

Climate Change: A Defining Issue for Our Age

Stephen E. Schwartz

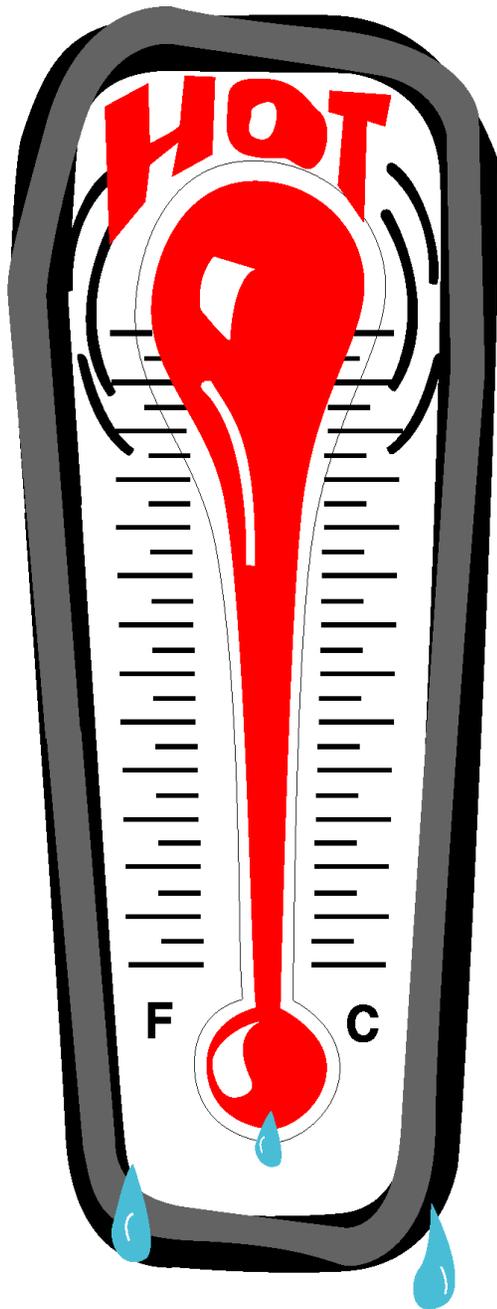
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Global temperature change

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Contributed by James Hansen, July 31, 2006

Global surface temperature has increased $\approx 0.2^\circ\text{C}$ per decade in the past 30 years, similar to the warming rate predicted in the 1980s in initial global climate model simulations with transient greenhouse gas changes. Warming is larger in the Western Equatorial Pacific than in the Eastern Equatorial Pacific over the past century, and we suggest that the increased West–East temperature gradient may have increased the likelihood of strong El Niños, such as those of 1983 and 1998. Comparison of measured sea surface temperatures in the Western Pacific with paleoclimate data suggests that this critical ocean region, and probably the planet as a whole, is approximately as warm now as at the Holocene maximum and within $\approx 1^\circ\text{C}$ of the maximum temperature of the past million years. We conclude that global warming of more than $\approx 1^\circ\text{C}$, relative to 2000, will constitute “dangerous” climate change as judged from likely effects on sea level and extermination of species.

climate change | El Niños | global warming | sea level | species extinctions

Global temperature is a popular metric for summarizing the state of global climate. Climate effects are felt locally, but the global distribution of climate response to many global climate forcings is reasonably congruent in climate models (1), suggesting that the global metric is surprisingly useful. We will argue further, consistent with earlier discussion (2, 3), that measurements in the Western Pacific and Indian Oceans provide a good indication of global temperature change.

We first update our analysis of surface temperature change based on instrumental data and compare observed temperature change with predictions of global climate change made in the 1980s. We then examine current temperature anomalies in the tropical Pacific Ocean and discuss their possible significance. Finally, we compare paleoclimate and recent data, using the Earth’s history to estimate the magnitude of global warming that is likely to constitute dangerous human-made climate change.

record low sea ice concentration and Arctic temperature anomalies inferred from infrared satellite data (9).

Our analysis includes estimated temperature anomalies up to 1,200 km from the nearest measurement station (7). Resulting spatial extrapolations and interpolations of temperature anomalies usually are meaningful for seasonal and longer time scales at middle and high latitudes, where the spatial scale of anomalies is set by Rossby waves (7). Thus, we believe that the unusual Arctic warmth of 2005 is real. Other characteristics of our analysis method are summarized in *Supporting Text*, which is published as supporting information on the PNAS web site.

Independent analysis by the National Climate Data Center (www.ncdc.noaa.gov/oa/climate/research/2005/ann/global.html), using a “teleconnection” approach to fill in data sparse regions, also finds 2005 to be the warmest year. The joint analysis of the University of East Anglia and the Hadley Centre (www.met-office.gov.uk/research/hadleycentre/obsdata/globaltemperature.html) also yields high global temperature for 2005, but a few hundredths of a degree cooler than in 1998.

Record, or near record, warmth in 2005 is notable, because global temperature did not receive a boost from an El Niño in 2005. The temperature in 1998, on the contrary, was lifted 0.2°C above the trend line by a “super El Niño” (see below), the strongest El Niño of the past century.

Global warming is now 0.6°C in the past three decades and 0.8°C in the past century. It is no longer correct to say “most global warming occurred before 1940.” A better summary is: slow global warming, with large fluctuations, over the century up to 1975, followed by rapid warming at a rate $\approx 0.2^\circ\text{C}$ per decade. Global warming was $\approx 0.7^\circ\text{C}$ between the late 19th century (the earliest time at which global mean temperature can be accurately defined) and 2000, and continued warming in the first half decade of the 21st century is consistent with the recent rate of $+0.2^\circ\text{C}$ per decade.

by far the most terrifying film
you will ever see.

an inconvenient truth

A GLOBAL WARNING

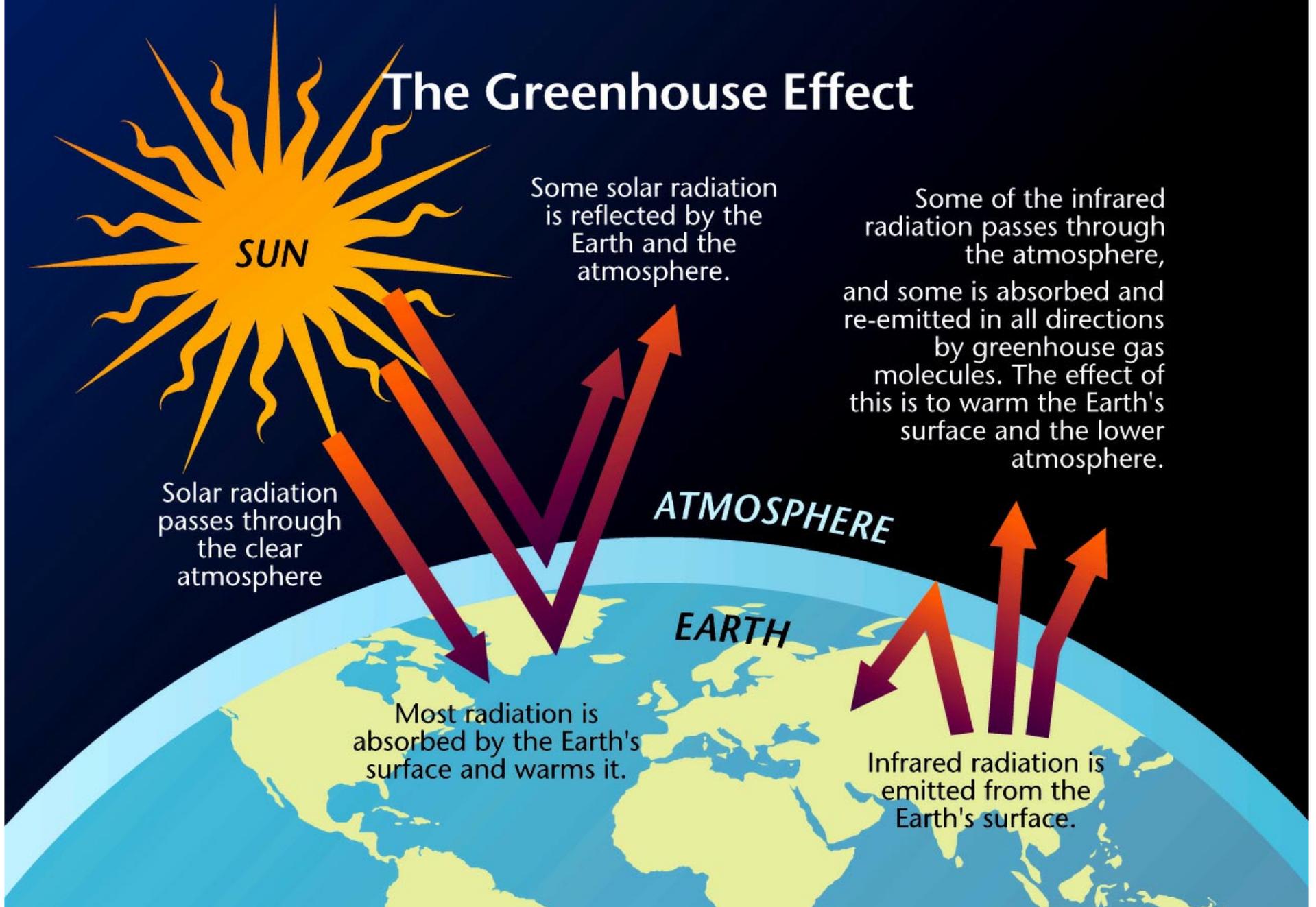
now playing in select theaters

PARTICIPANT

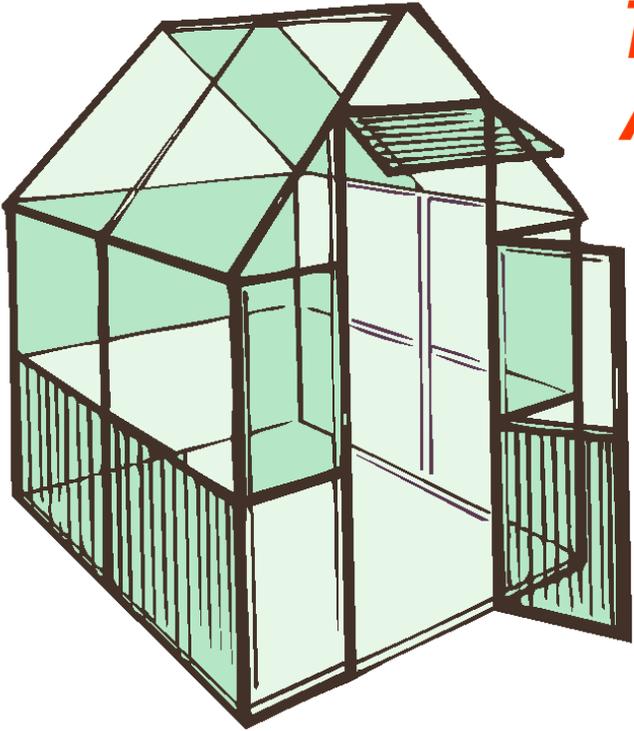
TIME MAGAZINE, APRIL 3, 2006



The Greenhouse Effect



THE GREENHOUSE EFFECT



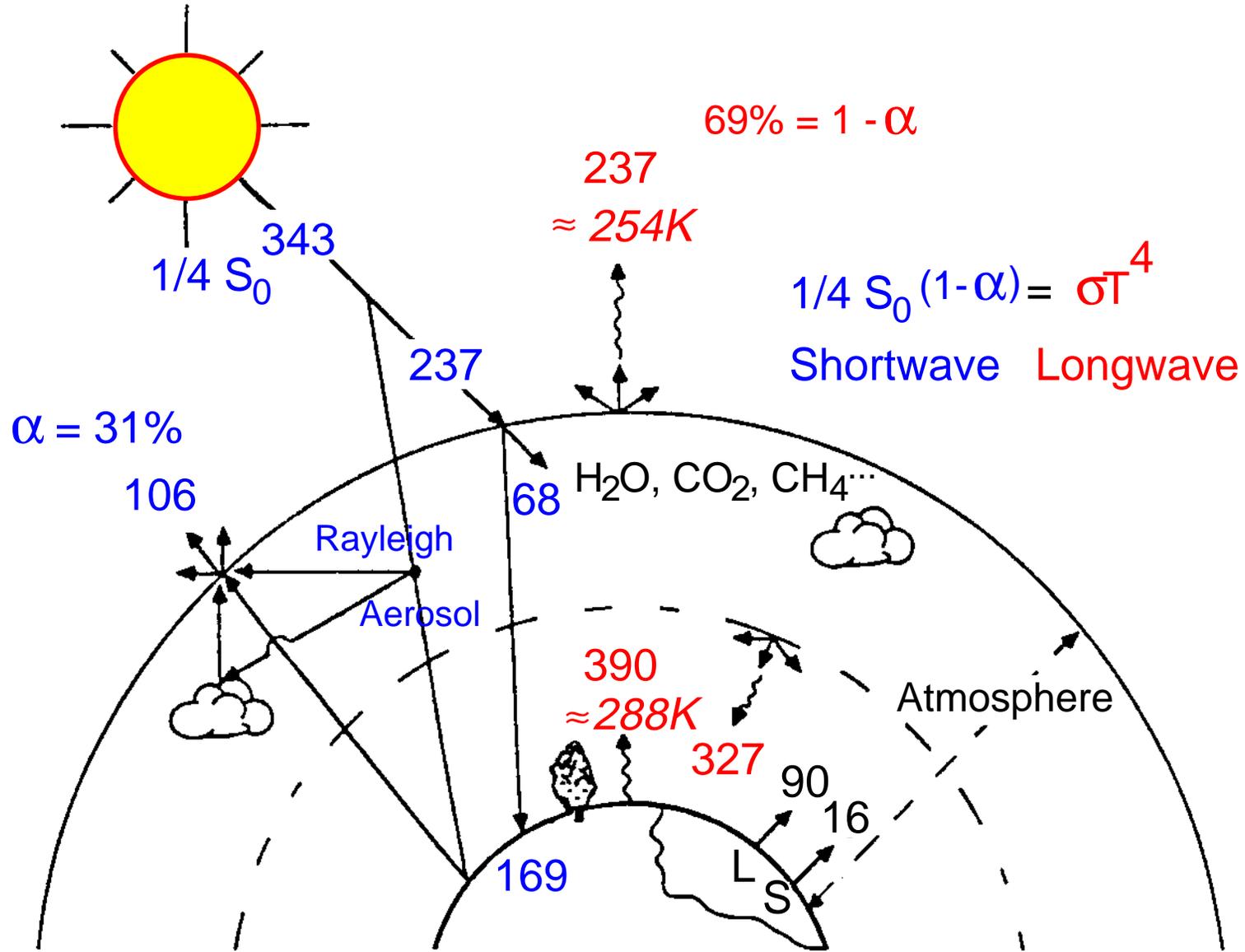
THE EARTH'S ENERGY BUDGET: A DELICATE BALANCE

- Sunlight heats the Earth.
- The warm Earth radiates energy (in the form of infrared radiation, or heat) back out to space.
- Some of this infrared radiation is trapped in the atmosphere, giving Earth its temperate climate.

This is the greenhouse effect.
Without it, the Earth's climate would be like the moon's, harsh and severe.

GLOBAL ENERGY BALANCE

Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

ATMOSPHERIC RADIATION

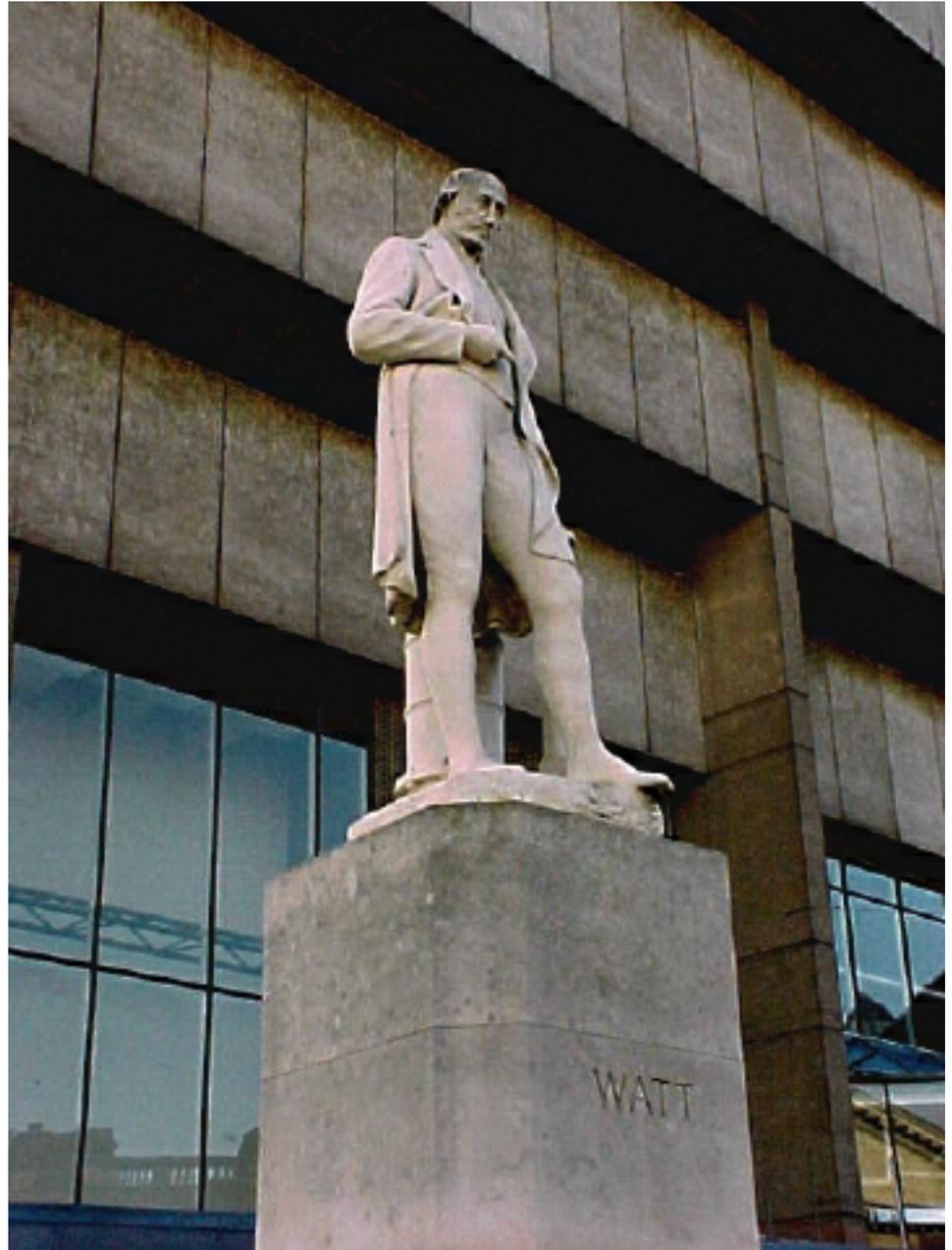
*Energy per area per
time*

Power per area

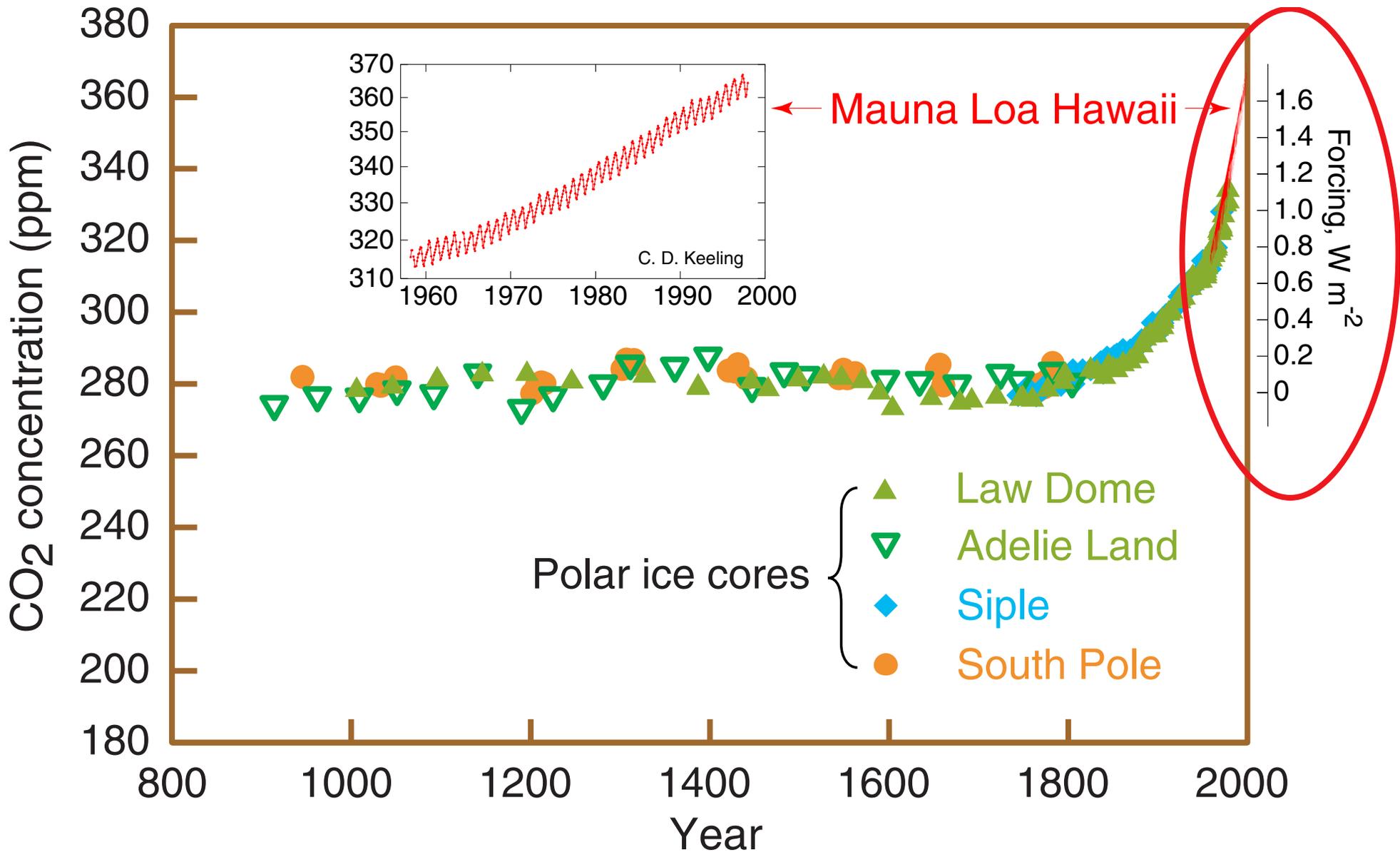
Unit:

Watt per square meter

$W m^{-2}$

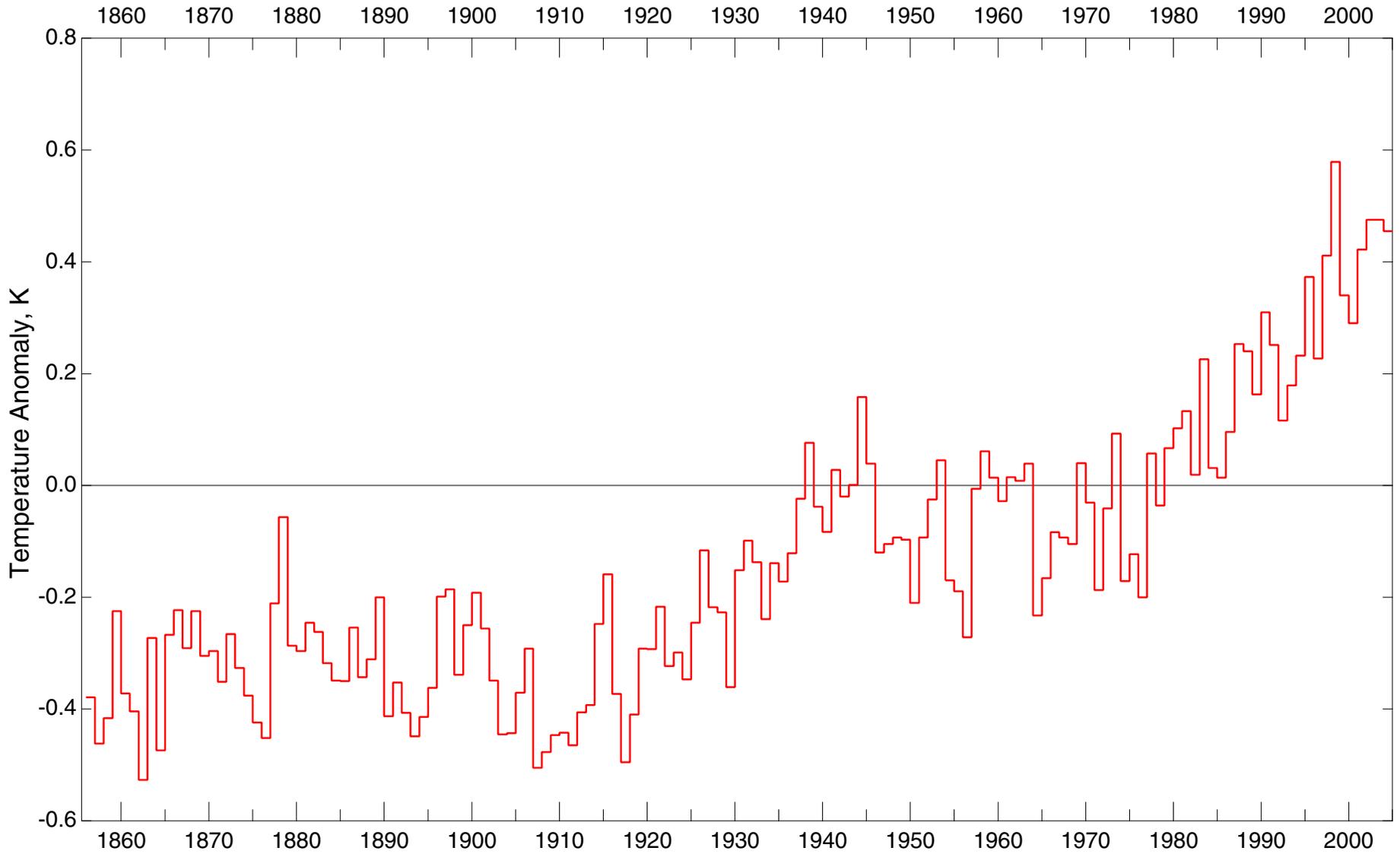


ATMOSPHERIC CARBON DIOXIDE IS INCREASING



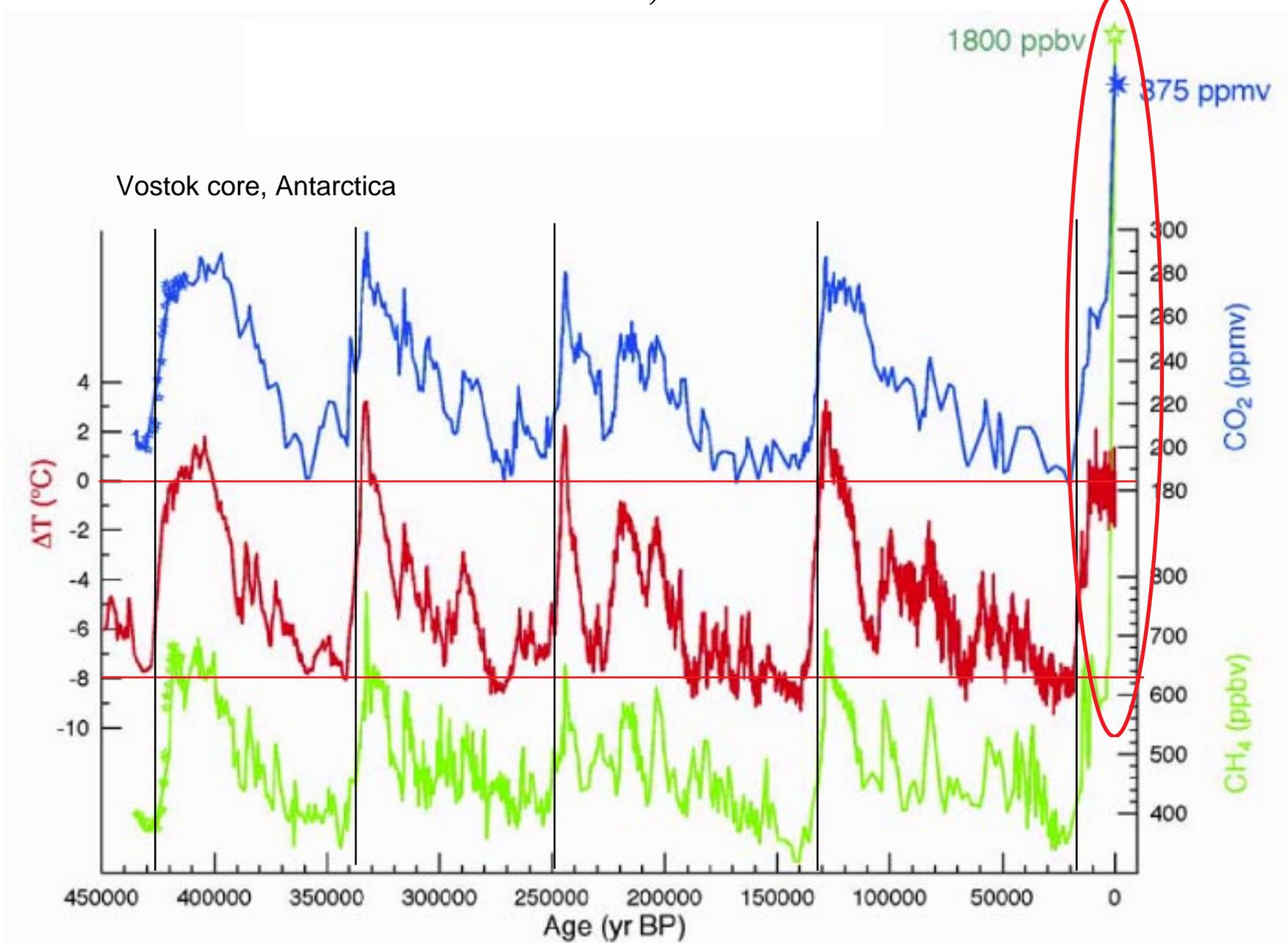
Global carbon dioxide concentration and infrared radiative forcing over the last thousand years

CHANGE IN GLOBAL MEAN SURFACE TEMPERATURE 1855-2004



Climate Research Unit, University of East Anglia, UK

GREENHOUSE GASES AND TEMPERATURE OVER 450,000 YEARS

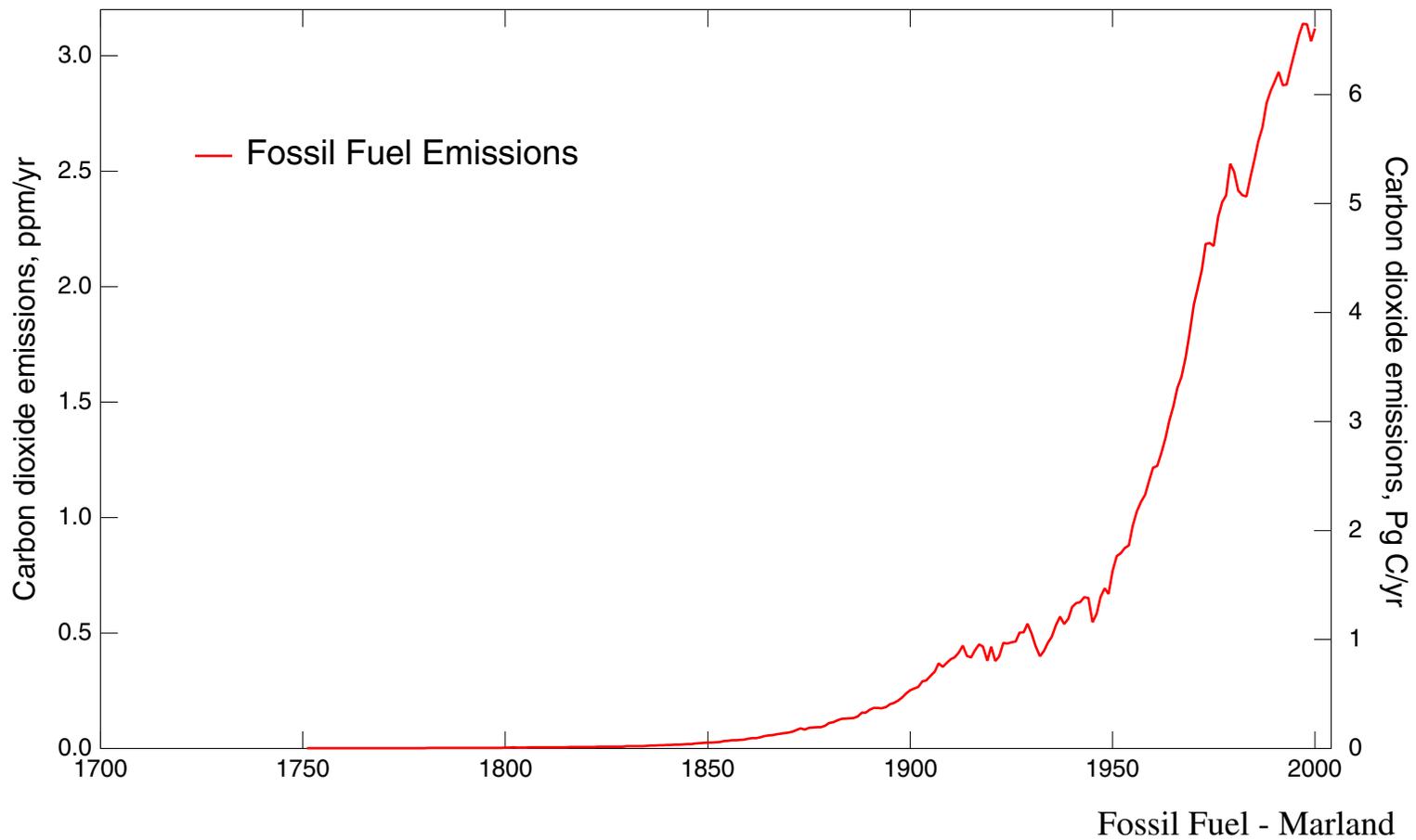


Modified from Petit et al., Nature, 1999

INCREASES IN CO₂ OVER THE INDUSTRIAL PERIOD

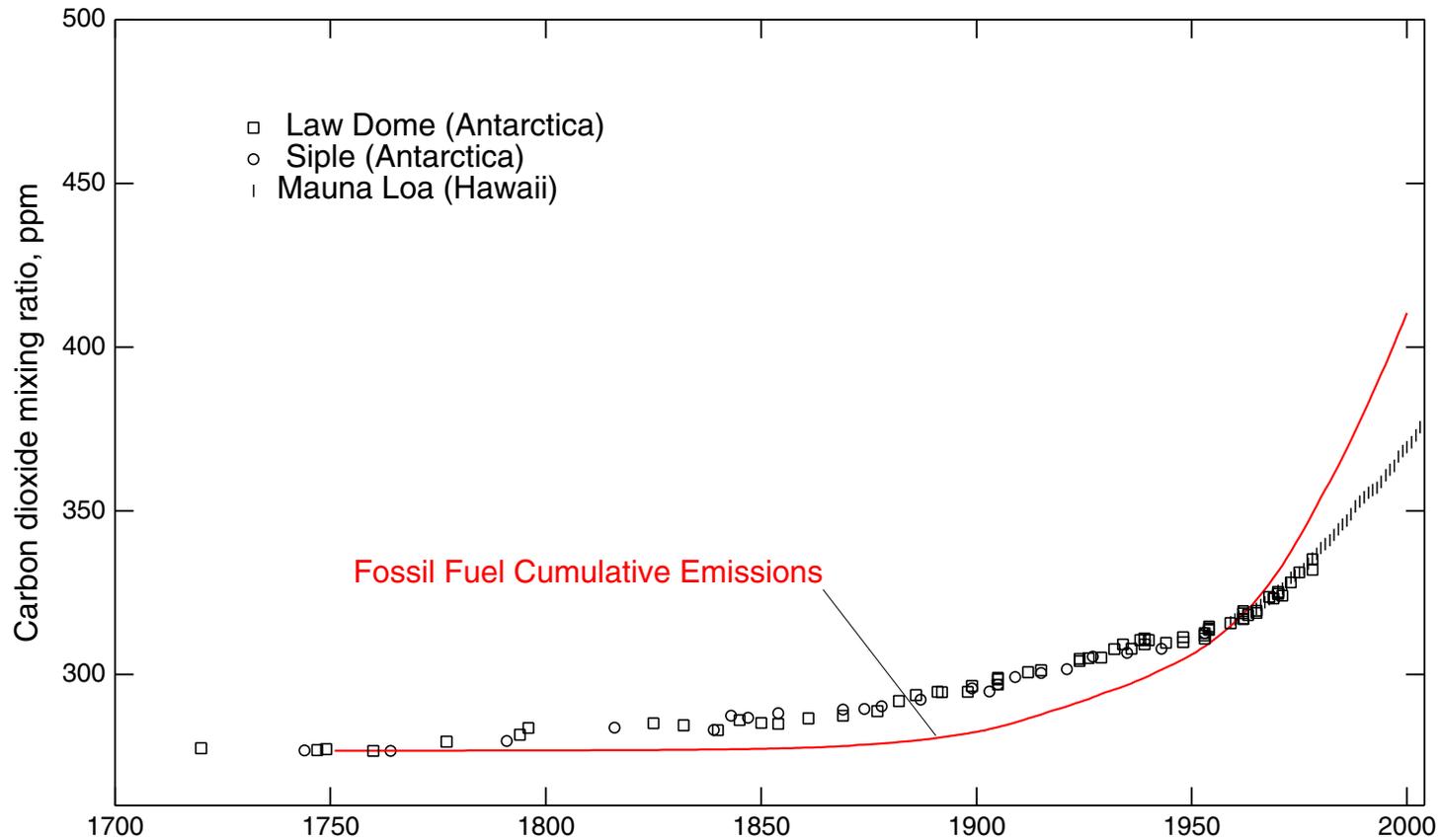
ATMOSPHERIC CO₂ EMISSIONS

Time series 1700 - 2003



ATMOSPHERIC CARBON DIOXIDE

Time series 1700 - 2003



Law - Etheridge et al.
Siple - Friedli et al.
Mauna Loa - Keeling
Fossil Fuel - Marland

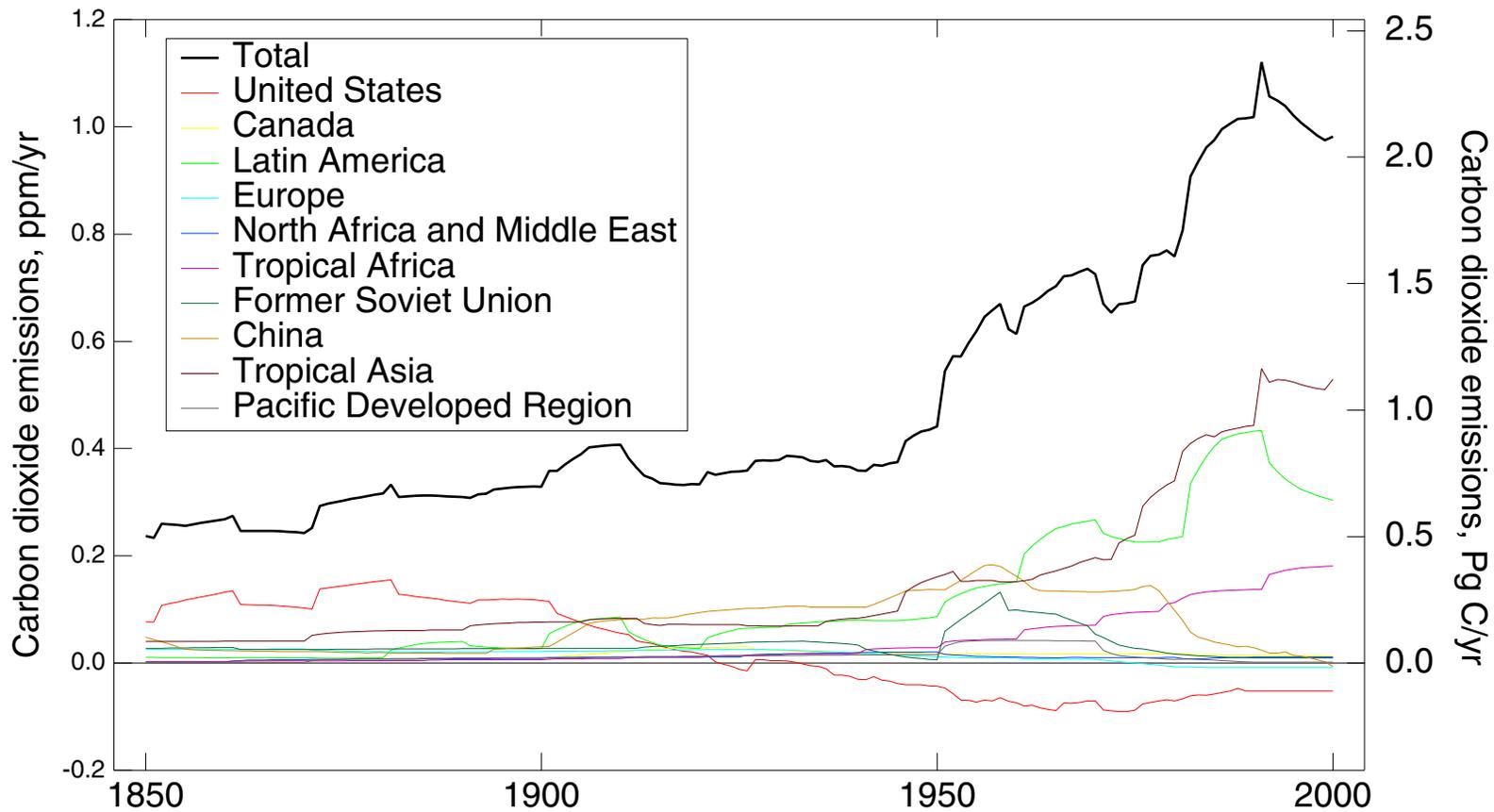
What's missing from this story?

DEFORESTATION AS A SOURCE OF ATMOSPHERIC CO₂



ATMOSPHERIC CO₂ EMISSIONS

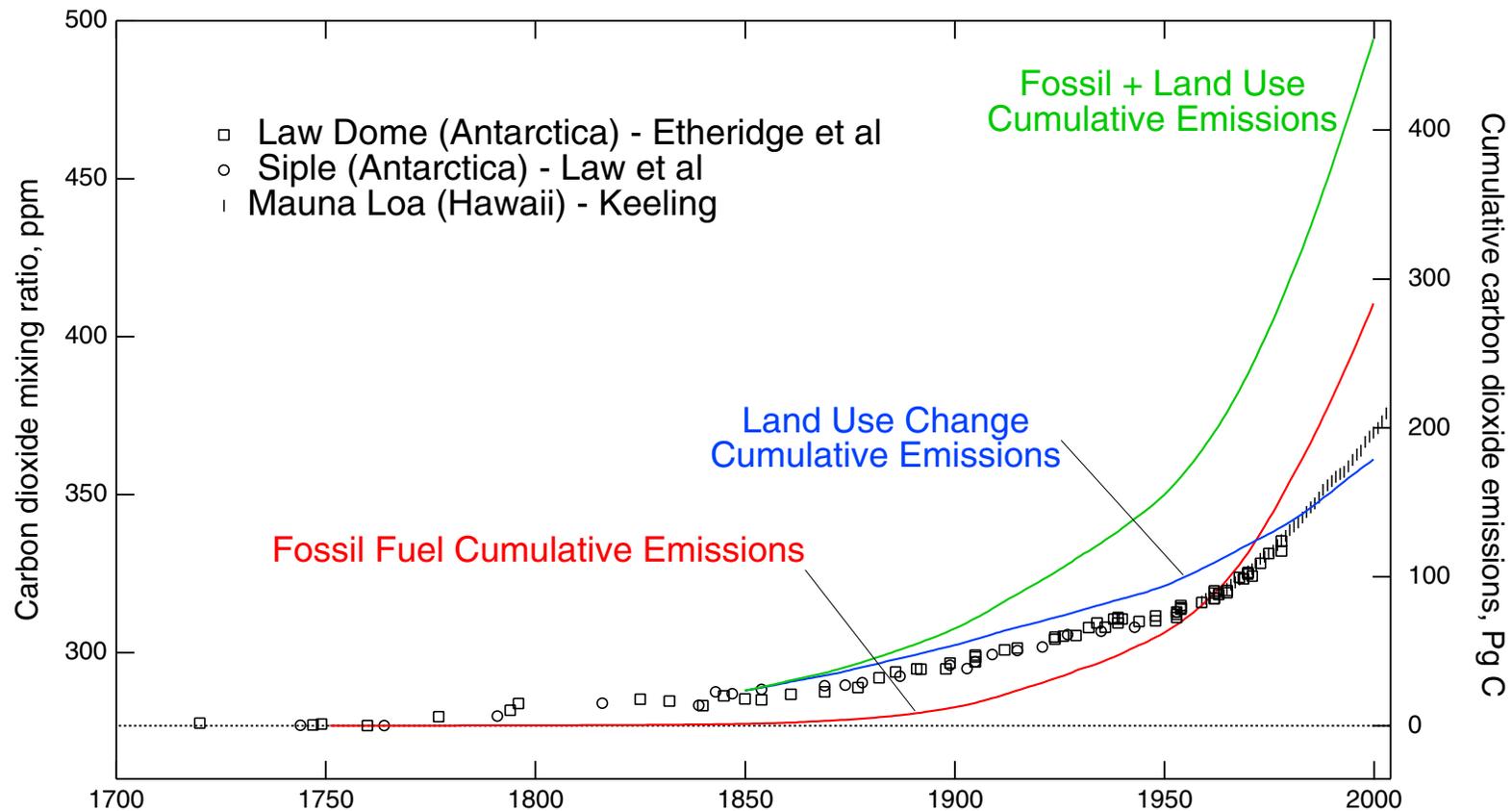
Land-use changes 1850 - 2000



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

ATTRIBUTION OF INCREASE IN ATMOSPHERIC CO₂

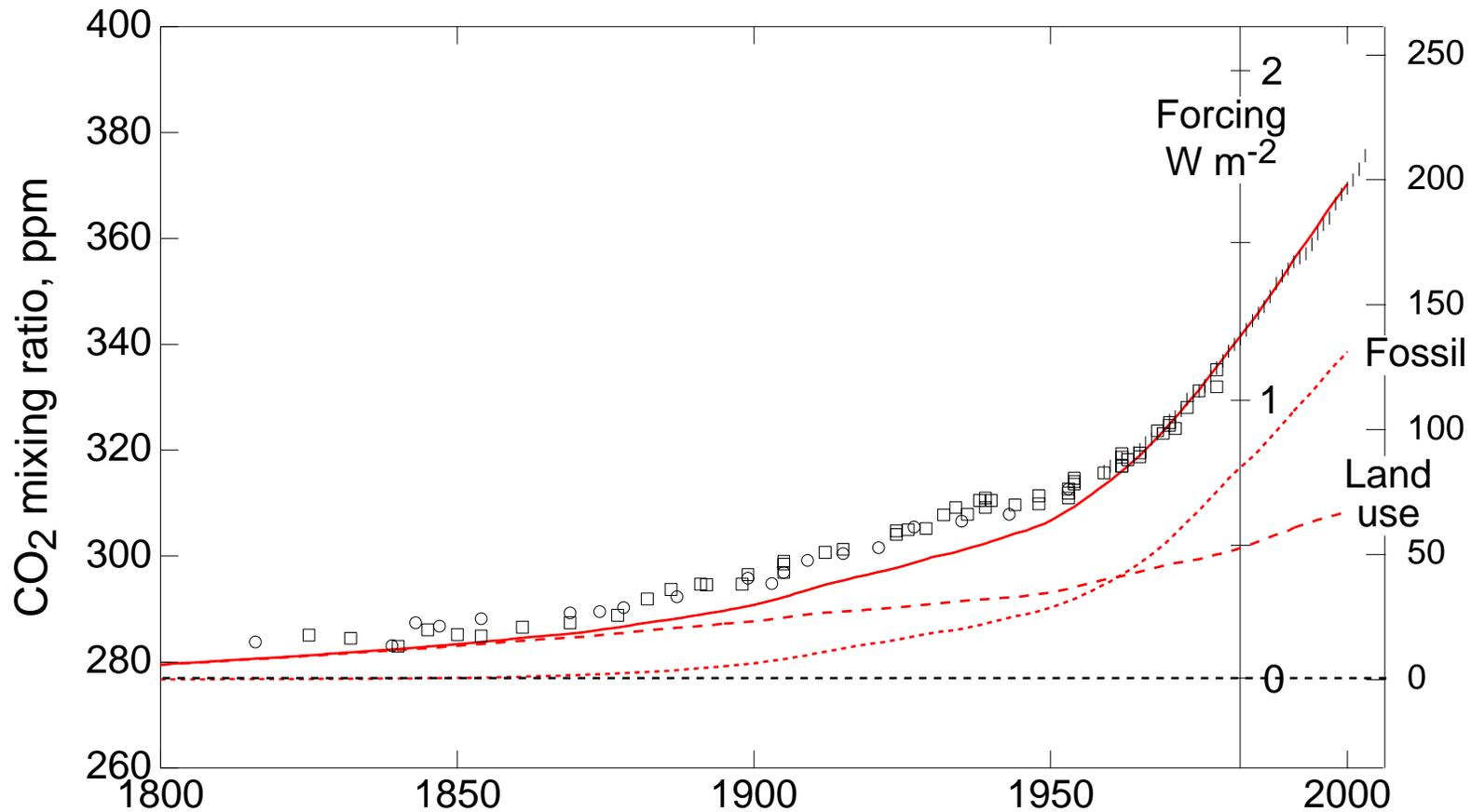
Comparison of *cumulative* CO₂ emissions from fossil fuel combustion and land use changes with measured increases in atmospheric CO₂.



Prior to 1970 the increase in atmospheric CO₂ was dominated by emissions from land use changes, not fossil fuel combustion.

ATTRIBUTION OF ATMOSPHERIC CO₂

Comparison of CO₂ mixing ratio *and forcing*
From fossil fuel combustion and land use changes

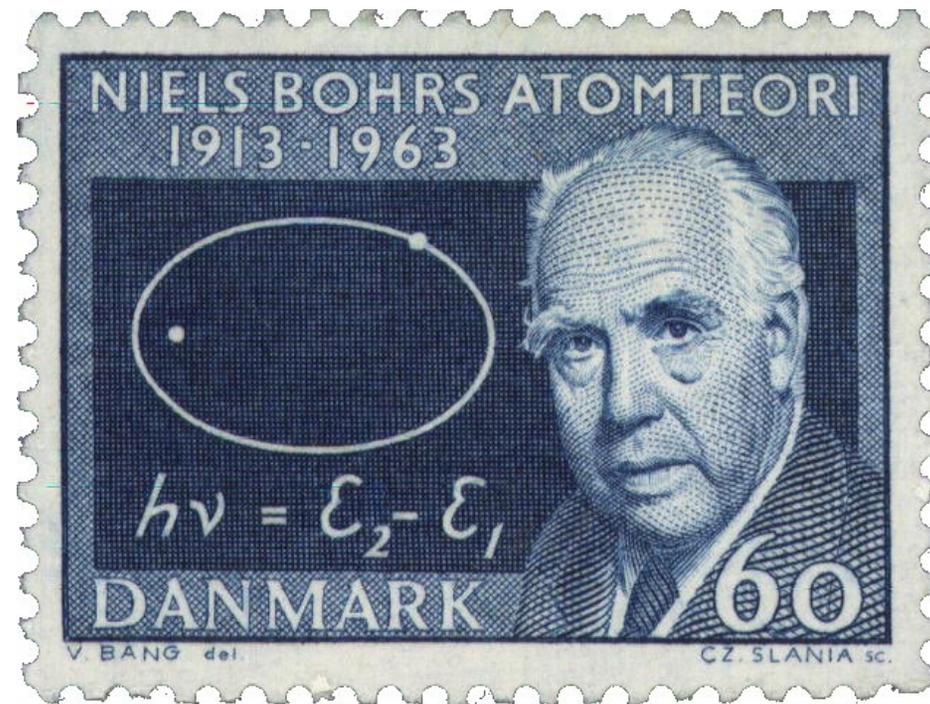


CO₂ from land use emissions – *not fossil fuel combustion* was the dominant contribution to atmospheric CO₂ *and forcing* over the 20th century.

*Looking to the
Future . . .*



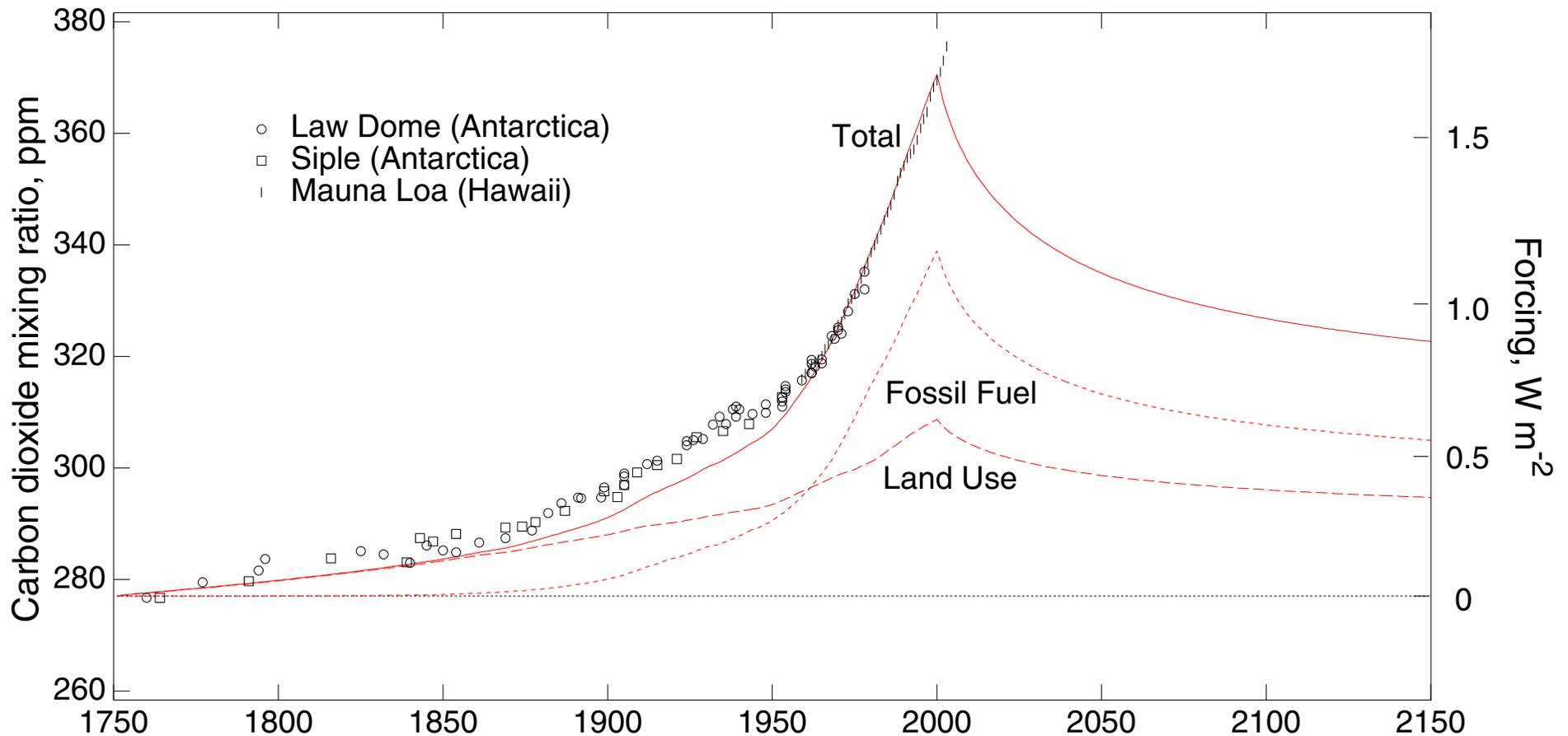
*Prediction is difficult,
especially about the future.*



– Niels Bohr

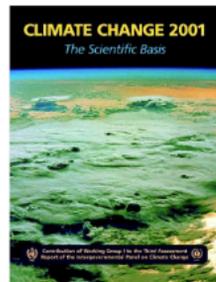
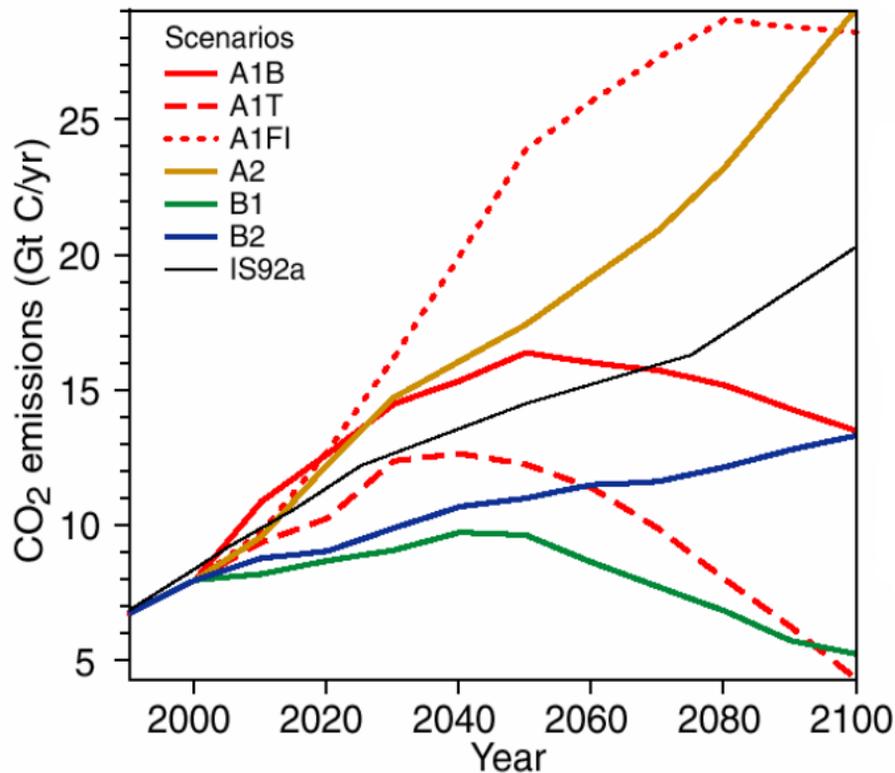
FUTURE ATMOSPHERIC CO₂

Projection of CO₂ *mixing ratio and forcing* due to anthropogenic emissions from 1750 to 2000

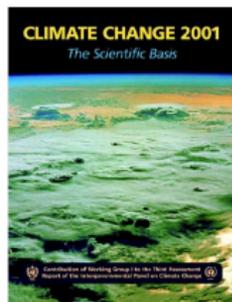
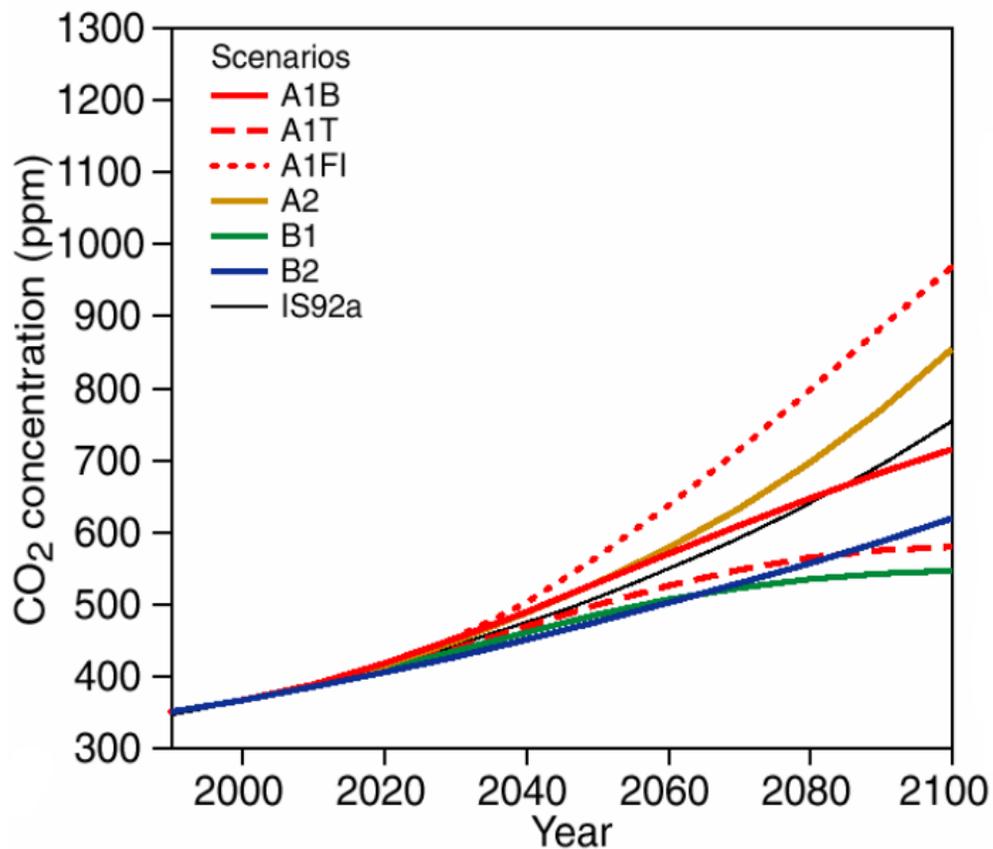


The footprint of prior CO₂ emissions lasts well beyond a century.

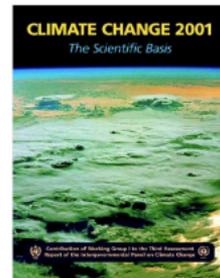
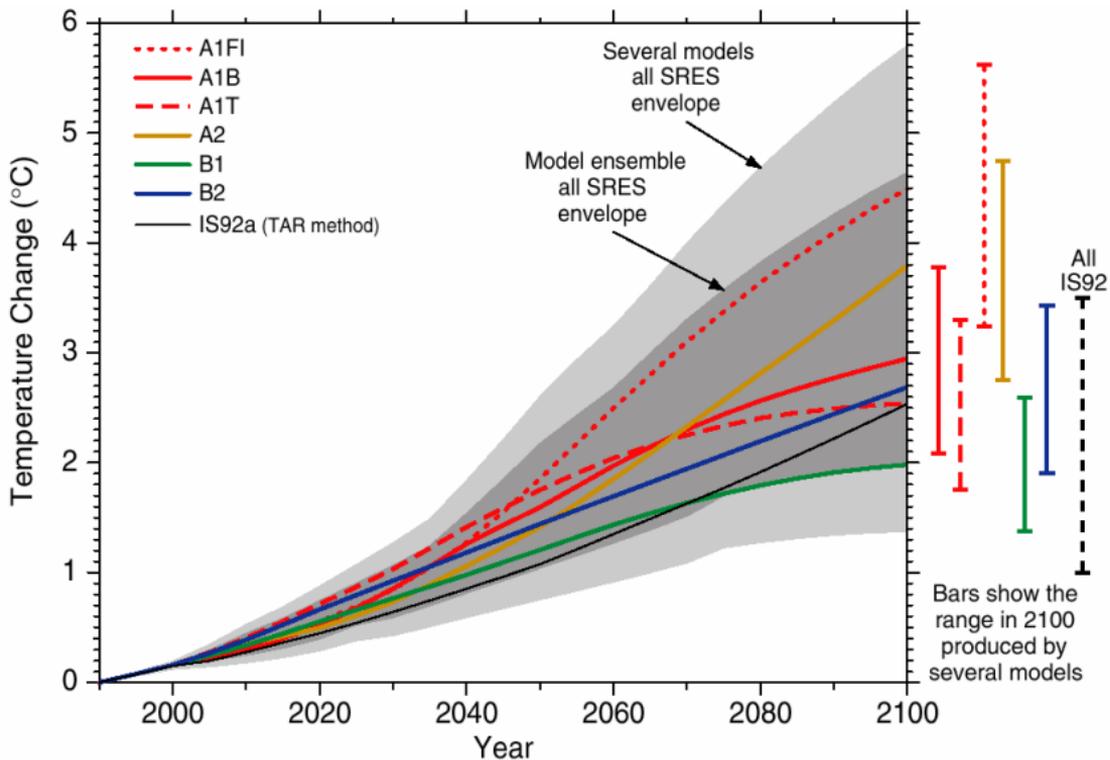
PROJECTIONS OF FUTURE CO₂ EMISSIONS



PROJECTIONS OF FUTURE CO₂ CONCENTRATIONS

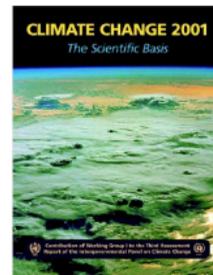
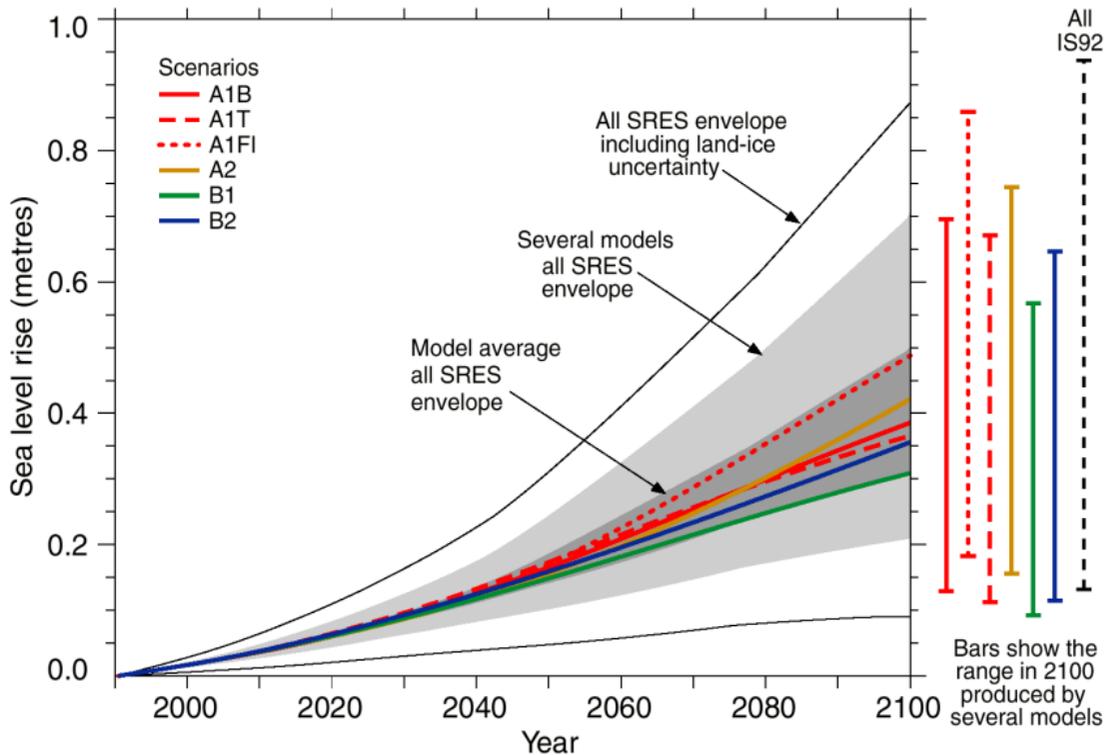


PROJECTIONS OF FUTURE TEMPERATURE CHANGE

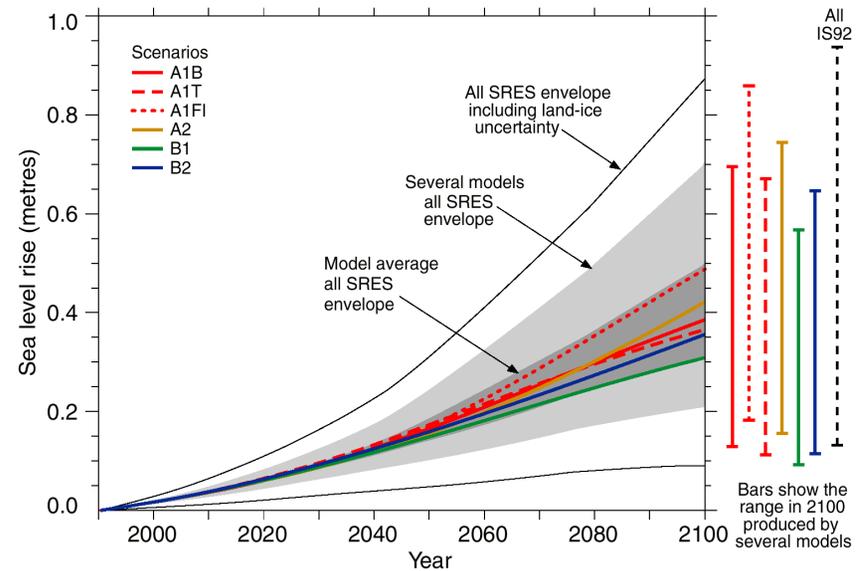
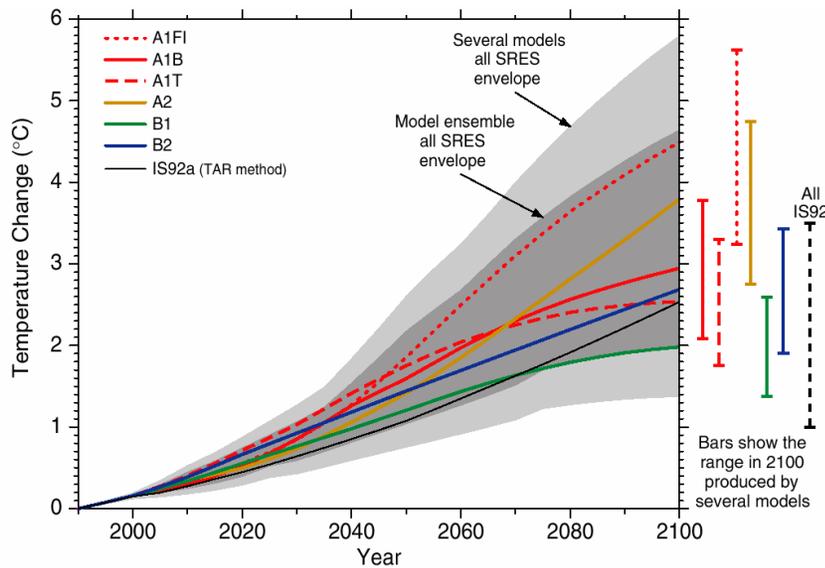
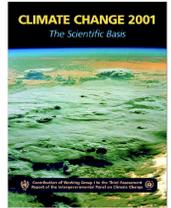
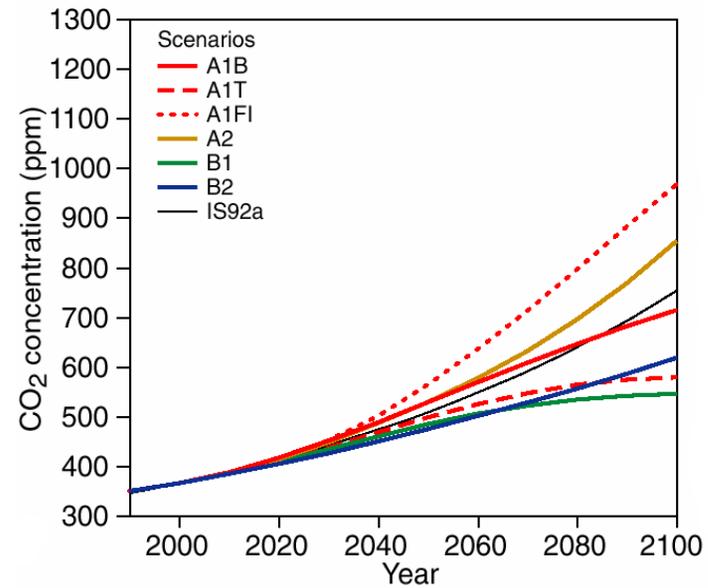
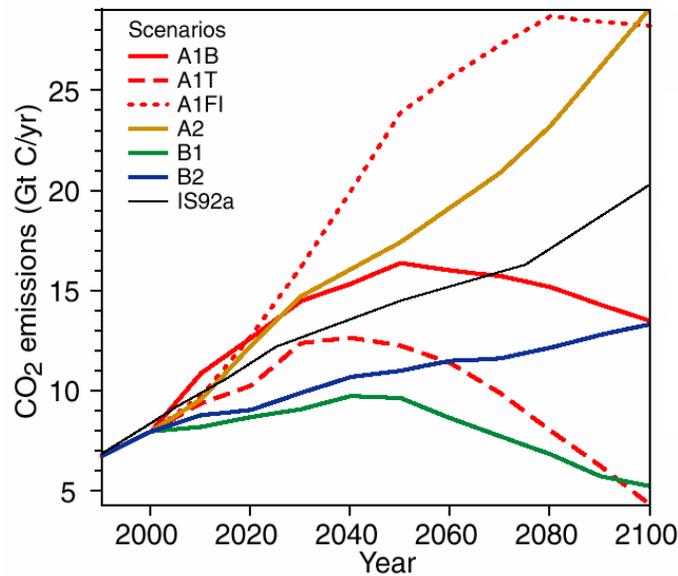


Bars show the range in 2100 produced by several models

PROJECTIONS OF FUTURE SEA LEVEL RISE



PROJECTIONS OF FUTURE CO₂, TEMPERATURE, AND SEA LEVEL



Contributors to uncertainty in future temperature include *emissions*, *concentrations*, and Earth's *climate sensitivity*.

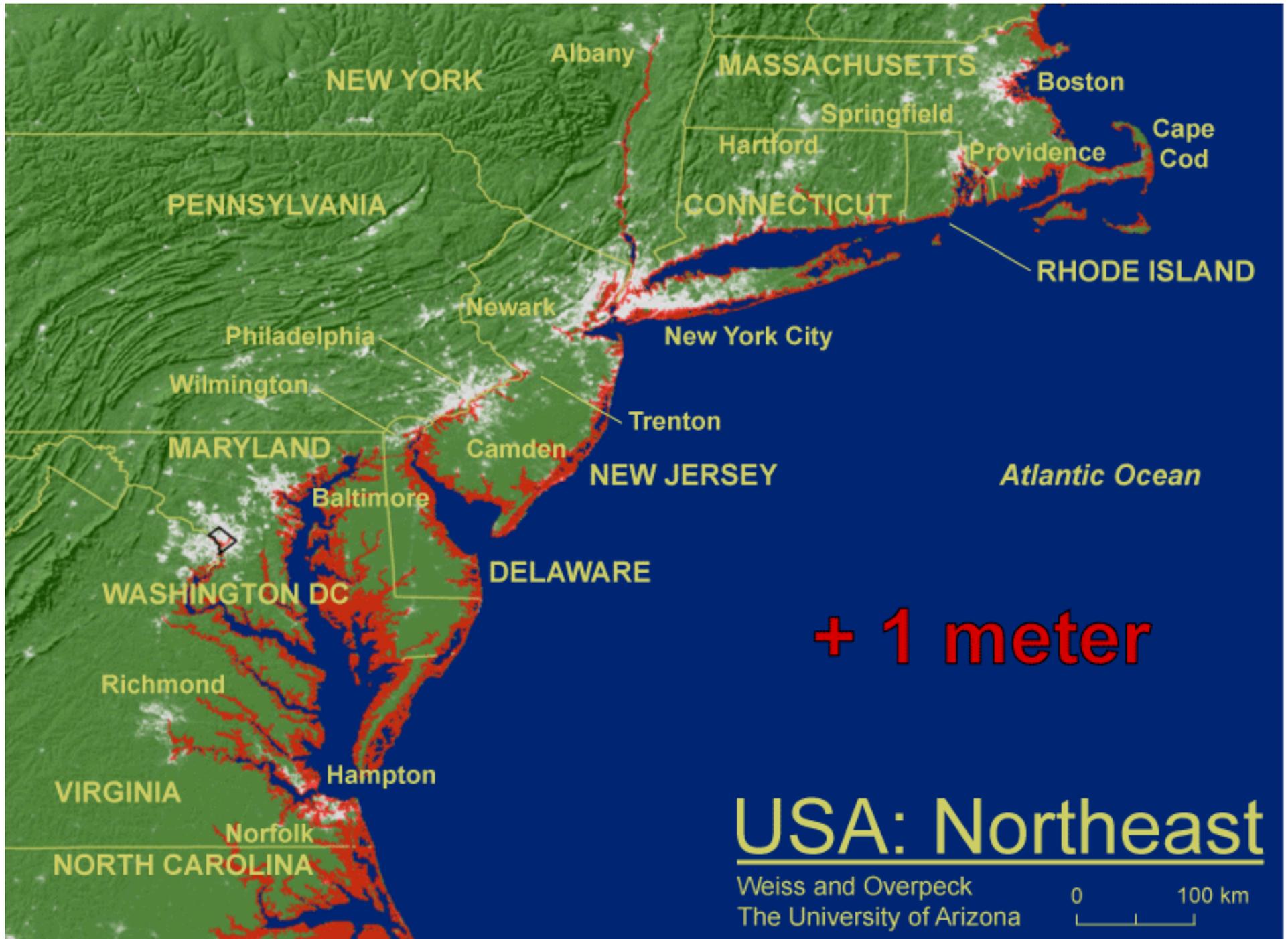


Present

USA: Northeast

Weiss and Overpeck
The University of Arizona







"Gentlemen, it's time we gave some serious thought to the effects of global warming."

***WHERE IS ALL
THIS CO₂
COMING FROM?***

***WHO IS
RESPONSIBLE?***



HOW MUCH CARBON IS IN A GALLON OF GASOLINE?



1 lb?

2 lbs?

3 lbs!?



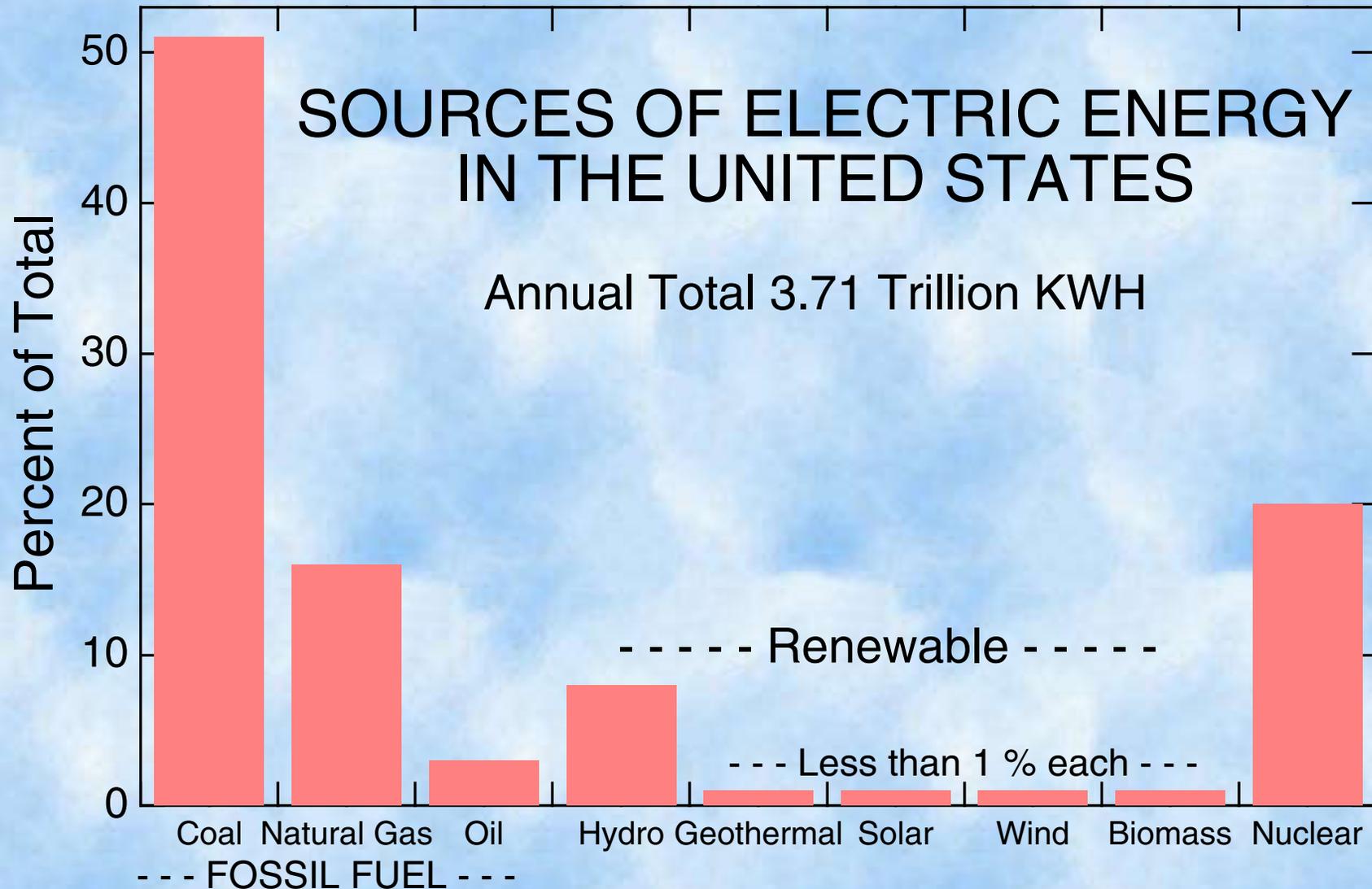
5 lbs!?!?



All of this carbon goes into the atmosphere as carbon dioxide when you burn the gasoline in your car.

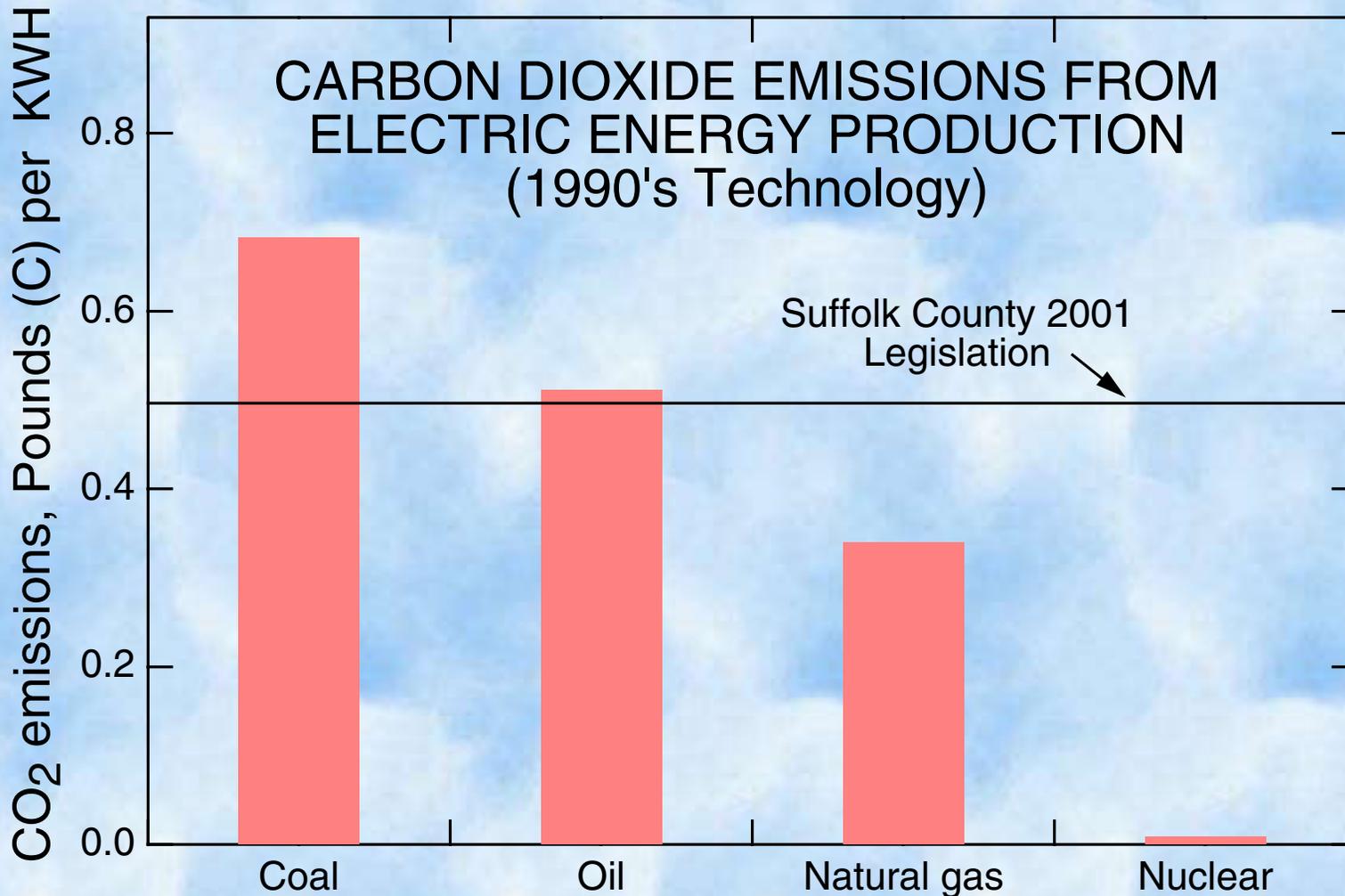


WHERE DOES YOUR ELECTRIC ENERGY COME FROM?



On Long Island most electric energy derives from combustion of oil.

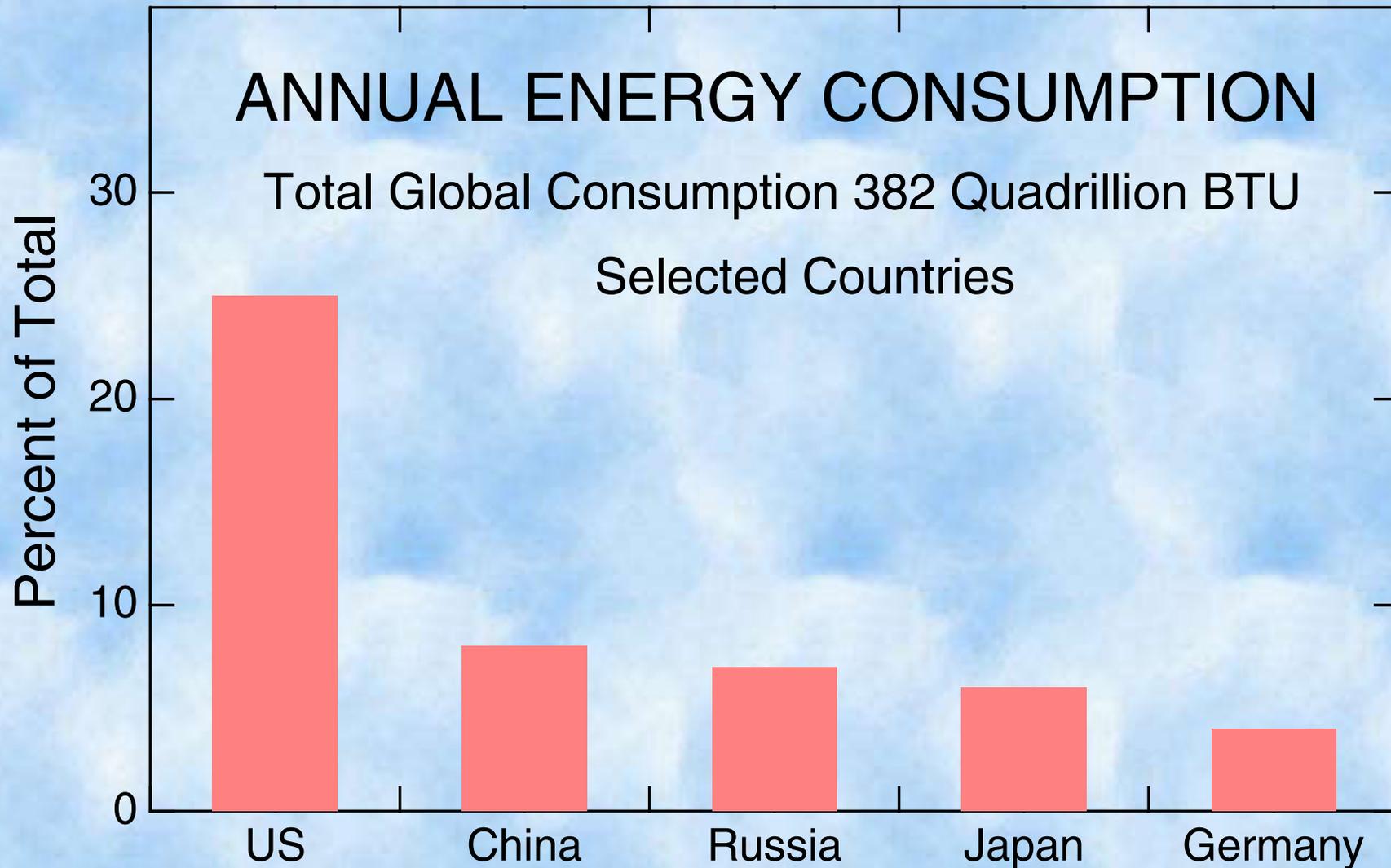
YOUR FAMILY'S CONTRIBUTION TO THE GREENHOUSE EFFECT



A typical household using 1000 kilowatt hours of electricity per month is responsible for emission of 3 tons of carbon a year in the form of carbon dioxide.

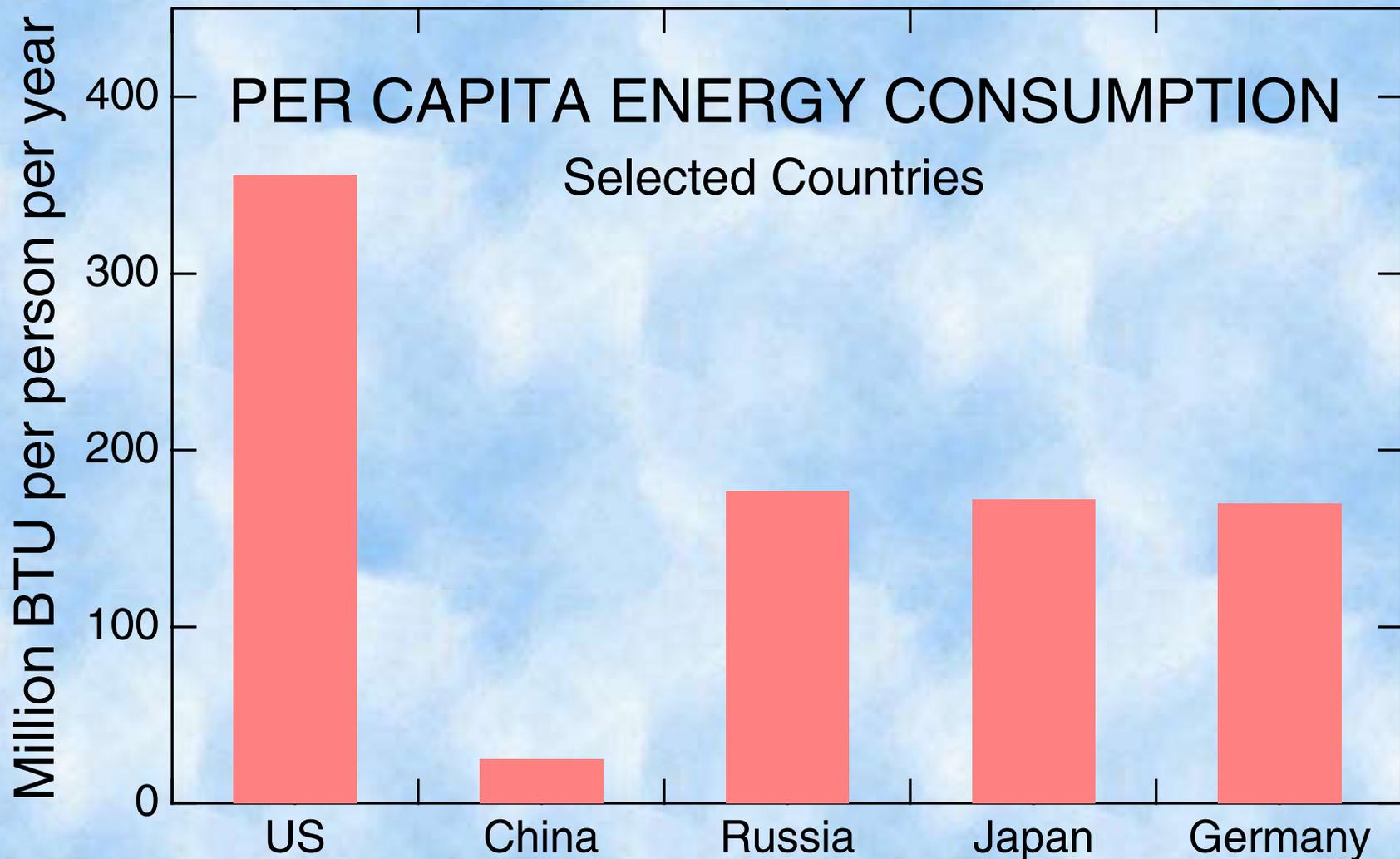
How much does your household contribute?

WHAT COUNTRY USES THE MOST ELECTRIC POWER?



No surprise. It's the United States.

WHAT COUNTRY USES THE MOST ELECTRIC POWER *PER CAPITA*?



No surprise. It's the United States again.

WORLD

U.S.

N.Y. / REGION

BUSINESS

TECHNOLOGY

SCIENCE

HEALTH

SPORTS

OPINION

AR

EDITORIALS

COLUMNISTS

CONTRIBUTORS

LETTERS

N.Y./REGION OPINIONS

READERS

OP-ED CONTRIBUTOR

Clean Air, Murky Precedent

By WILLIAM SWEET

Published: September 29, 2006

ON Wednesday, Gov. Arnold Schwarzenegger of California signed a bold bill pledging the state to cut its greenhouse gas emissions 25 percent by 2020. It was refreshing to hear a politician of national stature explain, with an air of true conviction, why global warming is an urgent problem. “It creeps up on you,” he told ABC News, the day he said he would sign the bill. “And then all of a sudden, it is too late to do something about it. ... We don’t want to go there.”

Just so. For the last nine years, since the United States refused to join in the Kyoto program to reduce greenhouse gas emissions, the country has acted in stubborn defiance of the obvious facts. Thus California is setting the country an admirable example. But there are a couple of worrisome aspects to the initiative: one is a possible reaction against greenhouse reductions elsewhere in America should California fail to meet its goals; the second is the question of whether this approach, even if successful, has much relevance for the rest of the country.

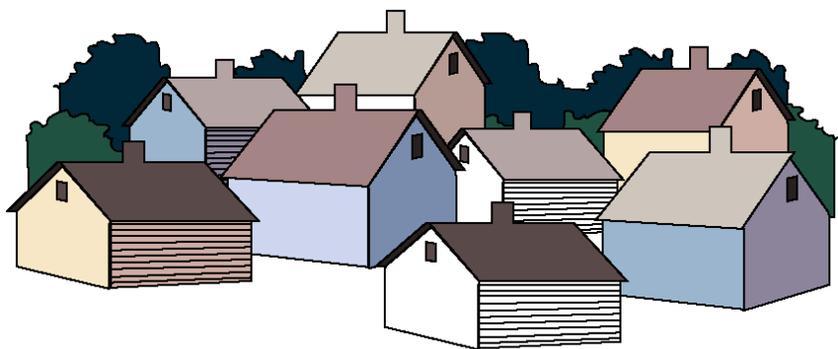
The new bill gives the California Air Resources Board, the state’s air-quality watchdog, sweeping powers to create and put in place a plan to slash the state’s greenhouse gas emissions back to 1990 levels. Although that still falls short of what the Kyoto Protocol asked of the United States — a cut to 7 percent below 1990 levels — the bill’s objectives are formidable enough.

***WHERE IS THIS CARBON DIOXIDE COMING FROM?
WE ARE ALL RESPONSIBLE.***



Burning a gallon of gasoline in your car puts 5 pounds of carbon in the atmosphere as carbon dioxide (CO₂), and it will stay there for decades — maybe a century!

Other sources are home heating and electric power production.



Global Atmosphere, Global Warming

QUESTIONS ABOUT GLOBAL WARMING

- IS IT REAL?
- IS IT IMPORTANT?
- WHAT IS IT DUE TO?
- HOW MUCH MORE CAN WE EXPECT?
- ARE WE SEEING JUST THE TIP OF THE ICEBERG?



***RESEARCH IS HELPING
TO ANSWER THESE QUESTIONS.***

www.ecd.bnl.gov/steve