CLIMATE SENSITIVITY AND THE ROLE OF AEROSOLS

Stephen E. Schwartz

BROOKHAVEN NATIONAL LABORATORY

Upton, New York

ARM

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OVERVIEW

Earth's energy balance

Perturbations to Earth's energy balance

Radiative forcing

Radiative forcing by incremental greenhouse gases and aerosols

Climate sensitivity

Estimates of climate sensitivity

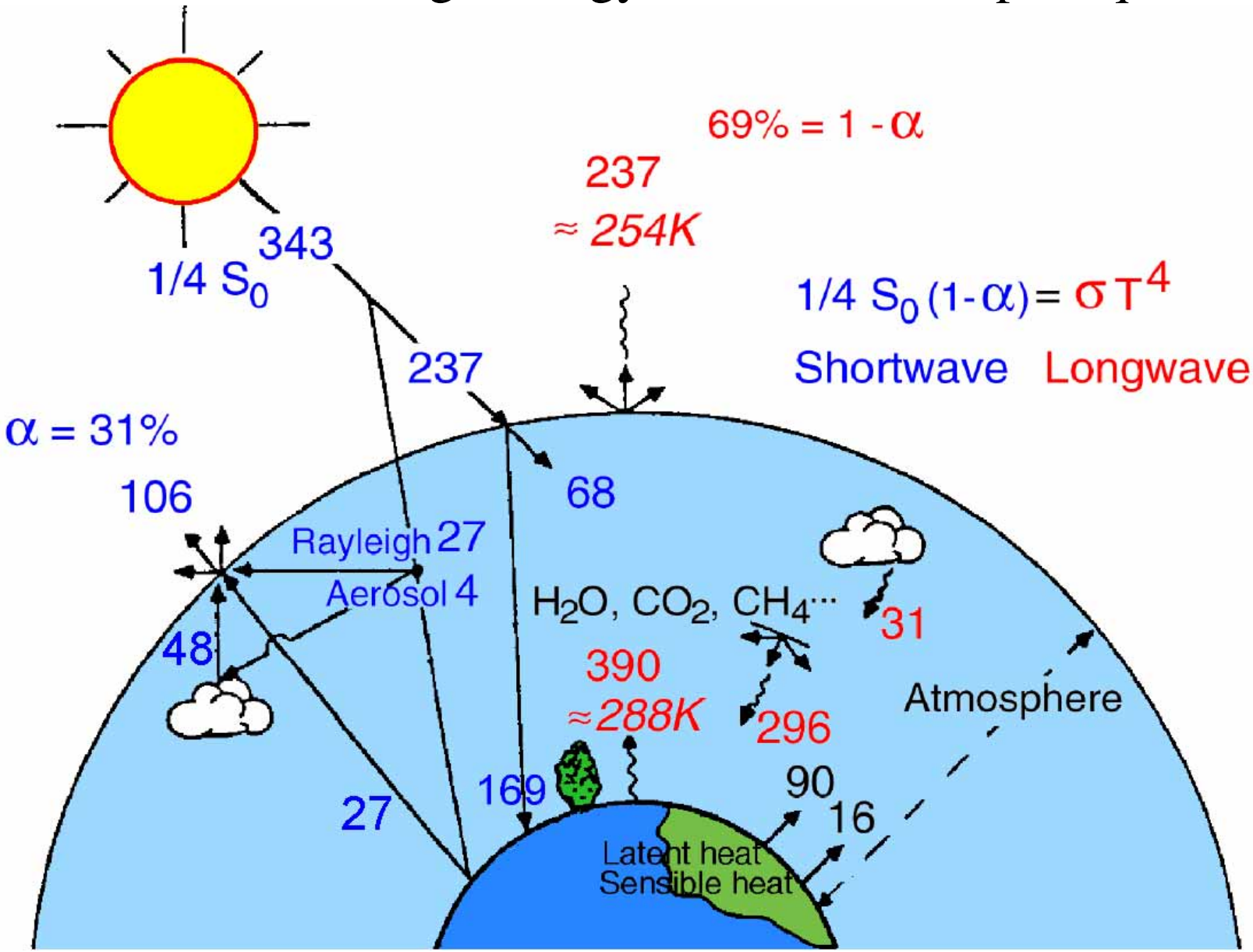
Approaches to determining Earth's climate sensitivity

Concerns with evaluation of climate models over the twentieth century – uncertainty in aerosol forcing

Implications of uncertainty in climate sensitivity

GLOBAL ENERGY BALANCE

Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

RADIATIVE FORCING

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

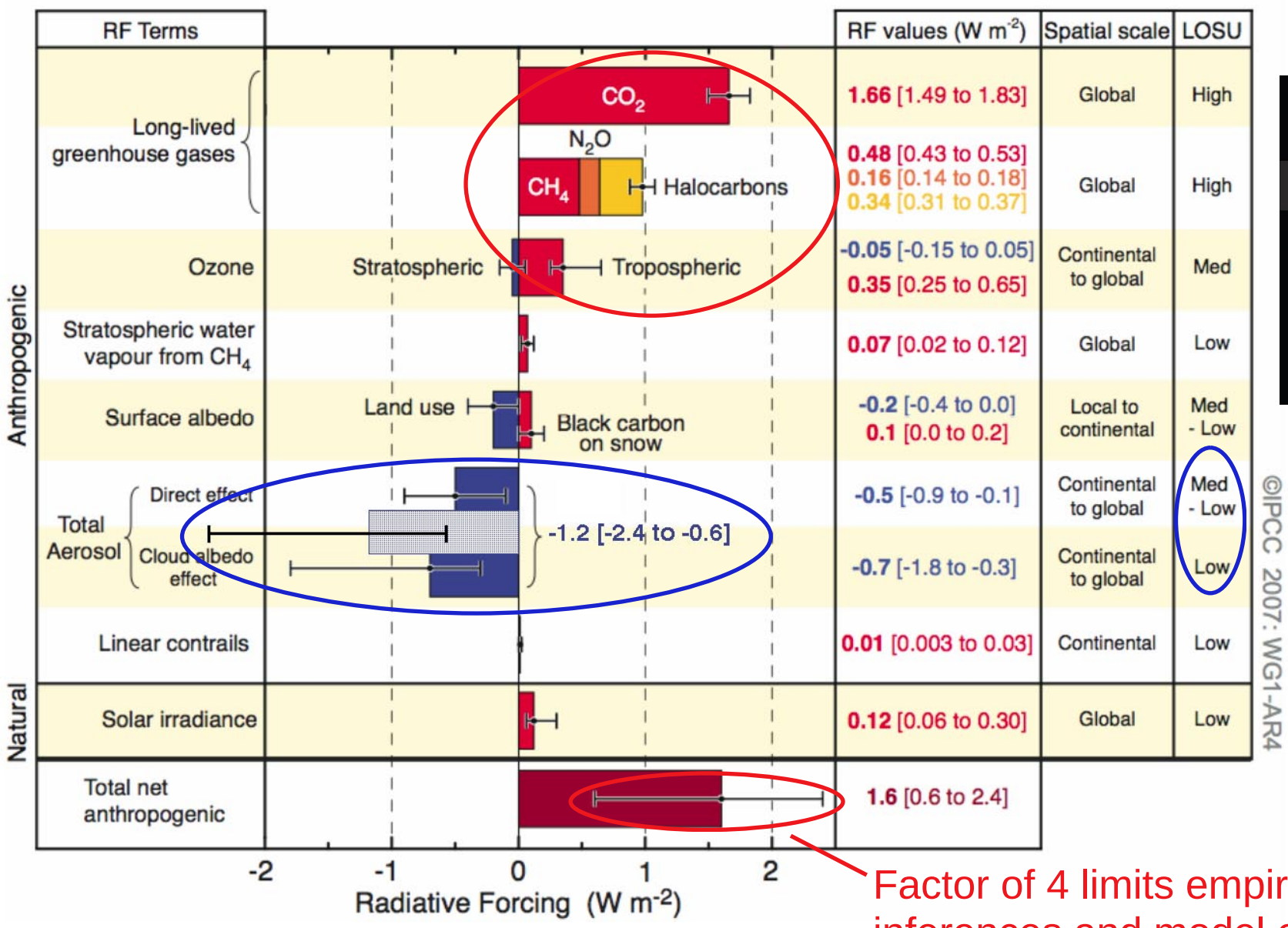
Working hypothesis:

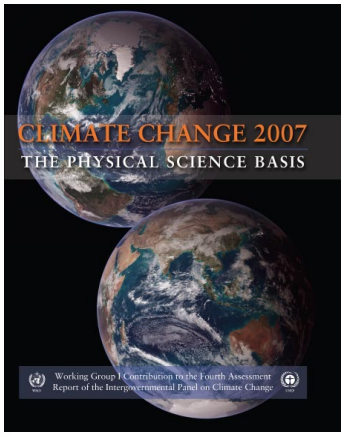
On a global basis radiative forcings are additive and fungible.

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

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.

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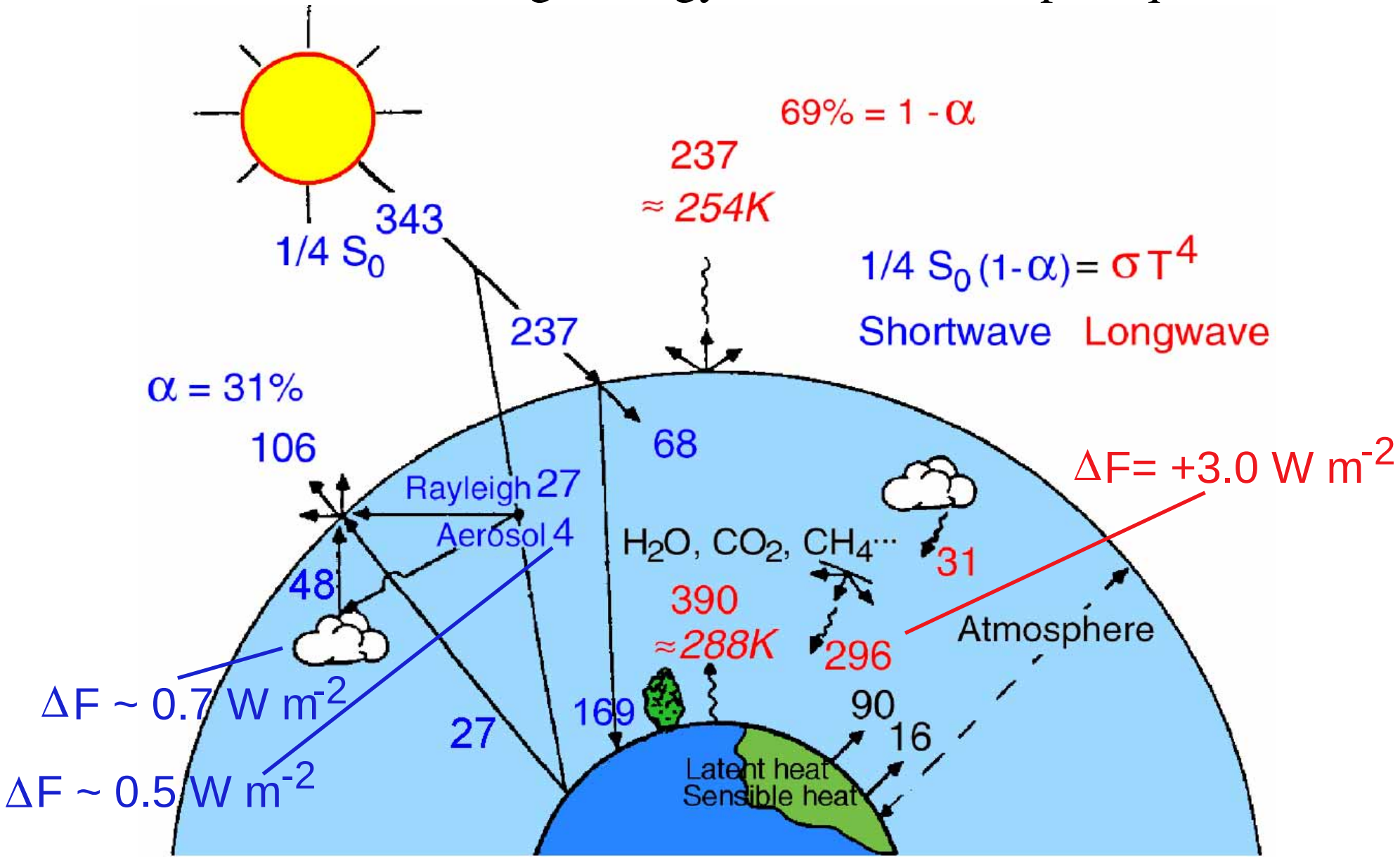

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CLIMATE RESPONSE

The ***change*** in global and annual mean temperature, ΔT, K, resulting from a given radiative forcing.

Working hypothesis:

The change in global mean temperature is proportional to the forcing, but independent of its nature and spatial distribution.

$$\Delta T = S\,\Delta F$$

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.

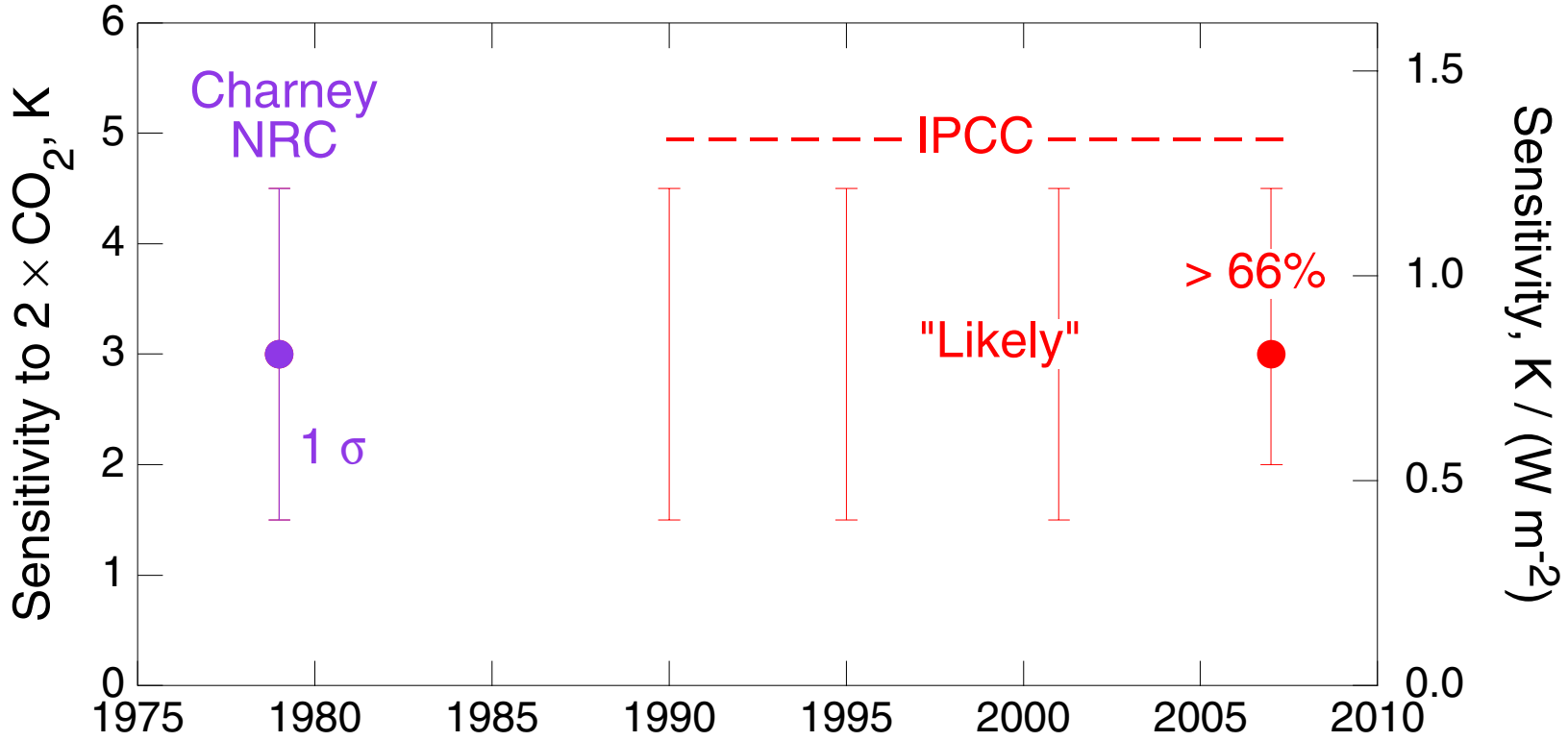
Climate sensitivity is often expressed as the temperature for doubled CO_2 concentration $\Delta T_{2\times}$.

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

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

CLIMATE SENSITIVITY ESTIMATES THROUGH THE AGES

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



KEY APPROACHES TO DETERMINING CLIMATE SENSITIVITY

- ***Paleoclimate studies***: Forcing and response over time scales from thousands to millions of years.

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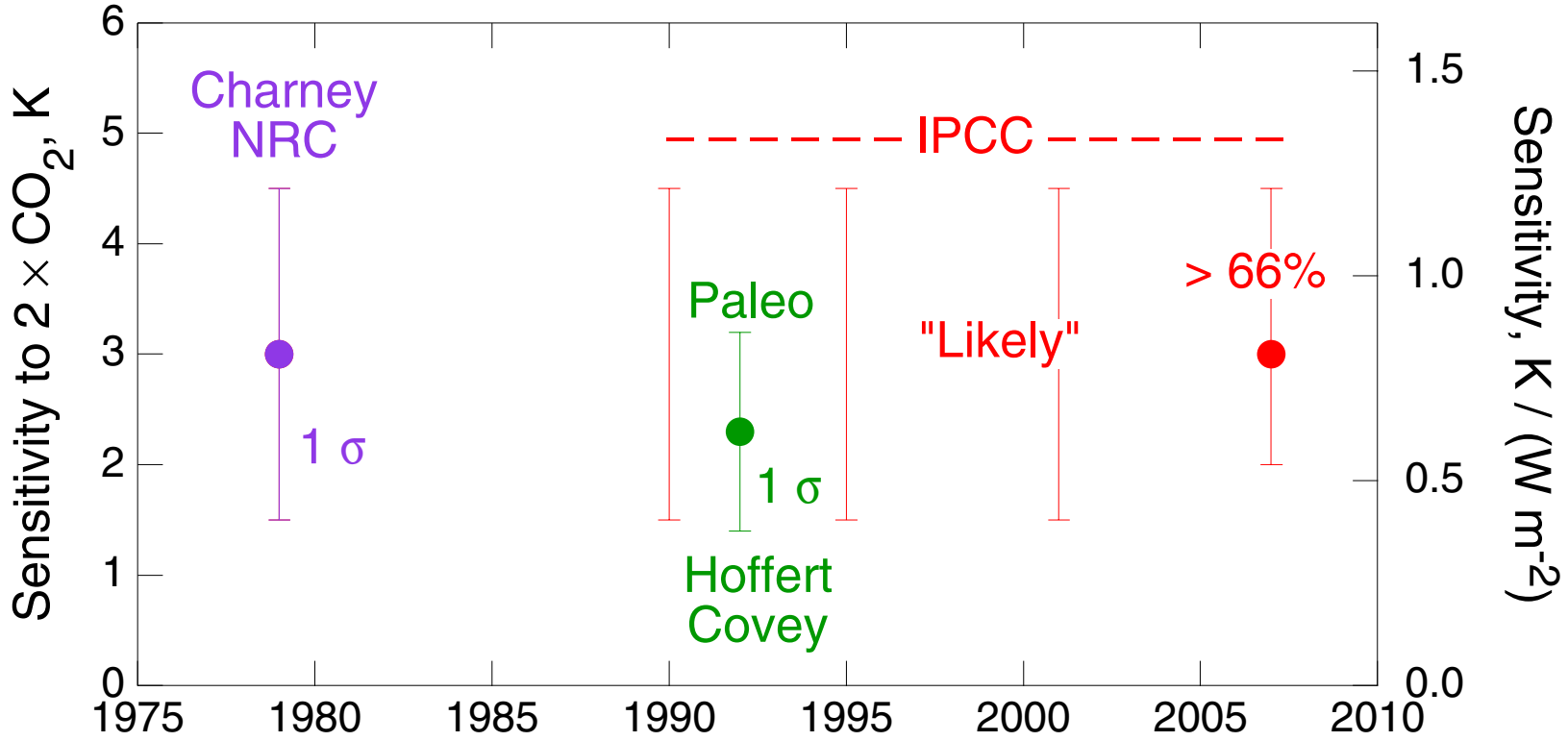

Climate sensitivity from paleo climate has been a major contributor to present assessment of climate sensitivity.

KEY APPROACHES TO DETERMINING CLIMATE SENSITIVITY

- ***Paleoclimate studies***: Forcing and response over time scales from thousands to millions of years.

- ***Empirical***: Forcing and response over the instrumental record.

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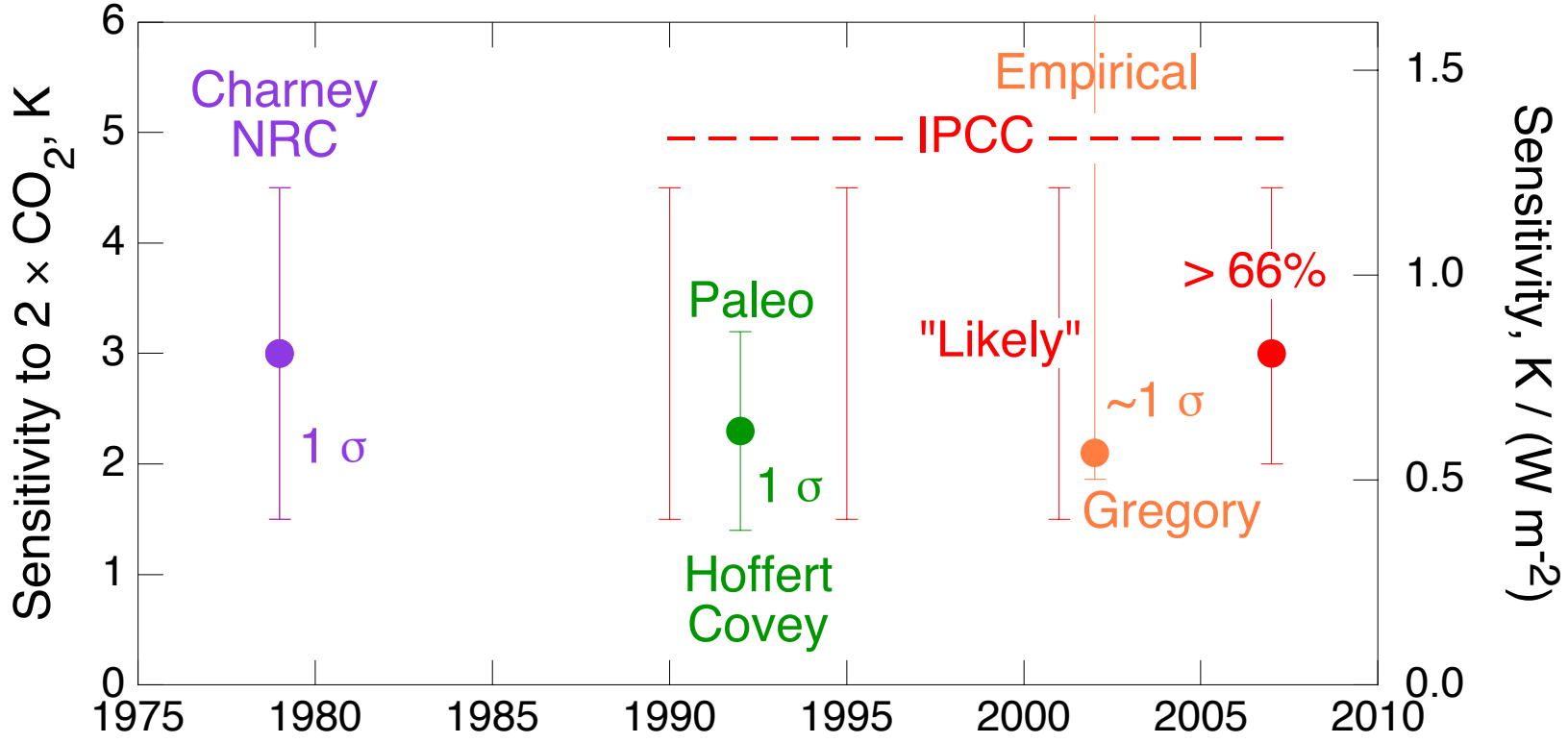


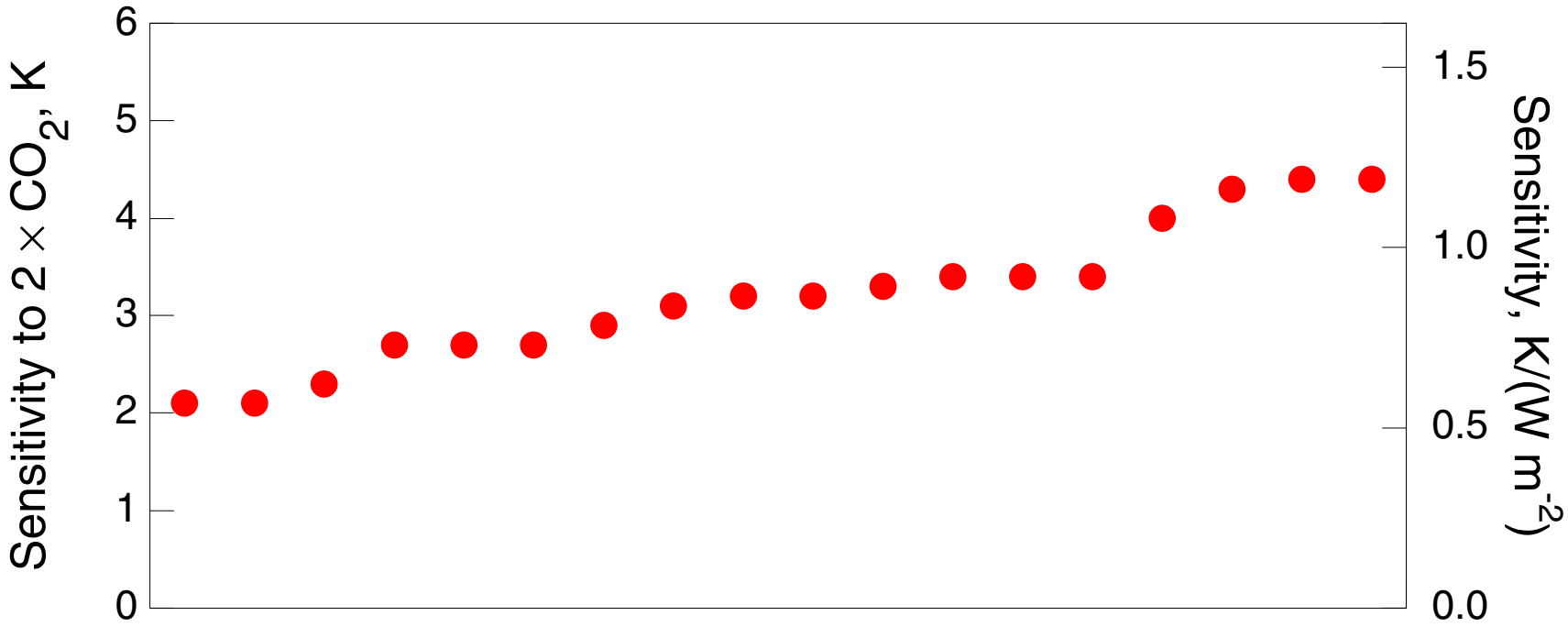
Empirical approach does not greatly constrain sensitivity because of uncertainty in aerosol forcing over the period of instrumental record.

KEY APPROACHES TO DETERMINING CLIMATE SENSITIVITY

- ***Paleoclimate studies***: Forcing and response over time scales from thousands 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.

CLIMATE SENSITIVITY ESTIMATES FROM GLOBAL CLIMATE MODELS

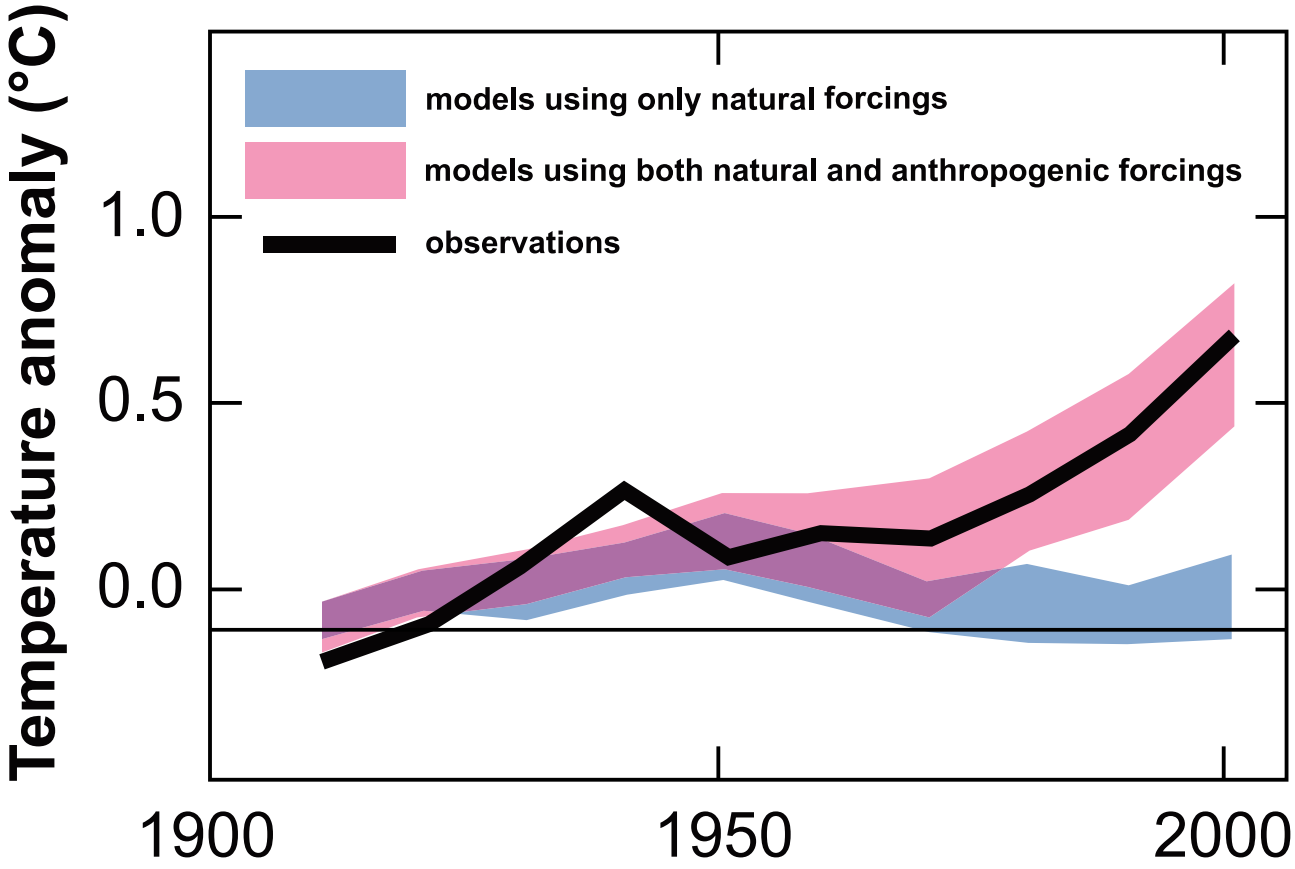
18 Current global climate models – IPCC AR4, 2007

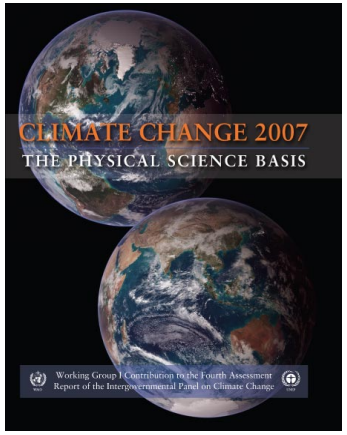


Range of model sensitivities is identical with range of current overall IPCC sensitivity estimate.

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***.

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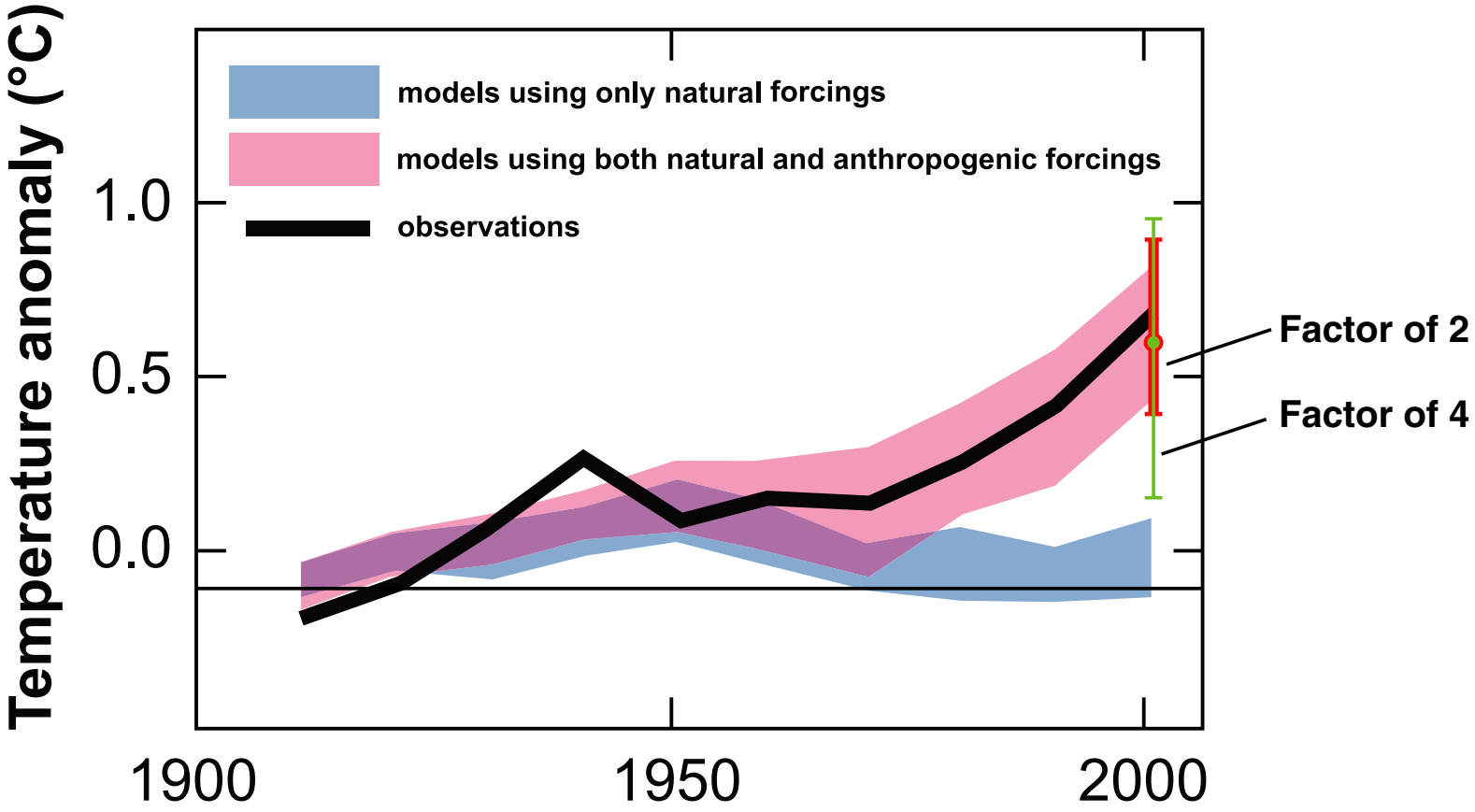


Schwartz, Charlson & Rodhe, Nature Reports – Climate Change, 2007

Uncertainty in modeled temperature increase – less than a factor of 2, red – is ***well less than uncertainty in forcing*** – a factor of 4, green.

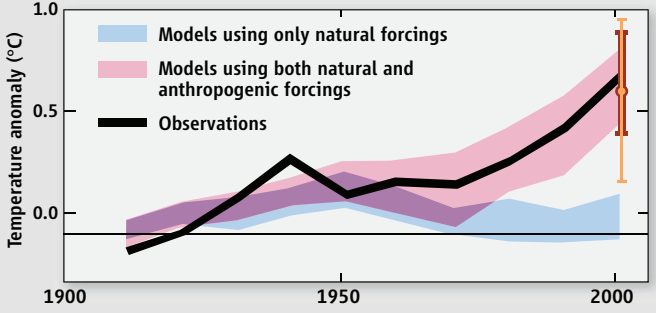
CLIMATE CHANGE —RICHARD A. KERR

Another Global Warming Icon Comes Under Attack

Climate scientists are used to skeptics taking potshots at their favorite line of evidence for global warming. It comes with the territory. But now a group of mainstream atmospheric scientists is disputing a rising icon of global warming, and researchers are giving some ground.

The challenge to one part of the latest climate assessment by the Intergovernmental Panel on Climate Change (IPCC) "is not a question of whether the Earth is warming or whether it will continue to warm" under human influence, says atmospheric scientist Robert Charlson of the University of Washington, Seattle, one of three authors of a commentary published online last week in *Nature Reports: Climate Change*.

Instead, he and his co-authors argue that the simulation by 14 different climate models of the warming in the 20th century is not the reassuring success IPCC claims it to be. Future warming could be much worse than that modeling suggests, they say, or even more moderate. IPCC authors concede the group has a point, but they say their report—rather well (see figure). A narrow range of simulated warmings (purple band) falls right on the actual warming (black line) and distinctly above simulations run under conditions free of human influence (blue band).



Not so certain. The uncertainty range in the modeled warming (red bar) is only half the uncertainty range (orange) of human influences.

But the group of three atmospheric scientists—Charlson; Stephen Schwartz of the Brookhaven National Laboratory in Upton, New York; and Henning Rodhe of Stockholm University, Sweden—says the close match between models and the actual warming is deceptive. The match "conveys a lot

gas changes are well known, they note, but not so the counteracting cooling of pollutant hazes, called aerosols. Aerosols cool the planet by reflecting away sunlight and increasing the reflectivity of clouds. Somehow, the three researchers say, modelers failed to draw on all the uncertainty inherent in aerosols so that the 20th-century simulations look more certain than they should.

Modeler Jeffrey Kiehl of the National Center for Atmospheric Research in Boulder, Colorado, reached the same conclusion by a different route. In an unpublished but widely circulated analysis, he plotted the combined effect of greenhouse gases and aerosols used in each of 11 models versus how responsive each model was to a given amount of greenhouse gases. The latter factor, called climate sensitivity, varies from model to model. He found that the more sensitive a model was, the stronger the aerosol cooling that drove the model. The net result of having greater sensitivity compensated by a greater aerosol effect was to narrow the

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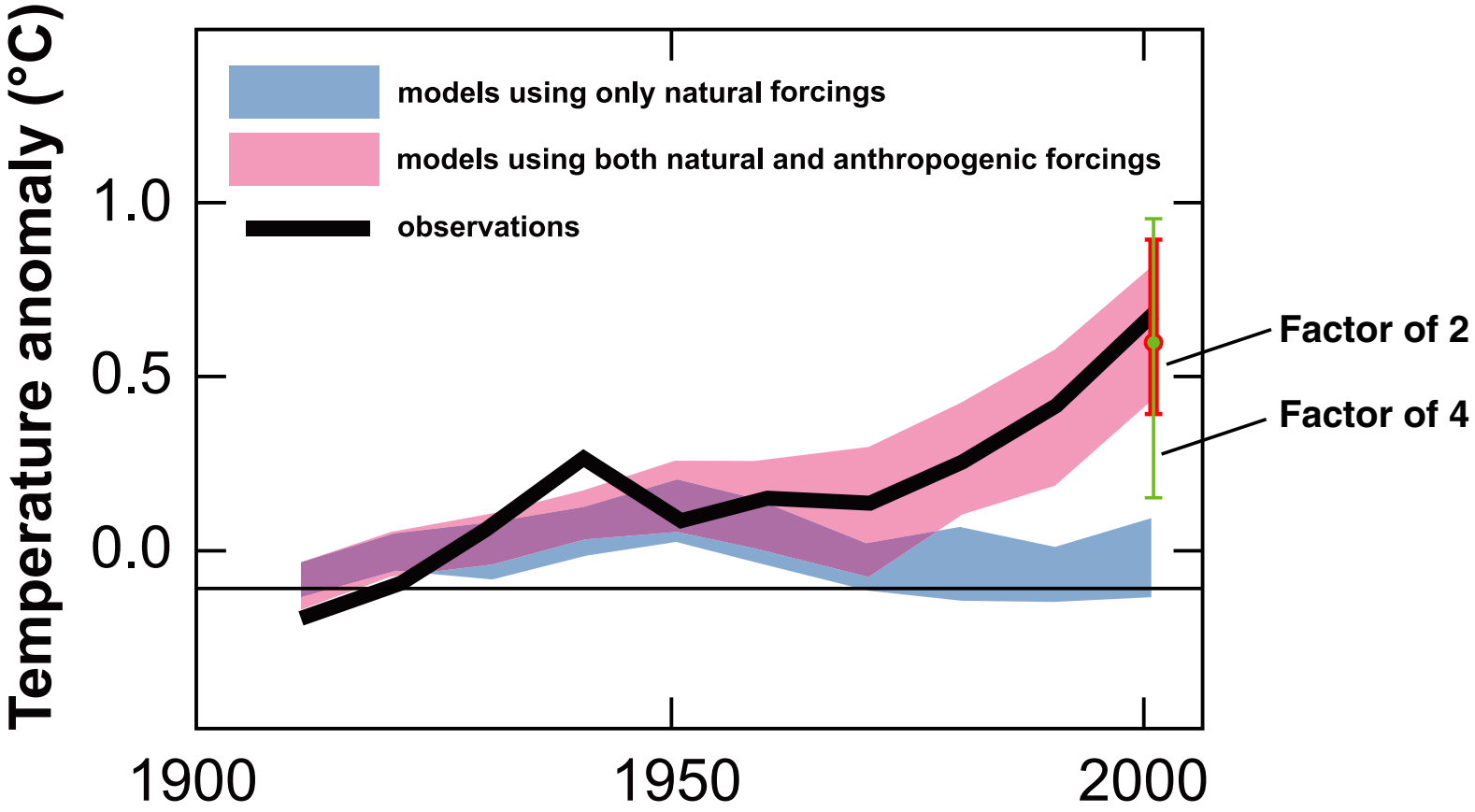


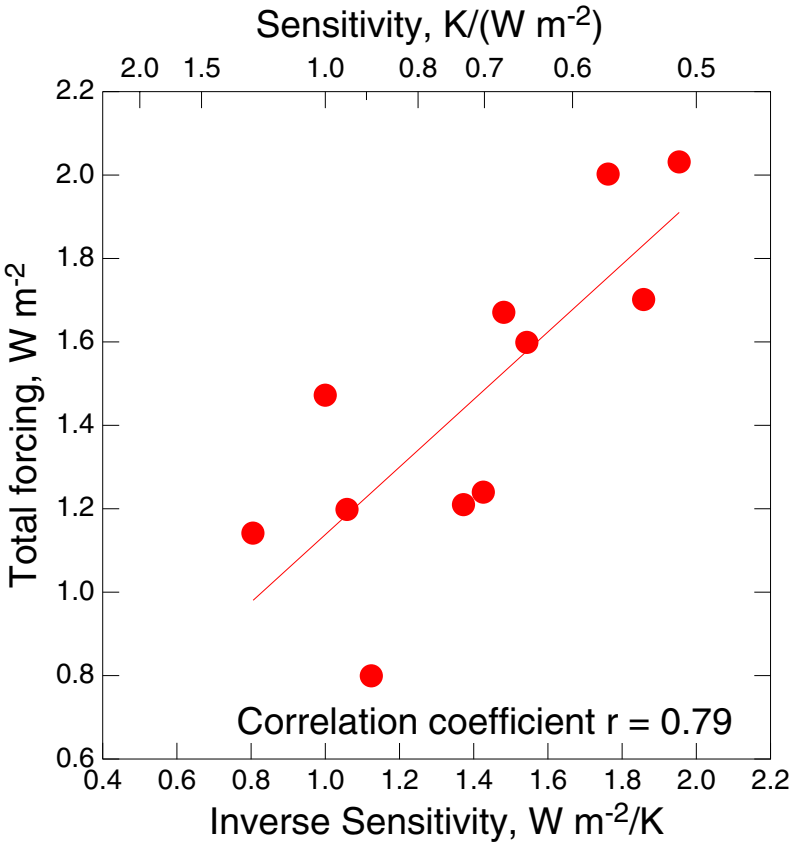
Schwartz, Charlson & Rodhe, Nature Reports – Climate Change, 2007

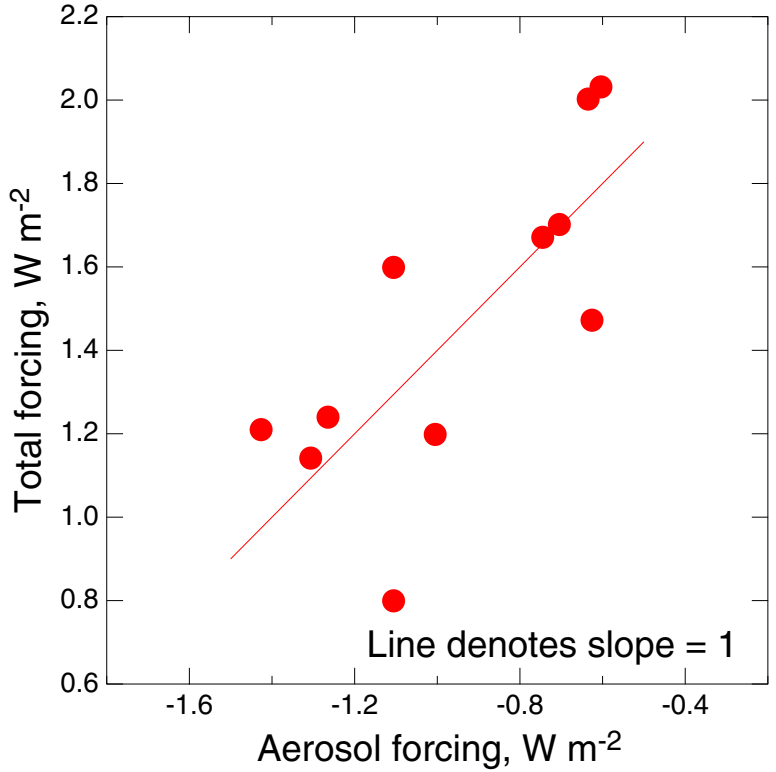
The models ***did not span the full range of the uncertainty*** and/or . . .

The forcings used in the model runs were ***anticorrelated with the sensitivities of the models***.

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.

IMPLICATIONS OF UNCERTAINTY IN CLIMATE SENSITIVITY

Uncertainty in climate sensitivity translates directly into . . .

- Uncertainty in the amount of ***incremental atmospheric*** **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 about a factor of 3.

This uncertainty is attributable largely to uncertainty in aerosol forcing.

Reduction in uncertainty in aerosol forcing is essential to reducing uncertainty in climate sensitivity.