The COMET Program

Our Climate: A Global Challenge

Academy for Lifelong Learning

Denver, CO

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2. Greenhouse Effect

**Originally a "hothouse" effect. Translated to "greenhouse".
It's an inexact analogy!**

Discovery

How it works

Climate Modeling

The Greenhouse effect

140 °F = 60 °C

I had a window blown out of my car left at an airport parking lot.

Cloudless night

What happens? It gets cold. Cold desert night!

Earth cools by radiation! You all know it!

The "Greenhouse Effect"
(aka global warming)
is based on
straightforward physics

not computer models ...
not recent temperatures ...
not complicated!

Worship the sun!
It is the ultimate source of all our energy.

"Radiation budget" describes the energy flow in and out of the Earth's system; input, reflection and emission.

Clouds, atmospheric water vapor and aerosol particles play important roles in determining global climate through their absorption, reflection, and emission of solar and thermal energy.
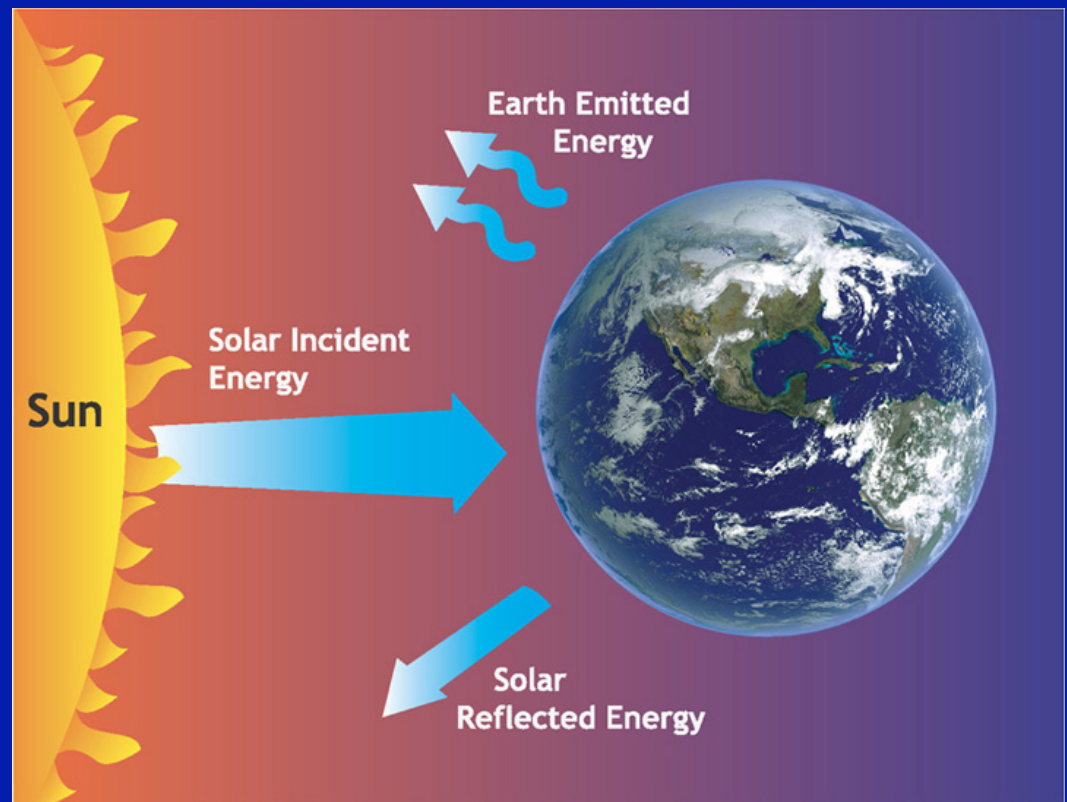
The Sun giveth plenty
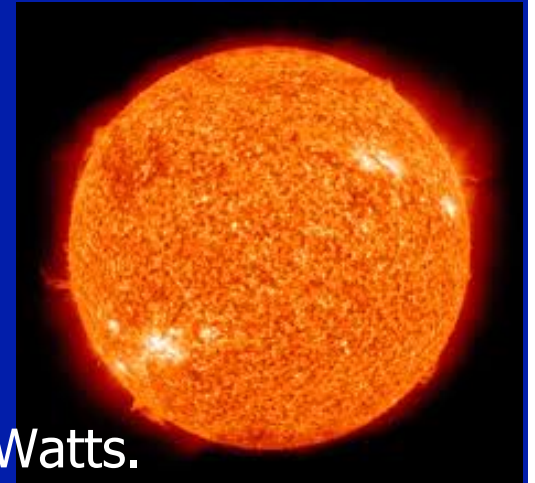
The incoming energy from the sun

amounts to 175 PetaWatts = 1.75 x 10^{17} Watts

=175,000,000 billion Watts = 175 quadrillion Watts.

About 122 PetaWatts is absorbed.

The biggest power plants are 1000 MegaWatts = 1 billion Watts.

We normally think of units of

1 KiloWatt (= 1 bar heater), or a 100 W light bulb.
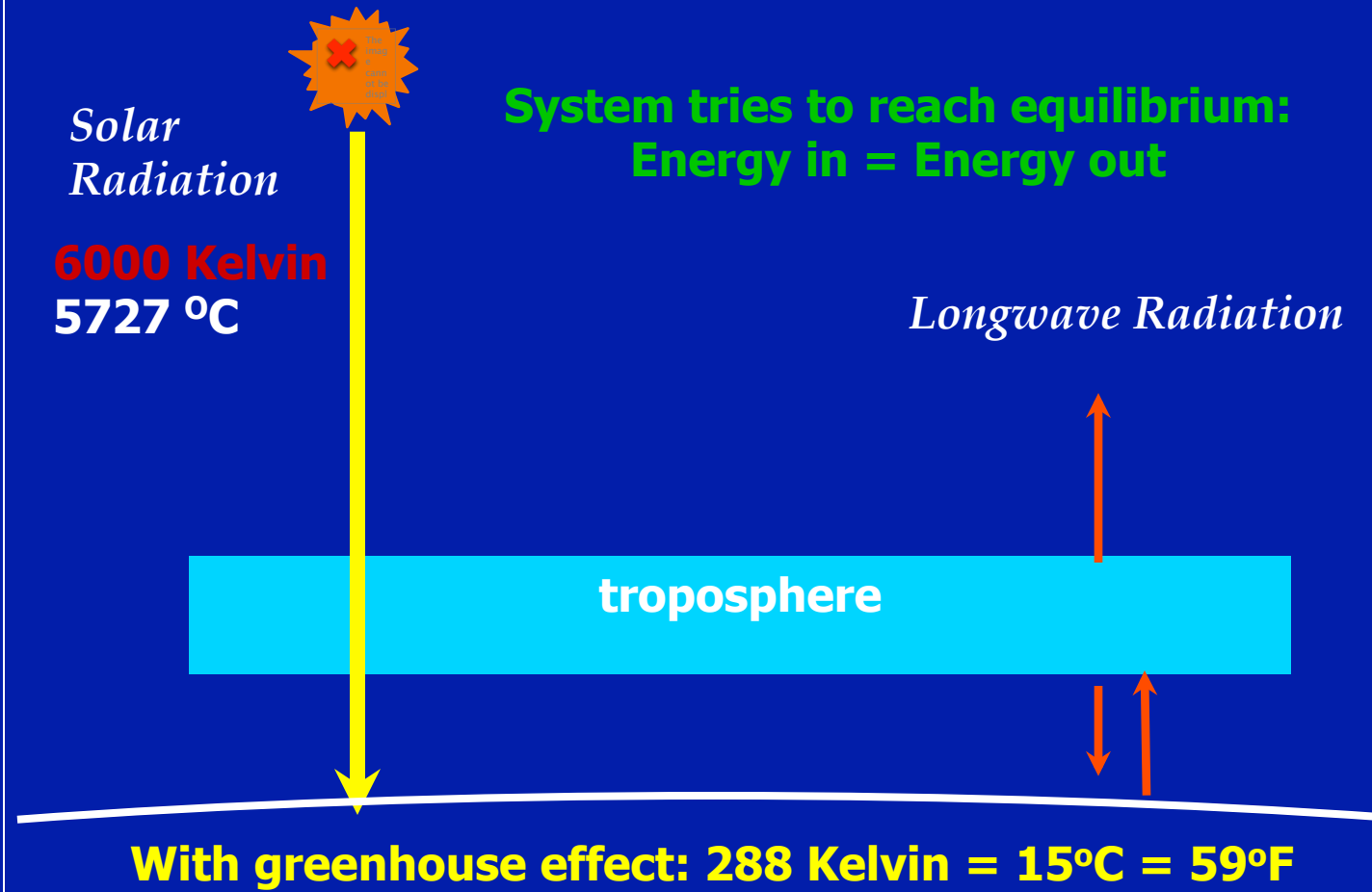
So the energy from the sun is 122 million of these power stations.

Direct human influences are <u>tiny</u> vs. nature.

The main way human activities can alter climate is by affecting its delicate balance on a time scale short compared to the reaction time of the system.
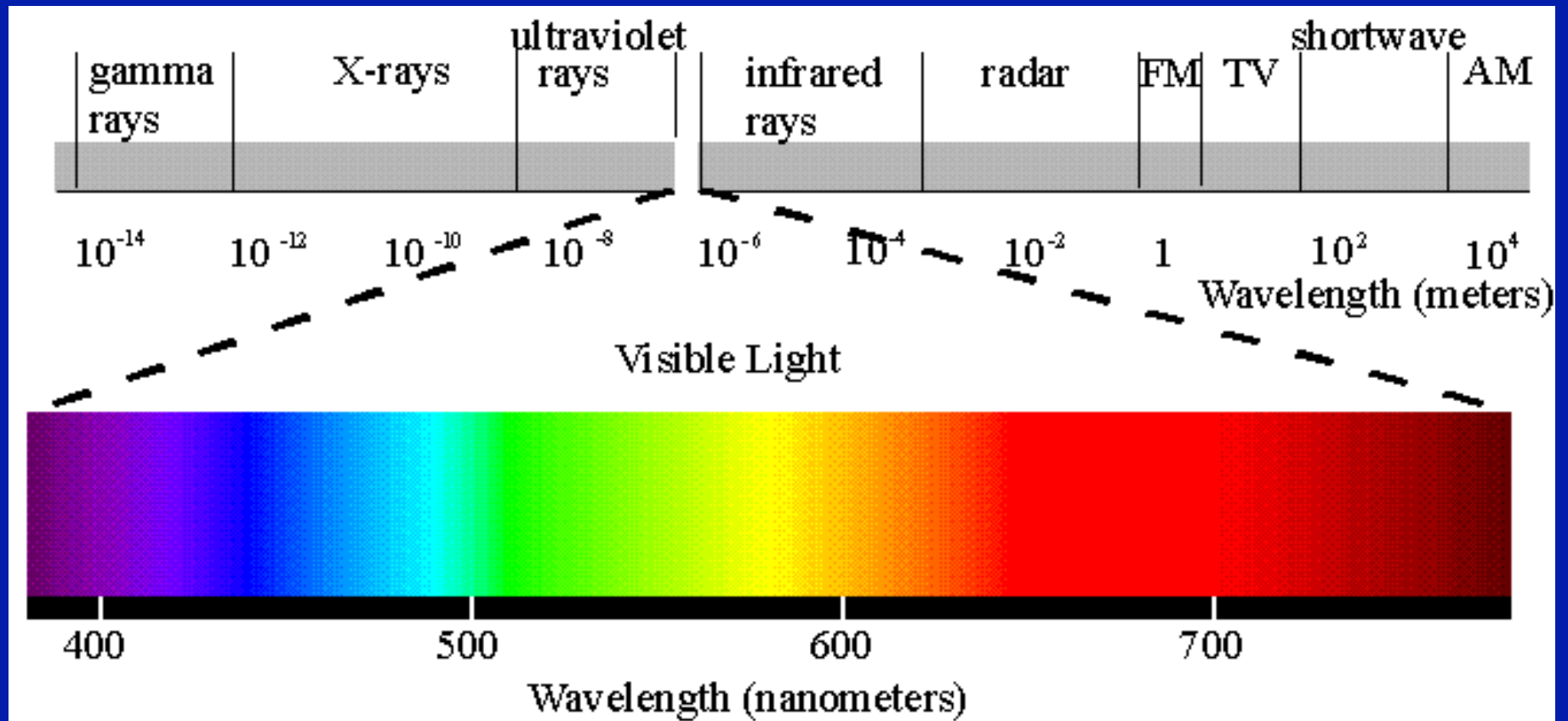
Earth is 33 °C (59°F) warmer that it would be without the current greenhouse effect. The effect is real.
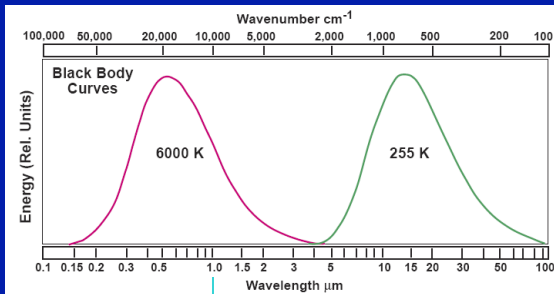
The Greenhouse Effect

Solar Radiation

6000 Kelvin
5727 °C

System tries to reach equilibrium:
Energy in = Energy out

Longwave Radiation

troposphere

With greenhouse effect: 288 Kelvin = 15°C = 59°F

Without greenhouse effect: 255 Kelvin = -18°C = 0°F

Electromagnetic Spectrum

Sun

Earth

Wavenumber cm⁻¹

Black Body Curves

Energy (Rel. Units)

6000 K

255 K

Wavelength μm

X-rays

ultraviolet rays

infrared rays

radar

FM

10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 1

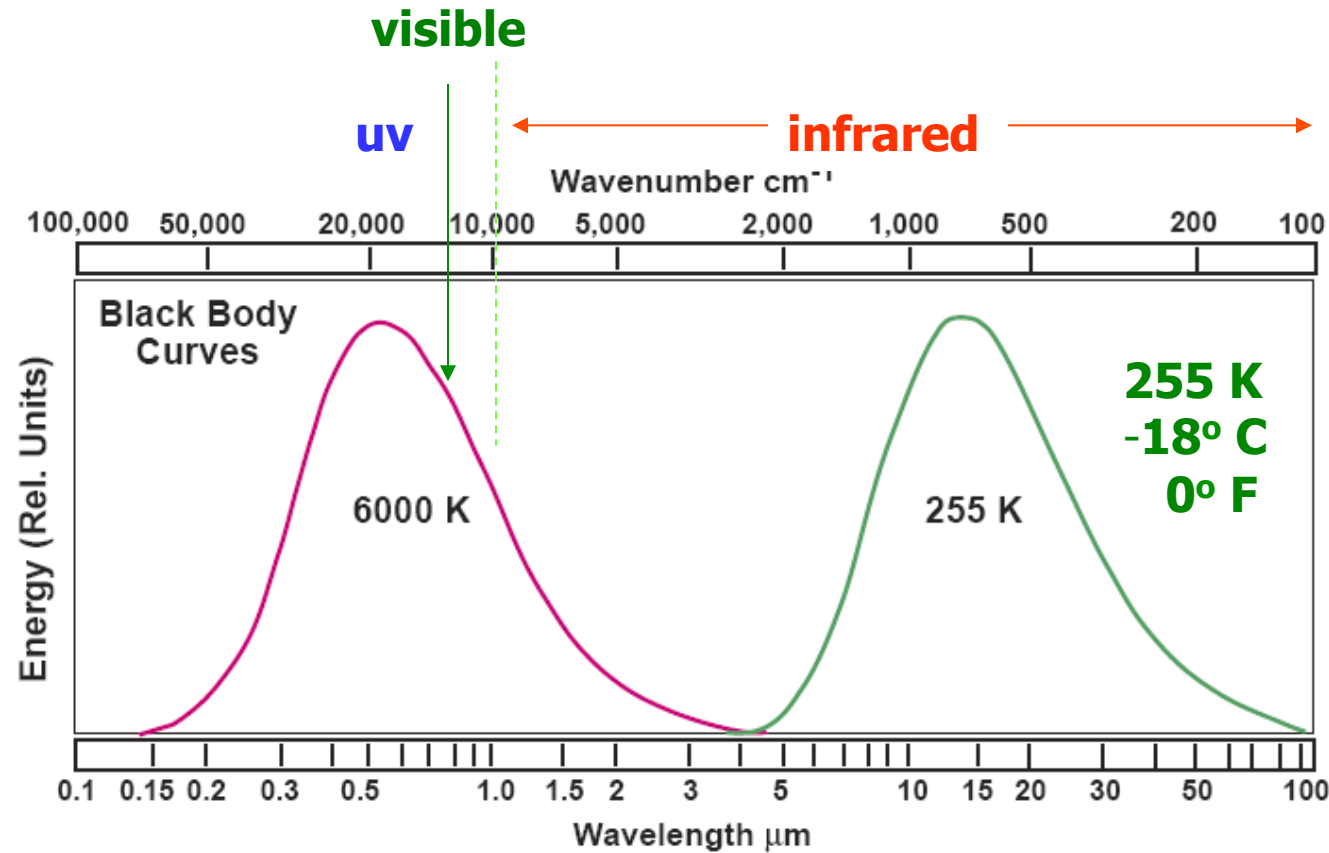Visible Light

Radiative equilibrium of the Earth

visible

uv   **infrared**

Wavenumber cm⁻¹

100,000 50,000   20,000   10,000   5,000   2,000   1,000   500   200   100

Black Body
Curves

255 K
-18º C
0º F

Energy (Rel. Units)

6000 K   255 K

0.1 0.15 0.2   0.3   0.5   1.0 1.5 2   3   5   10   15 20   30   50   100
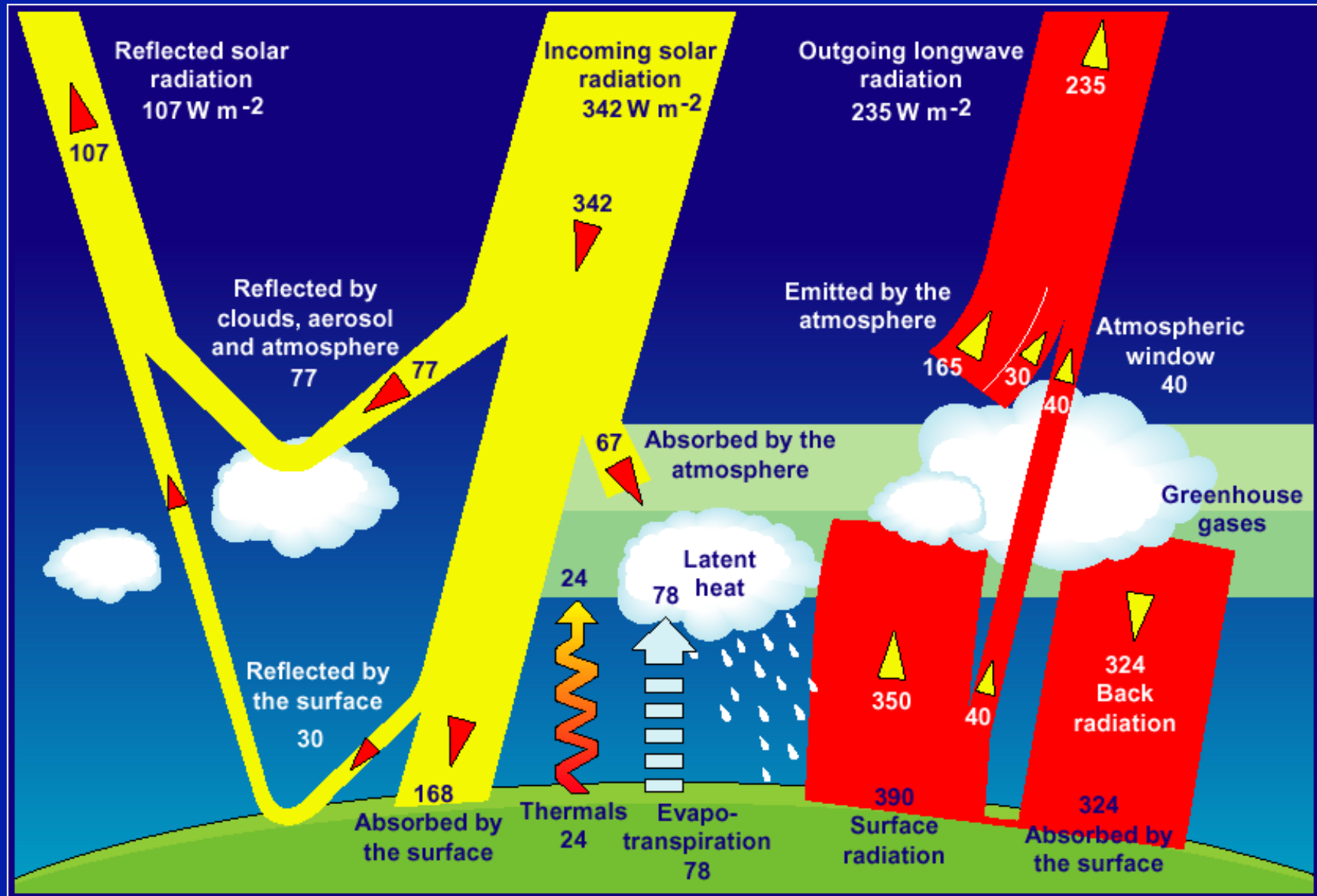
Wavelength μm

Figure 1. Blackbody Curves for 6,000 K and 255 K
(from Luther and Ellingson 1986)
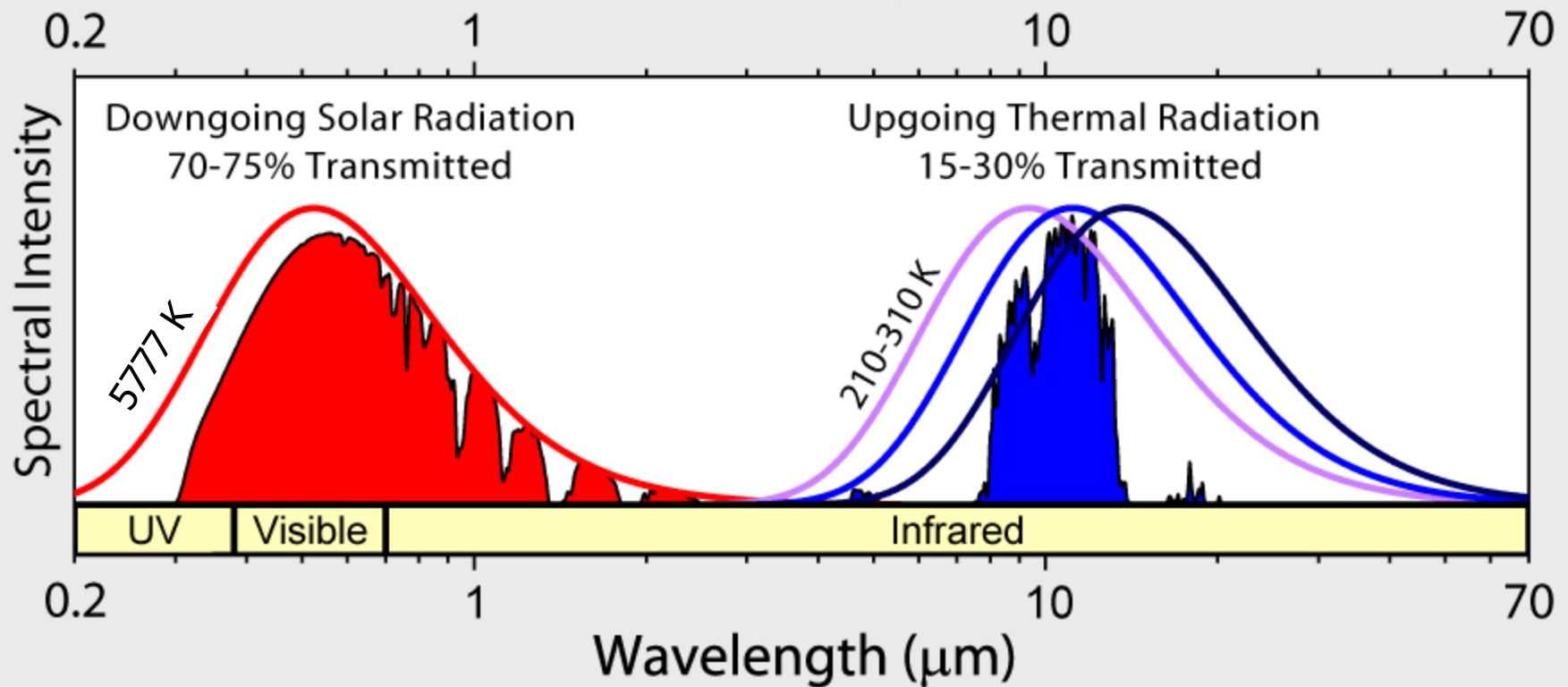
heating   **cooling**
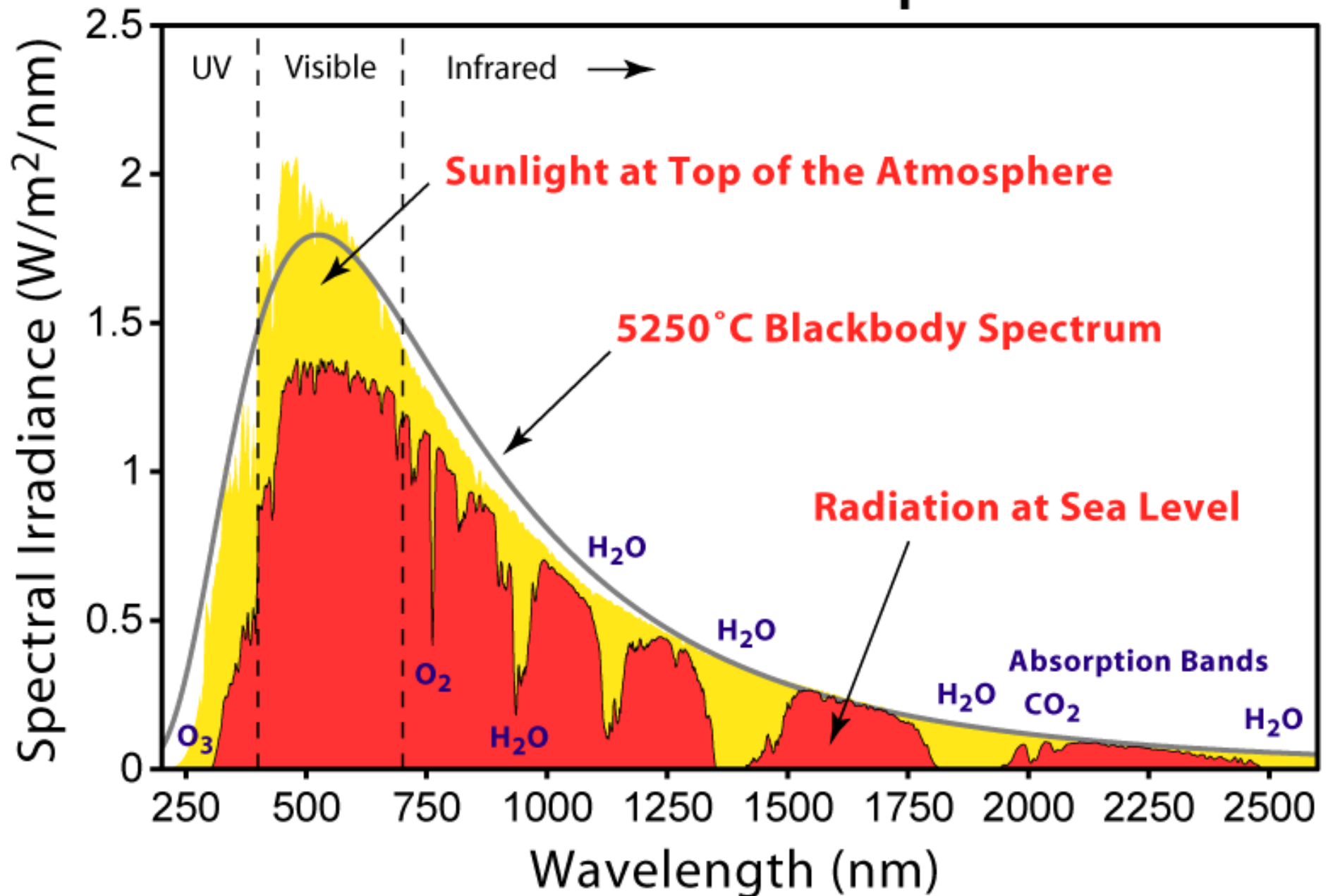
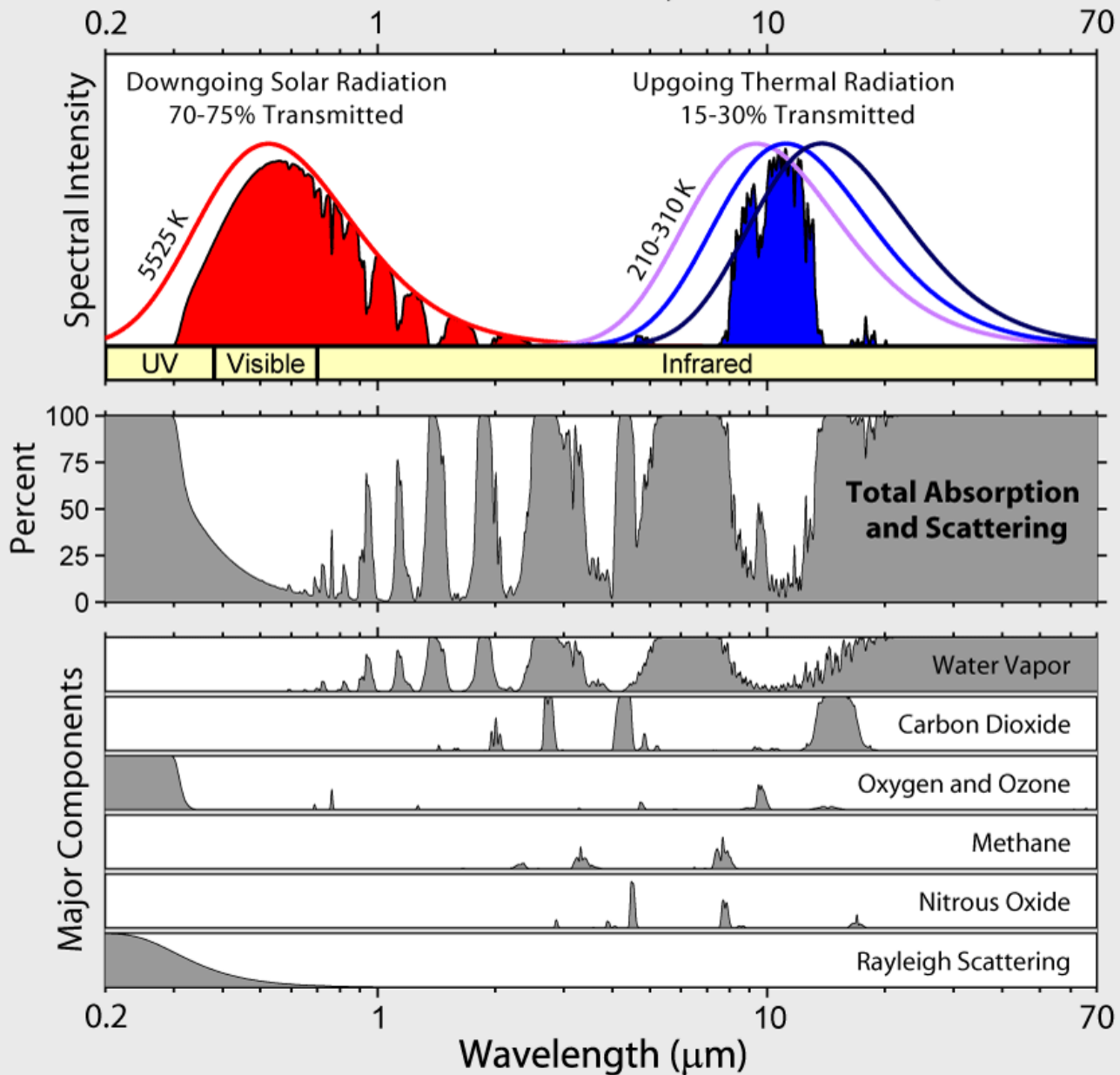# Global Radiation Budget

Radiation Transmitted by the Atmosphere

red λs come in   blue λs go out

Solar Radiation Spectrum

UV | Visible | Infrared →

Sunlight at Top of the Atmosphere

5250°C Blackbody Spectrum

Radiation at Sea Level

O_3

O_2

H_2O

H_2O

H_2O

H_2O

Absorption Bands
CO_2

H_2O

Spectral Irradiance ($W/m^2/nm$)

2.5
2
1.5
1
0.5
0

Wavelength (nm)

250 500 750 1000 1250 1500 1750 2000 2250 2500
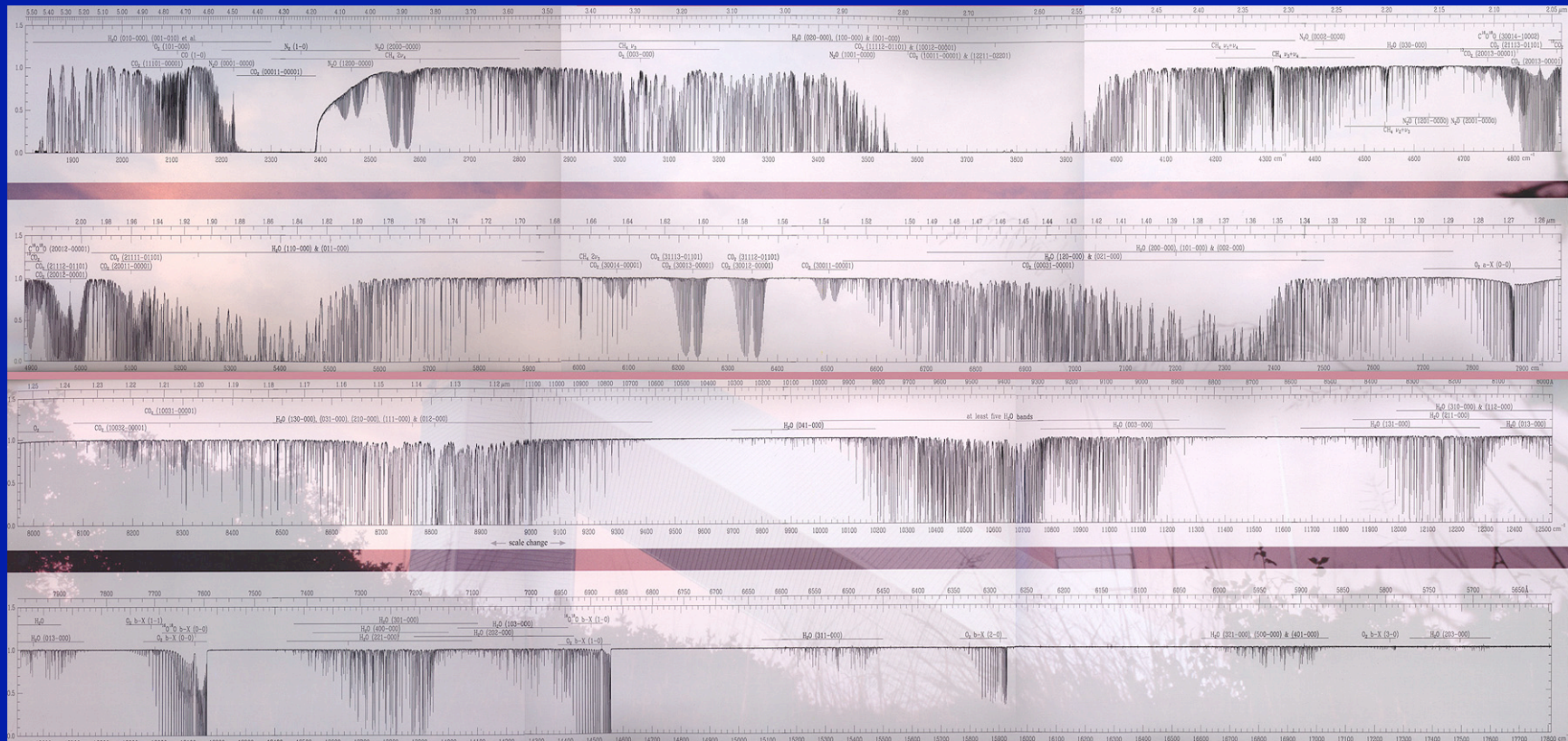
Radiation Transmitted by the Atmosphere

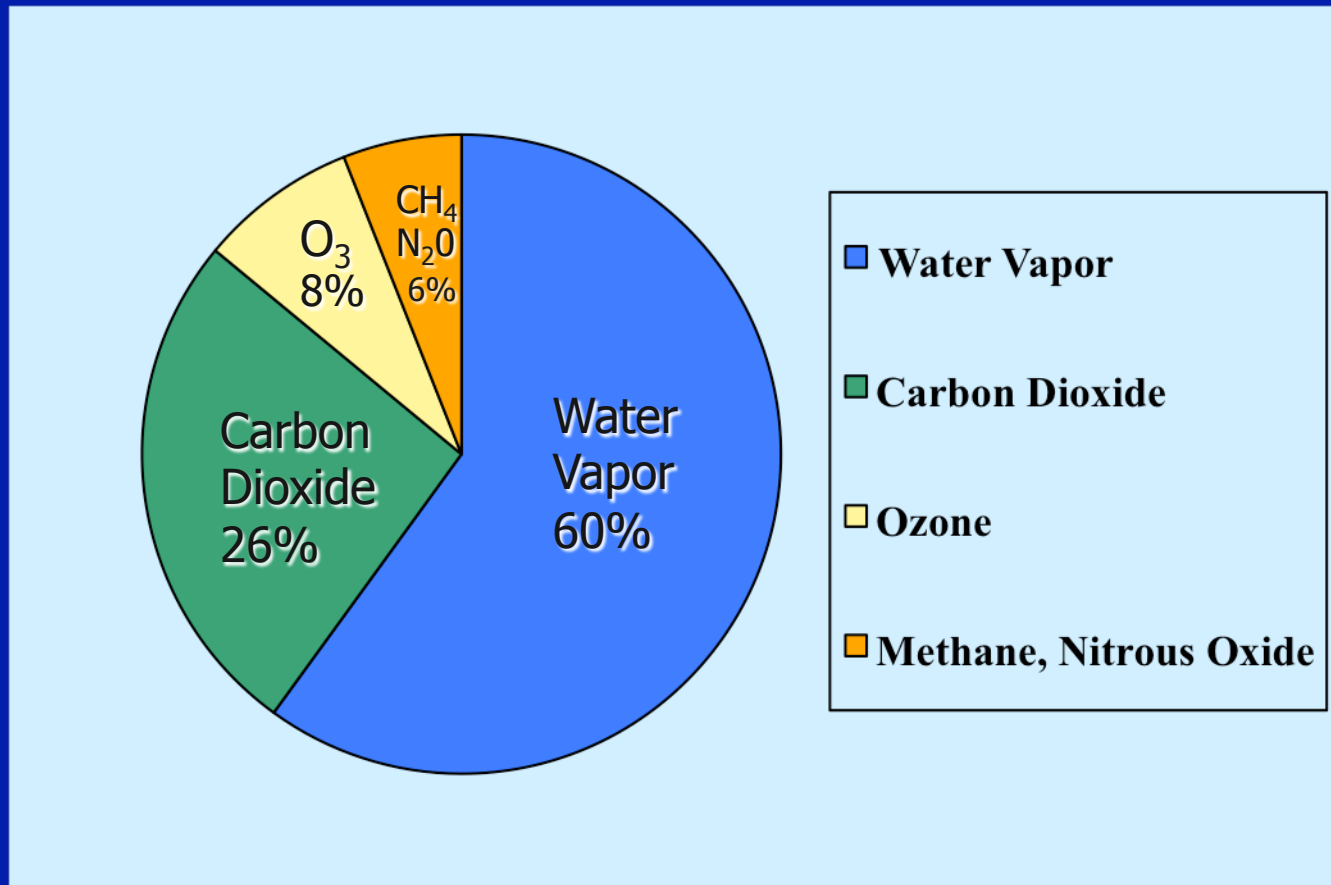# Atmospheric Absorption Bands
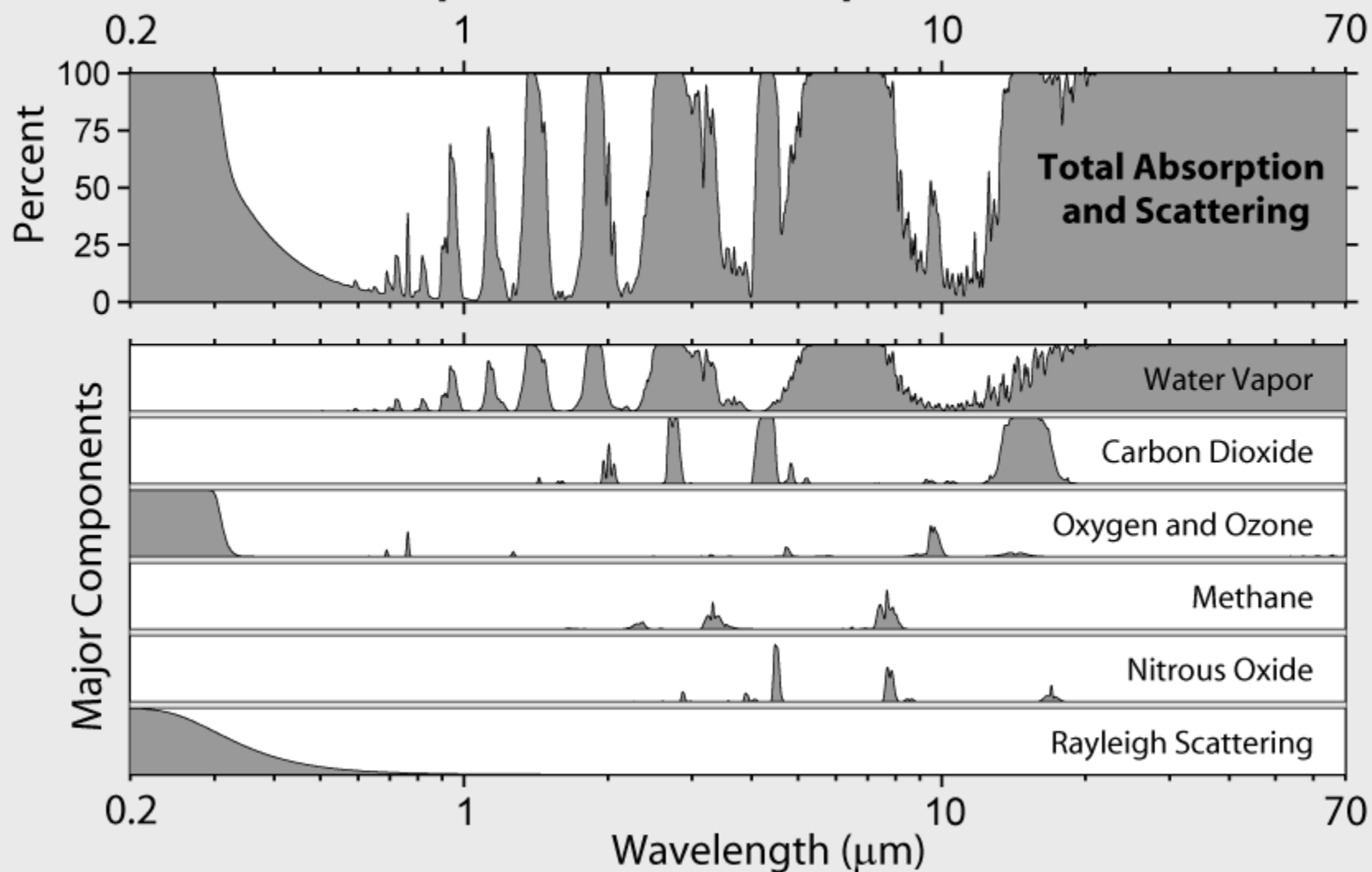
1800 cm⁻¹

17800 cm⁻¹

Atmospheric Absorption
0.5 to 5.5 micron spectrum

Higher resolution shows more detail!

The Natural Greenhouse Effect: clear sky

Clouds and water vapor also have a greenhouse effect
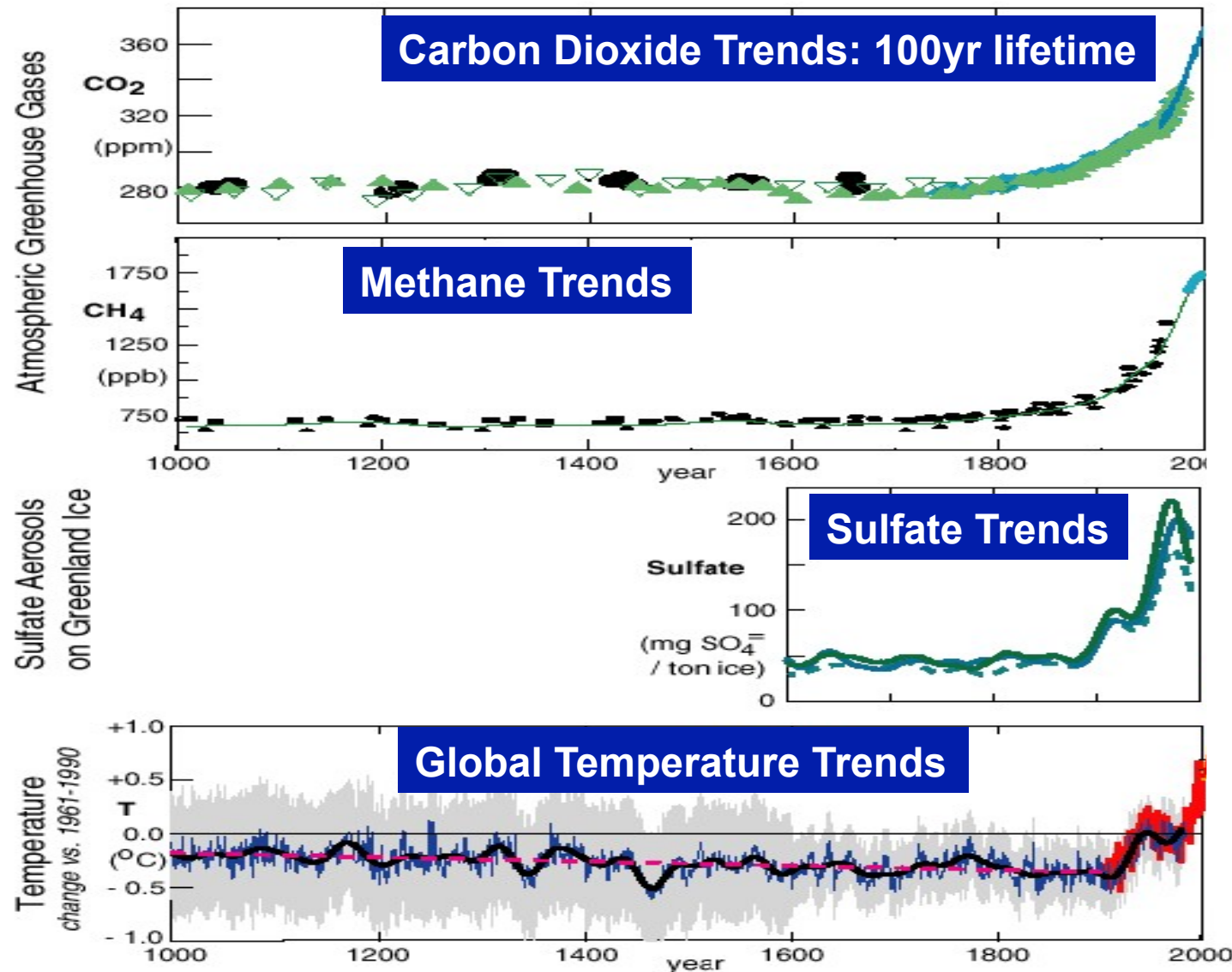
Kiehl and Trenberth 1997

Water is a greenhouse gas

- Water stays in atmosphere only a few days.
- When CO_2 goes up, atmosphere gets hotter and holds more water. The water vapor does not cause the rise in T, but it amplifies the effect of the CO_2.
- Water in atmosphere is least abundant and most variable in cold dry polar and high altitude climates.

CO$_2$ Absorbs and Emits IR (Heat)

- Because of its molecular structure!
- Not because capitalism is evil
- Not to punish greedy rich people
- It's just bad luck!
- More complex molecules are worse
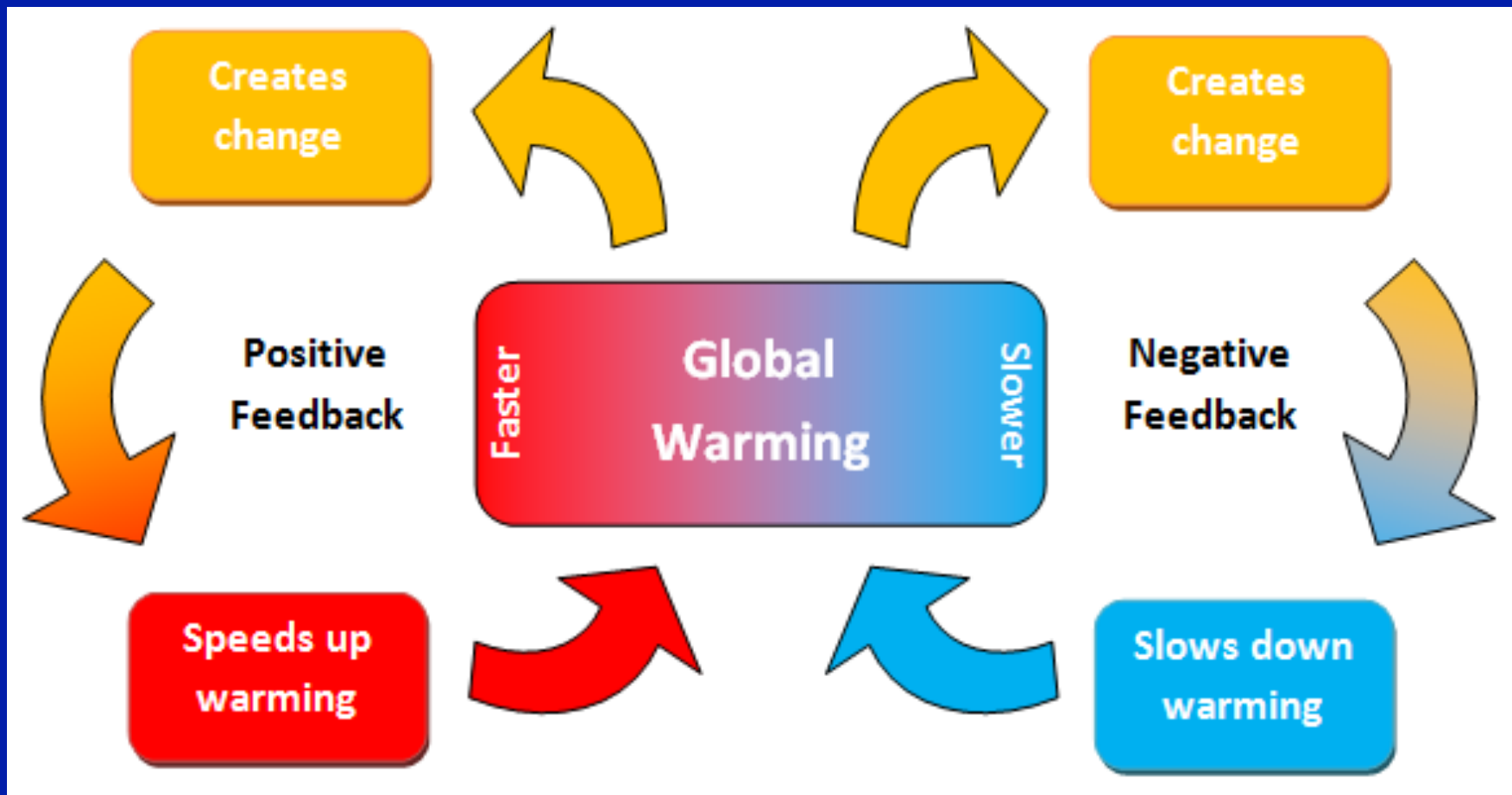 - CH$_4$
  - Chlorofluorocarbons

Human Influence on Climate

Carbon Dioxide Trends: 100yr lifetime

Methane Trends

Sulfate Trends

Global Temperature Trends

$\Delta T = 1\ ^oC$

3% increase in greenhouse temperature

Feedbacks

Vicious circle   **Virtuous circle**

Creates change

Creates change

Faster — Global Warming — Slower

Positive Feedback

Negative Feedback

Speeds up warming

Slows down warming

Climate is a complex system with lots of feedbacks.

Positive Feedback is most serious in the Arctic.

Arctic Monitoring and Assessment Programme
AMAP Assessment Report: Arctic Pollution Issues, Figure 11·1

Sea ice melts and shrinks

Temp ↗
CO_2 ↗

Add CO_2
Temp ↗

Temp ↗
CO_2 ↗

Water absorbs lots more solar radiation than ice.

Sea ice melts and shrinks

AMAP

CO$_2$ and other Feedbacks

Warming

Warmer ocean => increase in CO$_2$ release because saturation of CO$_2$ in water decreases with temperature. CO$_2$ increases broaden the band => enhanced greenhouse effect & warmer Earth (amplified by H$_2$O).

Increasing smoke, soot, SO$_2$ decreases absorption of solar energy.

Increased dust and soot on snow increases melting => heating.

Radiative forcing of climate between 1750 and 2005
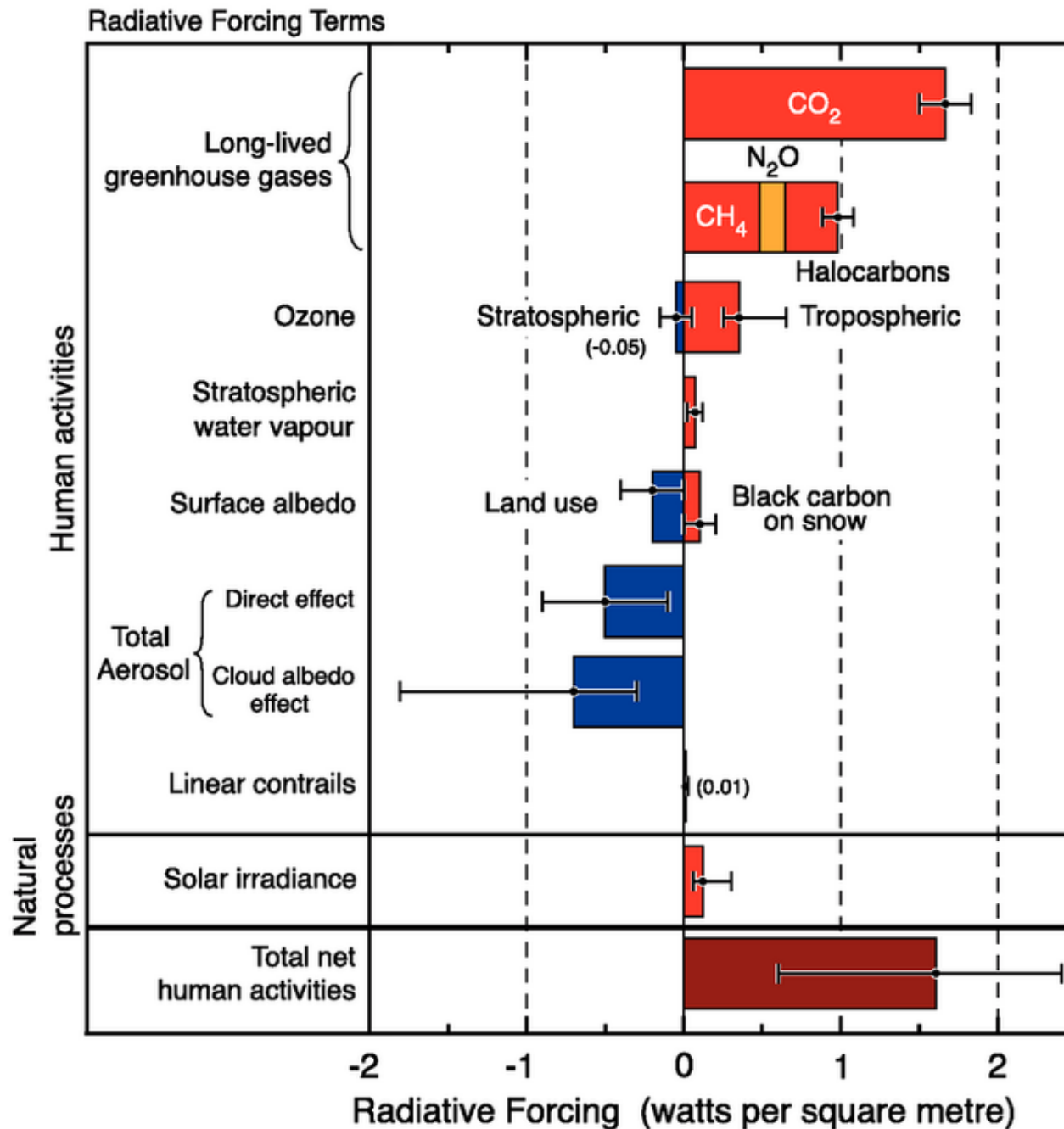
What is the relative contribution of human-induced and natural variations?

Another way is to compare the driving forces.

10:1 CO_2:solar

10 net human/1 solar with large uncertainty

What does sigma mean?
High 50%; Low 50%

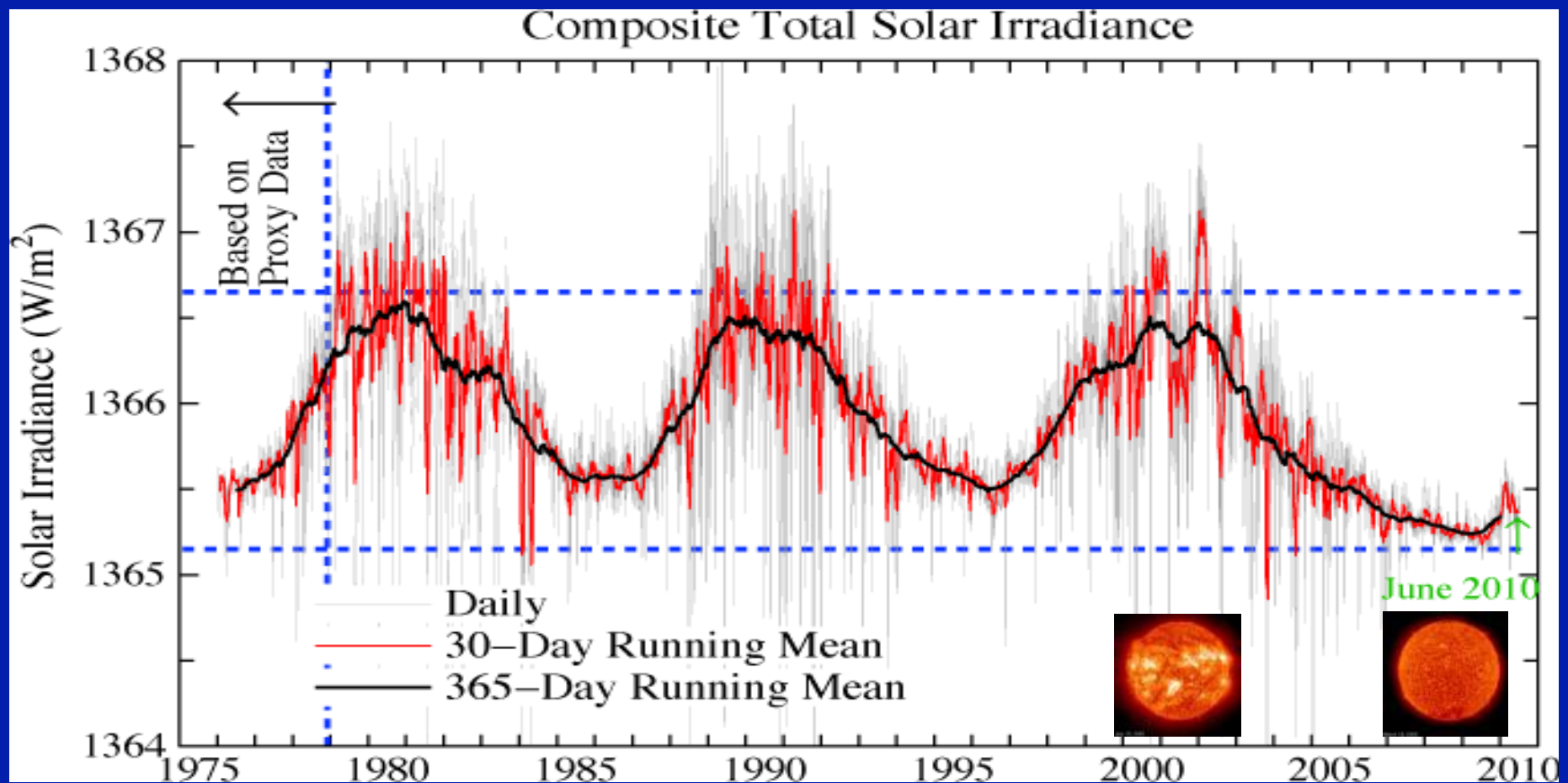- Probability of being wrong on the <u>low</u> side

1 sigma	15.87%
2 sigma	2.27%
3 sigma	0.135%
4 sigma	0.00317%
5 sigma	0.000029% (scientific "proof")
6 sigma	0.000000099%
7 sigma	0.000000000129%

Errors added in quadrature

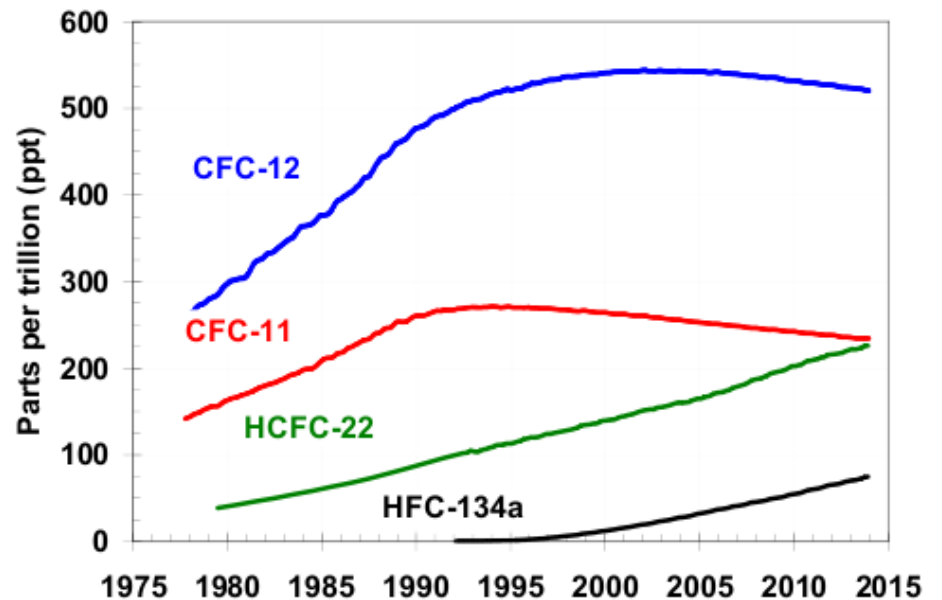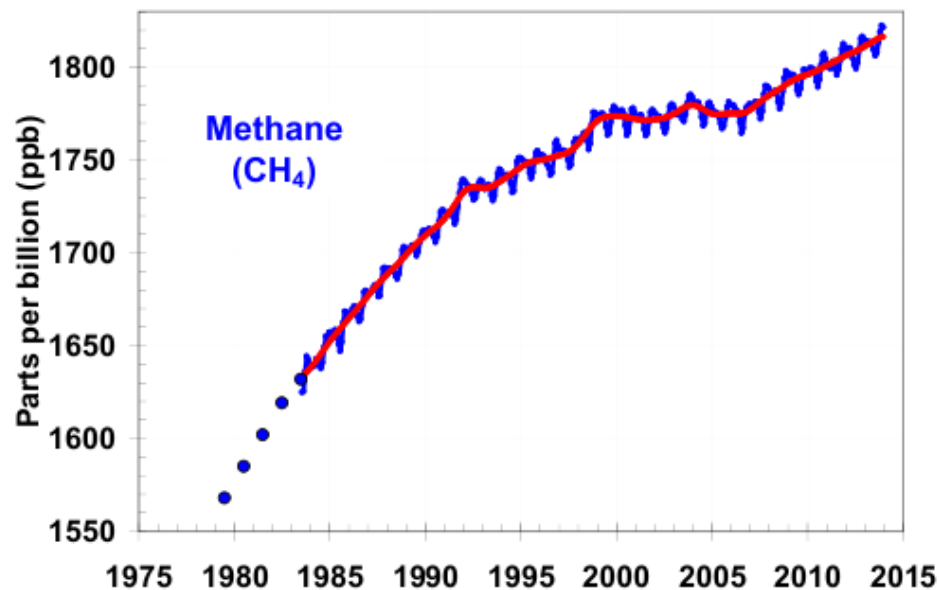$$\Delta Sum = \sqrt{(\Delta u)^2 + (\Delta v)^2 + (\Delta w)^2 + (\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}$$
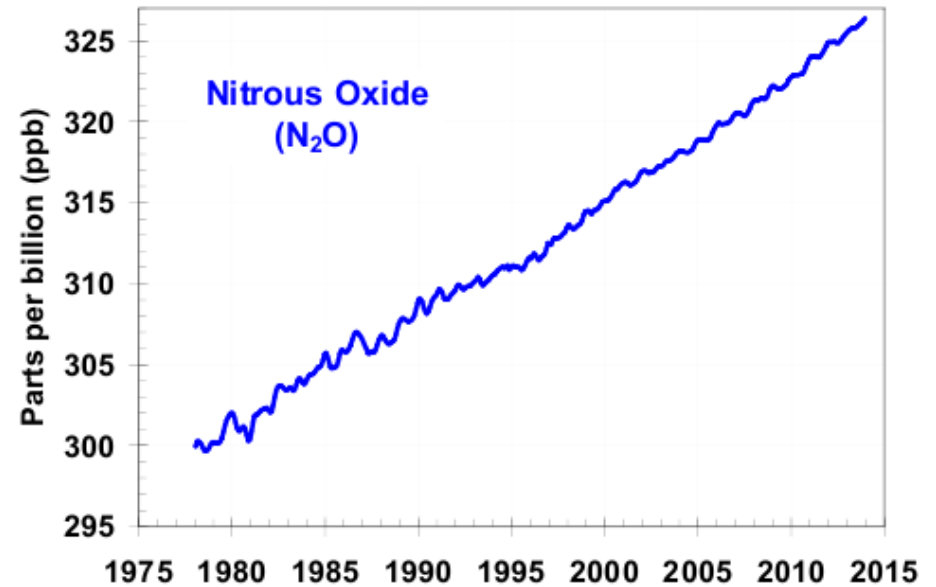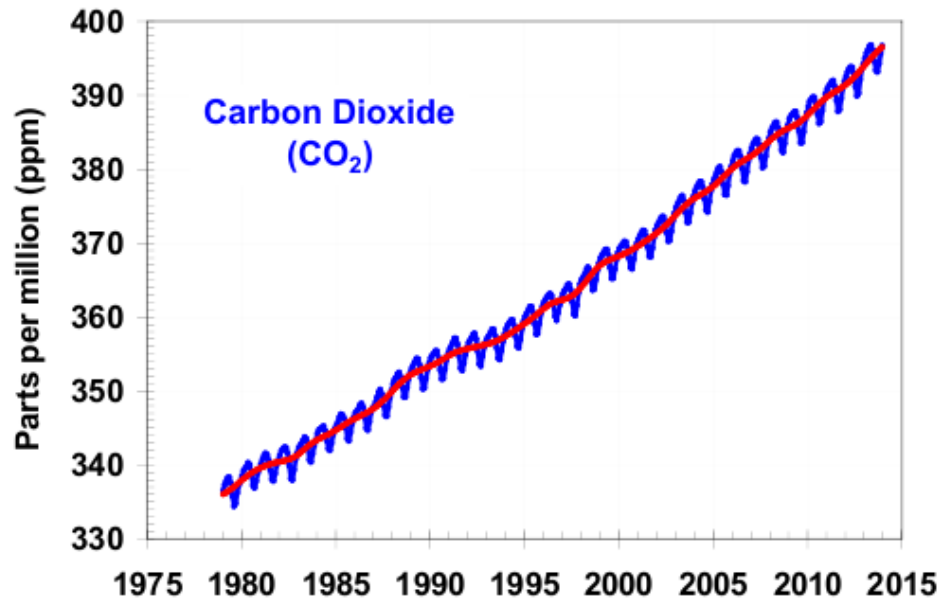
sqrt(7^2 + 2^2) = sqrt(49 + 4) = 7.28

Solar irradiance

Composite Total Solar Irradiance

The drop of 1.2 Wm⁻² since 2001 is equivalent to
-0.2 Wm⁻² in radiative forcing

Greenhouse gas (GHG) trend data

Global carbon emissions

Data for Global Carbon Emissions
(Fossil fuels, cement, land-use change)

Year Carbon Emissions (billions of metric tons)

Year	Carbon Emissions
2012	9.7 (+2.1%)
2011	9.47
2010	9.19
2009	8.74
2008	8.77
2007	8.57
2006	8.37

Growth rates for major emitter countries in 2012 were 5.9% (China), −3.7% (USA), −1.3% (EU28), and 7.7% (India).

The 2012 CO_2 emissions breakdown is coal (43%), oil (33%), gas (18%), cement (5.3%) and gas flaring (0.6%).

**Carbon release 10 billions of metric tons (1000 kg) annually.
For CO_2 mass multiply by 3.67.**

Why is global warming controversial?
Ans: We are looking for a needle in a haystack and not all details are completely understood.

- The size of the CO_2 effect is 1-2 W/m^2 compared to the total flux of 342 W/m^2.
  - It is a 0.5% effect among a set of competing effects.
- H_2O and CO_2 both cause the same thing. Which is it?
- Feedbacks are complex and important.
  - Natural systems tend to adjust.
- Carbon cycle, CO_2 uptake and sequestration in the ocean, plant uptake and respiration, are poorly understood.
- Computers are not powerful enough to include all the details of carbon cycle, surface albedo, clouds, etc.
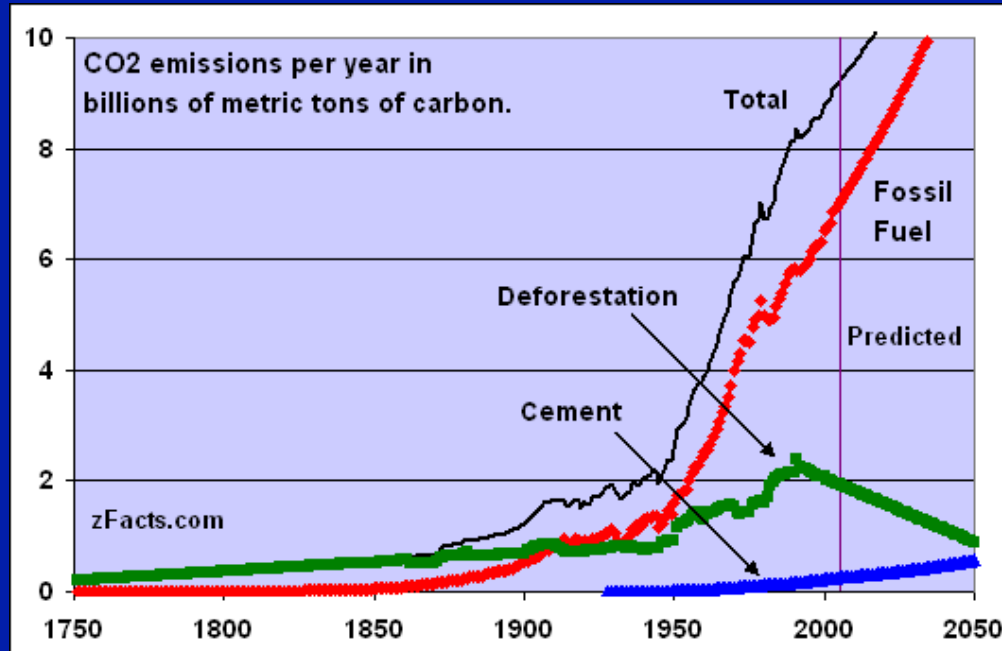 - Global averages are used. Errors are estimated, but…

Sources of CO$_2$

- volcanoes on land and under the sea release a total of about 200 million metric tons of CO$_2$ annually
- fossil fuel burning CO$_2$ emissions >30 billion tons
  - deforestation and agriculture add ~6 billion tons
  - $200 \times 10^6 / 36 \times 10^9 = 7.5 \times 10^{-3}$ so < 0.6%
  - 1 billion tons = 1 gigaton = 1 petagram (1 ton = 1000 kg)

CO2 emissions per year in billions of metric tons of carbon.

Total

Fossil Fuel

Deforestation

Predicted

Cement

zFacts.com

Be careful: mass of carbon dioxide is 44/12 = 3.67 times the mass of carbon. Scientists (and government) tend to use mass of C whereas business and the public tend to use CO$_2$ mass because this is what we emit.