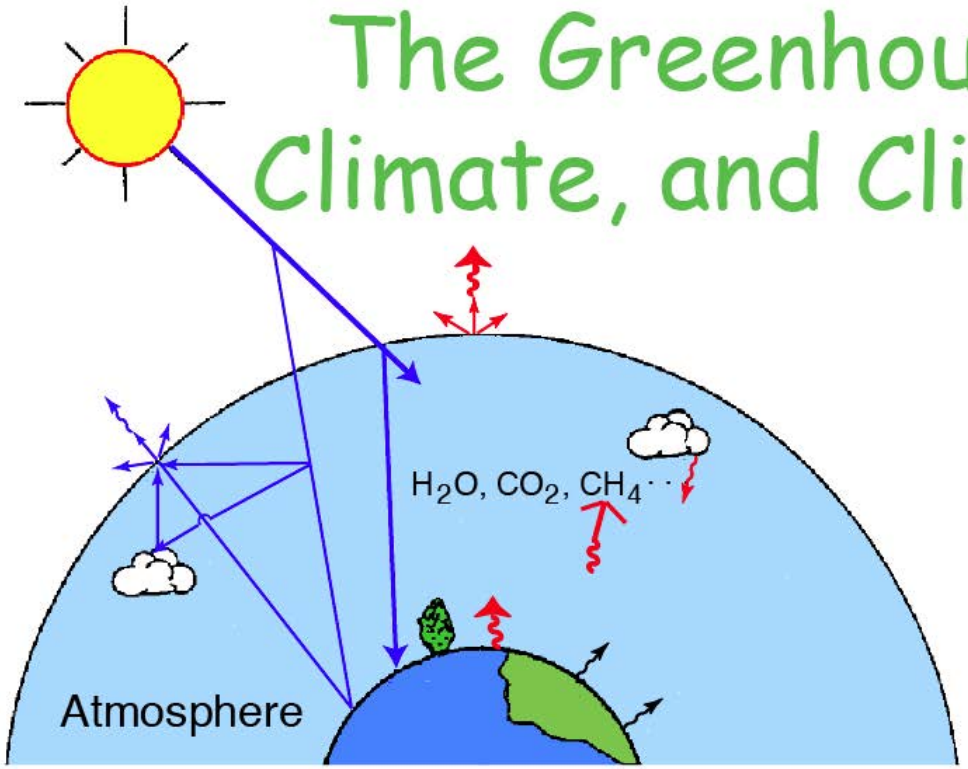
The Greenhouse Effect, Climate, and Climate Change



Stephen E. Schwartz

BROOKHAVEN NATIONAL LABORATORY

Upton, Long Island, NY

www.ecd.bnl.gov

Sigma Pi Sigma Induction Ceremony

ST. JOHN'S UNIVERSITY

April 6, 2016

HOW MUCH POWER DO YOU RADIATE?

STEFAN–BOLTZMANN RADIATION LAW

Radiative emission of a black body

Power density $J = \sigma T^4$

Power density J Unit: $W\ m^{-2}$

Temperature T Unit: K

Stefan-Boltzmann const σ

Unit: $W\ m^{-2}\ K^{-4}$

$$\sigma = 5.67 \times 10^{-8}\ W\ m^{-2}\ K^{-4}$$

RADIATION POWER DENSITY

Power per area

Unit:

Watt per square meter

W m^{-2}

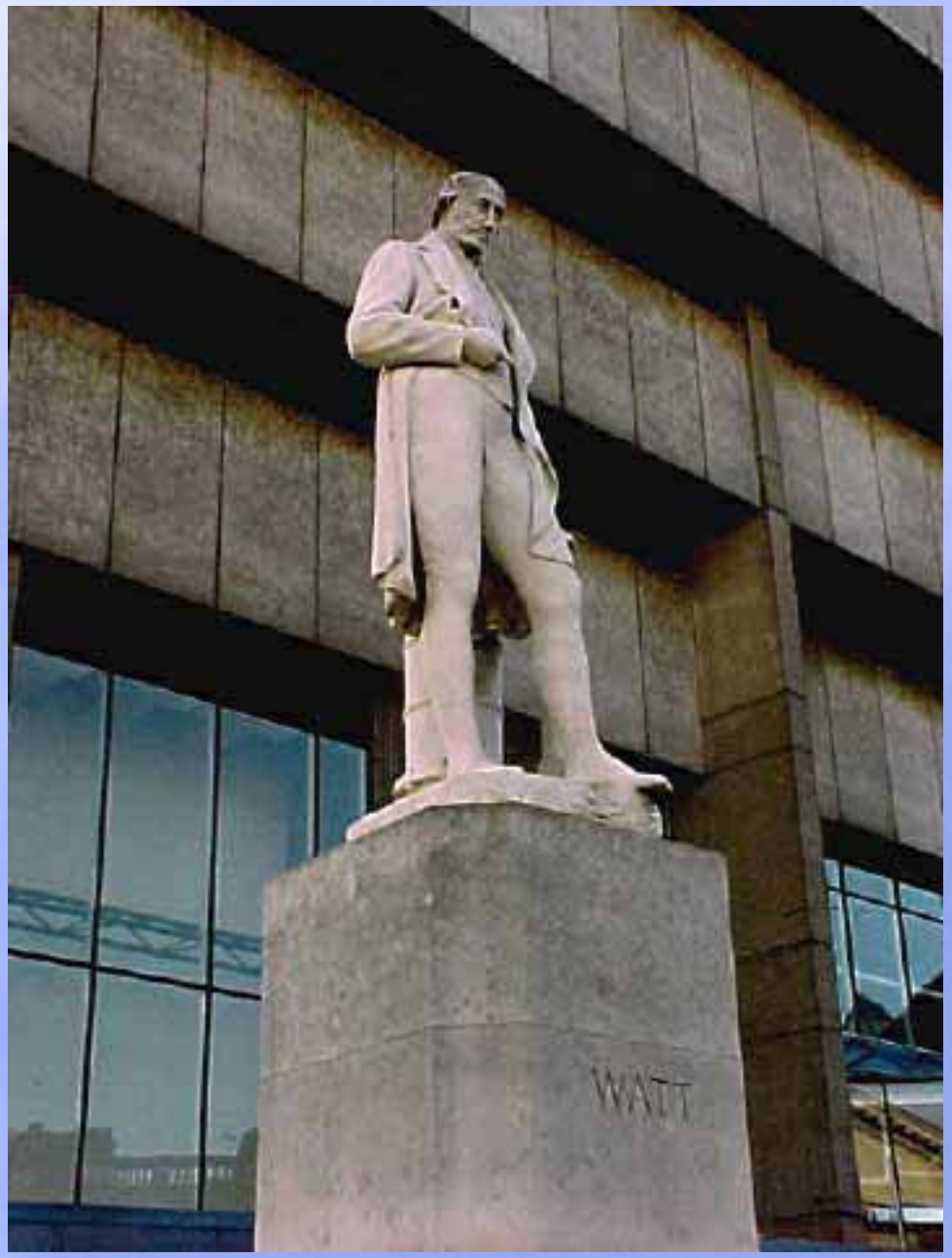


Photo: S. E. Schwartz

STEFAN - BOLTZMANN RADIATION LAW

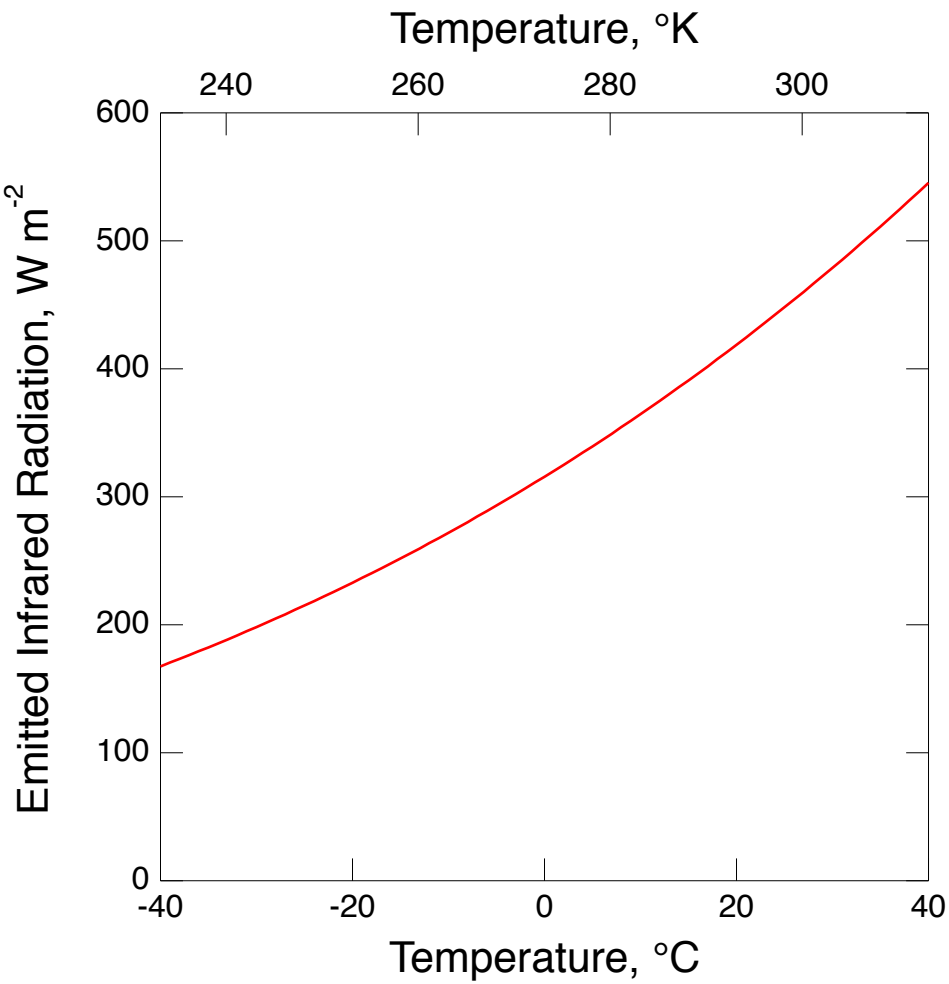
Emitted thermal radiative flux from a black body

$$F = \sigma T^4$$

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

T = Absolute temperature, K

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



Stefan-Boltzmann law calculates radiative flux (power density) emitted by a perfect radiator based on its absolute temperature.

HOW MUCH POWER DENSITY DO YOU EMIT?

Power density $J = \sigma T^4$

$\sigma = 5.67 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$

Temperature $T = 37^\circ\mathrm{C} = 310\ \mathrm{K}$

$310^2 = 1 \times 10^5$; $310^4 = 1 \times 10^{10}$

$J \approx 500\ \mathrm{W\ m^{-2}}$

STEFAN - BOLTZMANN RADIATION LAW

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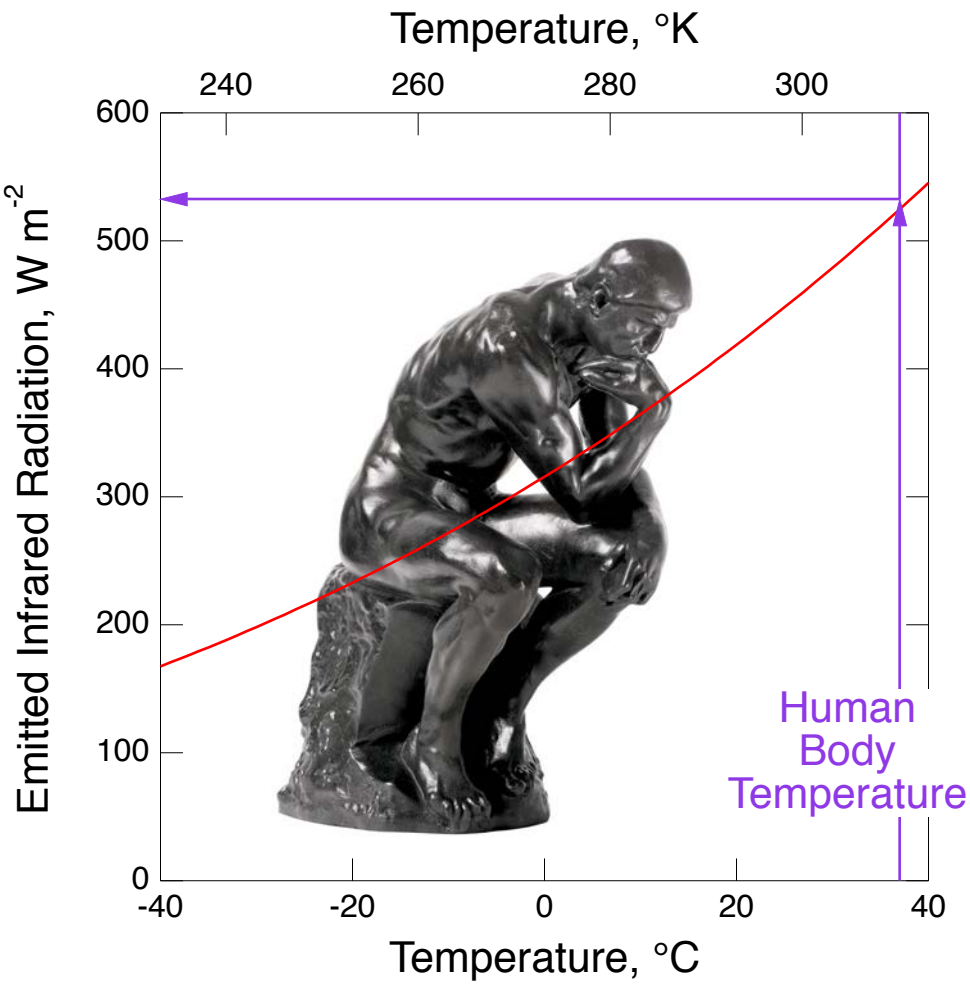


Stefan-Boltzmann law "converts" temperature to radiative flux.

A human being at 37 °C (310 K) emits about 500 W m^{-2}.

Consider a Spherical Cow

A Course in Environmental Problem Solving

JOHN HARTE

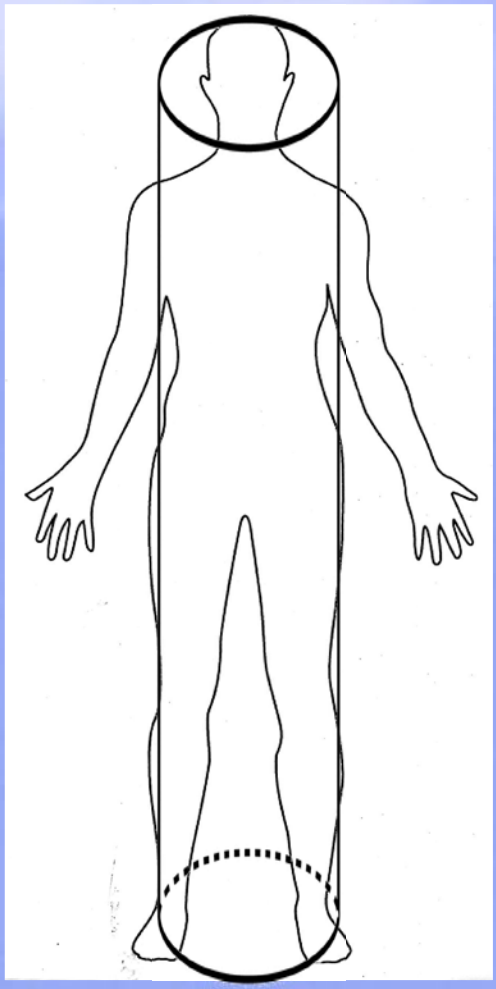
CONSIDER A CYLINDRICAL HUMAN

Area = Height × Circumference

Height = 2 m

Circumference = 1/2 m

Area = 1 m^2



HOW MUCH POWER DO YOU EMIT?

Emitted power =

Power density × Area

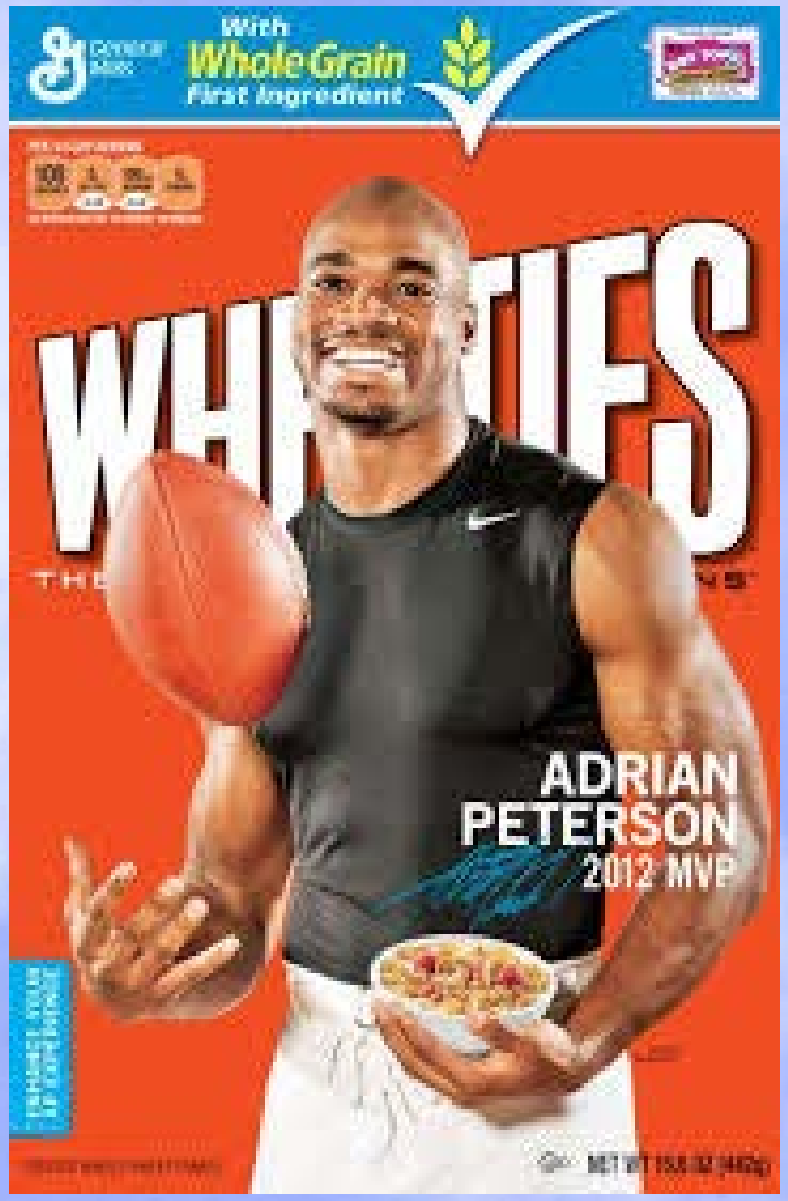
$$P = J\,A$$

Power density $J \approx 500\ \mathrm{W\ m^{-2}}$

Area $A \approx 1\ \mathrm{m^2}$

Power $P \approx 500\ \mathrm{W}$

WHERE DO YOU GET YOUR ENERGY?



HOW MUCH POWER DO YOU EAT?

Standard adult diet is 2000 "Calories" (actually kilocalories) per day.

1 calorie = 4.19 joules.

8×10^6 joules per day.

1 day = 24×3600 s = 8×10^4 s.

Standard adult diet is 100 watts.

RIDDLE

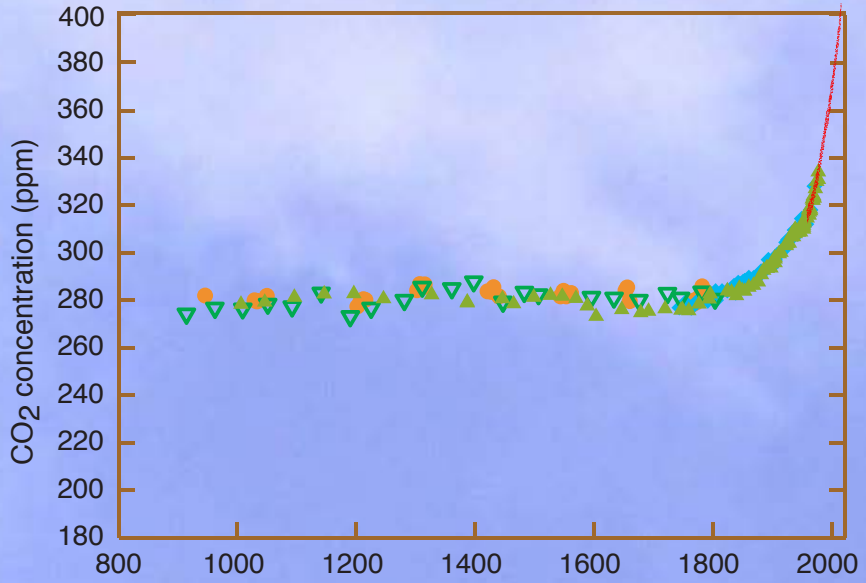
You eat 100 watts.

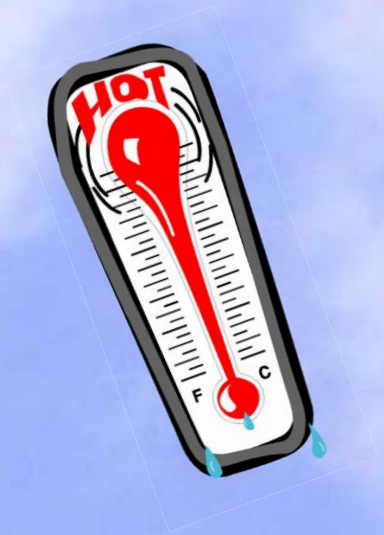
You emit 500 watts.

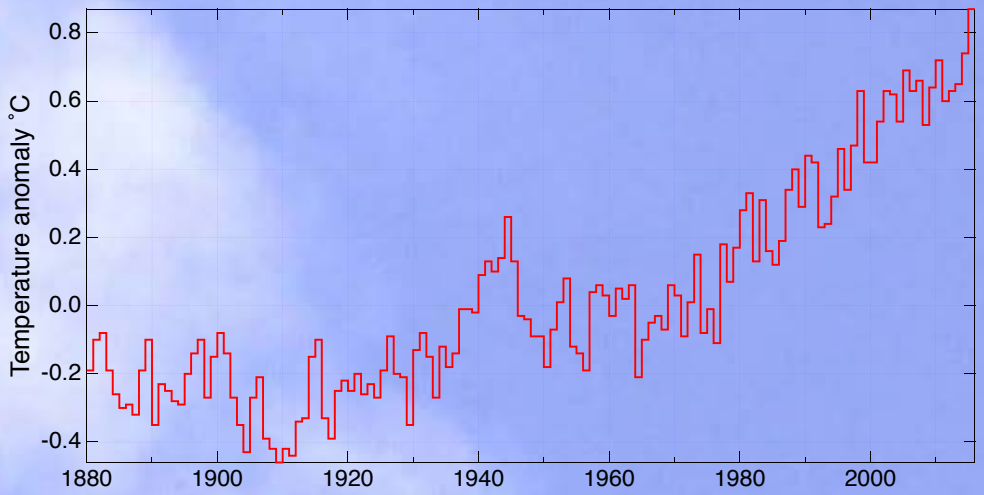
How can this be ? ? ?

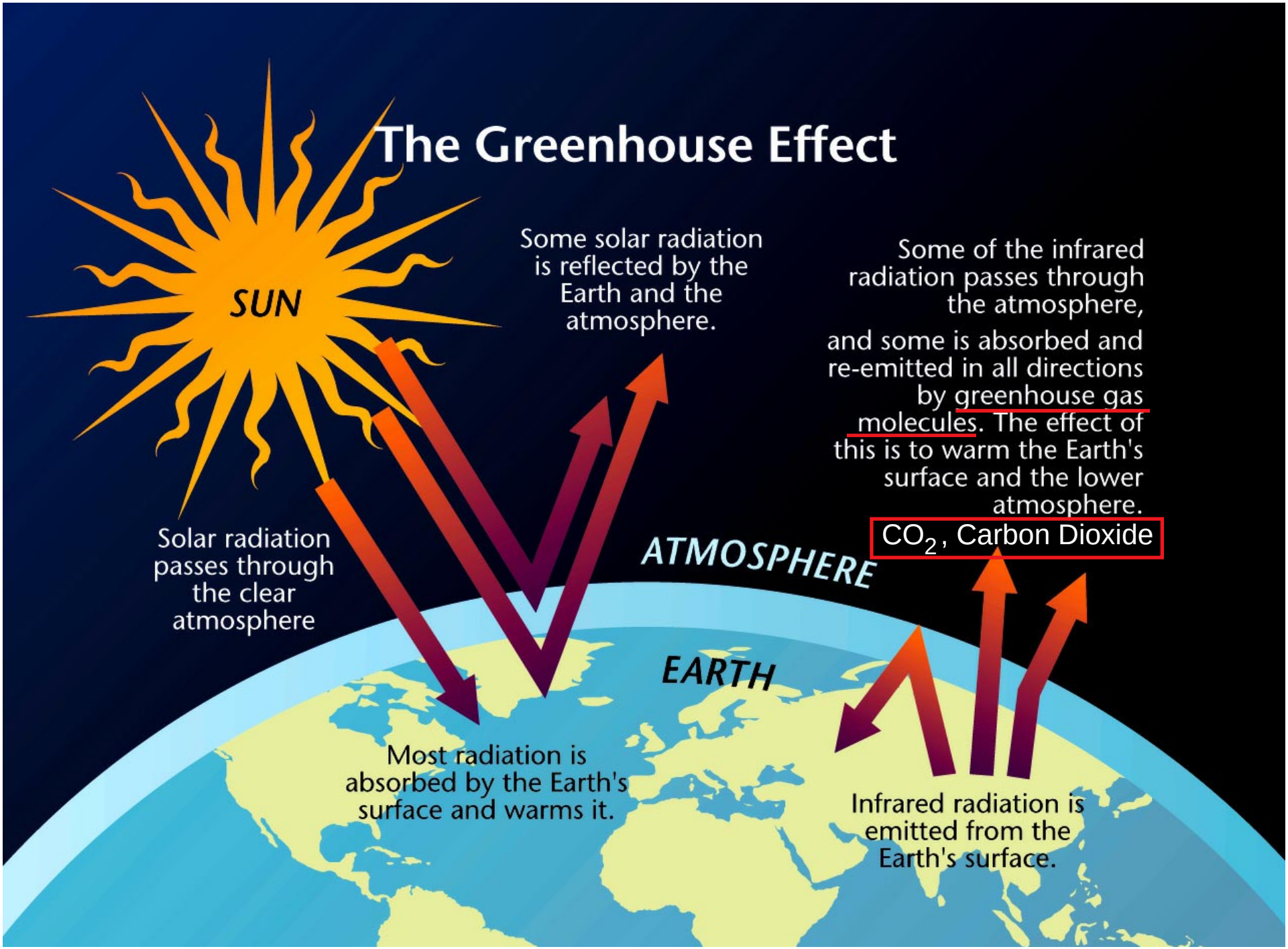
Explain

The Greenhouse Effect, Climate, and Climate Change








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.
CO_2, Carbon Dioxide
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.

STEFAN - BOLTZMANN RADIATION LAW

Emitted thermal radiative flux from a black body

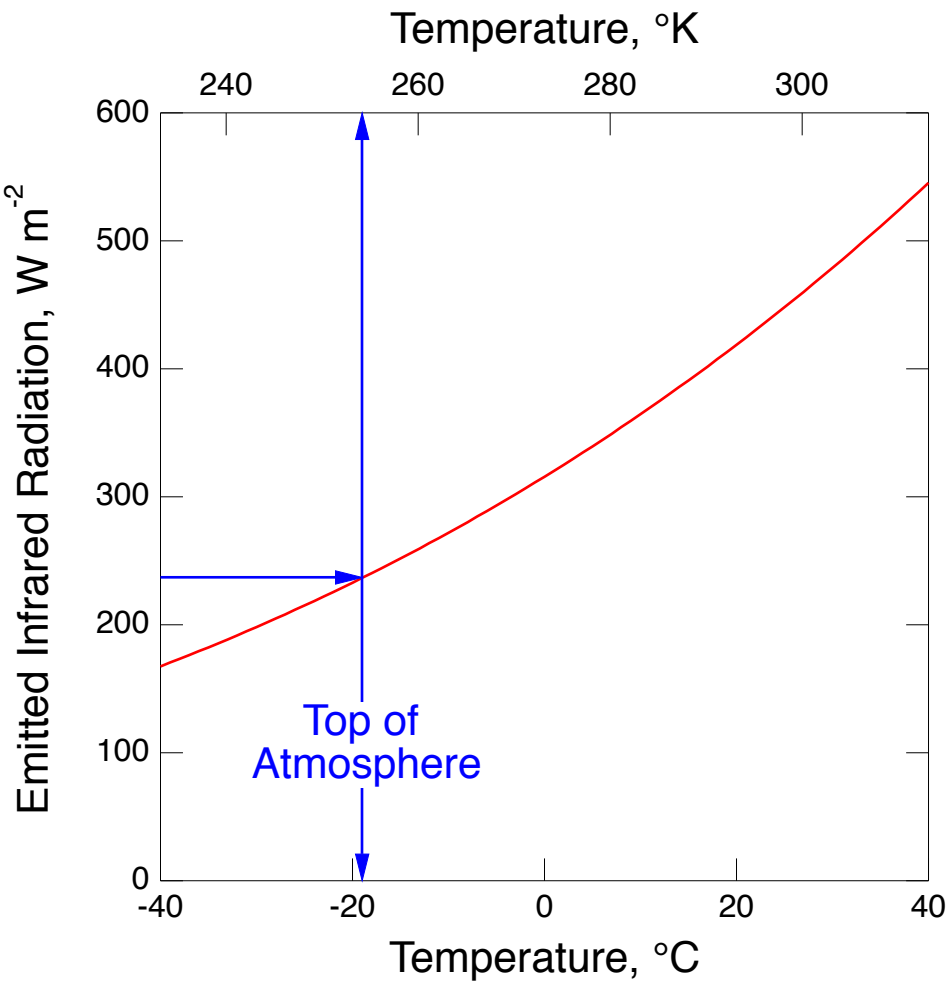
$$F = \sigma T^4$$

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

T = Absolute temperature, K

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

$$T = (J / \sigma)^{1/4}$$



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

Viewed from space Earth's temperature is 254 K (-19 °C).

STEFAN - BOLTZMANN RADIATION LAW

Emitted thermal radiative flux from a black body

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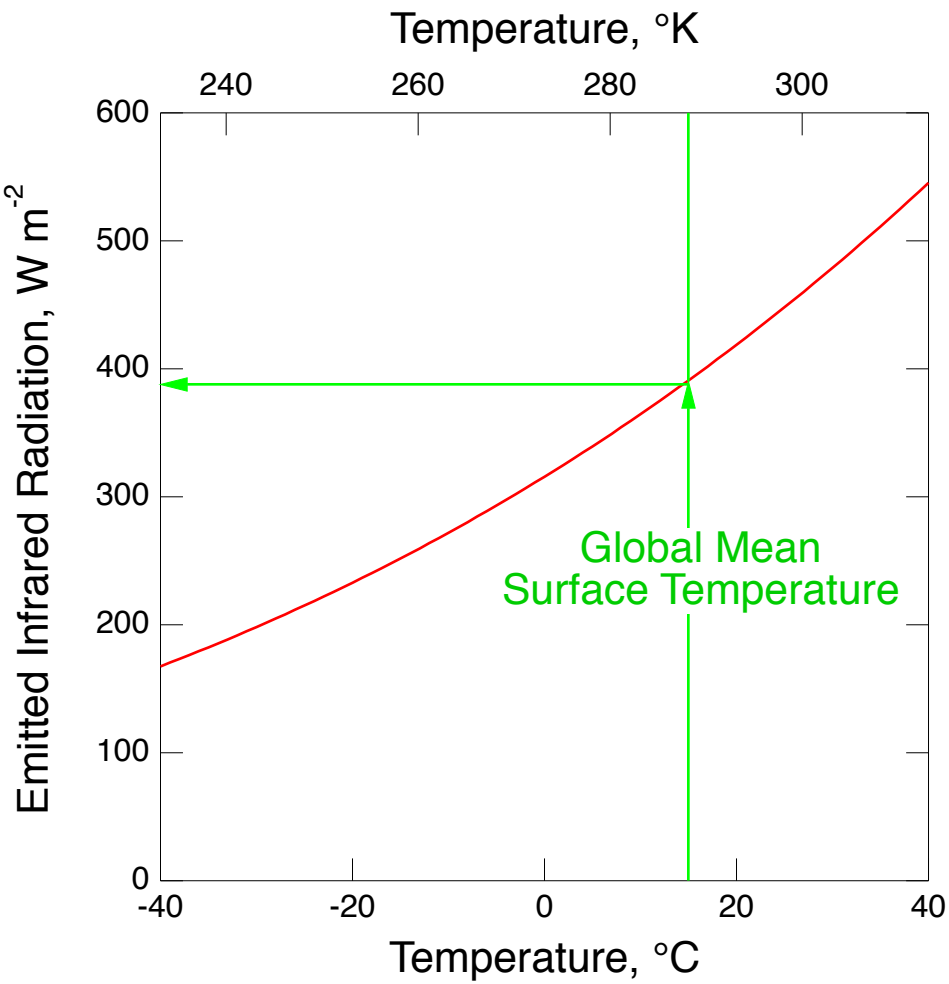
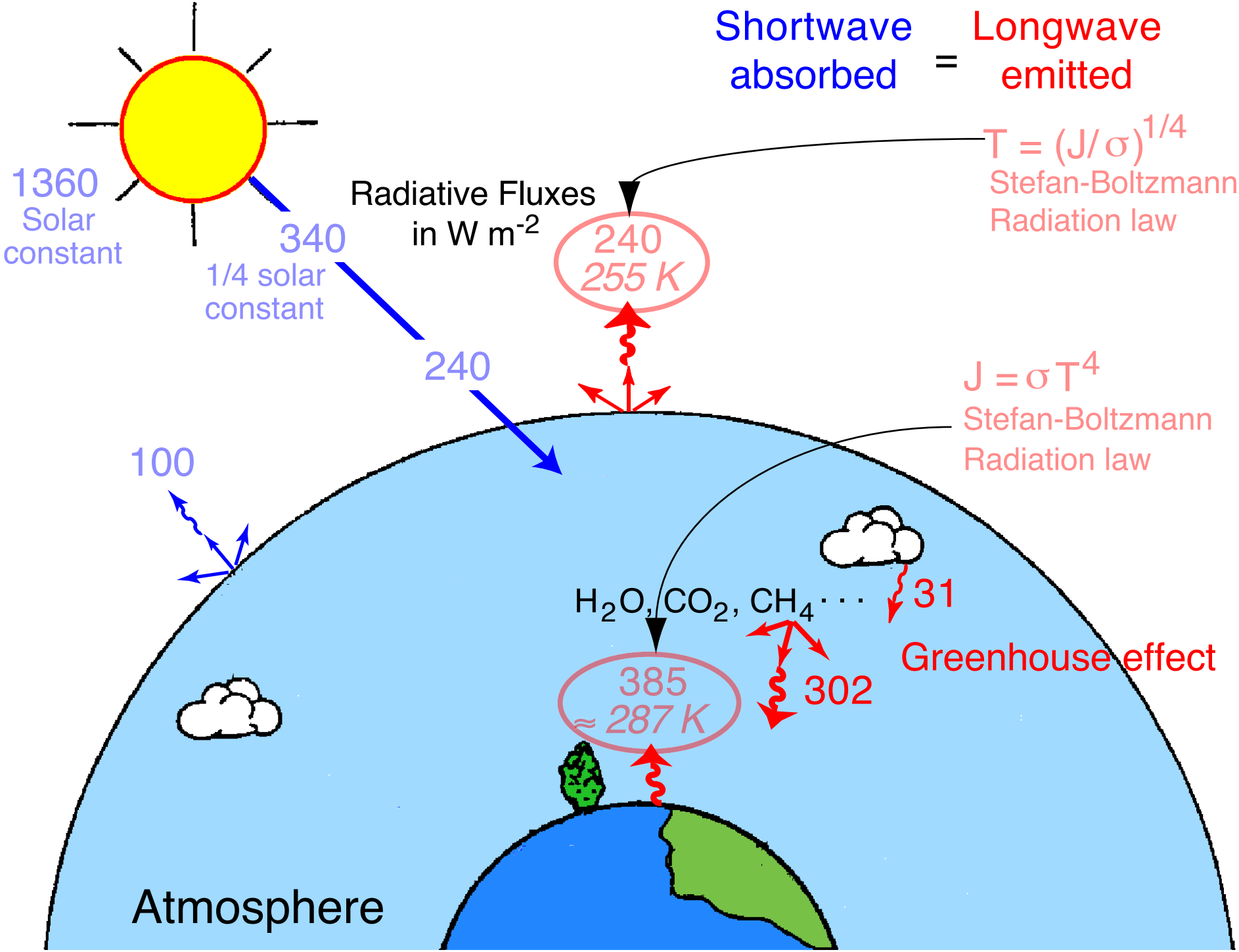


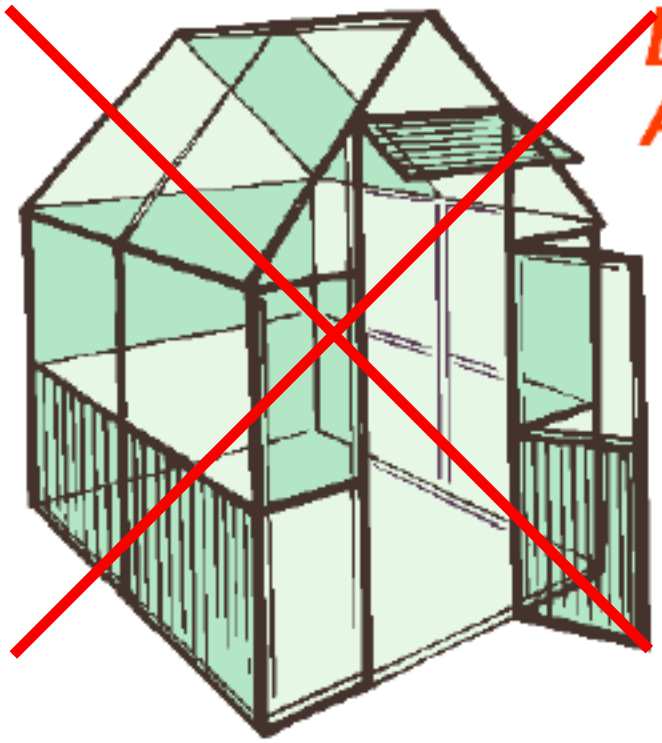
Stefan-Boltzmann law "converts" temperature to radiative flux.

Earth's surface at 15 °C (288 K) emits 390 W m^{-2}.

EARTH'S RADIATION BUDGET AND THE GREENHOUSE EFFECT



THE GREENHOUSE EFFECT



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.

Global average temperature 15°C or 59°F

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

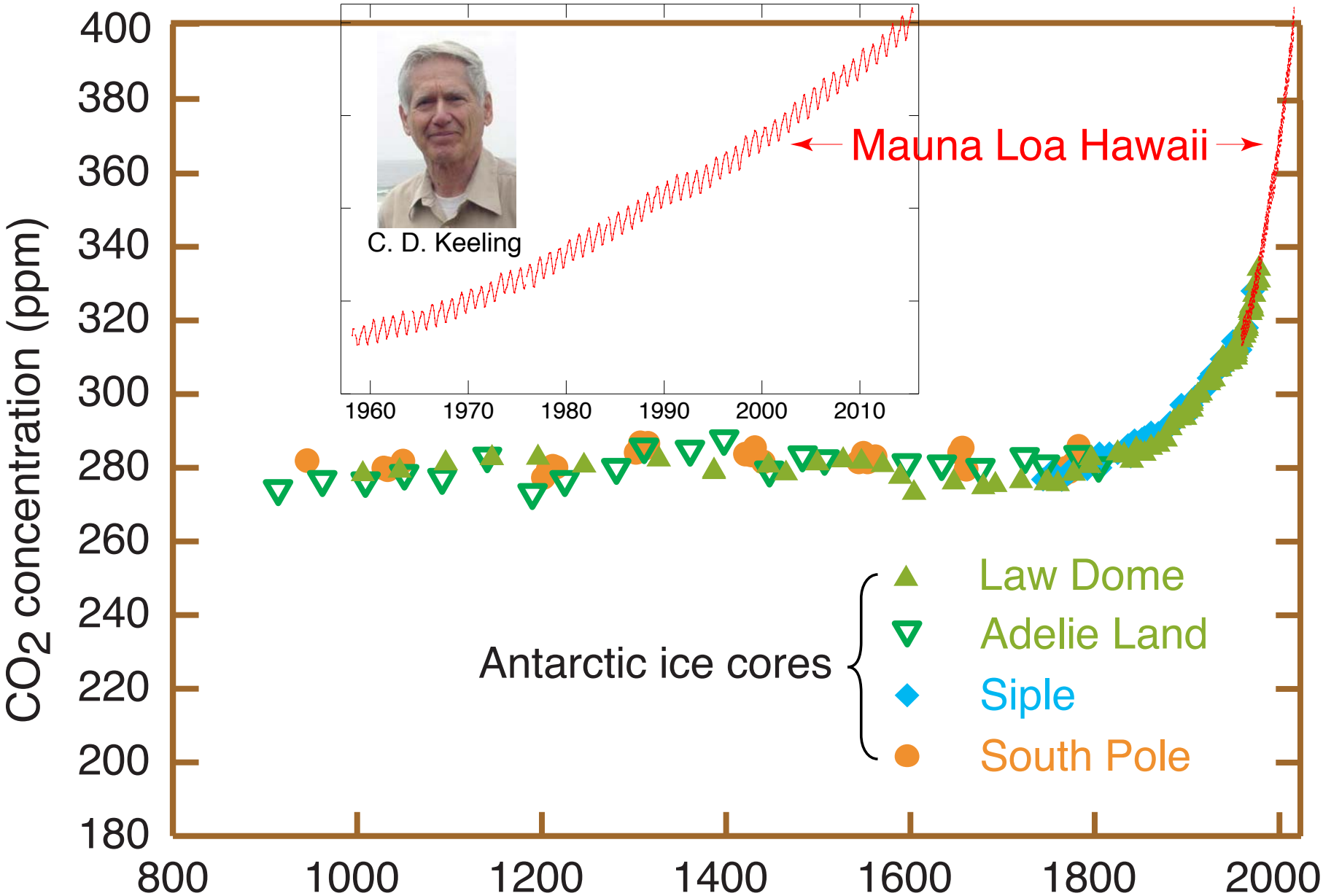
Global average temperature -19°C or -2 °F

GLACIERS ARE OUR TIME MACHINE

New York Times, July 2, 2012

Lonnie Thompson, Ohio State University glaciologist, studies Earth's climate history by the ice archive.

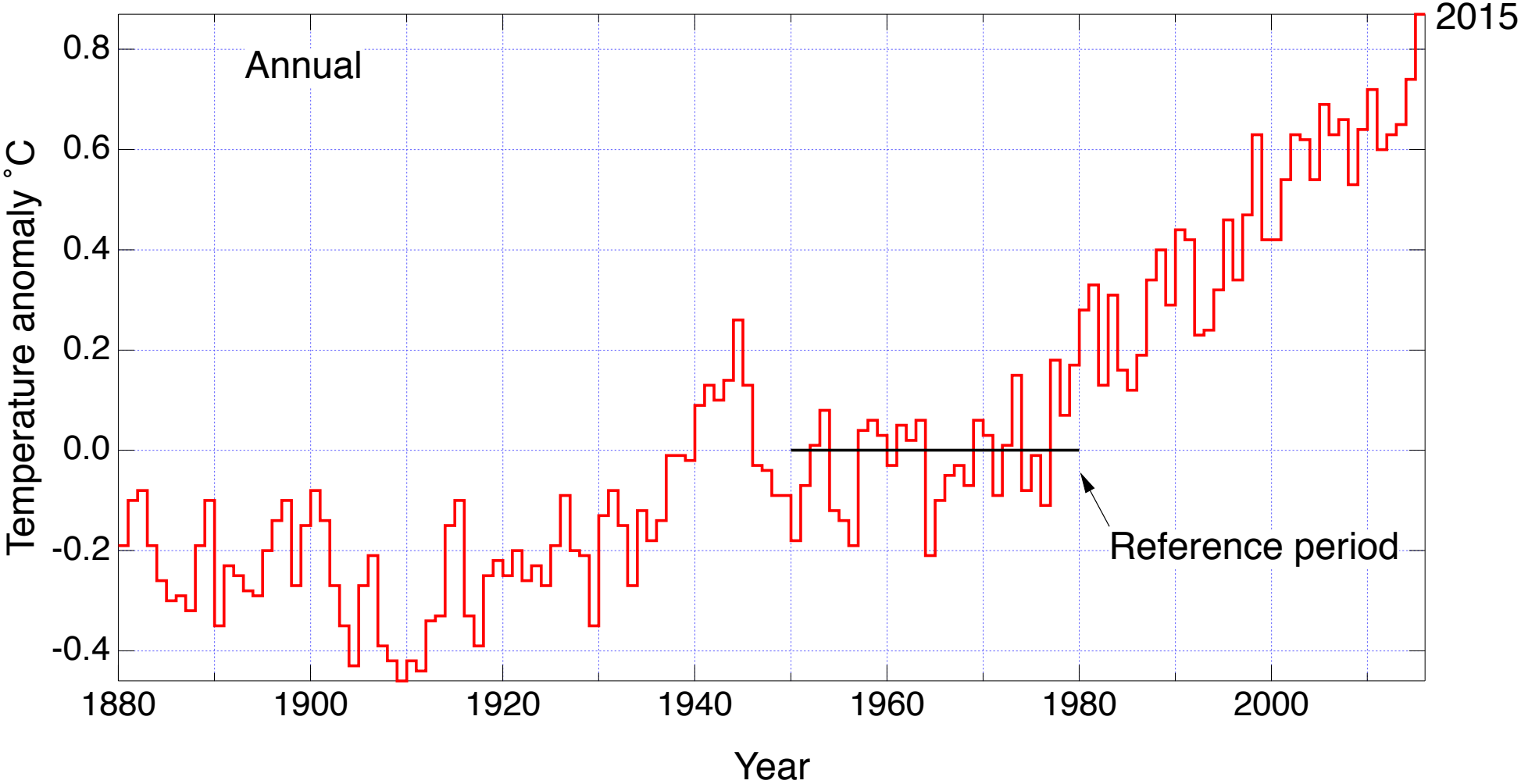
ATMOSPHERIC CARBON DIOXIDE IS INCREASING



Global carbon dioxide concentration over the last thousand years

Too much of a good thing?

GLOBAL TEMPERATURE CHANGE SINCE 1880



NASA, Goddard Institute for Space Studies

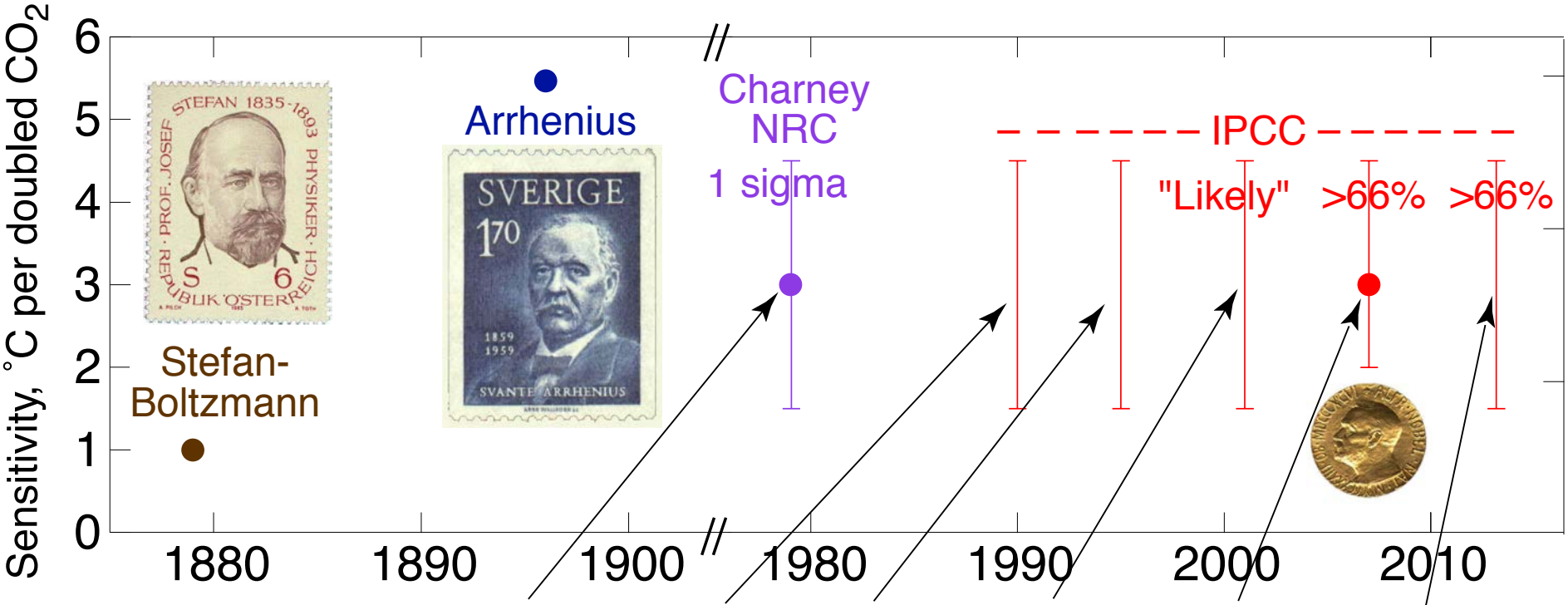
2015 was the hottest year on record.

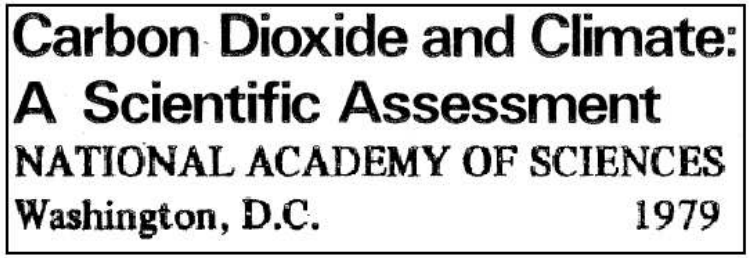
14 of the hottest 15 years have been since 2000.

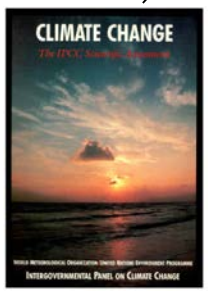
How much more will global temperature increase?

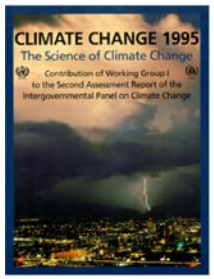
CLIMATE SENSITIVITY ESTIMATES THROUGH THE AGES

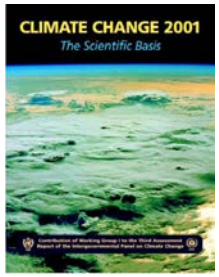
Estimates of central value and uncertainty range from major national and international assessments

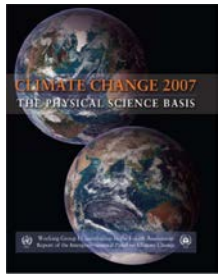










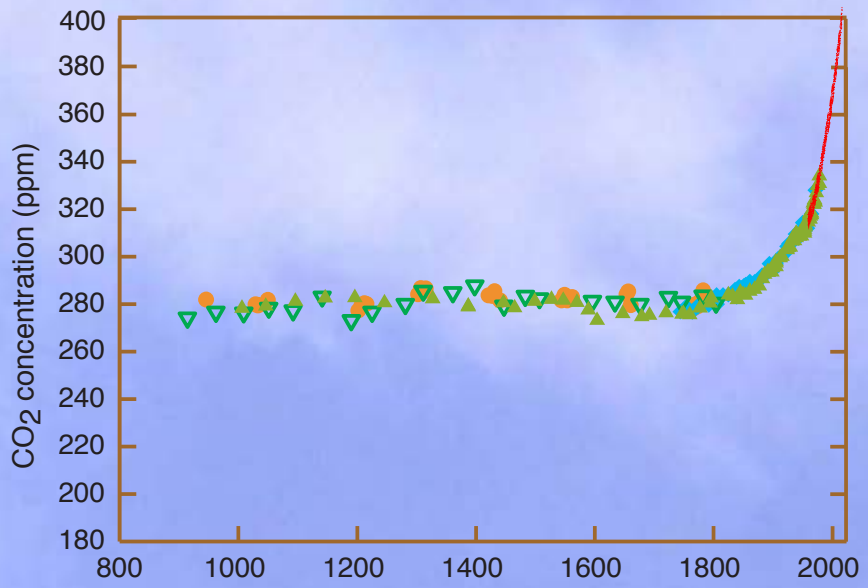


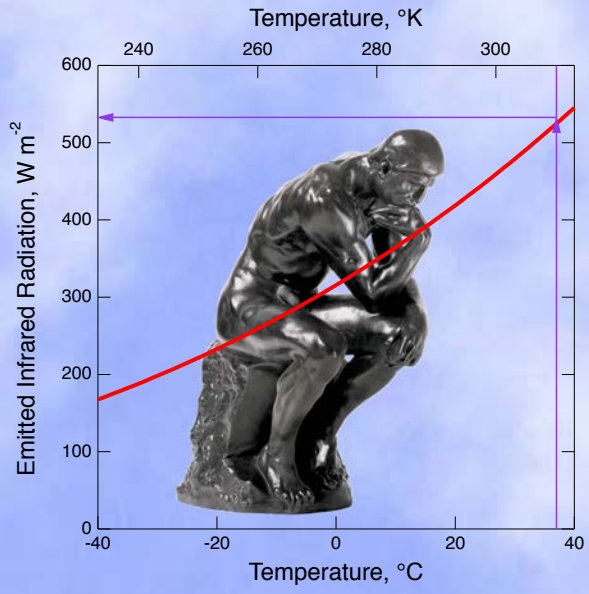
Despite extensive research, climate sensitivity remains ***highly uncertain***.

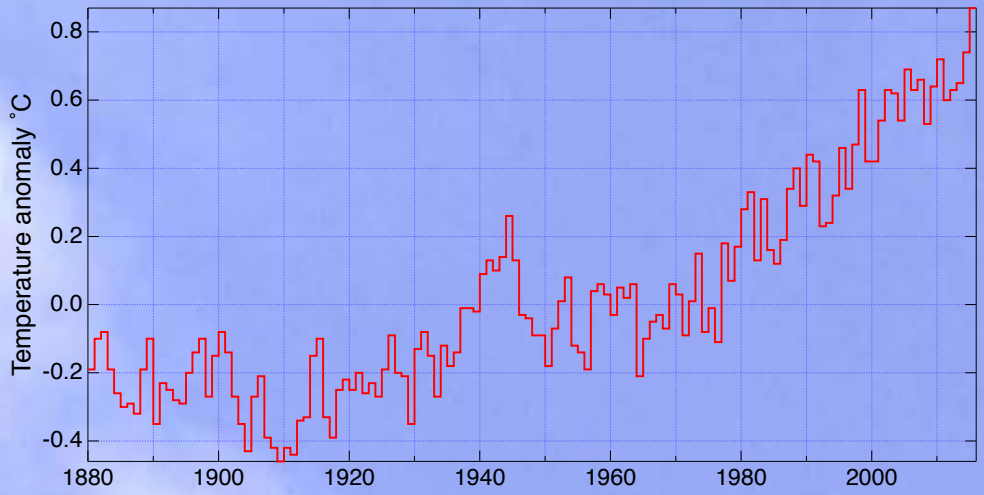
PARIS CLIMAT 2015

THANK YOU!

SUN
ATMOSPHERE
EARTH


CO_2 concentration (ppm)
400
380
360
340
320
300
280
260
240
220
200
180
800
1000
1200
1400
1600
1800
2000


Temperature, °K
240
260
280
300
Emitted Infrared Radiation, W m^{-2}
600
500
400
300
200
100
0
-40
-20
0
20
40
Temperature, °C


Temperature anomaly °C
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
1880
1900
1920
1940
1960
1980
2000