KEY APPROACHES TO DETERMINING CLIMATE SENSITIVITY

- ***Paleoclimate studies***: Forcing and response over time scales from millennial to millions of years.
- ***Empirical***: Forcing and response over the instrumental record.
- ***Climate modeling***: Understanding the processes that comprise Earth's climate system and representing them in large-scale numerical models.
- ***Energy-balance model***: Empirical determination from integral properties of Earth's climate system.

GLOBAL-MEAN RADIATIVE FORCINGS (RF)

Pre-industrial to present (Intergovernmental Panel on Climate Change, 2007)

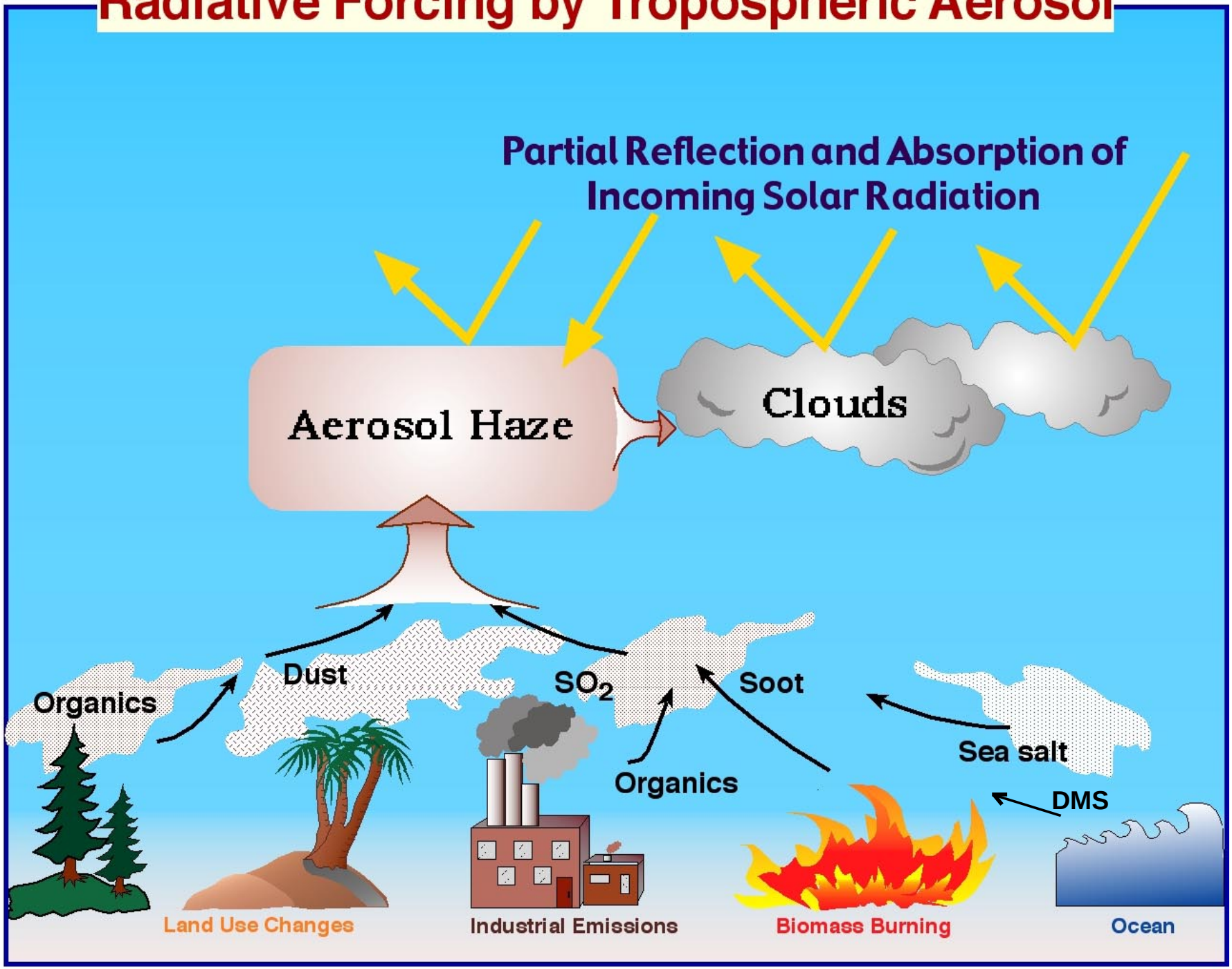




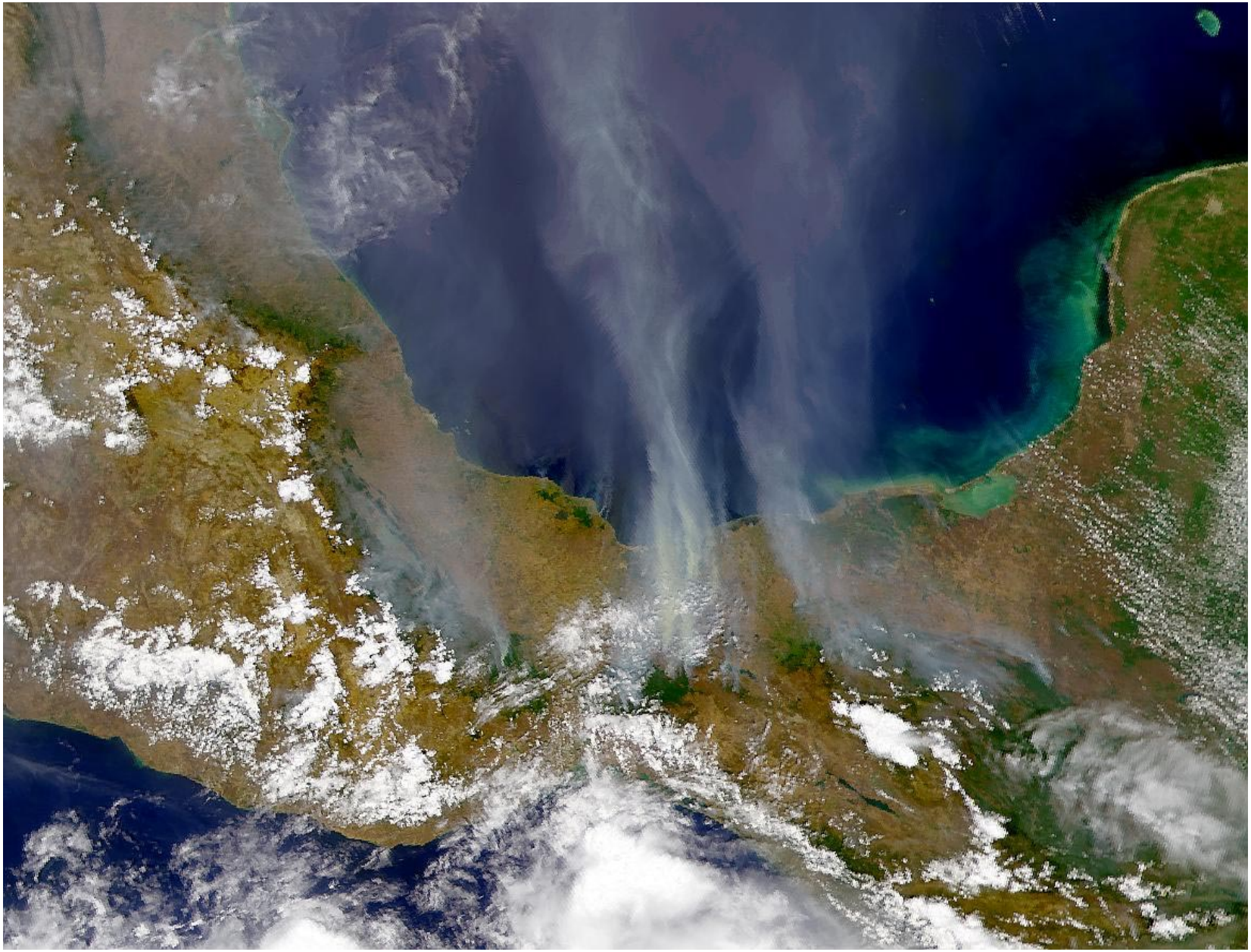
LOSU denotes level of scientific understanding.

ATMOSPHERIC AEROSOLS – A CONFOUNDING INFLUENCE

Radiative Forcing by Tropospheric Aerosol



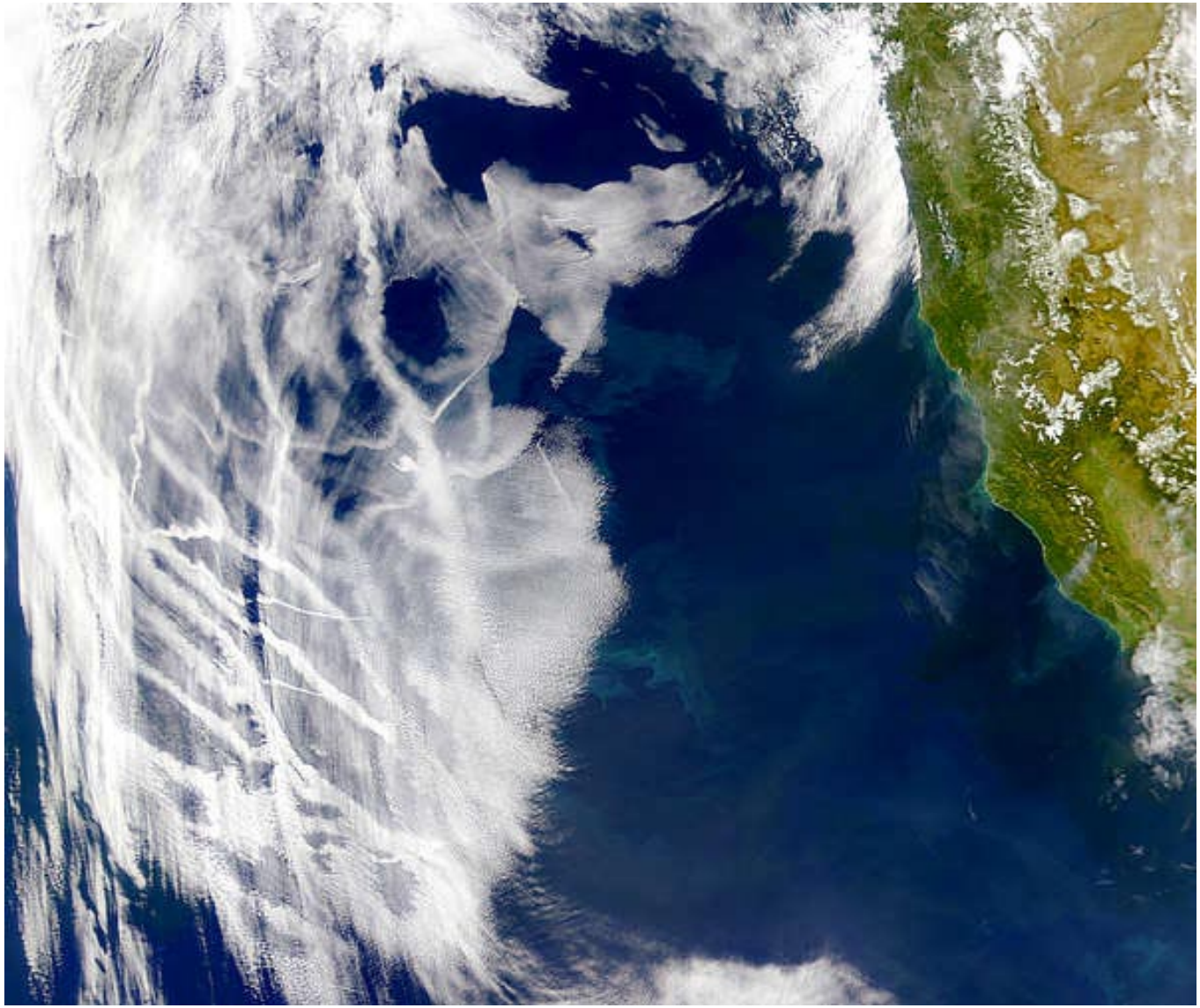
AEROSOLS AS SEEN FROM SPACE



Fire plumes from southern Mexico transported north into Gulf of Mexico.

CLOUD BRIGHTENING BY SHIP TRACKS

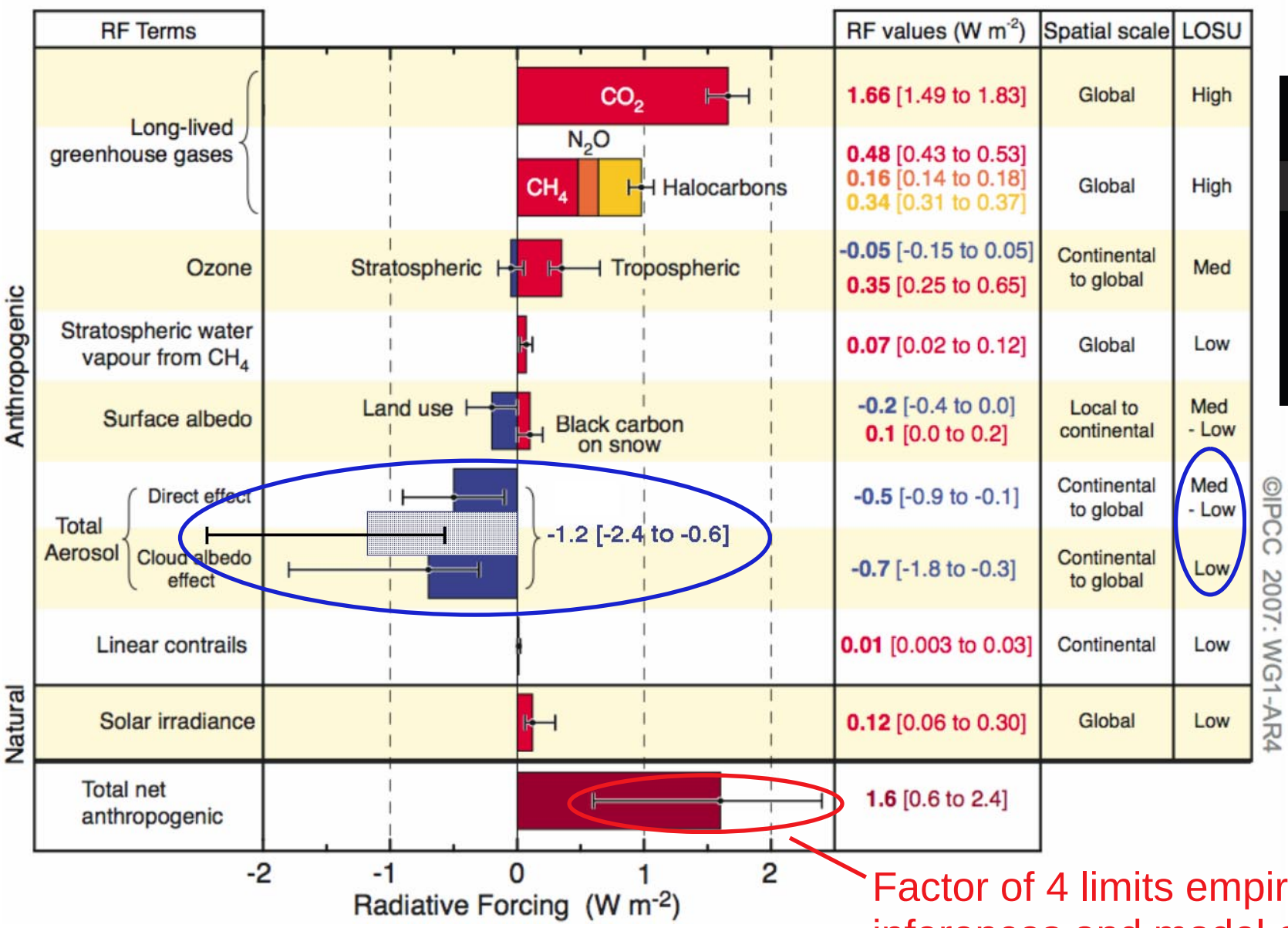
Satellite photo off California coast

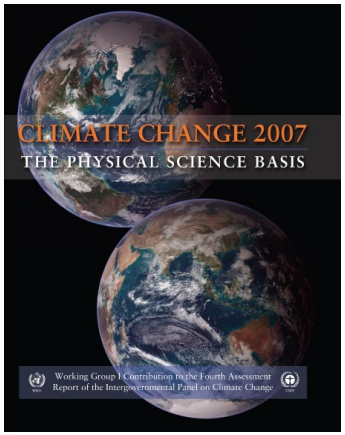


Aerosols from ship emissions enhance reflectivity of marine stratus.

GLOBAL-MEAN RADIATIVE FORCINGS (RF)

Pre-industrial to present (Intergovernmental Panel on Climate Change, 2007)



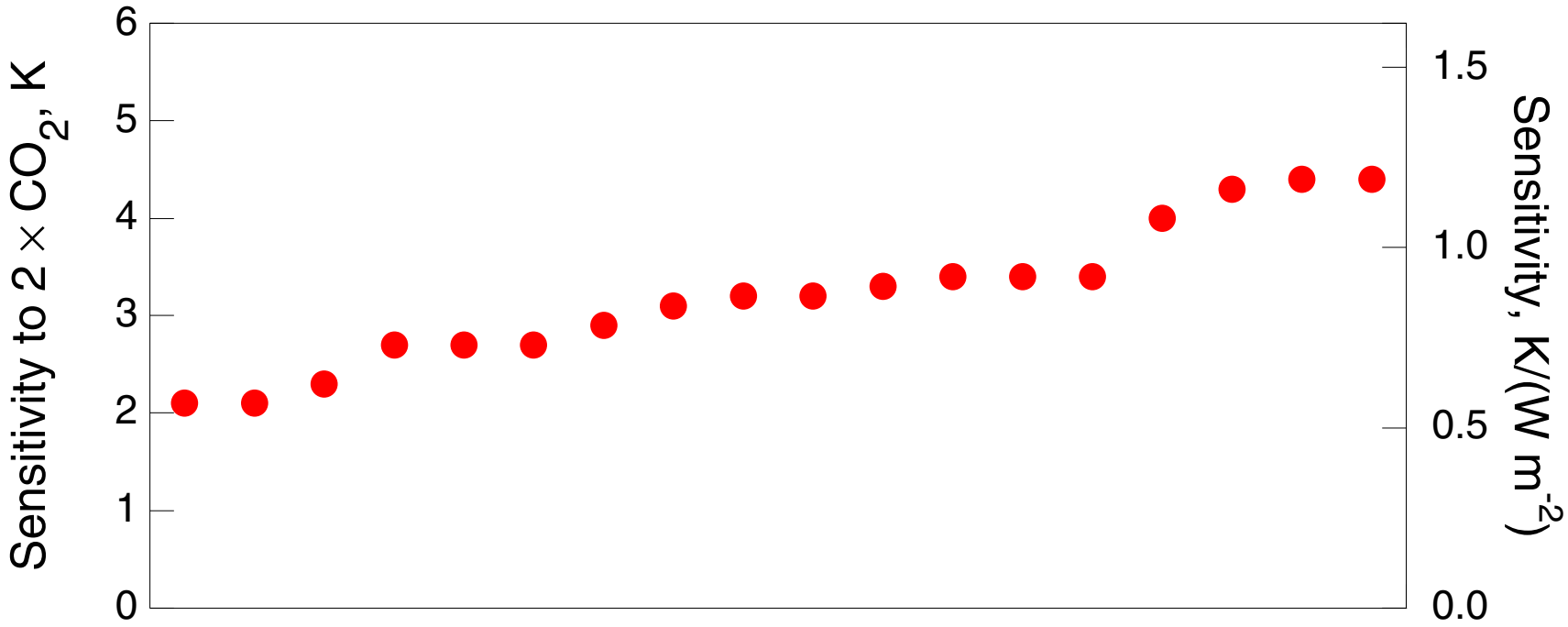


Factor of 4 limits empirical inferences and model evaluation.

LOSU denotes level of scientific understanding.

CLIMATE SENSITIVITY ESTIMATES FROM GLOBAL CLIMATE MODELS

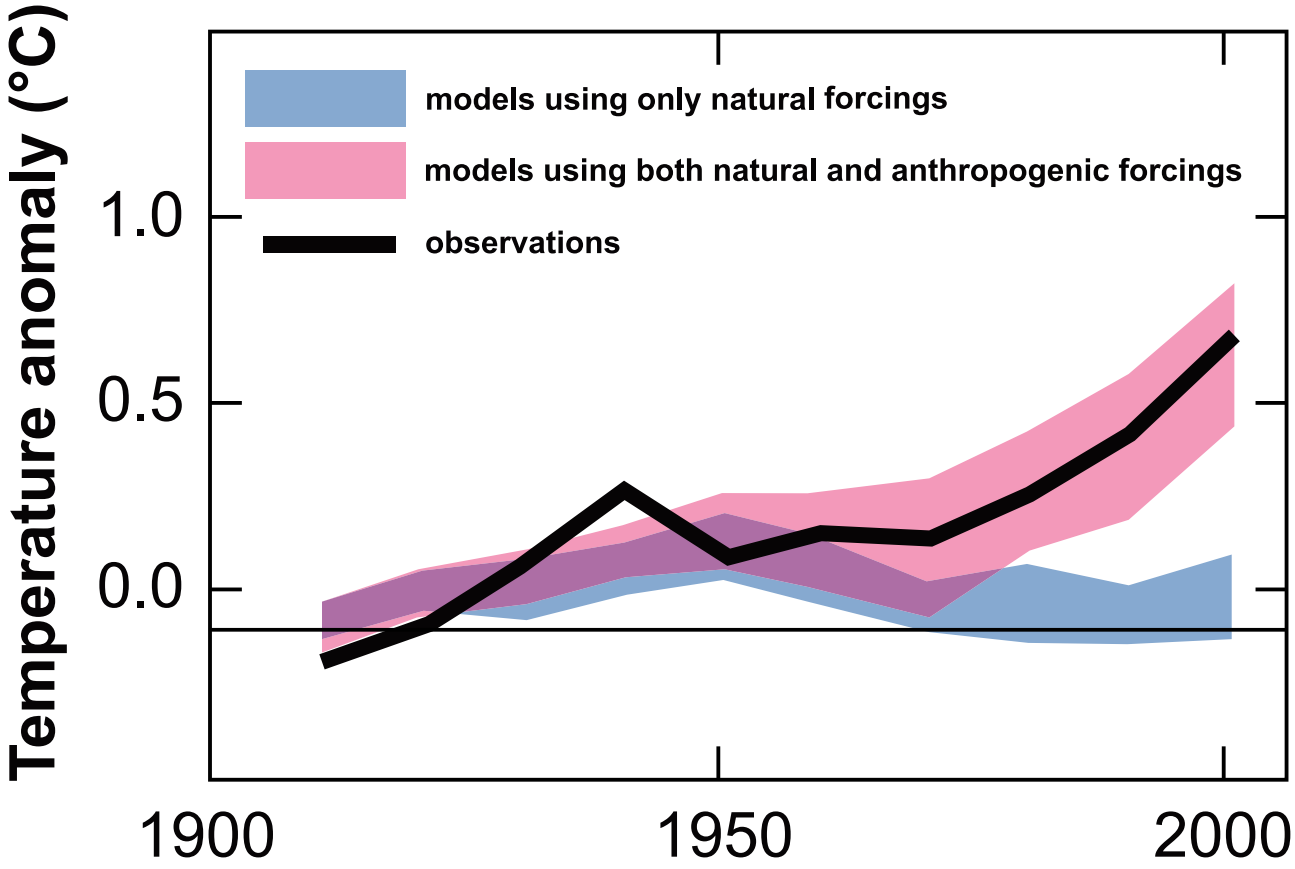
18 Current global climate models – IPCC AR4, 2007

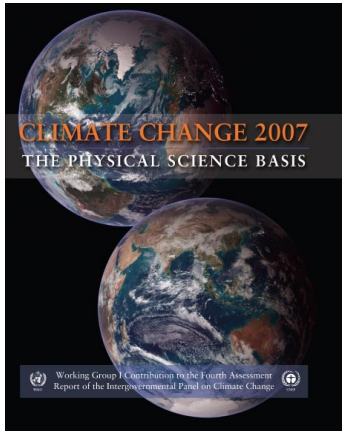


Range of model sensitivities is identical with range of current overall IPCC sensitivity estimate.

TOO ROSY A PICTURE?

Ensemble of 58 model runs with 14 global climate models

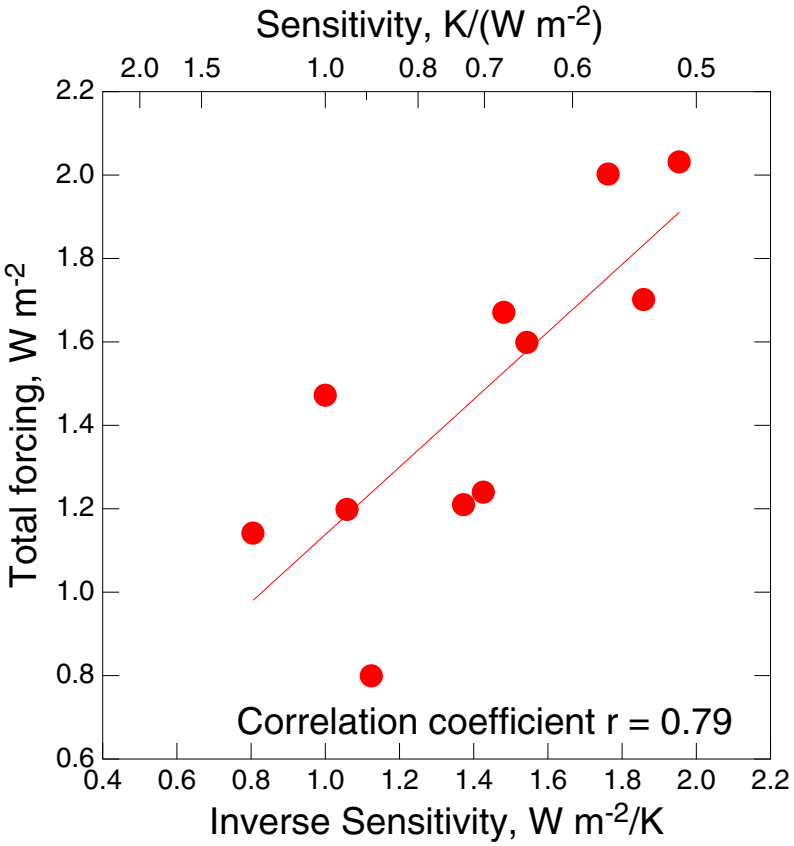


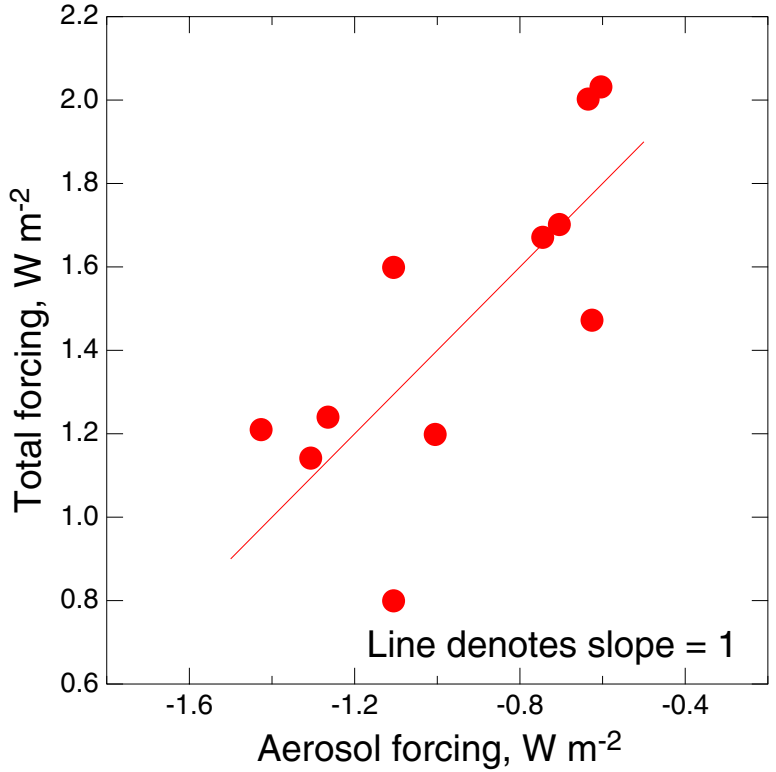


- Simulations that incorporate anthropogenic forcings, including increasing greenhouse gas concentrations and the effects of aerosols, and that also incorporate natural external forcings provide a ***consistent explanation of the observed temperature record***.
- These simulations used models with ***different climate sensitivities, rates of ocean heat uptake and magnitudes and types of forcings***.

CORRELATION OF AEROSOL FORCING, TOTAL FORCING, AND SENSITIVITY IN CLIMATE MODELS

Eleven models used in 2007 IPCC analysis





Modified from Kiehl, GRL, 2007

Climate models with lower sensitivity (higher inverse sensitivity) employed a greater total forcing.

Greater total forcing is due to lower magnitude (less negative) aerosol forcing.

SIGNIFICANCE OF AEROSOL FORCING

Aerosols are offsetting a substantial but unknown fraction of global warming from CO_2 and other greenhouse gases.

Aerosol forcing is highly uncertain.

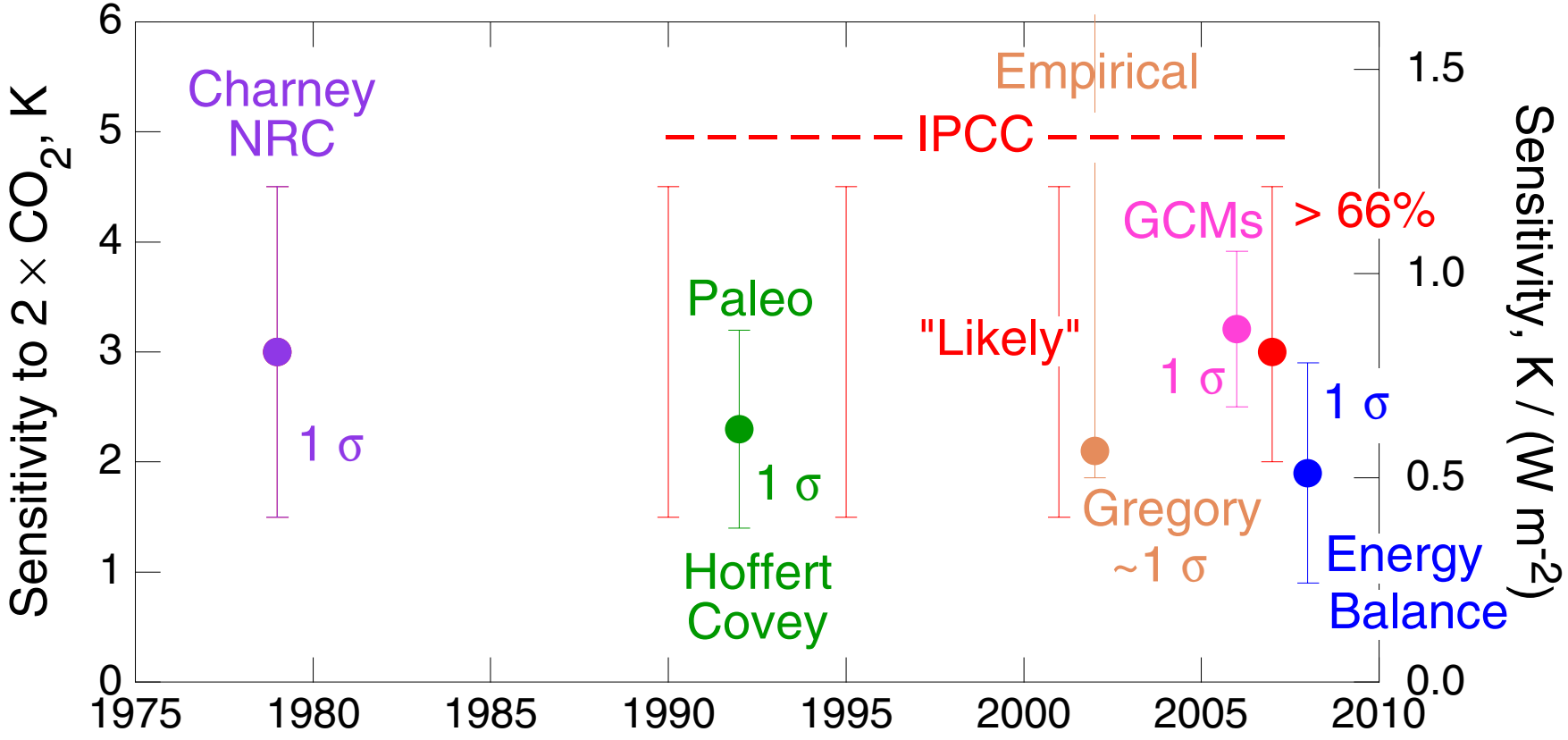
This uncertainty limits present understanding of climate sensitivity.

Aerosols are short lived in the atmosphere – about a week.

Hence aerosol forcing cannot be viewed as a viable means of forestalling global warming from increases in CO_2.

CLIMATE SENSITIVITY ESTIMATES

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



Despite much research climate sensitivity remains uncertain to a factor of 2 or 3.

IMPLICATIONS OF UNCERTAINTY IN CLIMATE SENSITIVITY

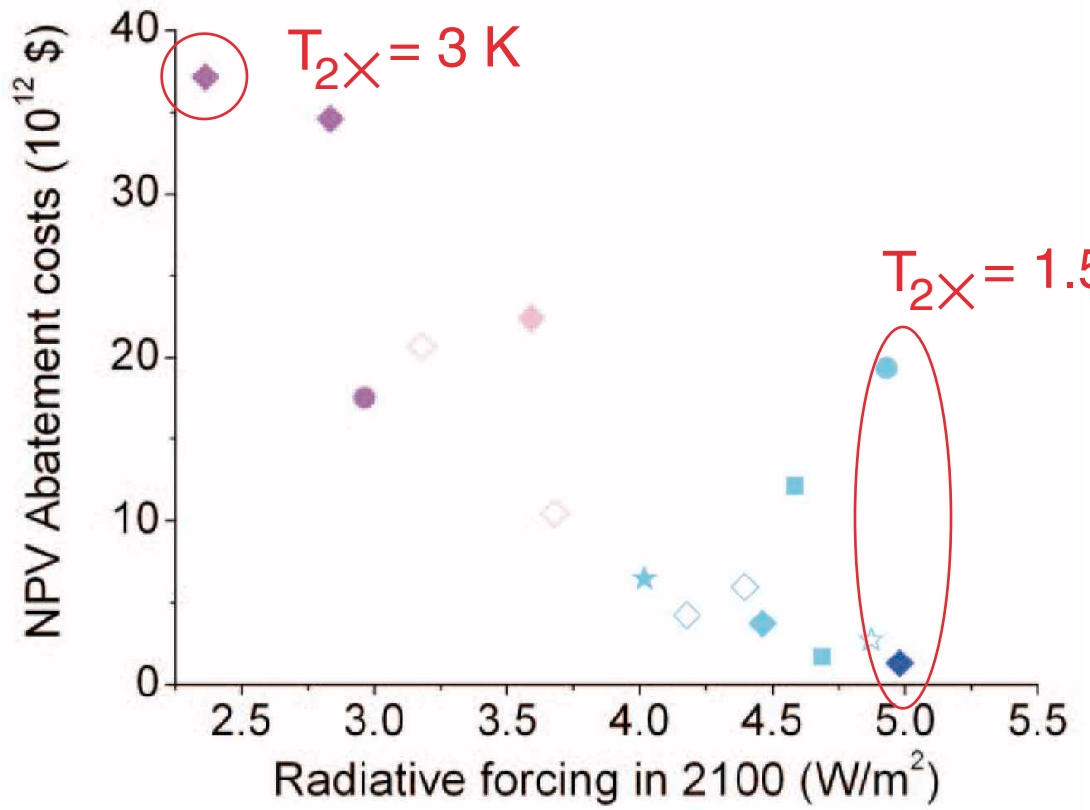
Uncertainty in climate sensitivity translates directly into . . .

- Uncertainty in the amount of ***incremental atmospheric*** $\mathbf{CO_2}$ that would result in a given increase in global mean surface temperature.
- Uncertainty in the amount of ***fossil fuel carbon*** that can be combusted consonant with a given climate effect.

At present this uncertainty is at least a factor of 2.

COST OF ACHIEVING TARGET RADIATIVE FORCINGS AND TEMPERATURE INCREASE

Radiative forcings relative to preindustrial



Van Vuuren et al PNAS, 2008

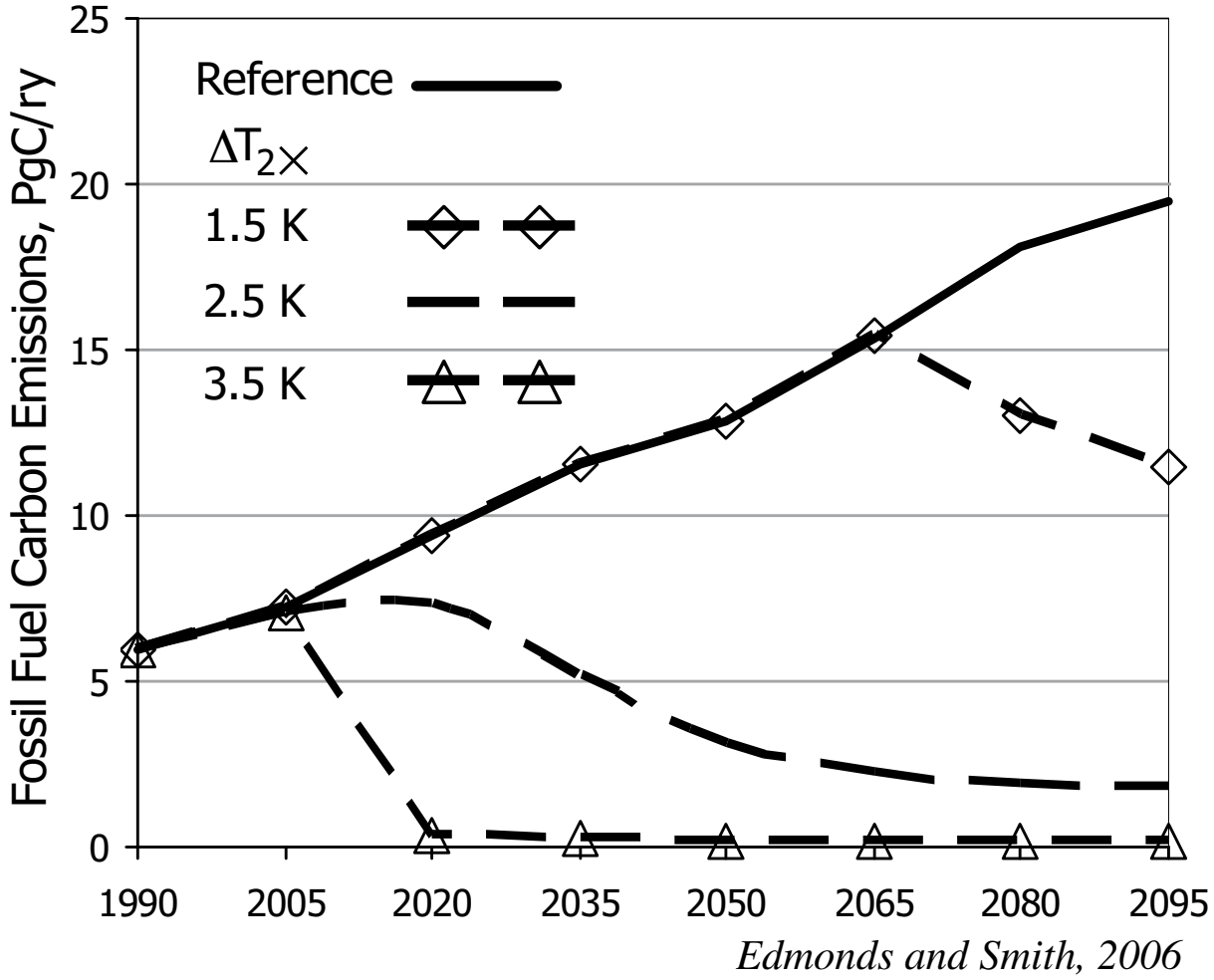
Globally integrated net present value calculated for 5% discount rate.

Different symbols denote different economic models.

Ellipses denote maximum forcing for temperature increase of 2 K for indicated climate sensitivities, and associated projected costs.

CO_2 EMISSIONS STRATEGIES TO ACHIEVE 2 DEGREES ABOVE PREINDUSTRIAL

Emissions profiles for assumed climate sensitivities $\Delta T_{2\times}$



Edmonds and Smith, 2006

Timing and amount of required emissions reductions depend strongly on climate sensitivity.

IMPORTANCE OF KNOWLEDGE OF CLIMATE SENSITIVITY TO INFORMED DECISION MAKING

- The lifetime of incremental atmospheric CO_2 is about 100 years.
- The expected life of a new coal-fired power plant is 50 to 75 years.

Actions taken today will have long-lasting effects.

Early knowledge of climate sensitivity can result in huge averted costs.

CARBON DIOXIDE IN A SHARED GLOBAL ATMOSPHERE

Burning fossil carbon confers a direct benefit but introduces CO_2 into the atmosphere.

The half-life of incremental CO_2 in the atmosphere is about 100 years; incremental CO_2 is well mixed in the atmosphere.

The consequences of incremental CO_2 are global, independent of where and by whom it was emitted.

These consequences are distributed and shared – by those alive now and by future generations.

The amount of CO_2 that can be introduced into the atmosphere consonant with a given climatic impact is a shared global resource.

Uncertainty in climate sensitivity results in a corresponding uncertainty in this shared resource.

This uncertainty limits effective and cost efficient energy planning, with enormous cost implications.