

# EARTH'S CLIMATE SENSITIVITY AND WHY IT IS IMPORTANT



Stephen E. Schwartz

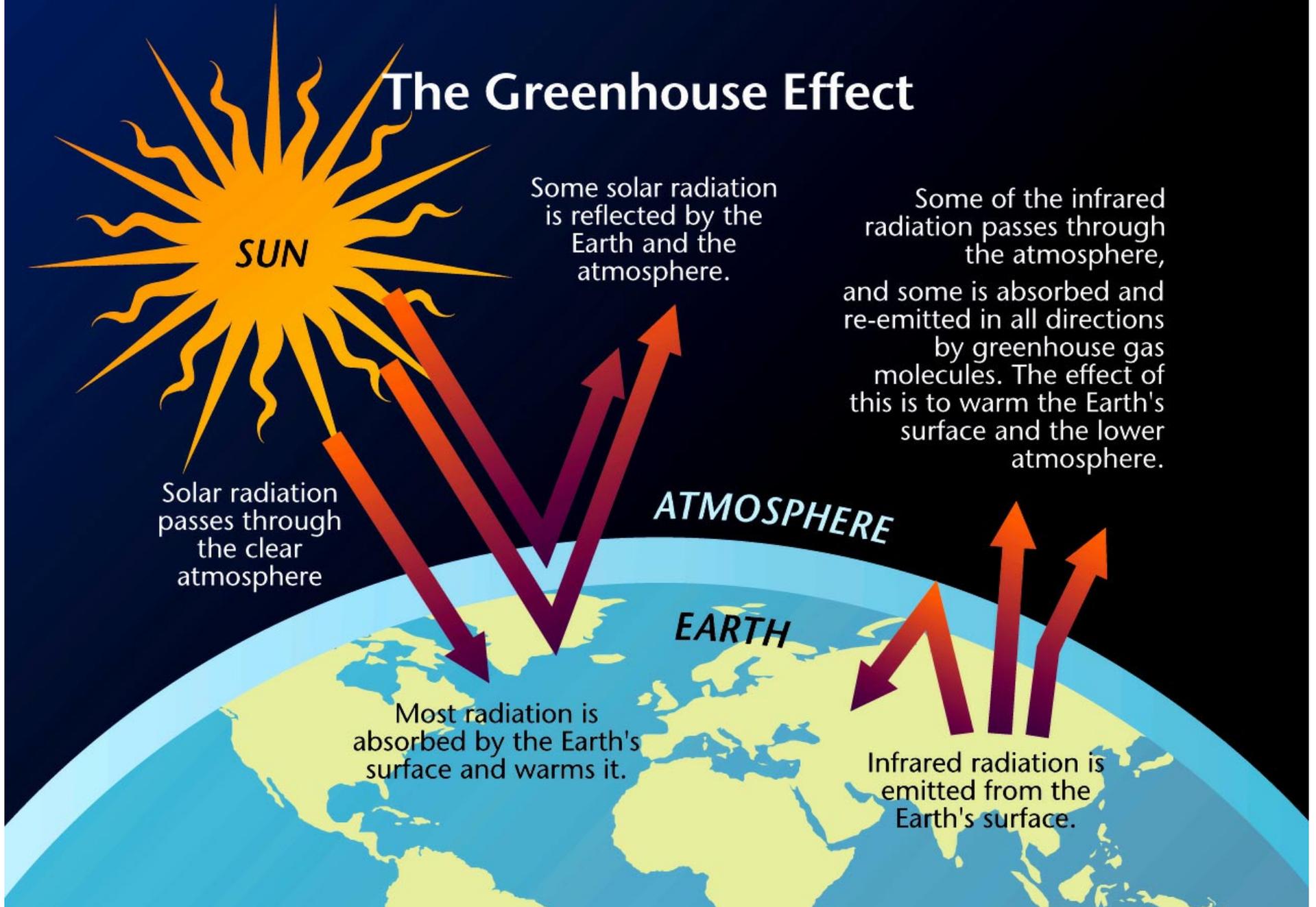


Upton NY

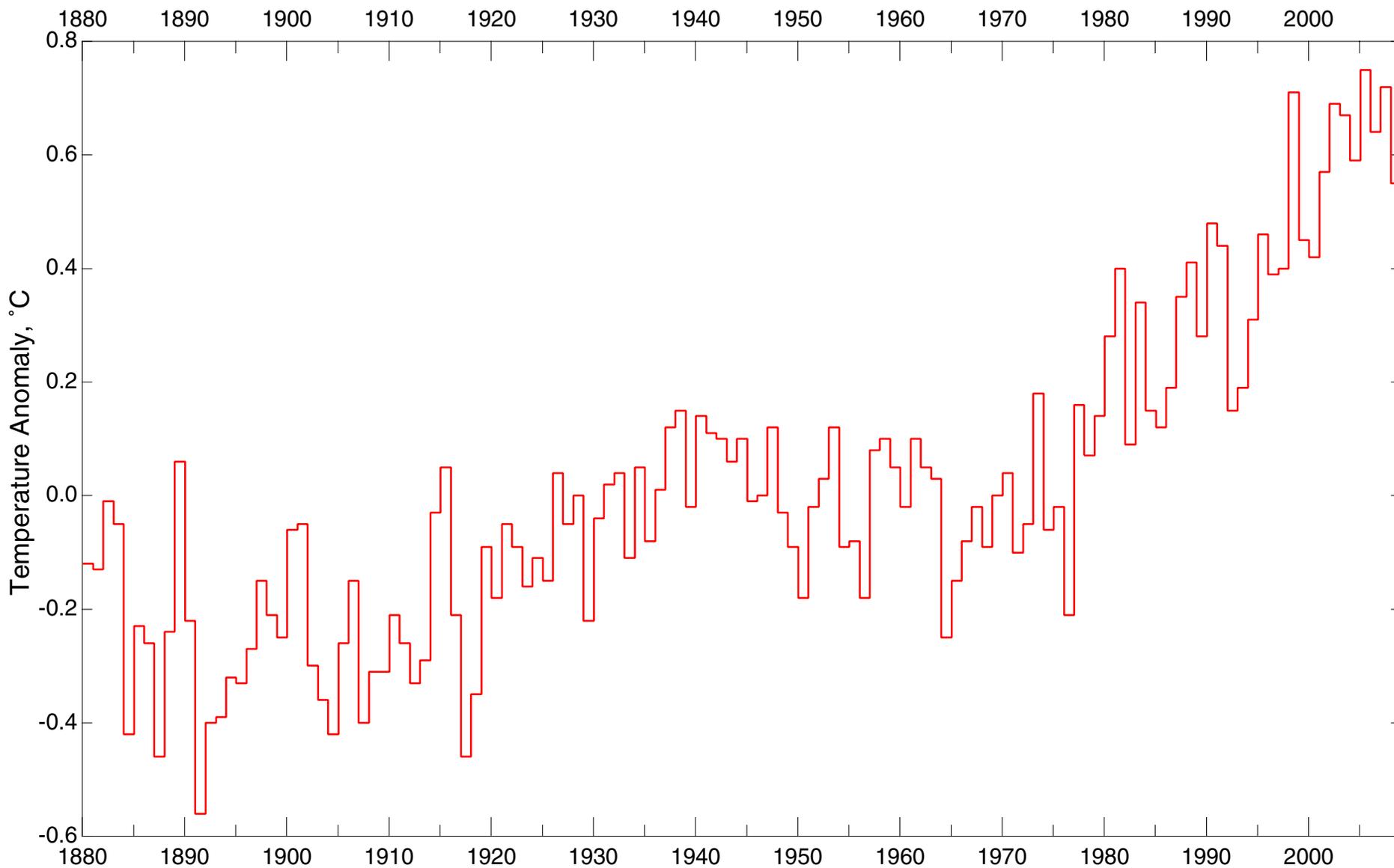
July 23, 2010

*[www.ecd.bnl.gov/steve](http://www.ecd.bnl.gov/steve)*

# The Greenhouse Effect



# GLOBAL ANNUAL TEMPERATURE ANOMALY, 1880-2008



*Data: Goddard Institute for Space Studies*

# ***RADIATIVE FORCING***

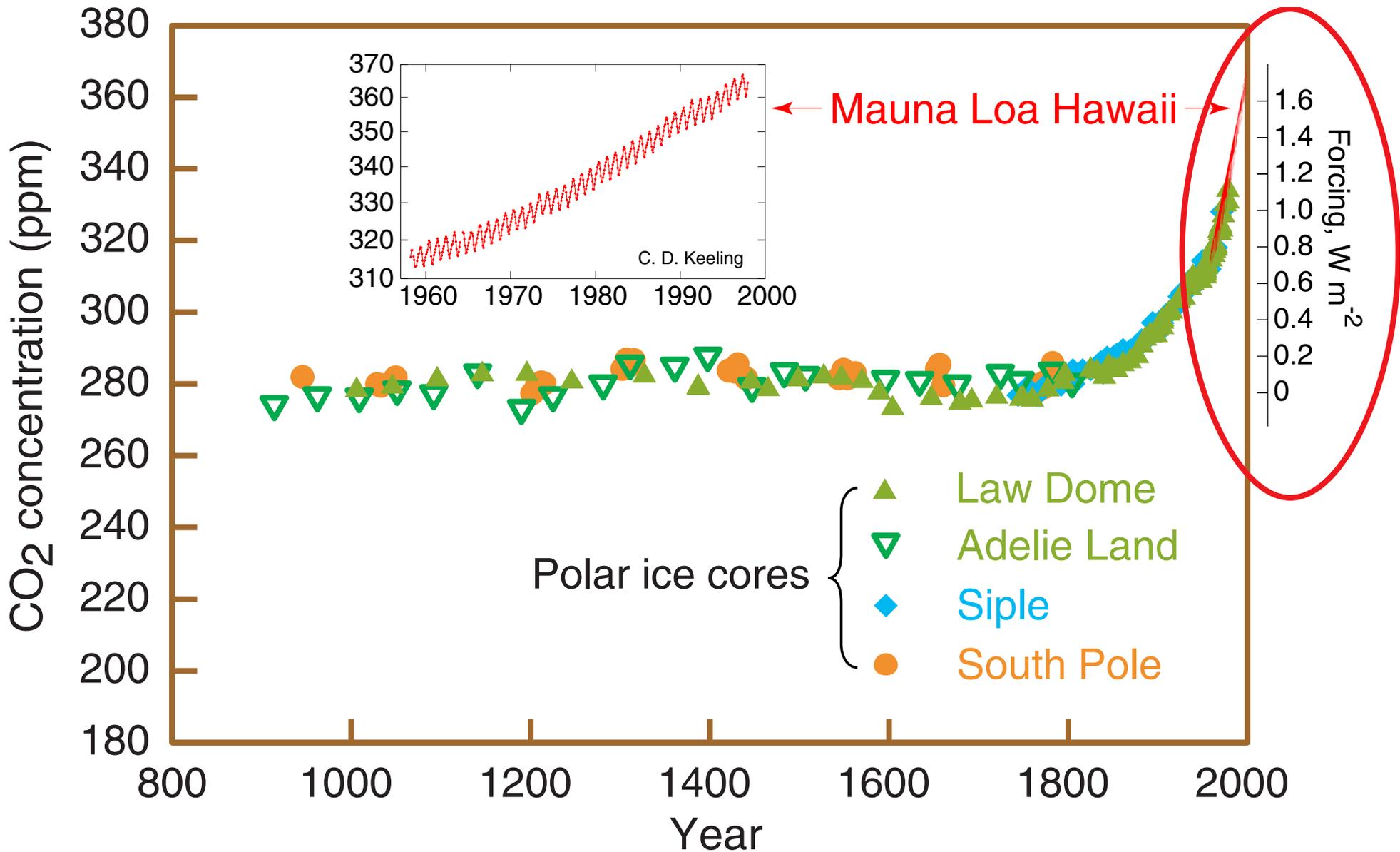
A *change* in a radiative flux term in Earth's radiation budget,  $\Delta F$ ,  $\text{W m}^{-2}$ .

## ***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.

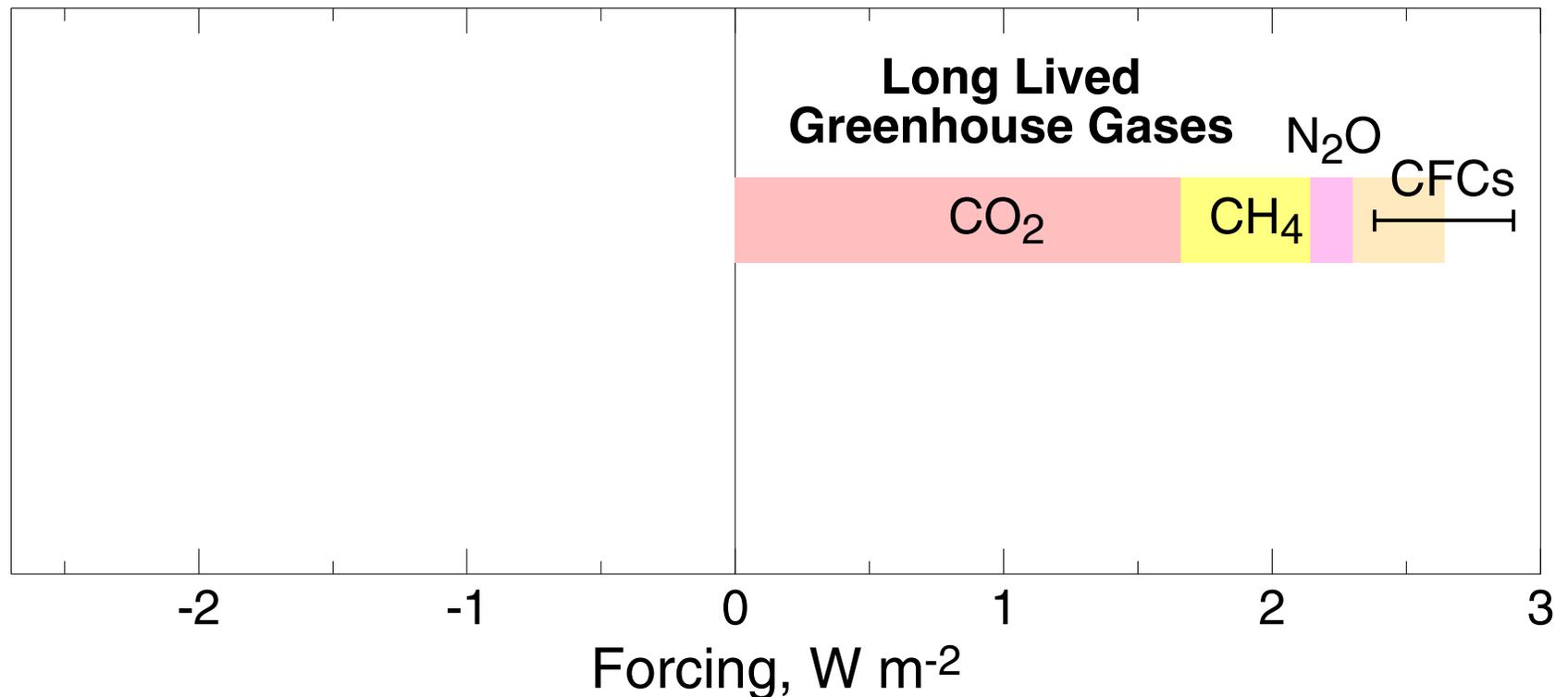
# ATMOSPHERIC CARBON DIOXIDE IS INCREASING



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

# CLIMATE FORCINGS OVER THE INDUSTRIAL PERIOD

Extracted from IPCC AR4 (2007)



Greenhouse gas forcing is considered accurately known.

Gases are uniformly distributed; radiation transfer is well understood.

# ***CLIMATE RESPONSE***

The *change* in global and annual mean temperature,  $\Delta T$ , 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,  $S$ ,  $\text{K}/(\text{W m}^{-2})$ ,

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

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

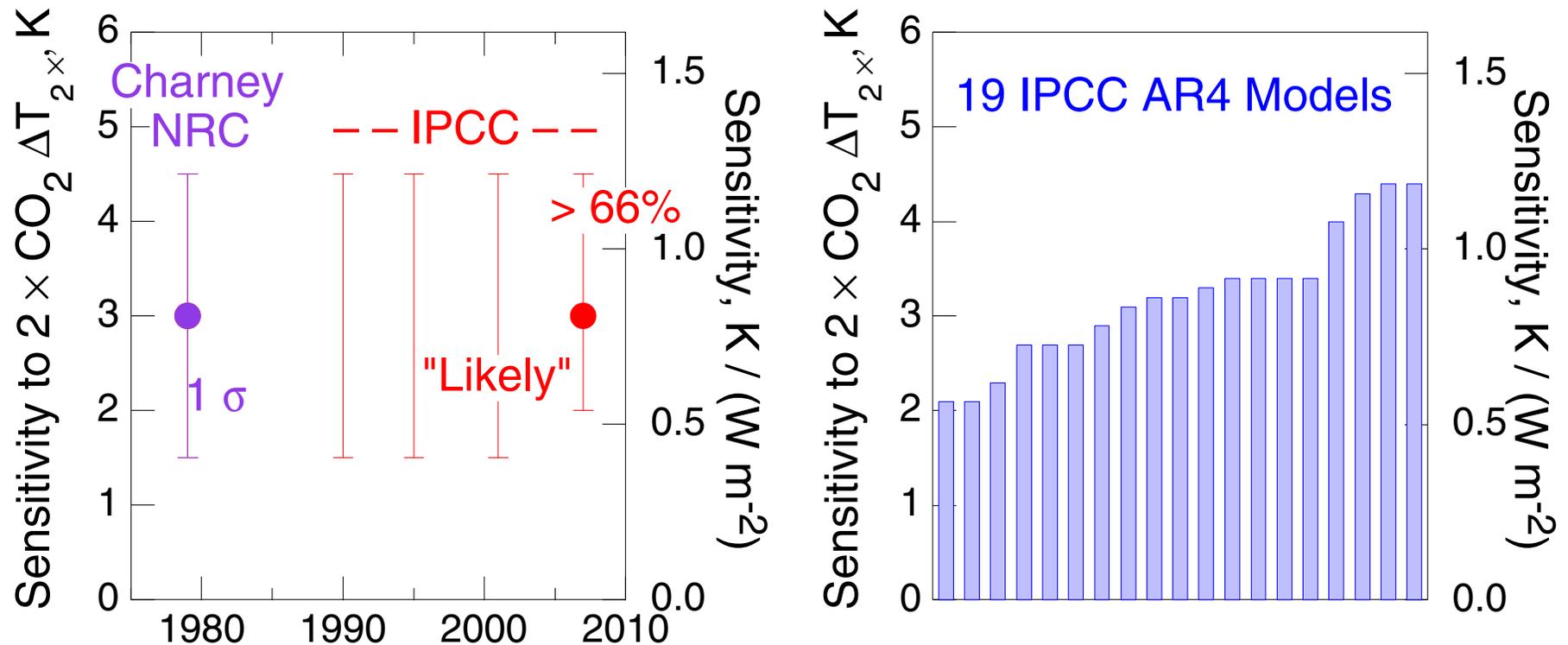
Climate sensitivity is often expressed as the temperature for doubled  $\text{CO}_2$  concentration  $\Delta T_{2\times}$ .

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

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

# ESTIMATES OF EARTH'S CLIMATE SENSITIVITY AND ASSOCIATED UNCERTAINTY

Major national and international assessments and current climate models



Current estimates of Earth's climate sensitivity are centered about a  $\text{CO}_2$  doubling temperature  $\Delta T_{2 \times} = 3 \text{ K}$ , but with substantial uncertainty.

Range of sensitivities of current models roughly coincides with IPCC "likely" range.

# HOW MUCH WARMING IS EXPECTED?

For increases in CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, and CFCs over the industrial period

$$F = 2.6 \text{ W m}^{-2}$$

*Expected* temperature increase:

$$\Delta T_{\text{exp}} = \frac{F}{F_{2\times}} \times \Delta T_{2\times} = \frac{2.6}{3.7} \times 3 \text{ K} = 2.1 \text{ K}$$

IPCC, 2007  
Best Estimate

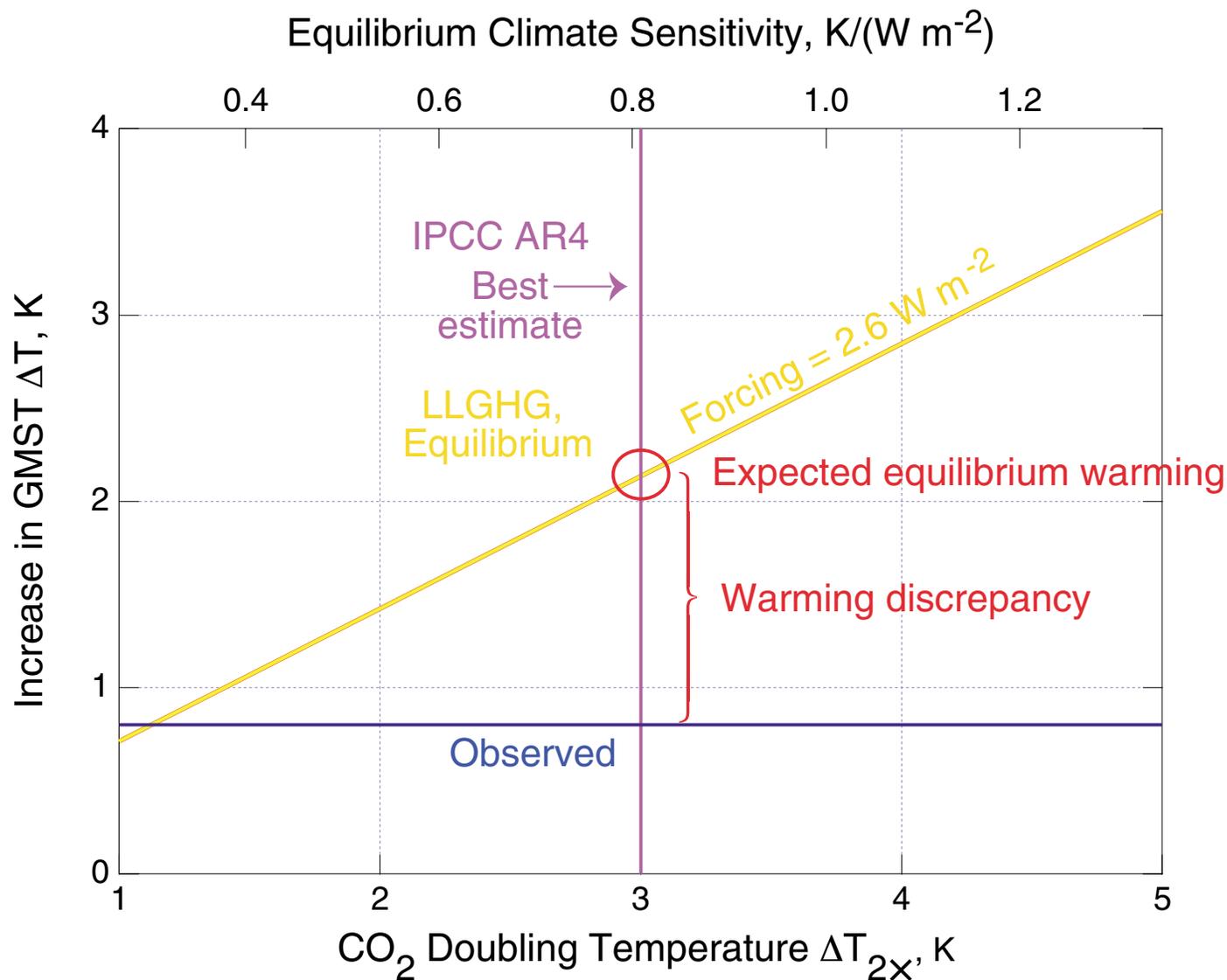
*Observed* temperature increase:

$$\Delta T_{\text{obs}} = 0.8 \text{ K}$$

Warming  
discrepancy

# EXPECTED INCREASE IN GLOBAL TEMPERATURE

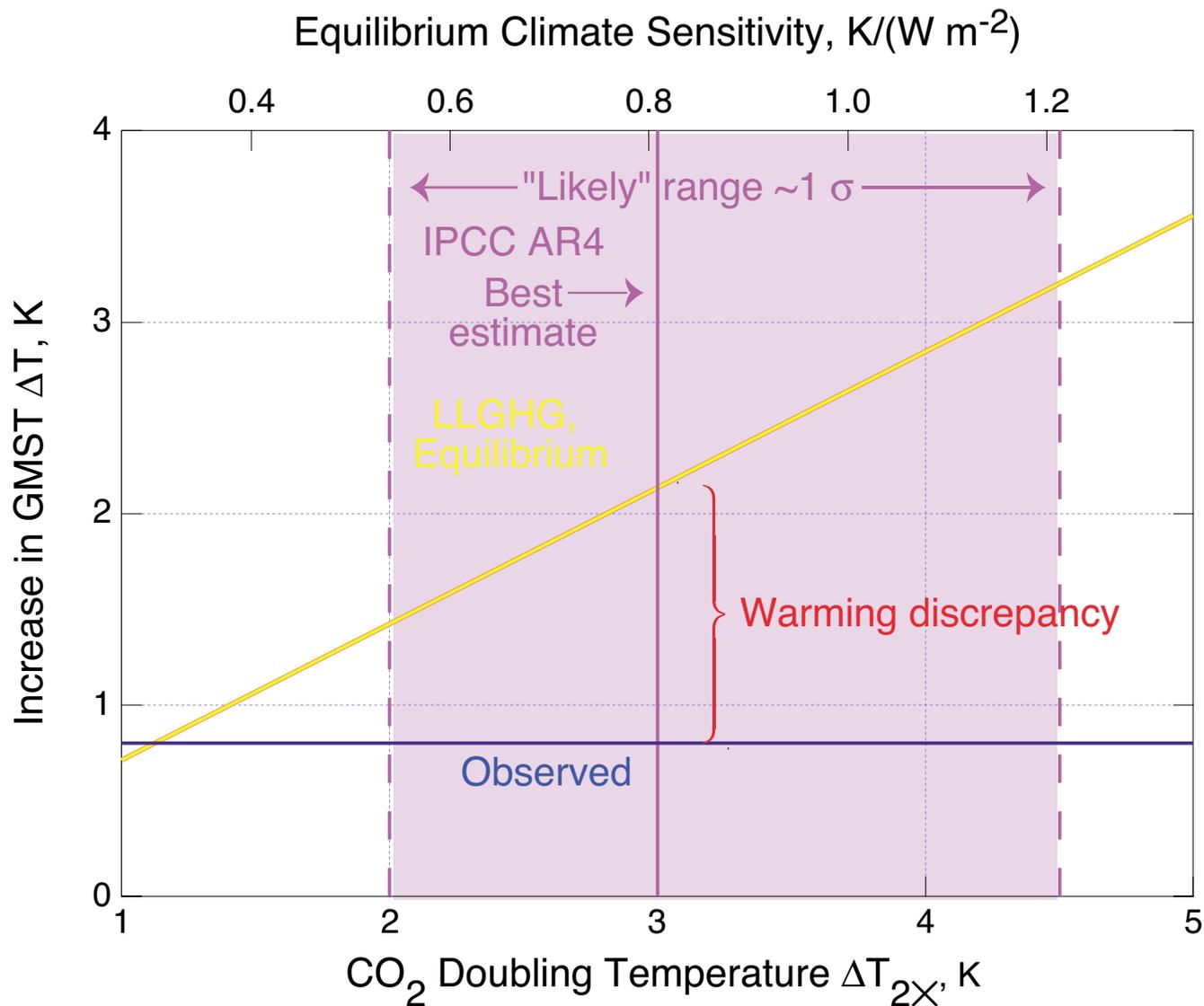
## Long-lived GHGs only – Dependence on climate sensitivity



**Warming discrepancy** denotes the expected warming that has not occurred: ~60% of the expected warming.

# EXPECTED INCREASE IN GLOBAL TEMPERATURE

## Long-lived GHGs only – Dependence on climate sensitivity



This discrepancy holds throughout the IPCC AR4 “likely” range for climate sensitivity.

# HOW MUCH WARMING IS EXPECTED?

For increases in CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, and CFCs over the industrial period

$$F = 2.6 \text{ W m}^{-2}$$

*Expected* temperature increase:

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Committed  
warming

*Observed* temperature increase:

$$\Delta T_{\text{obs}} = 0.8 \text{ K}$$

*Because of uncertainty in climate sensitivity the committed warming is likewise uncertain.*

# IMPLICATIONS

## ALLOWABLE FUTURE CO<sub>2</sub> EMISSIONS

How much fossil carbon can be burned and emitted into the atmosphere (as CO<sub>2</sub>) without exceeding a given threshold for “dangerous anthropogenic interference” with the climate system?

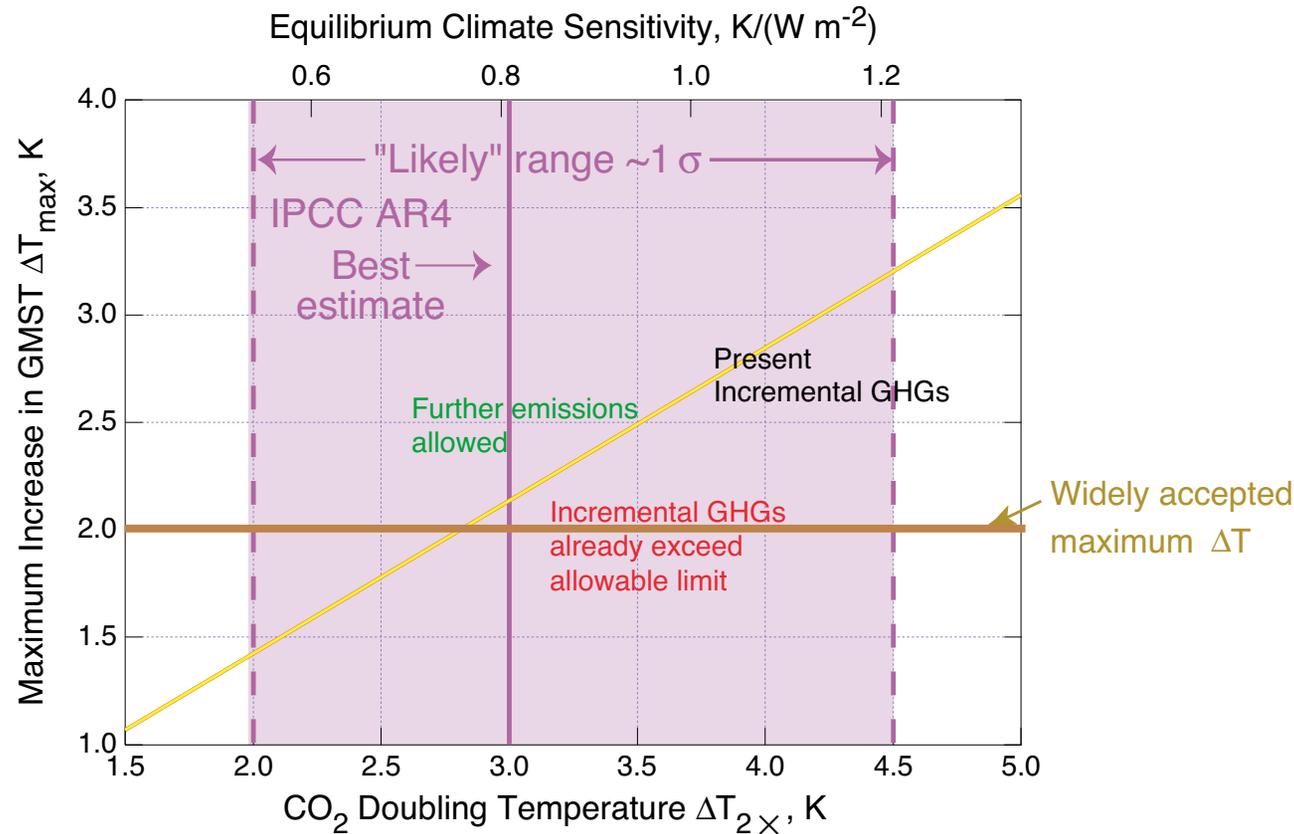
Answer depends on target threshold and climate sensitivity.

Premise of the calculation:

Forcings by LLGHG's only; result expressed as equivalent CO<sub>2</sub>.

# ALLOWABLE FUTURE CO<sub>2</sub> EMISSIONS

Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial

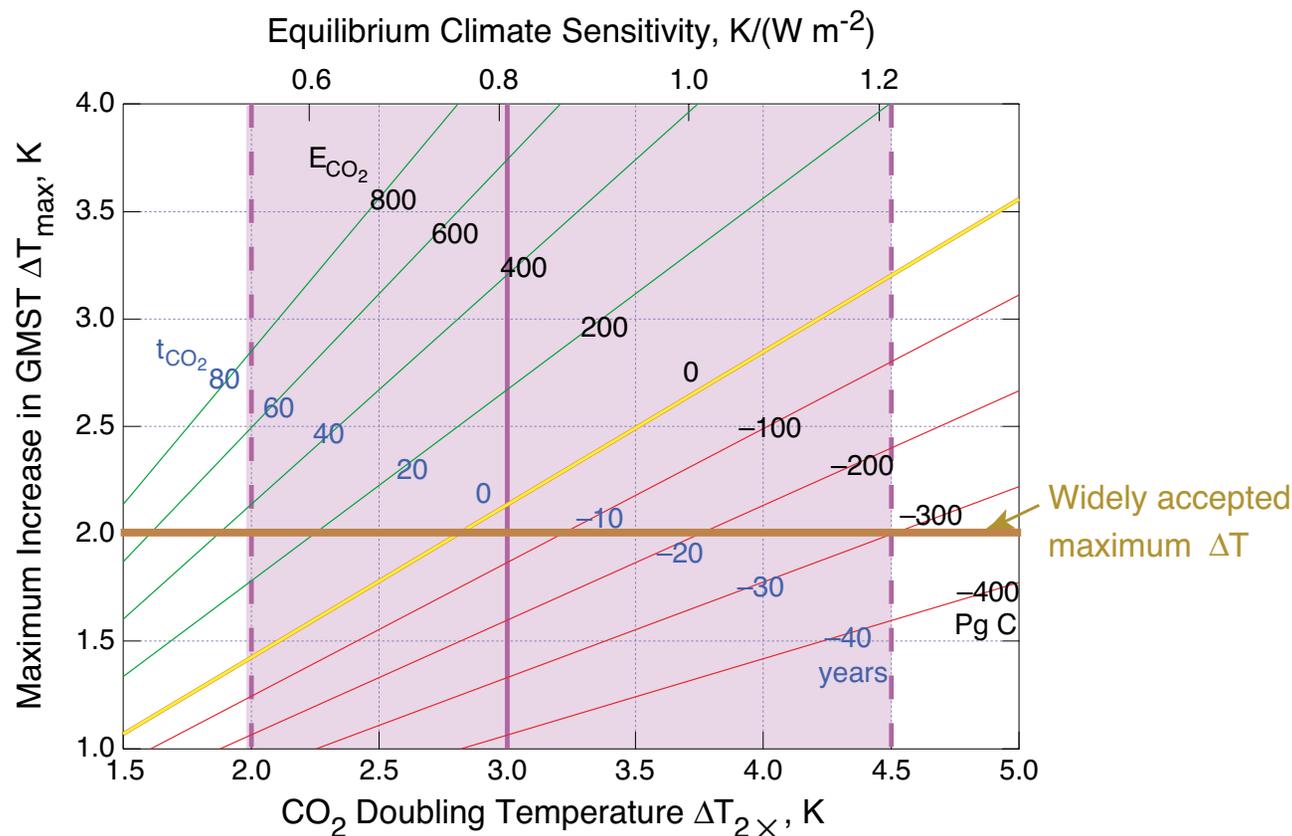


If  $\Delta T_{max} > 2.1$  K and/or sensitivity  $\Delta T_{2x} < 3$  K, further emissions are allowed without exceeding  $\Delta T_{max}$ .

If  $\Delta T_{max} < 2.1$  K and/or sensitivity  $\Delta T_{2x} > 3$  K, committed temperature increase already exceeds  $\Delta T_{max}$ .

# ALLOWABLE FUTURE CO<sub>2</sub> EMISSIONS

Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial



For  $\Delta T_{\max} = 2$  K . . .

If sensitivity  $\Delta T_{2\times}$  is 3 K, *no more emissions*.

If sensitivity  $\Delta T_{2\times}$  is 2 K, ~ **30 more years of emissions at present rate**.

If sensitivity  $\Delta T_{2\times}$  is 4.5 K, **threshold is exceeded by ~30 years**.



AMERICAN  
METEOROLOGICAL  
SOCIETY

*Journal of Climate*

**EARLY ONLINE RELEASE**  
**From Forcing by Long-Lived Greenhouse Gases**  
**Why Hasn't Earth Warmed as Much as Expected?**

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Brookhaven National Laboratory, Upton, New York

Robert J. Charlson  
University of Washington, Seattle, Washington

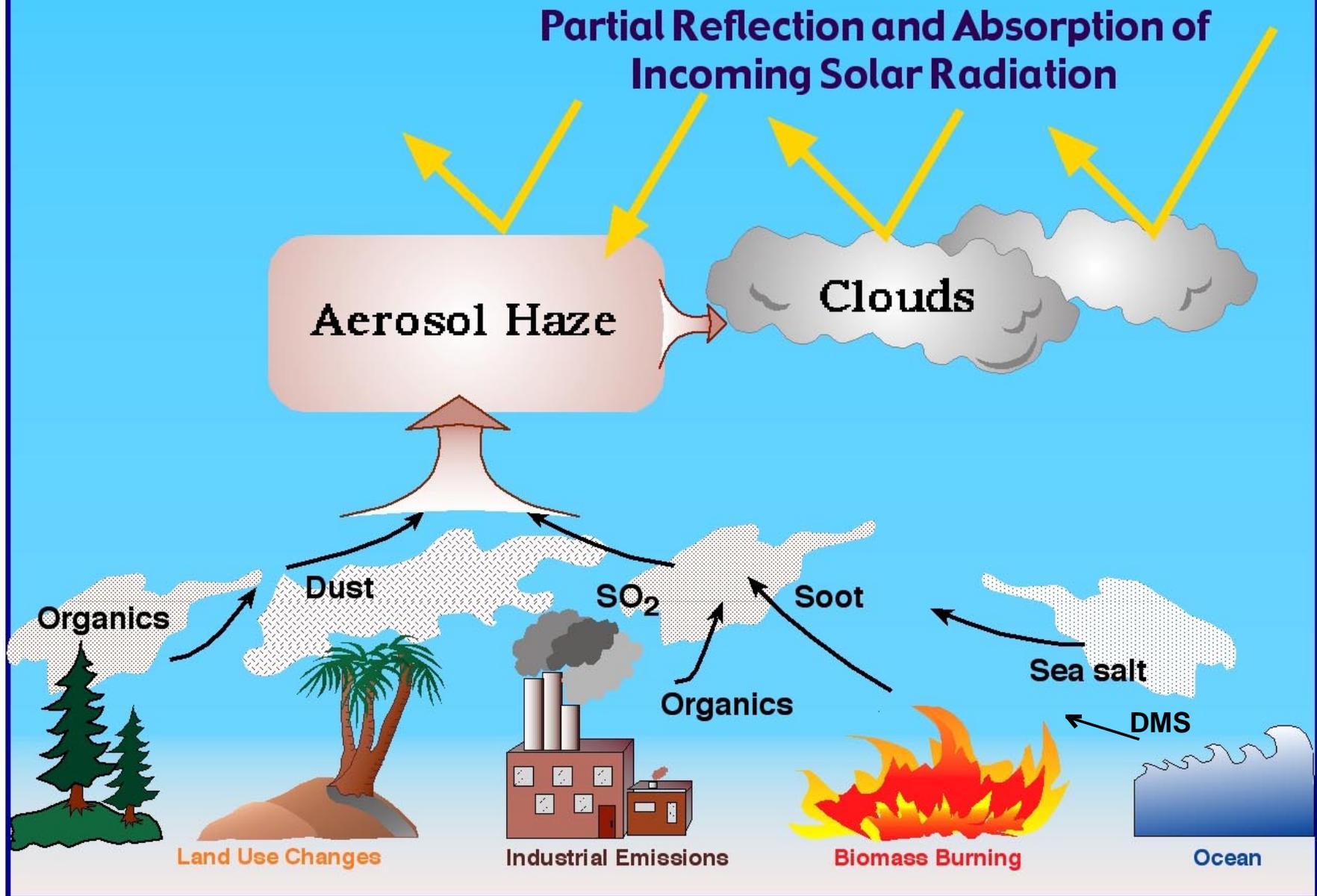
Ralph A. Kahn  
NASA Goddard Space Flight Center, Greenbelt, Maryland

John A. Ogren  
NOAA Earth System Research Laboratory, Boulder, Colorado

Henning Rodhe  
Department of Meteorology, Stockholm University, Stockholm, Sweden

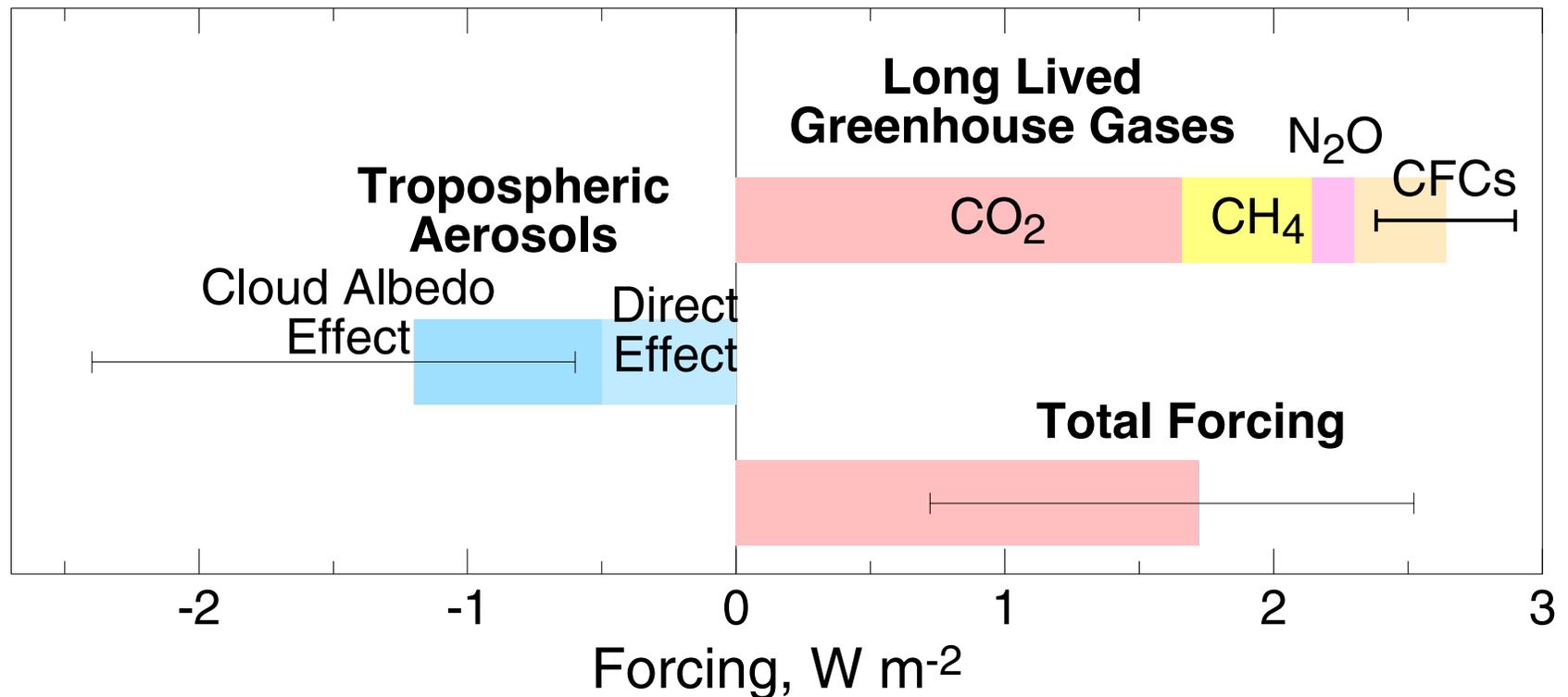
The DOI for this manuscript is doi:10.1175/2009JCLI3461.1

# Radiative Forcing by Tropospheric Aerosol



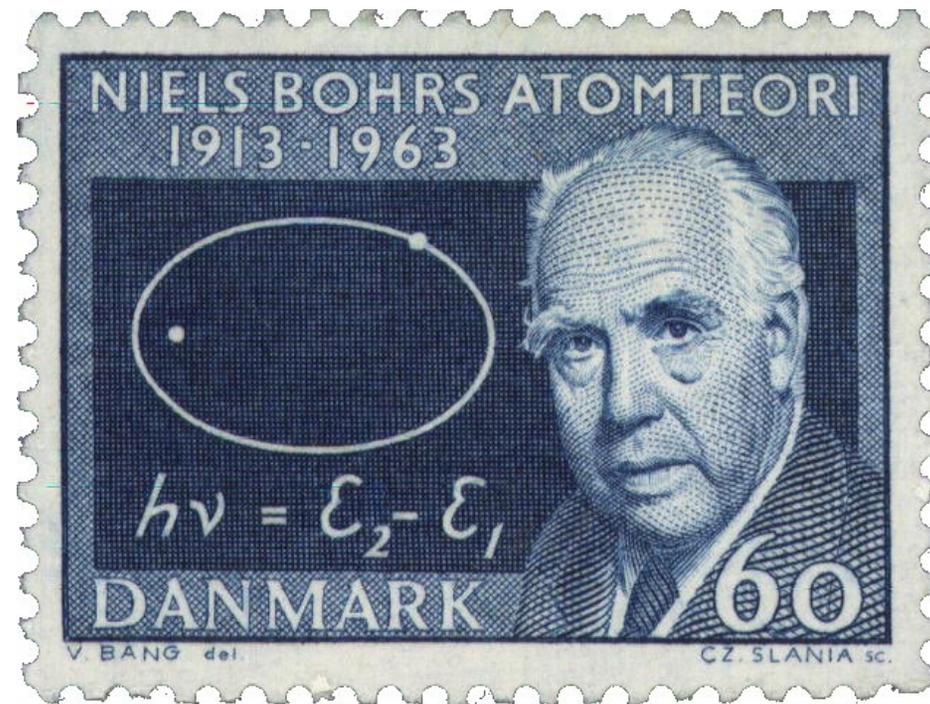
# CLIMATE FORCINGS OVER THE INDUSTRIAL PERIOD

Extracted from IPCC AR4 (2007)



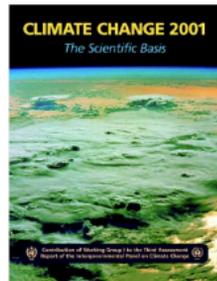
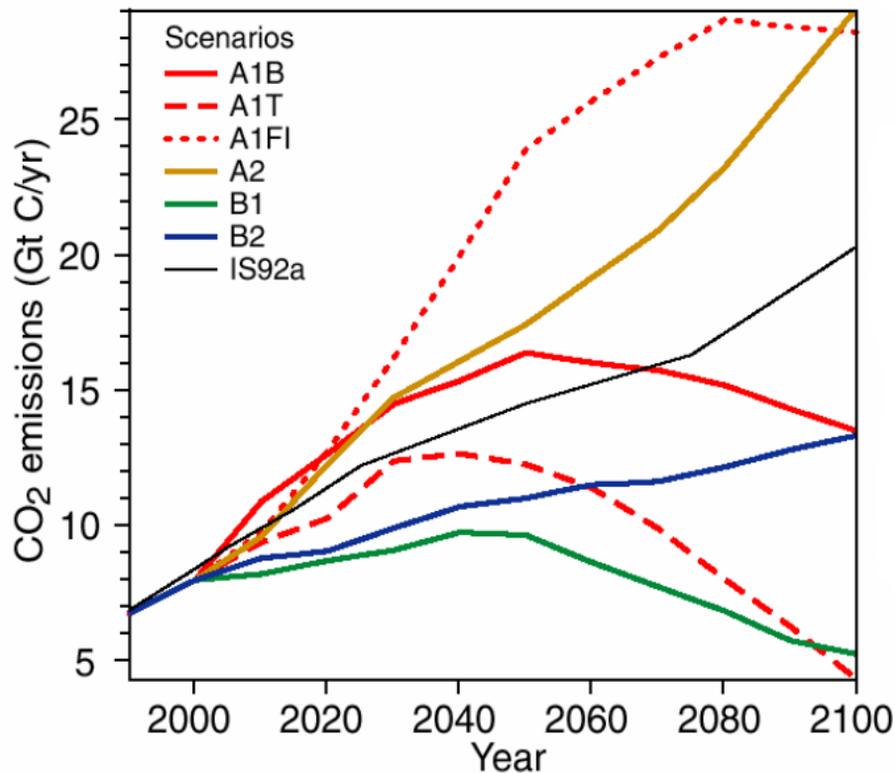
Total forcing includes other anthropogenic and natural (solar) forcings. Forcing by tropospheric ozone,  $\sim 0.35 \text{ W m}^{-2}$ , is the greatest of these. Uncertainty in aerosol forcing dominates uncertainty in total forcing.

*Prediction is difficult,  
especially about the future.*

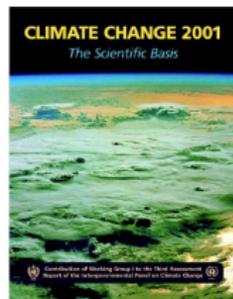
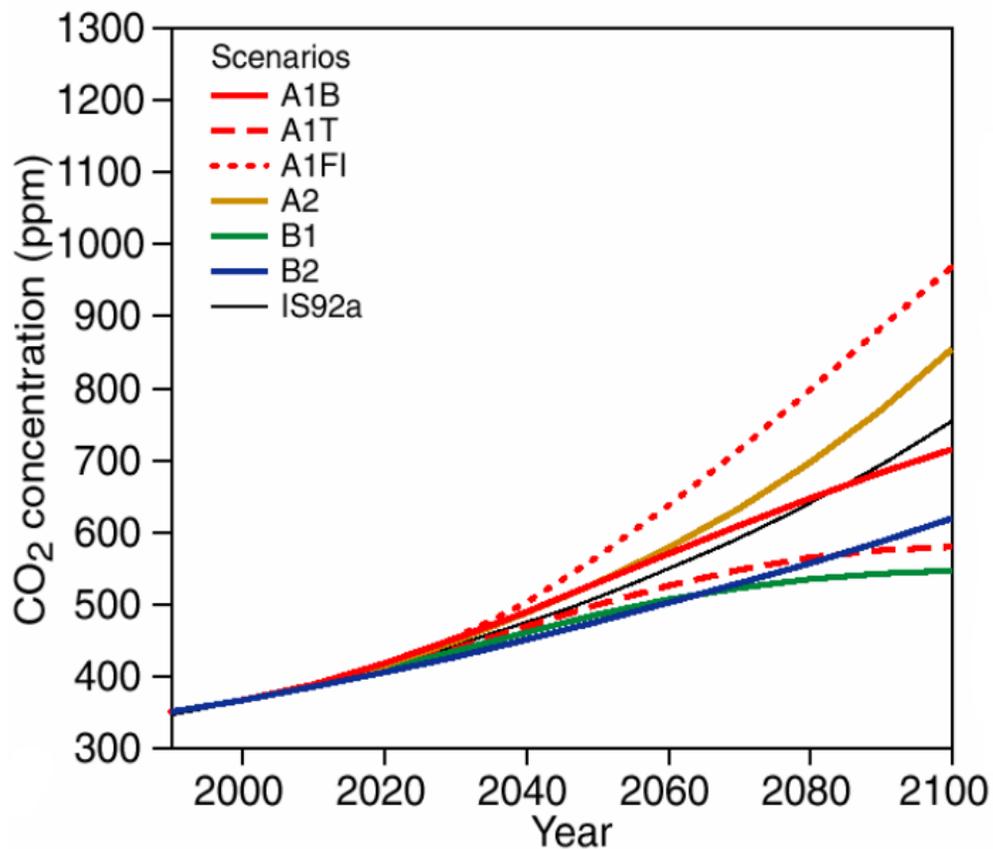


*– Niels Bohr*

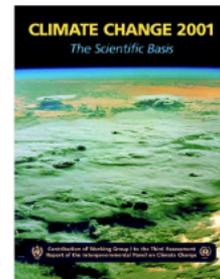
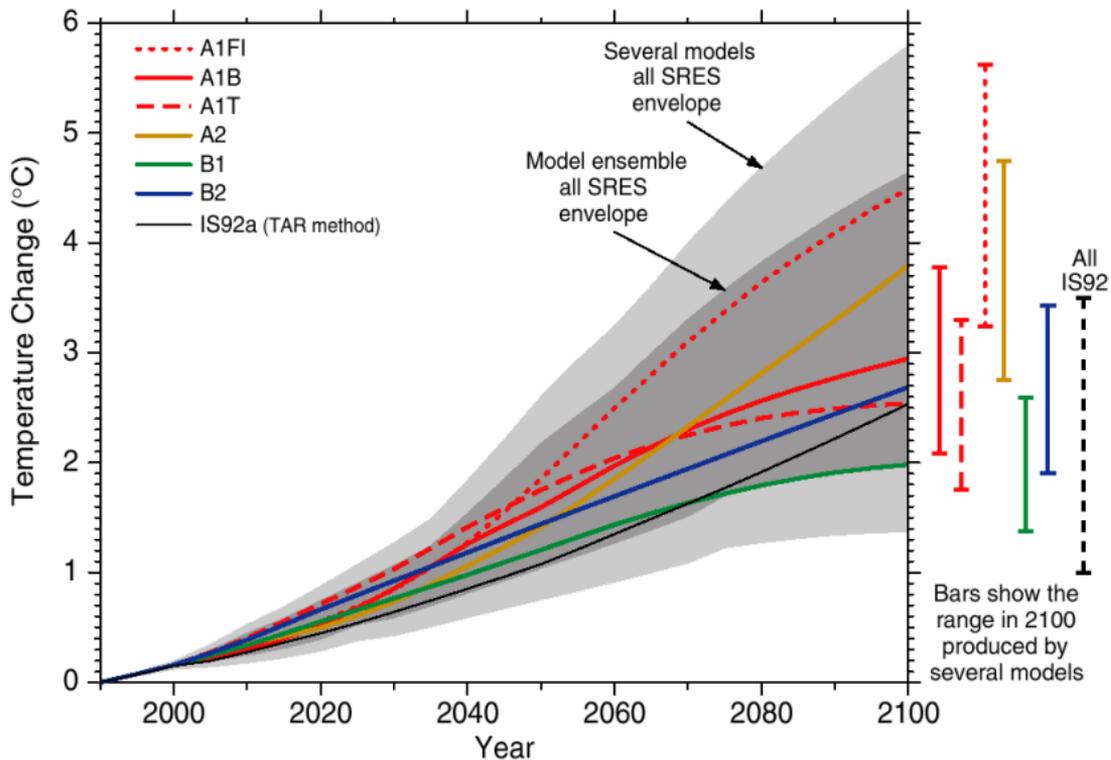
# PROJECTIONS OF FUTURE CO<sub>2</sub> EMISSIONS



# PROJECTIONS OF FUTURE CO<sub>2</sub> CONCENTRATIONS



# PROJECTIONS OF FUTURE TEMPERATURE CHANGE

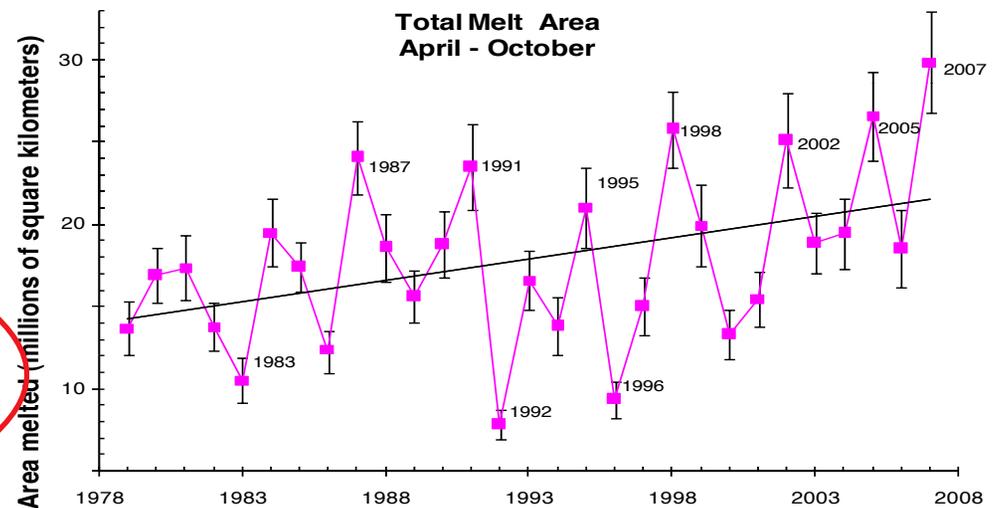
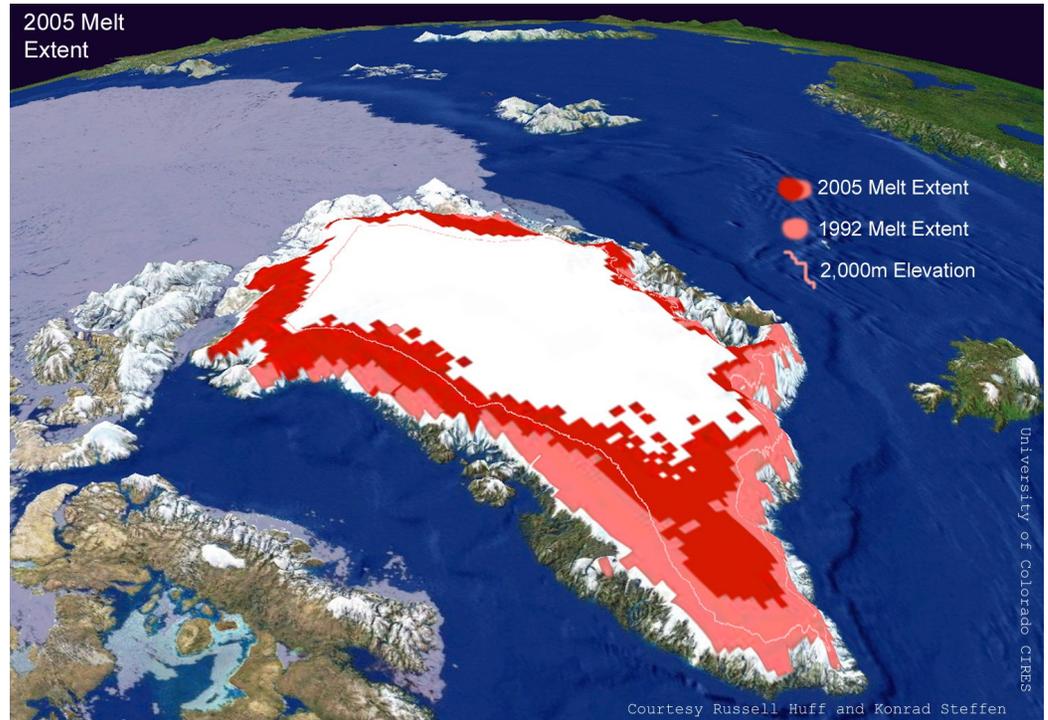


# MELTING OF GREENLAND ICE CAP

Satellite determination of maximum extent of glacial melt



NASA

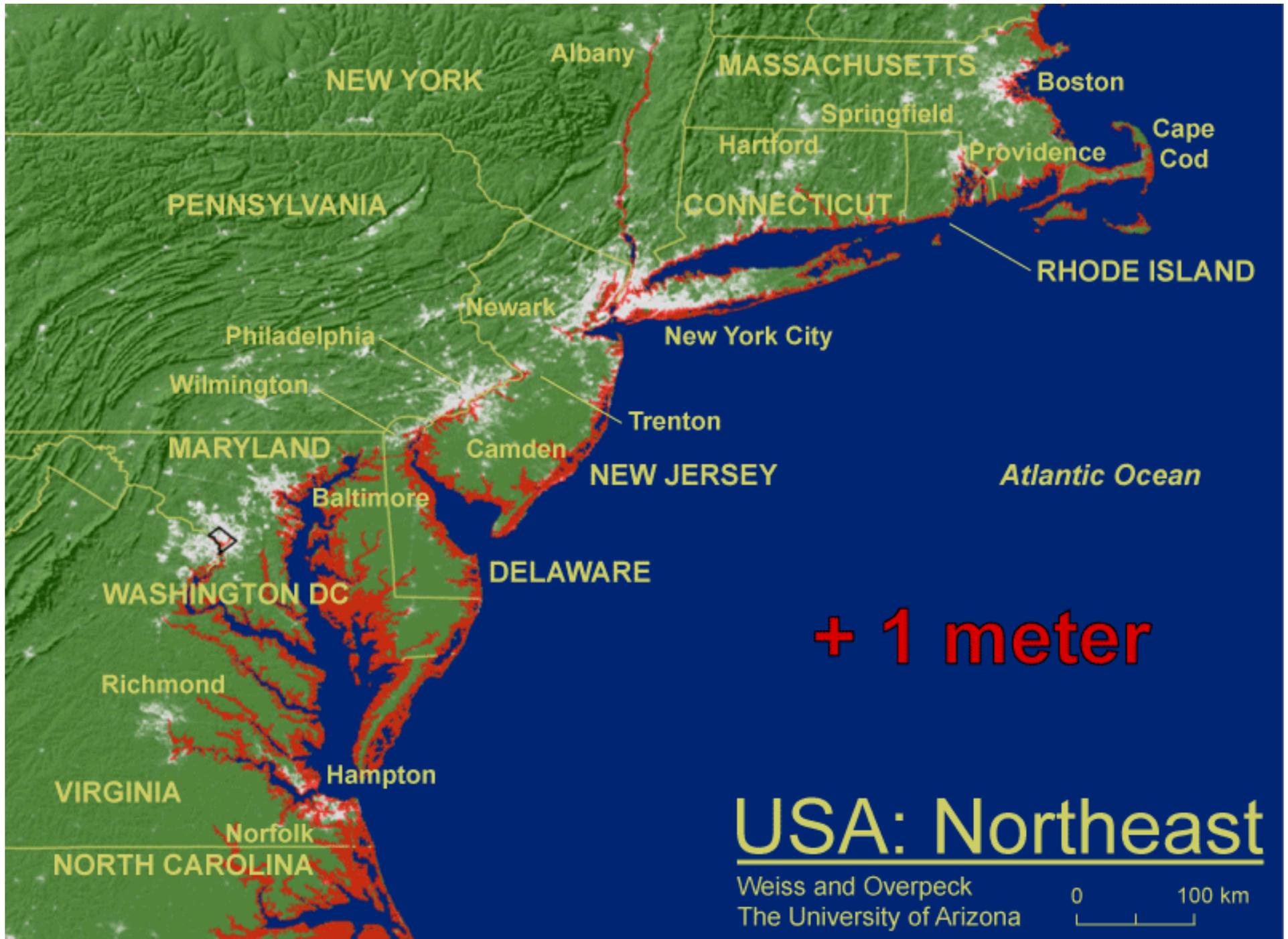


Steffen & Huff, Univ. Colo., 2005

Complete melt of the Greenland ice sheet would raise the level of the global ocean 7 meters.









# HOW MUCH CARBON IS IN A GALLON OF GASOLINE?



1 lb?

2 lbs?

3 lbs!?



5 lbs!?!?

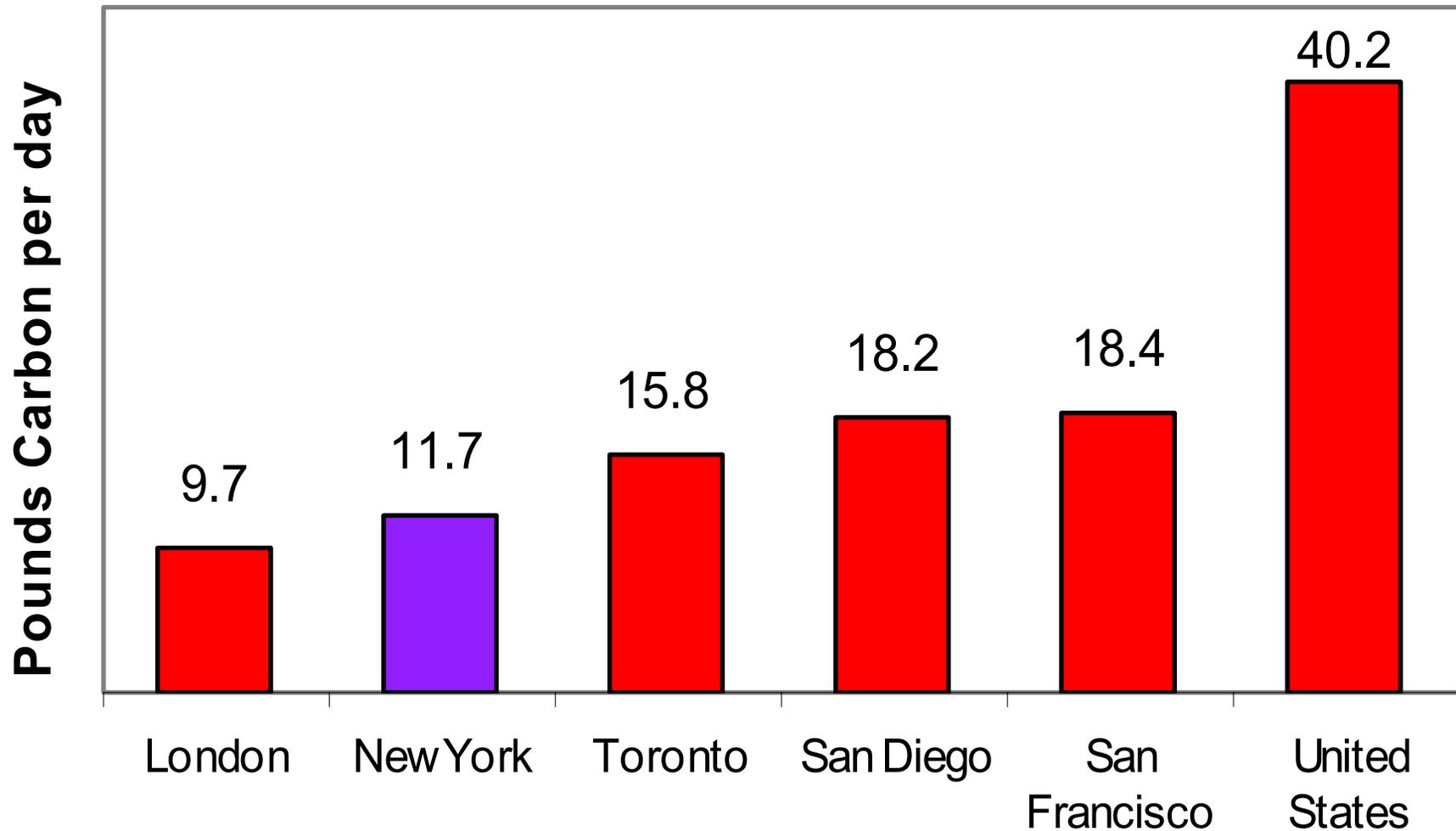


All of this carbon goes into the atmosphere as carbon dioxide when you burn the gasoline in your car.



# CARBON DIOXIDE EMISSIONS IN SELECTED CITIES

Pounds of carbon per person per day

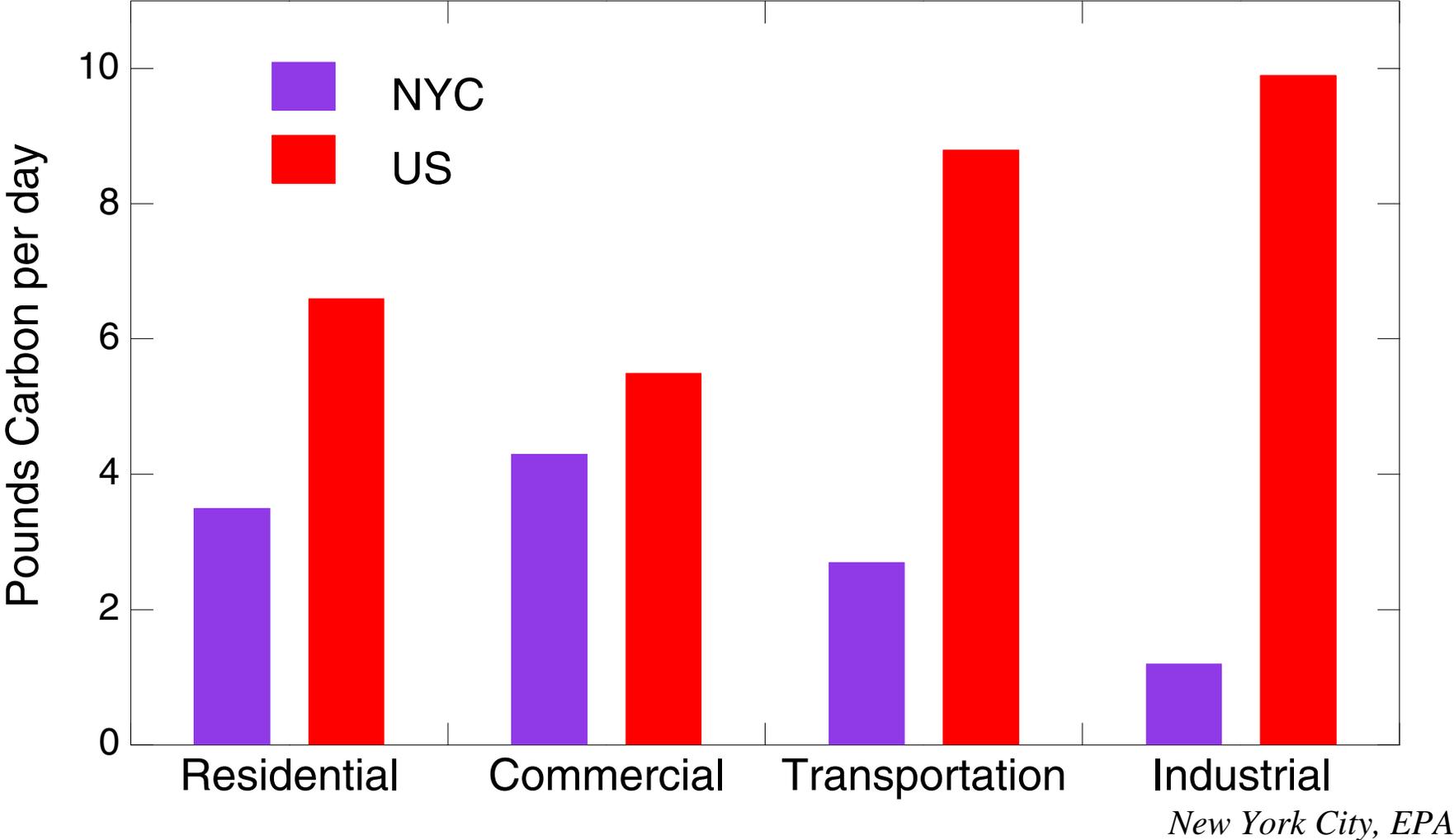


*New York City Greenhouse Gas Emissions, April, 2007*

Cities are energy efficient.

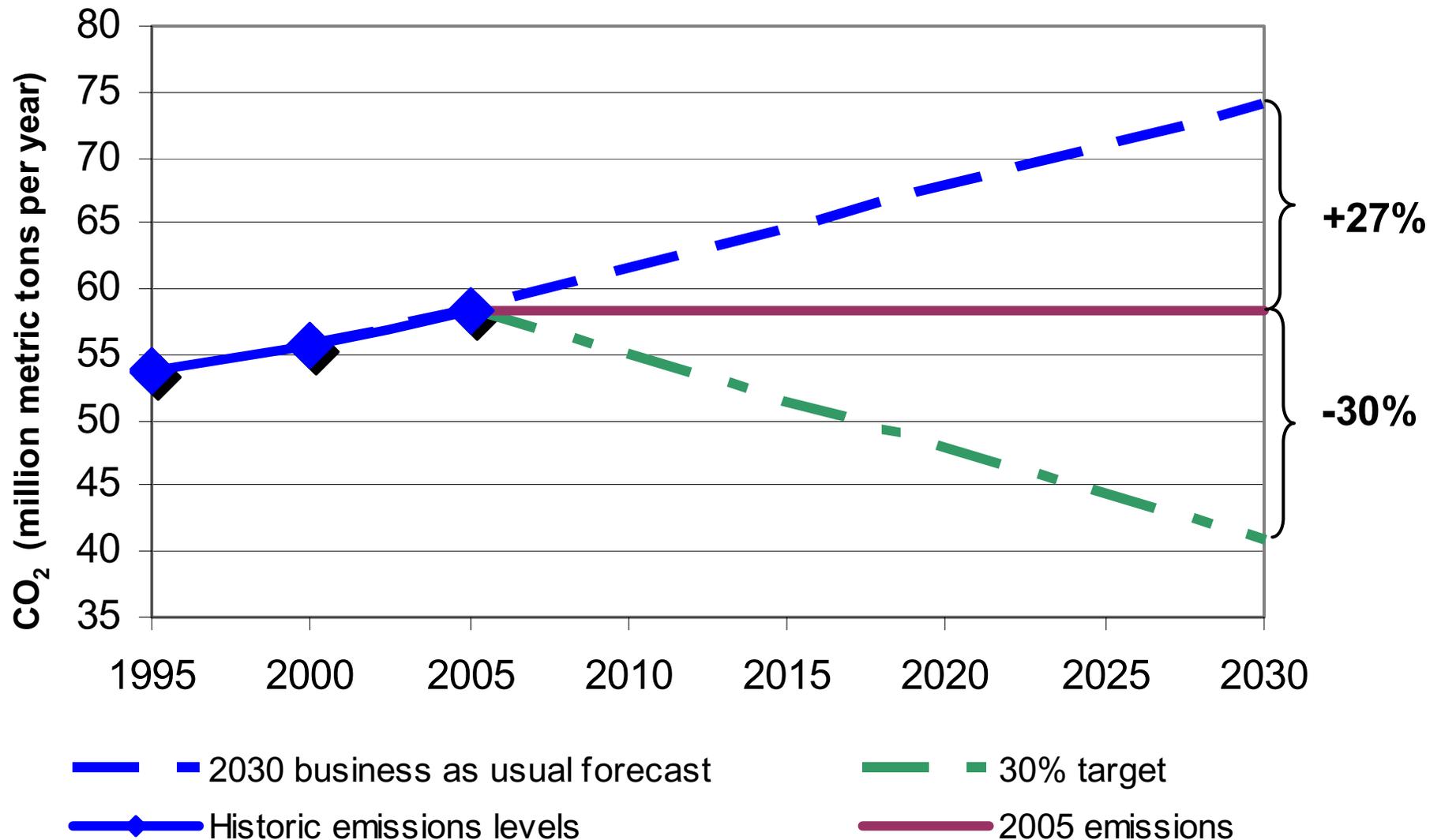
# CARBON DIOXIDE EMISSIONS BY SECTOR

Comparison of New York City vs. United States Average  
Pounds of carbon per person per day



# PROJECTED CARBON DIOXIDE EMISSIONS FOR NEW YORK CITY

2005 - 2030



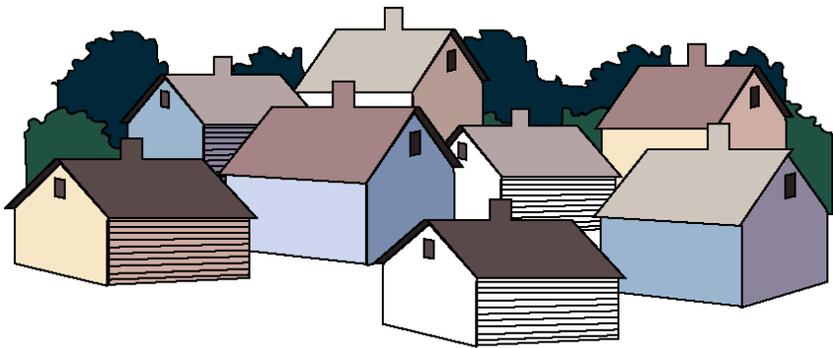
*New York City Greenhouse Gas Emissions, April, 2007*

***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 (CO<sub>2</sub>), 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](http://www.ecd.bnl.gov/steve)***