EARTH'S CLIMATE, THE GREENHOUSE EFFECT, AND ENERGY

AN INTRODUCTION

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College Mini-semester Program

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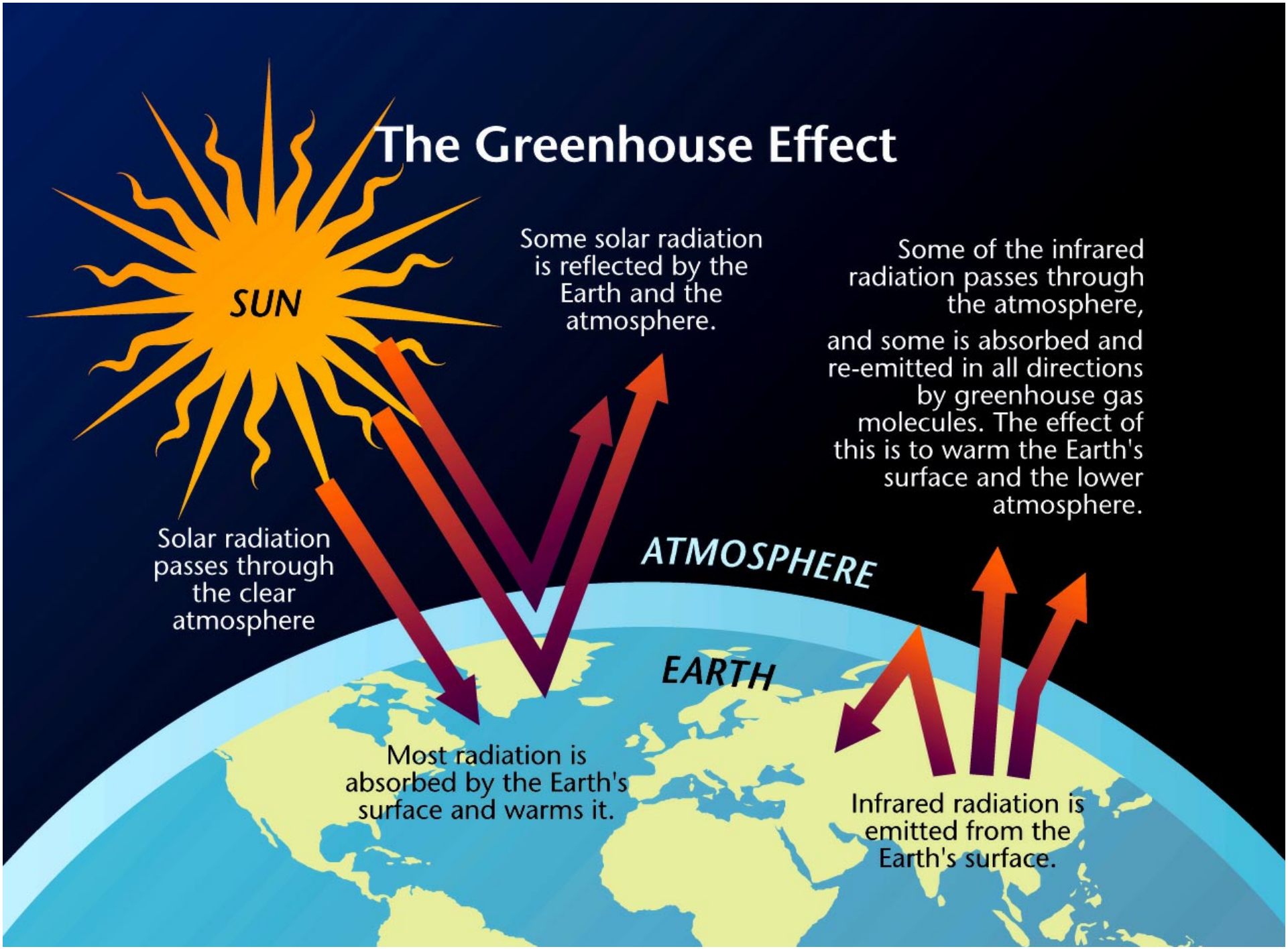
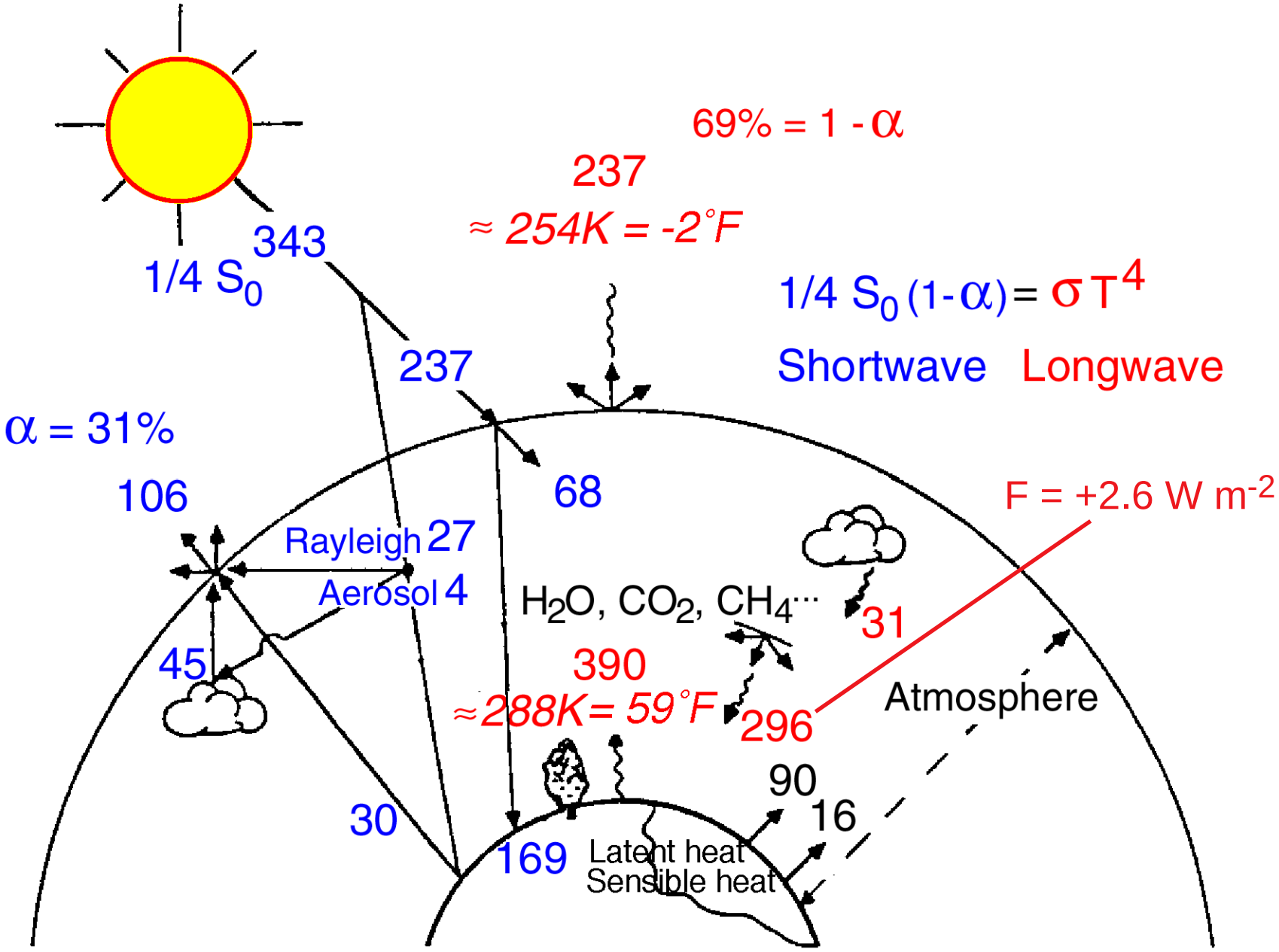
http://www.ecd.bnl.gov/steve


The Greenhouse Effect
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere,
and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.
Solar radiation passes through the clear atmosphere
ATMOSPHERE
EARTH
Most radiation is absorbed by the Earth's surface and warms it.
Infrared radiation is emitted from the Earth's surface.

GLOBAL ENERGY BALANCE

Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

ATMOSPHERIC RADIATION

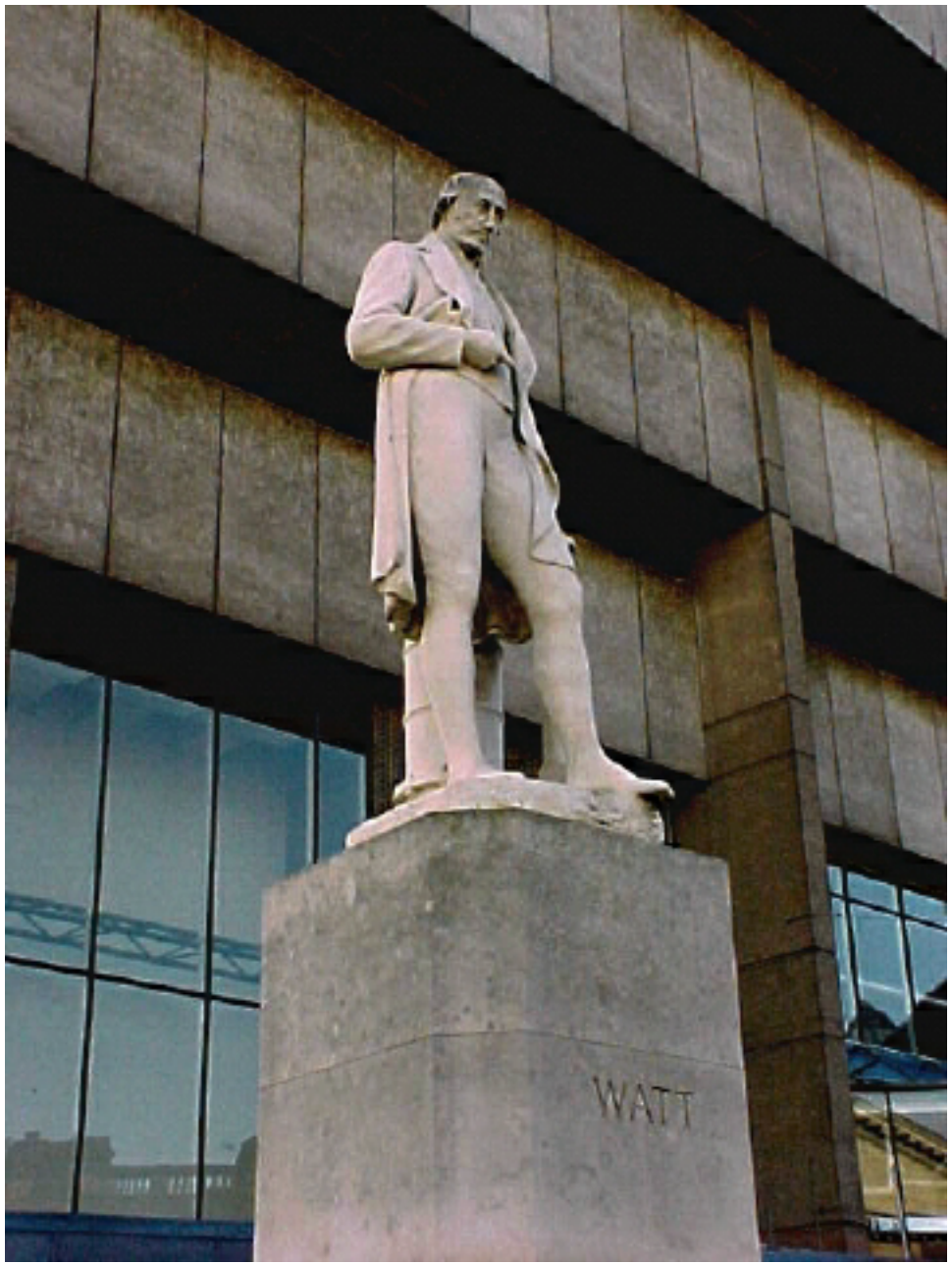
Energy per area per time

Power per area

Unit:

Watt per square meter

$W\ m^{-2}$



STEFAN - BOLTZMANN RADIATION LAW

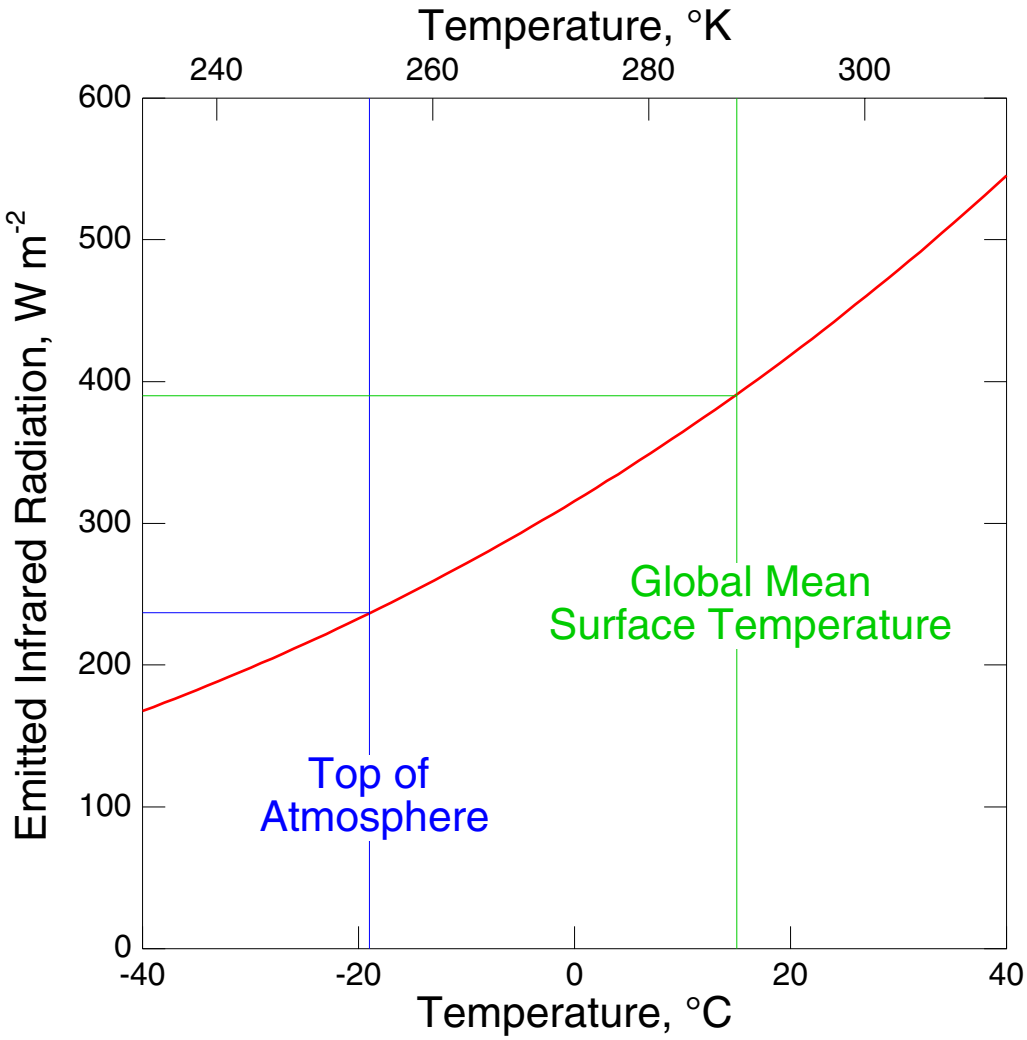
Emitted thermal radiative flux from a black body

$$F = \sigma T^4$$

F = Emitted flux, W m^{-2}

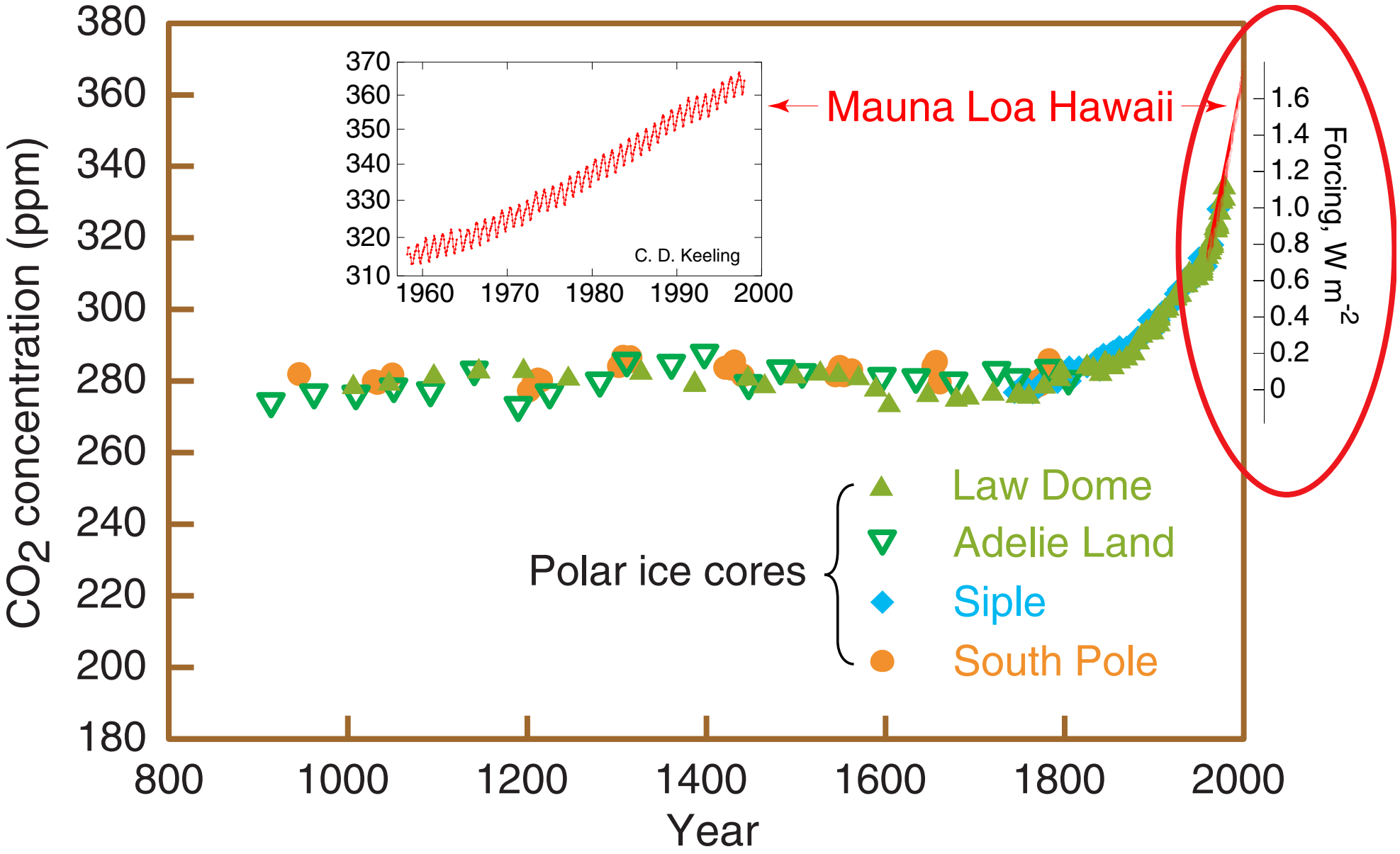
T = Absolute temperature, K

σ = Stefan-Boltzmann constant, W m^{-2} K^{-4}



Stefan-Boltzmann law "converts" temperature to radiative flux.

ATMOSPHERIC CARBON DIOXIDE IS INCREASING



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

RADIATIVE FORCING

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

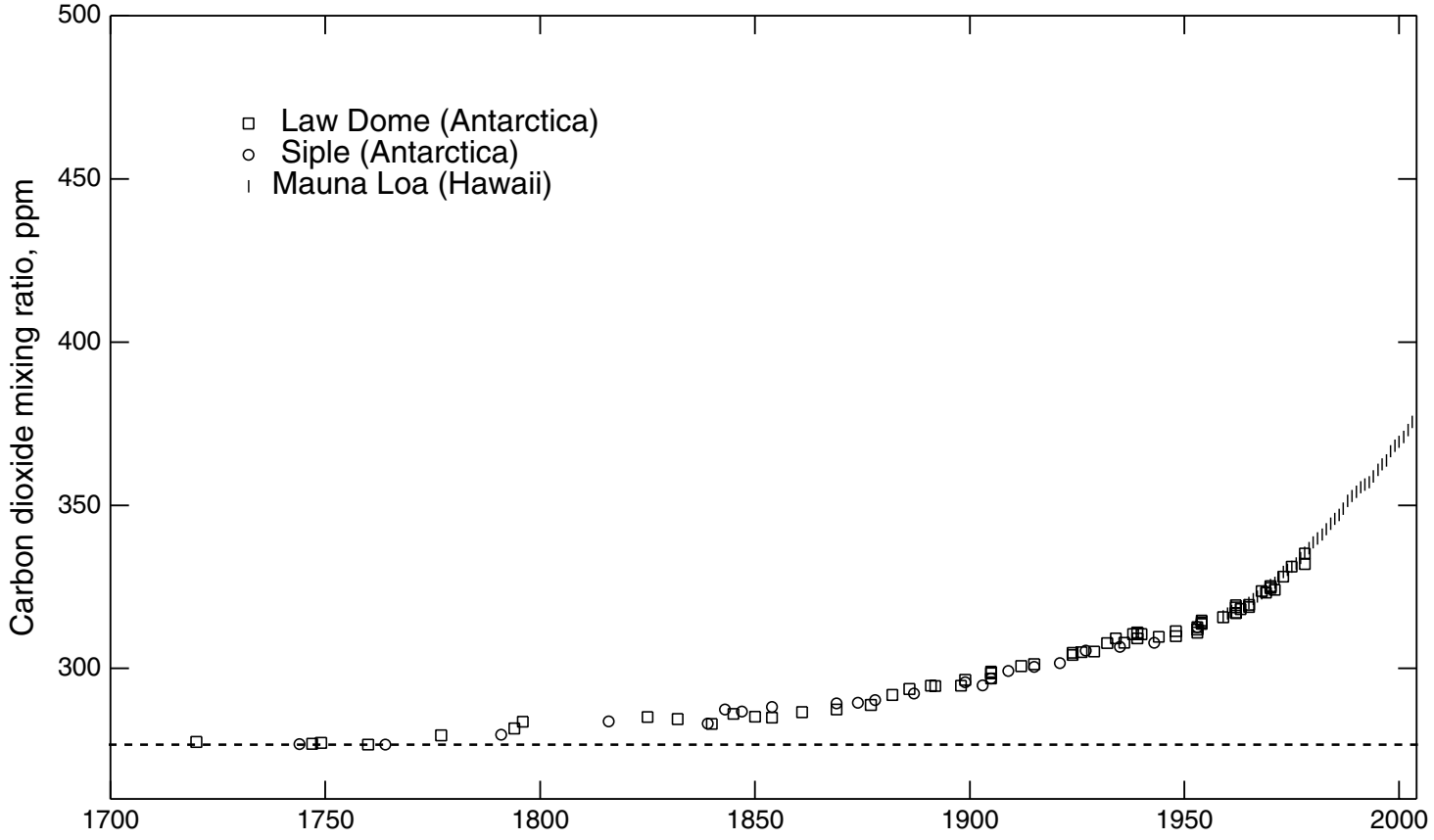
Working hypothesis:

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.

ATMOSPHERIC CARBON DIOXIDE

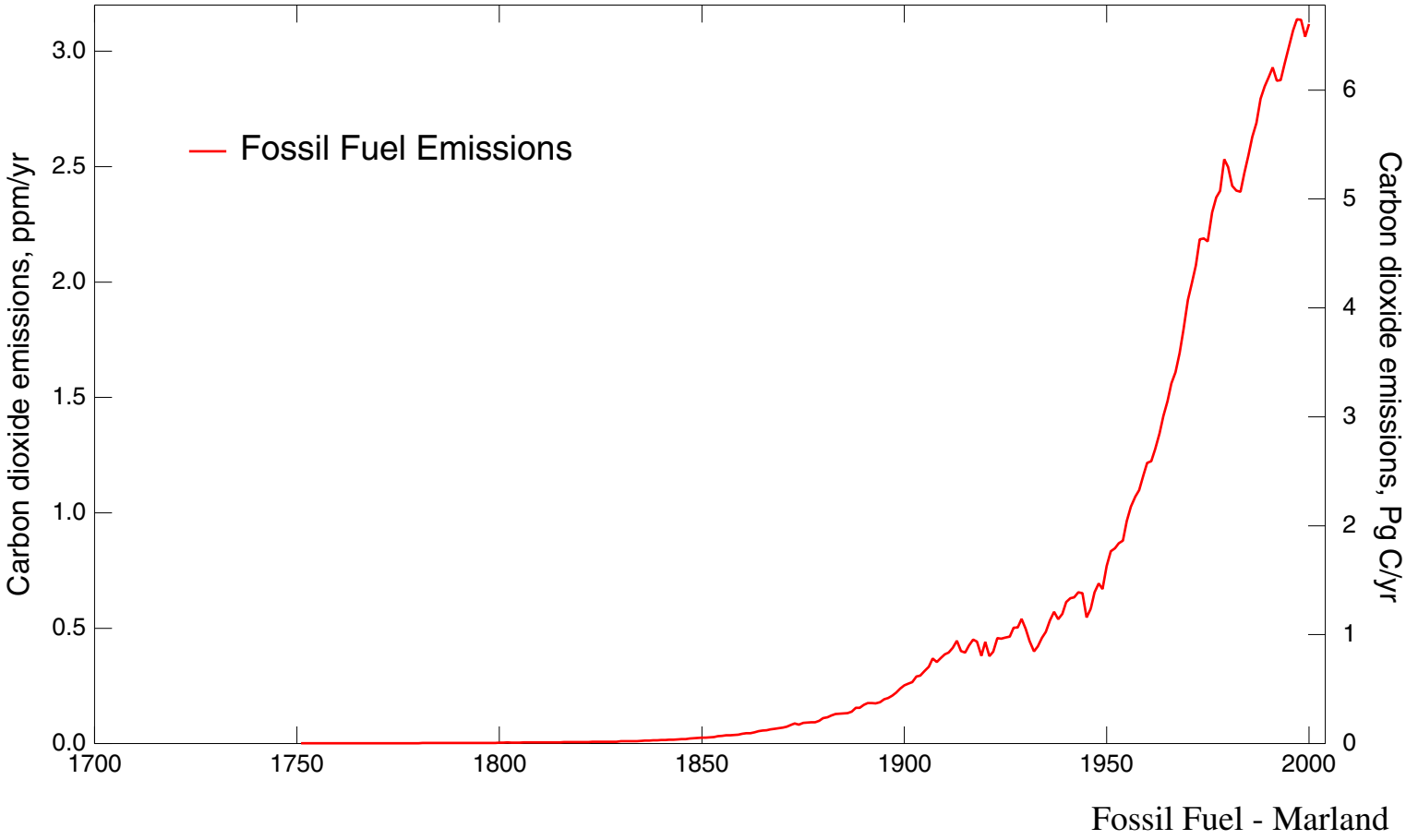
Time series 1700 - 2003



Law - Etheridge et al.
Siple - Friedli et al.
Mauna Loa - Keeling

ATMOSPHERIC CO_2 EMISSIONS

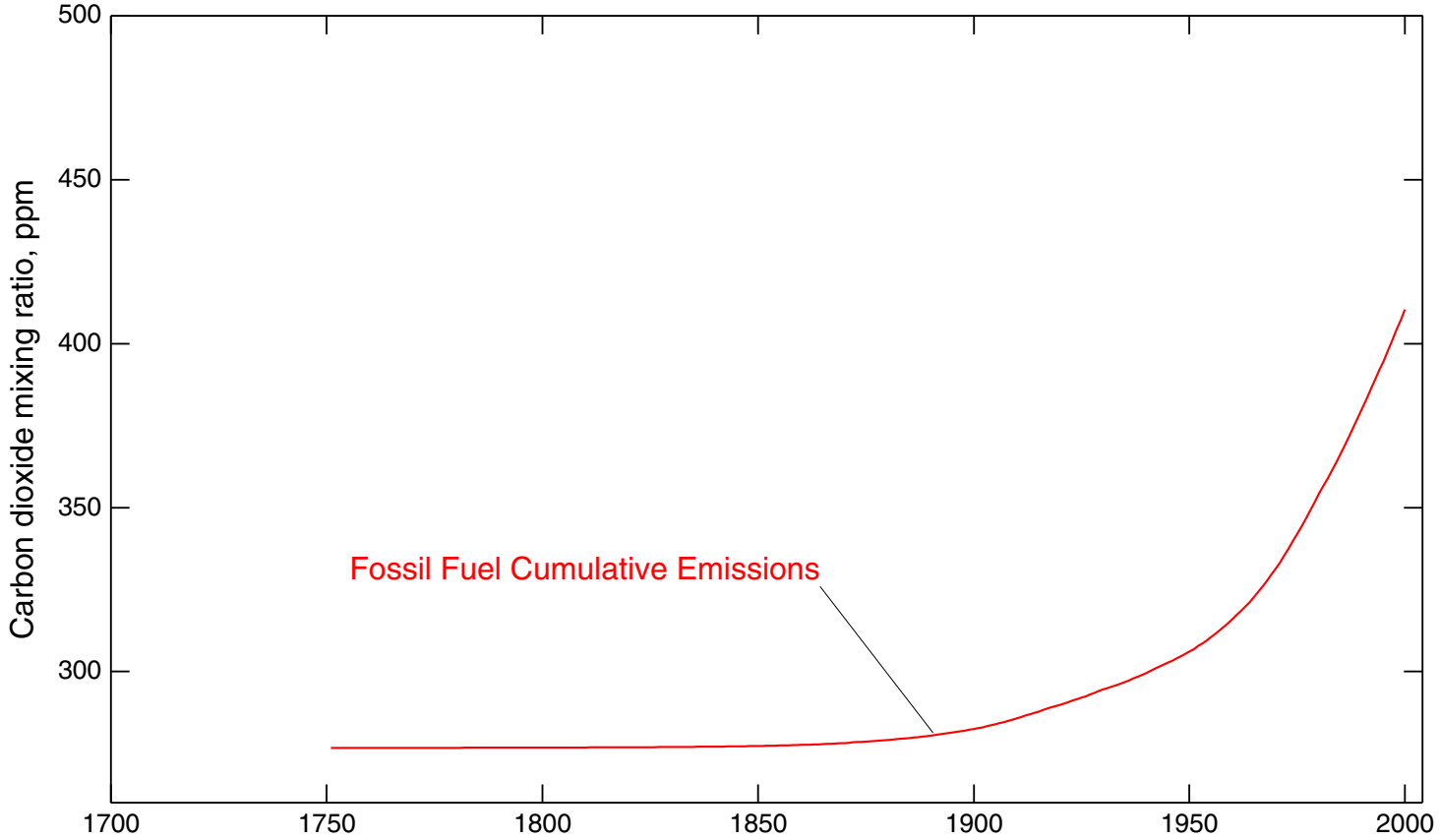
Time series 1700 - 2003



Fossil Fuel - Marland

ATMOSPHERIC CARBON DIOXIDE

Time series 1700 - 2003



Fossil Fuel - Marland

ATMOSPHERIC CARBON DIOXIDE

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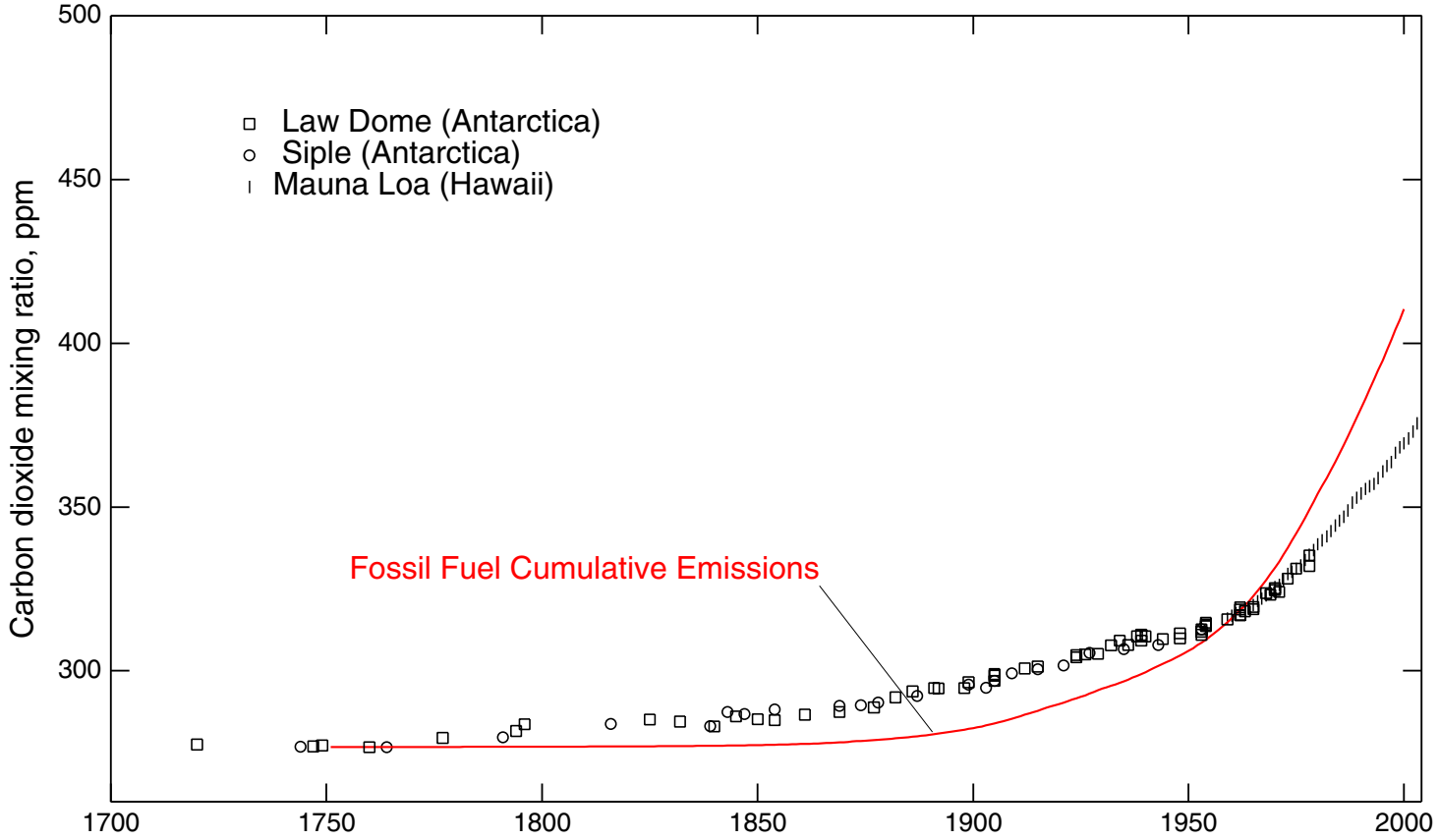

Law - Etheridge et al.
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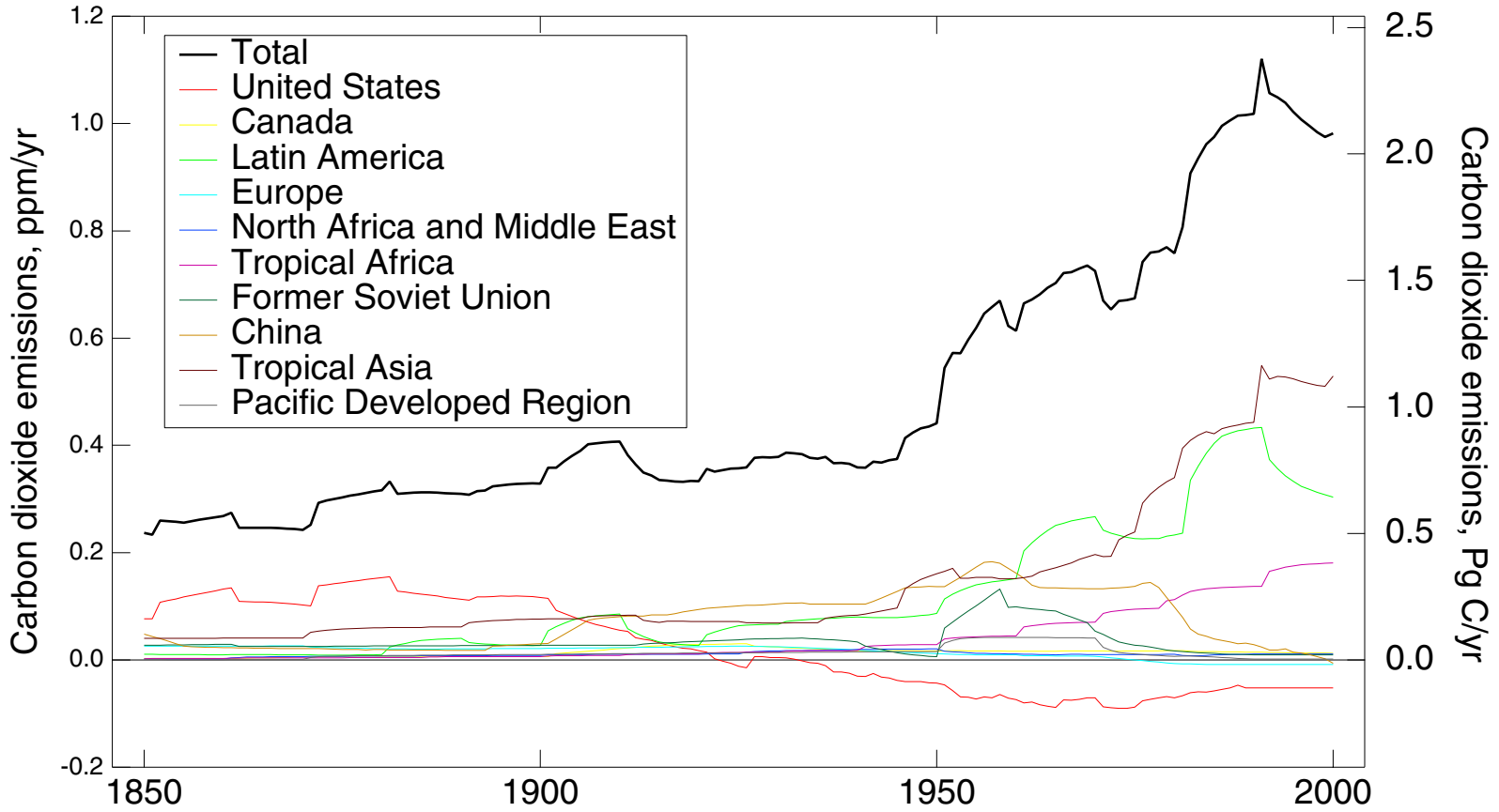
What's missing?

DEFORESTATION AS A SOURCE OF ATMOSPHERIC CO_2

ATMOSPHERIC CO_2 EMISSIONS

Land-use changes 1850 - 2000



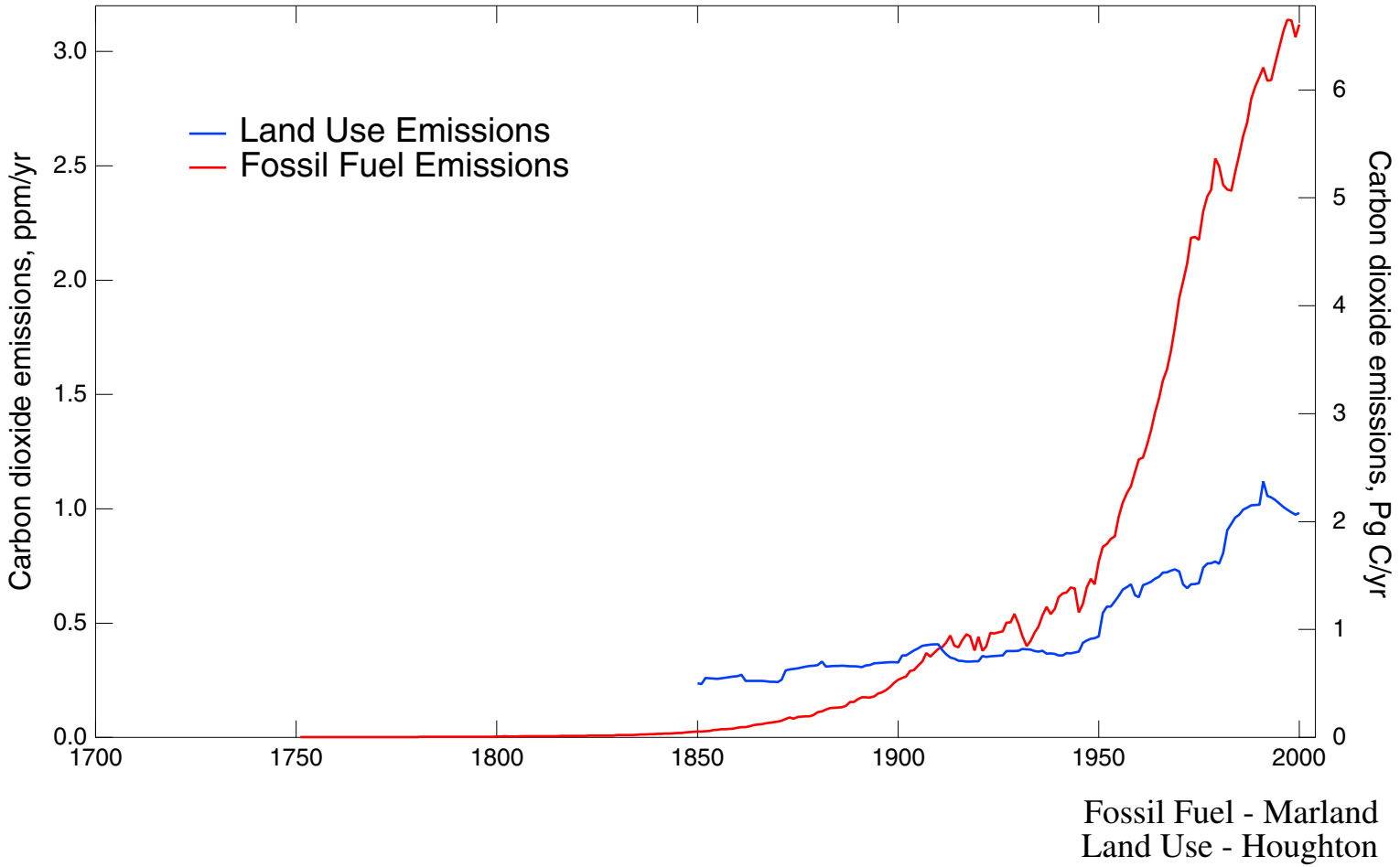
Houghton, *Tellus*, 1999; Houghton and Hackler, 2002

Carbon flux estimated as land area times carbon emissions associated with deforestation (or uptake associated with afforestation).

United States dominates emissions before 1900 and uptake after 1940.

ATMOSPHERIC CO_2 EMISSIONS

Time series 1700 - 2003

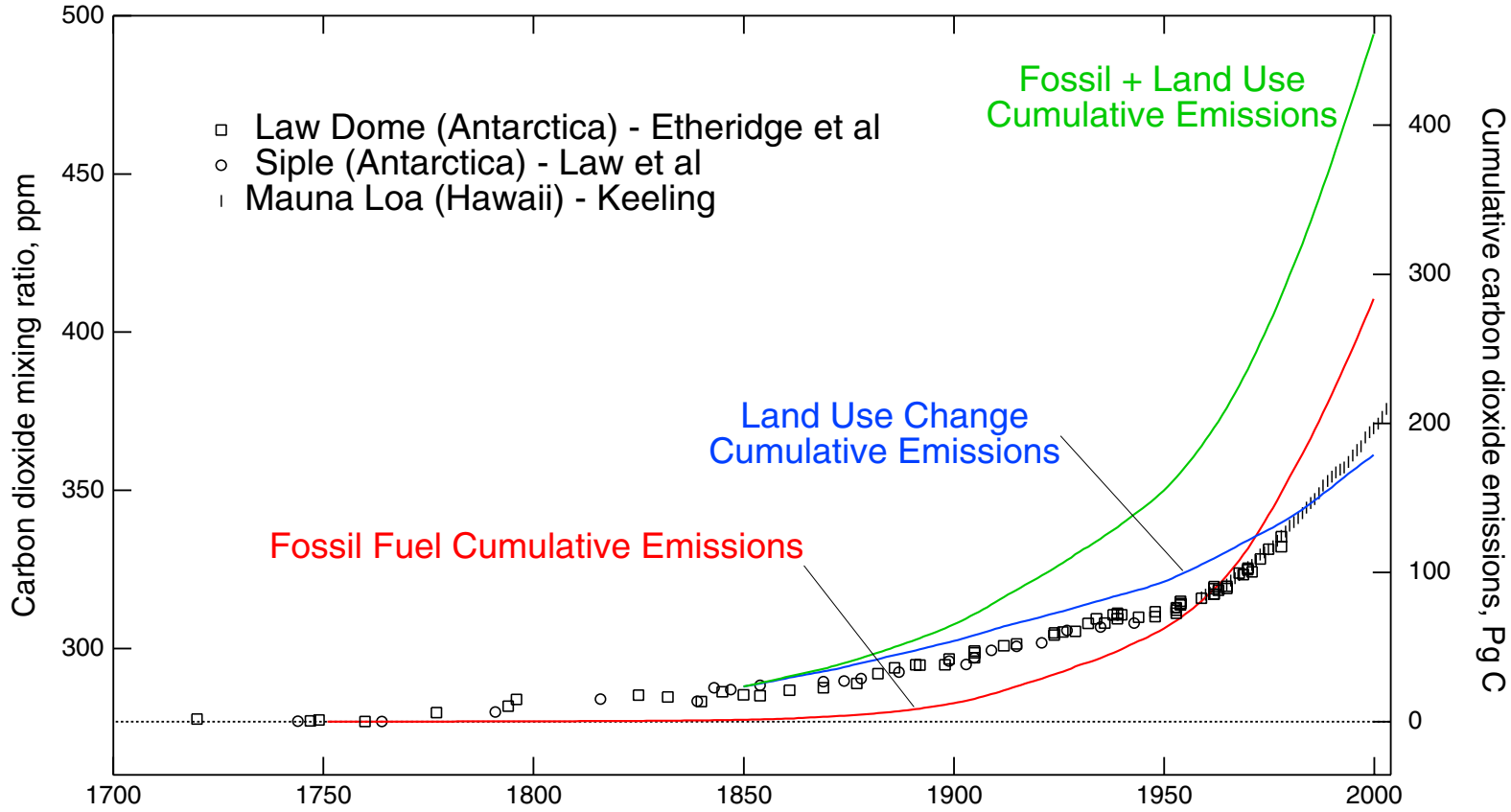


Prior to 1910 CO_2 emissions from land use changes were dominant.

Subsequently fossil fuel CO_2 has been dominant and rapidly increasing!

ATTRIBUTION OF INCREASE IN ATMOSPHERIC CO_2

Comparison of ***cumulative*** CO_2 emissions from fossil fuel combustion and land use changes with measured increases in atmospheric CO_2.



Prior to 1970 the increase in atmospheric CO_2 was dominated by emissions from land use changes, not fossil fuel combustion.

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.

$$\Delta T = \lambda \, \Delta F$$

CLIMATE SENSITIVITY

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

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

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

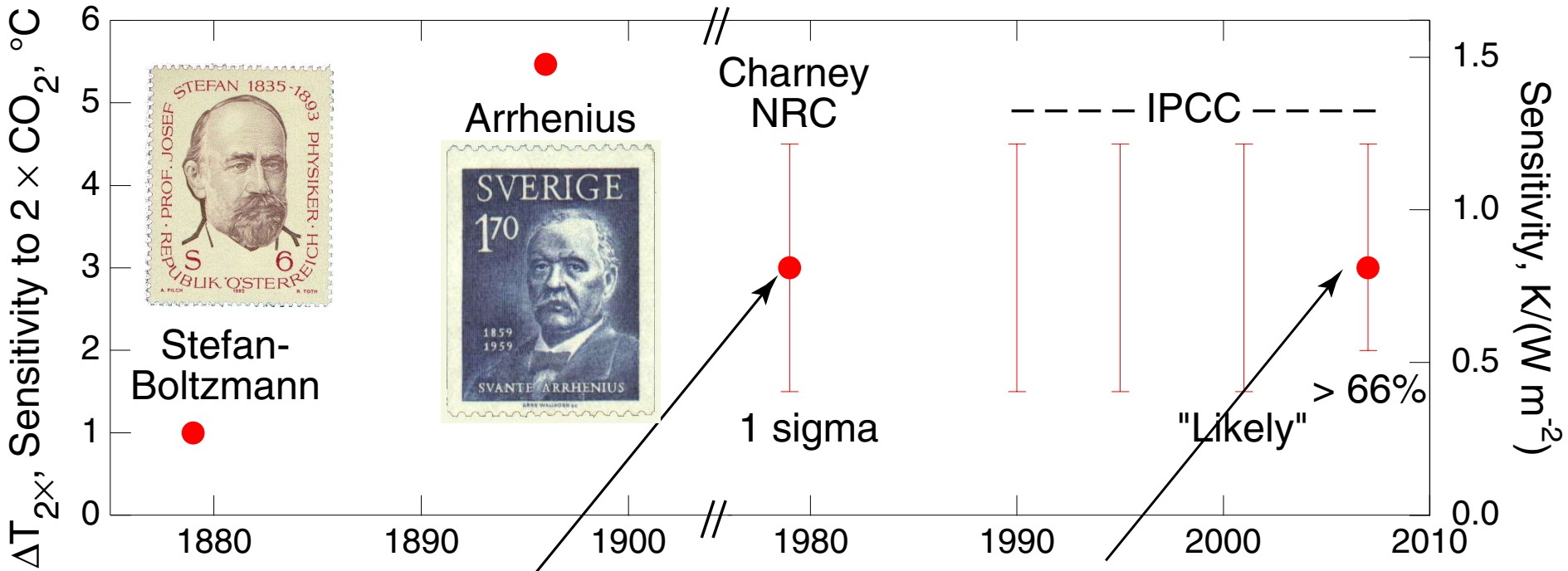
Climate sensitivity is often expressed as the temperature for doubled CO_2 concentration $\Delta T_{2\times}$.

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

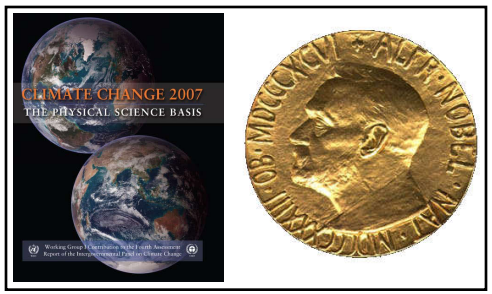
$$\Delta F_{2\times} \approx 3.7 \text{ W m}^{-2}$$

CLIMATE SENSITIVITY ESTIMATES THROUGH THE AGES

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



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



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

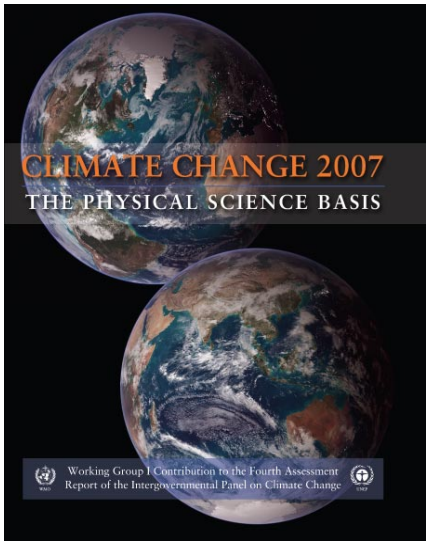
THE ‘BIBLE’ OF CLIMATE CHANGE

It's big and thick.

Every household should have one.

No one reads it from cover to cover.

You can open it up on any page and find something interesting.



It was written by a committee.

It is full of internal contradictions.

It deals with cataclysmic events such as floods and droughts.

It has its true believers and its rabid skeptics.

http://ipcc-wg1.ucar.edu/wg1/wg1-report.html

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 about a factor of 3.

IMPORTANCE OF KNOWLEDGE OF CLIMATE 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.

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.

Climate models evaluated by comparison with observations are essential to informed decision making.