Wind Crest Learners

Lecture 2: Climate basics

Climate Redux

February 12, 2021

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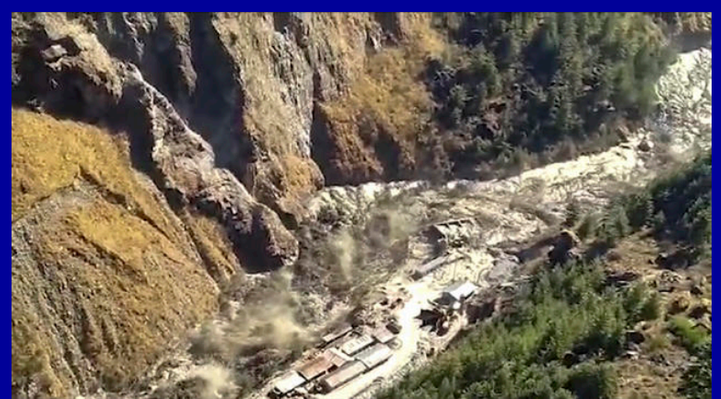
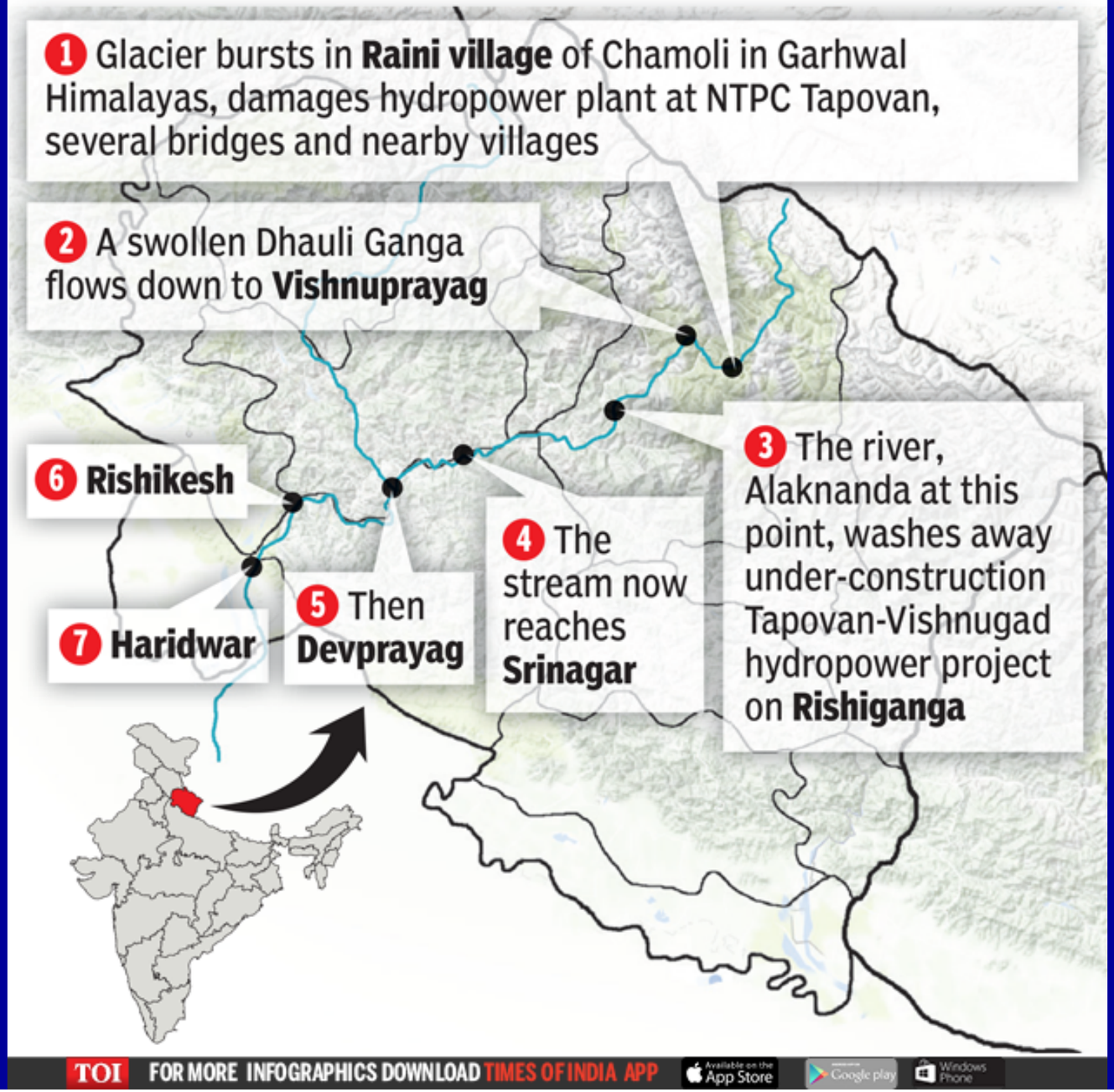
Glacier *Uttarakhand* collapses in Himalayas on 25,600 ft high Nanda

Feb. 8, 2021



TRAIL OF DESTRUCTION



Mass loss across the Himalayas

Khumbu Glacier Mt Everest

1975-2000: -0.22 m.w.e. per year

2000-2016: -0.43 m.w.e. per year

Maurer et al., 2019, *Science Advances,* **5**, no. 6, eaav7266

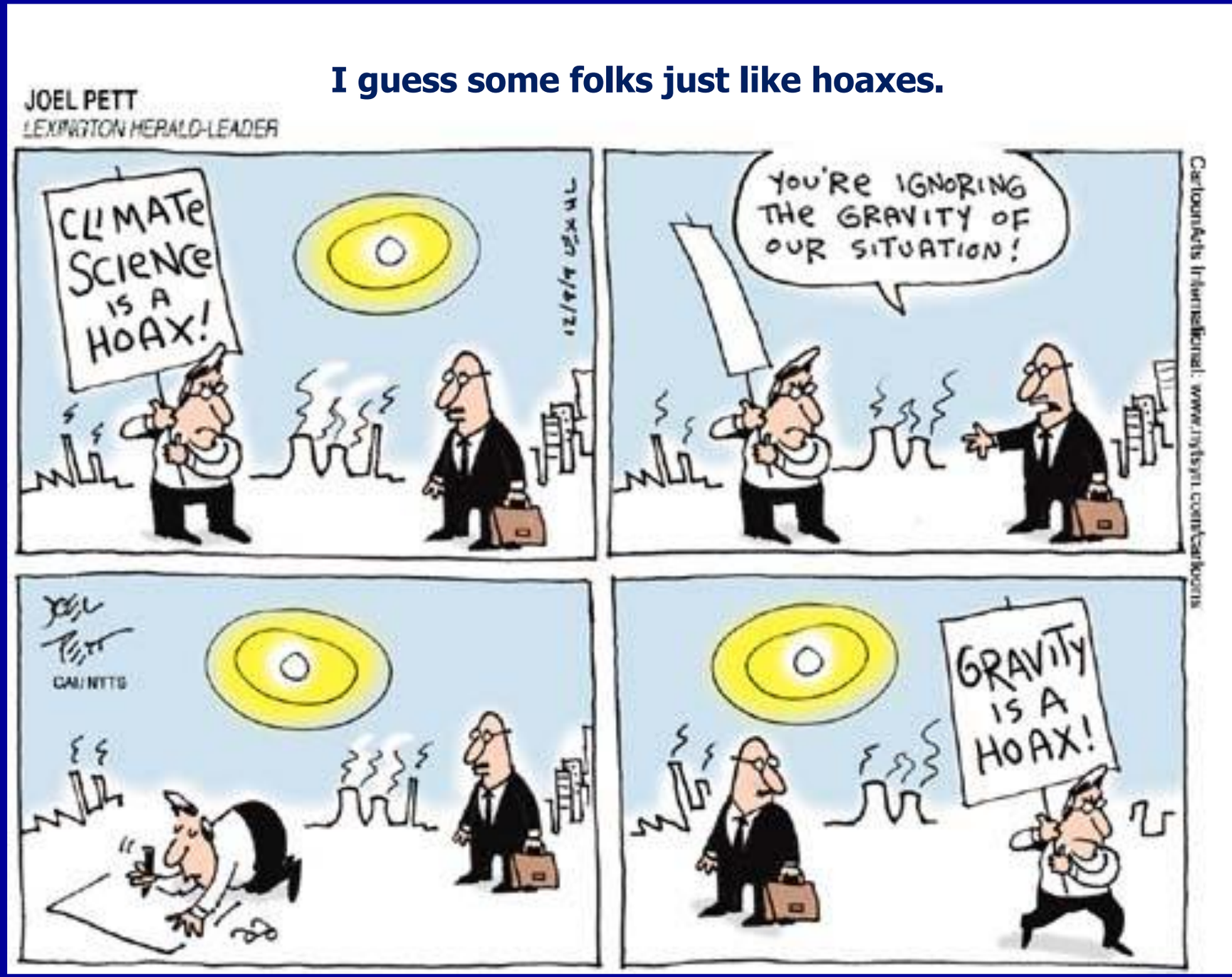
It's a complex business

- Climate science is multi-disciplinary
  - Astrophysics, physics, chemistry, geology, biology, glaciology, fluid dynamics, etc.
- Now add the human social and geopolitical aspects of the problem, etc.
- It's an interesting complex problem keeping the mind of an old man active.

What I’m going to discuss today

- Temperature in perspective
- Energy and heat (infrared radiation)
- Trapping of heat by the atmosphere
- Greenhouse gases, especially CO_2 & H_2O
- Aerosols, clouds and other climate drivers

I guess some folks just like hoaxes.



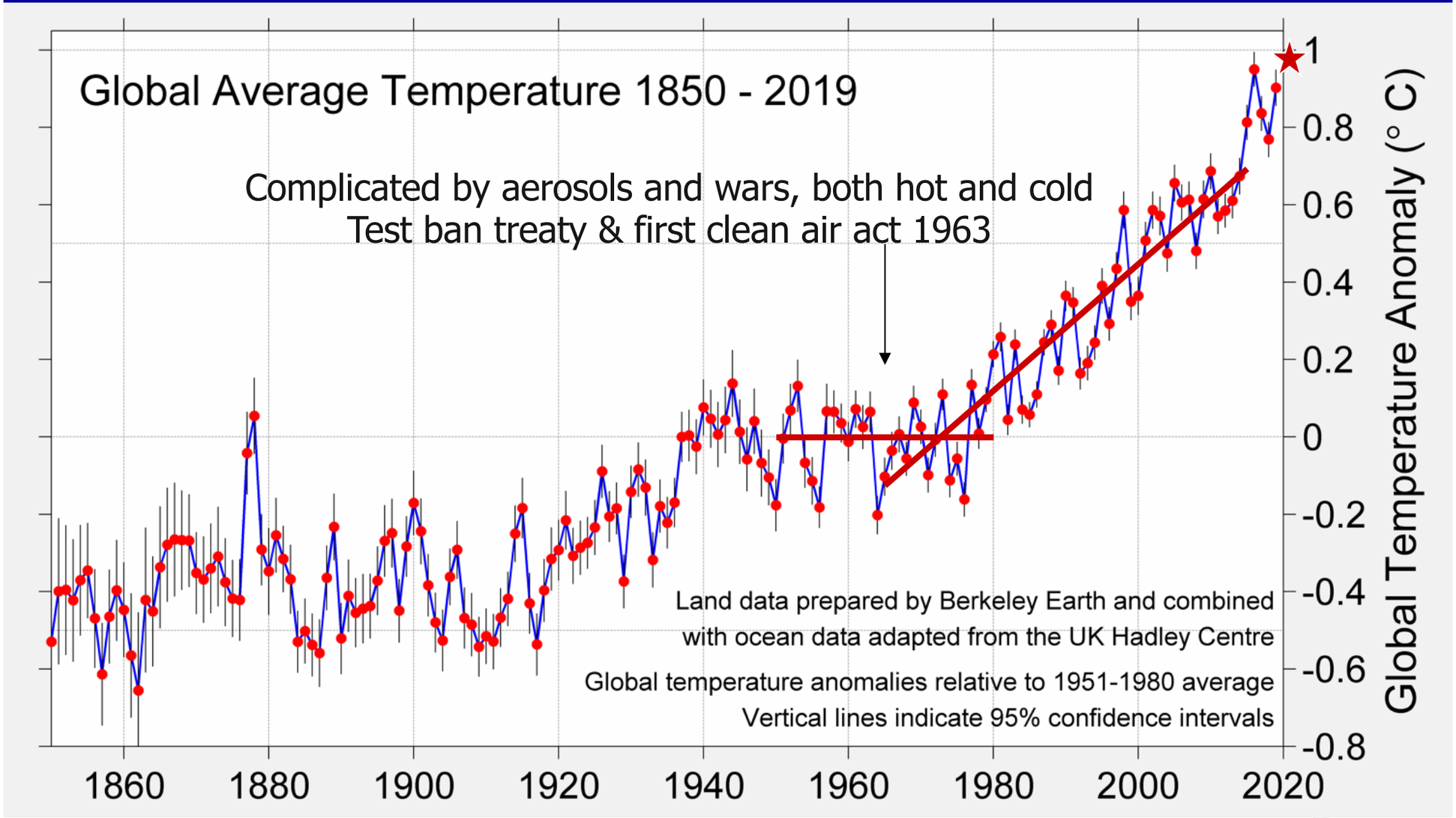
Effect of the sun

- I once had a colleague tell me that the sun has nothing to do with our climate.

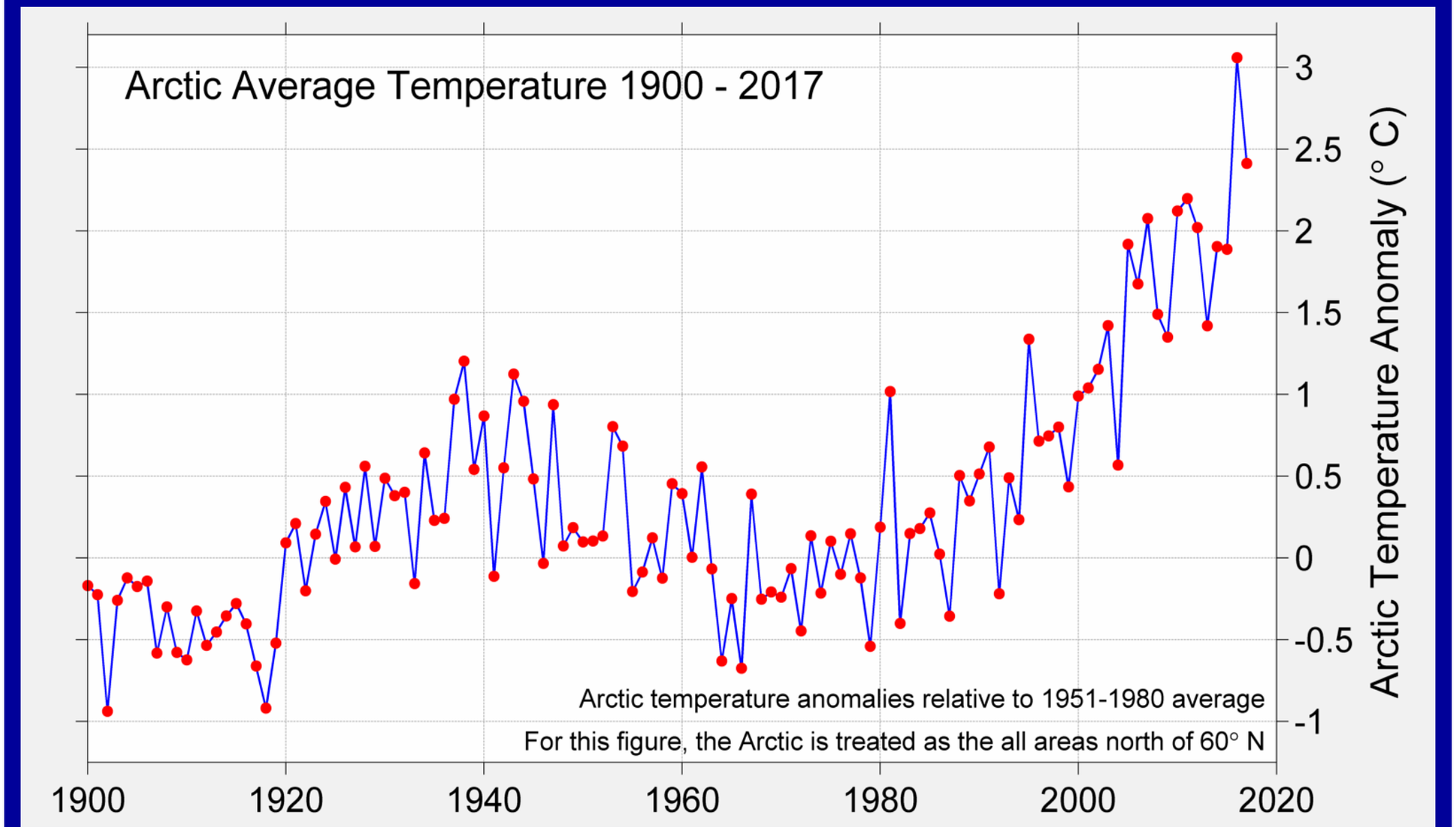
- My reply: "Oh yeah, just try turning it off and see what happens."

- Of course, this person was talking about the variability of the sun, but this is an object lesson in how hard it is to be sufficiently precise in talking about such subjects.

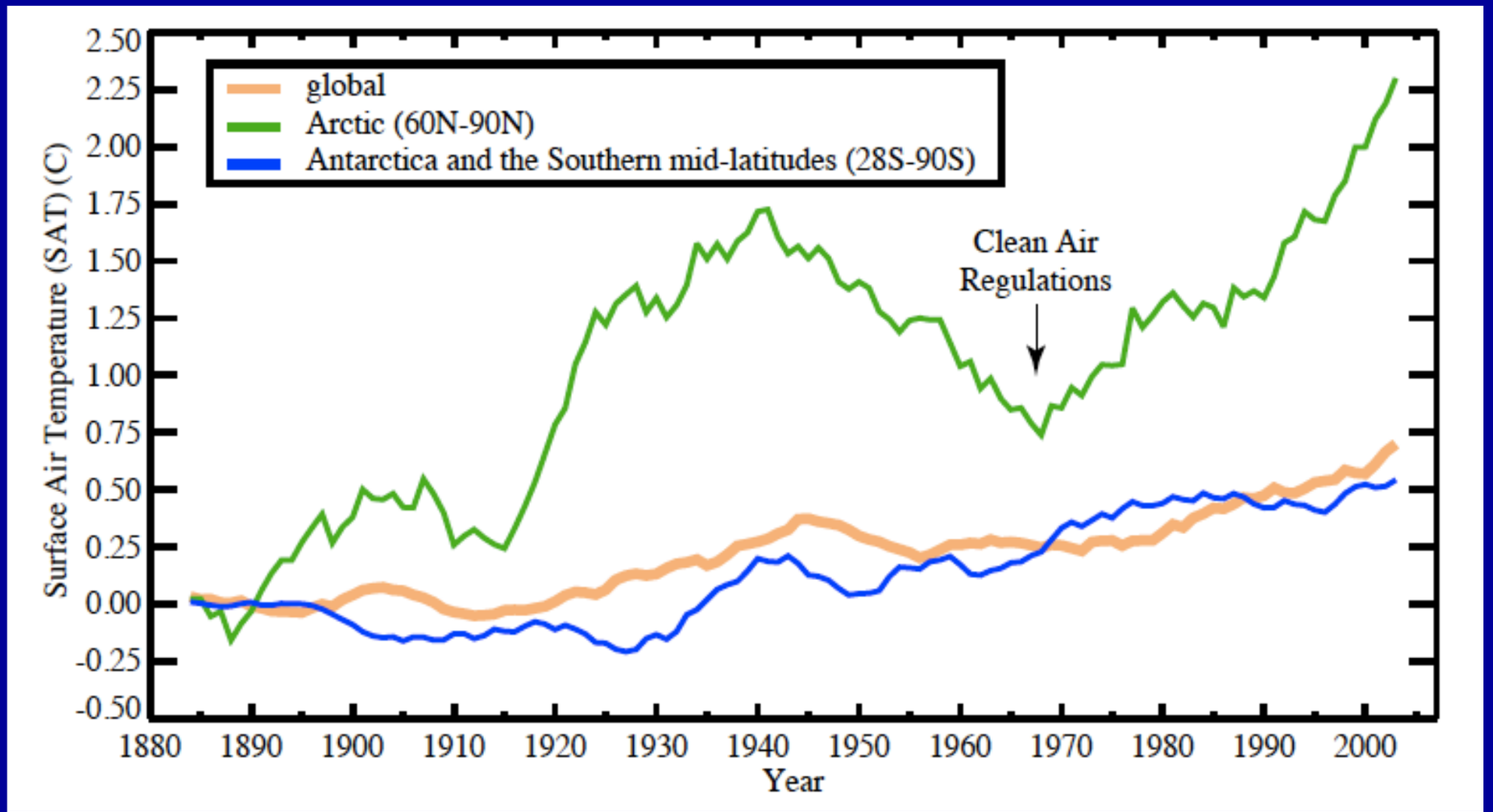
Global Average Surface Temperature



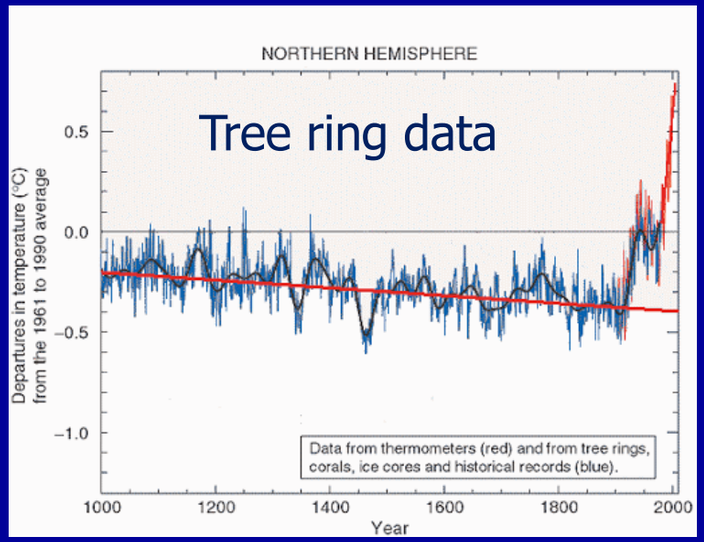
Arctic Temperature north of 60°C



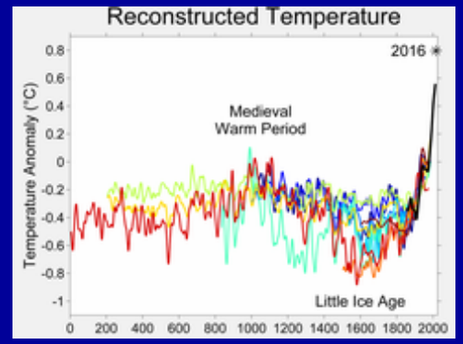
Cooling by carbon aerosols in the Arctic



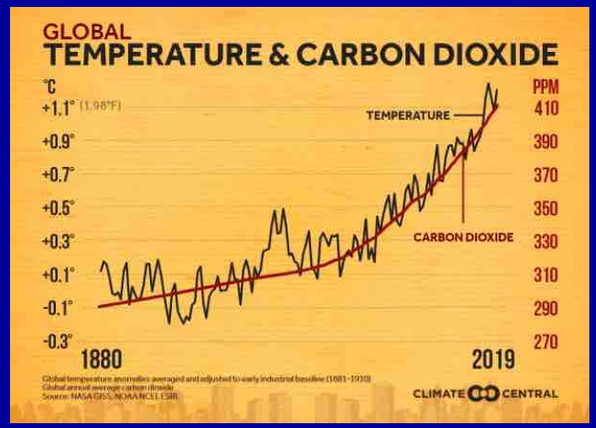
Temperature profiles

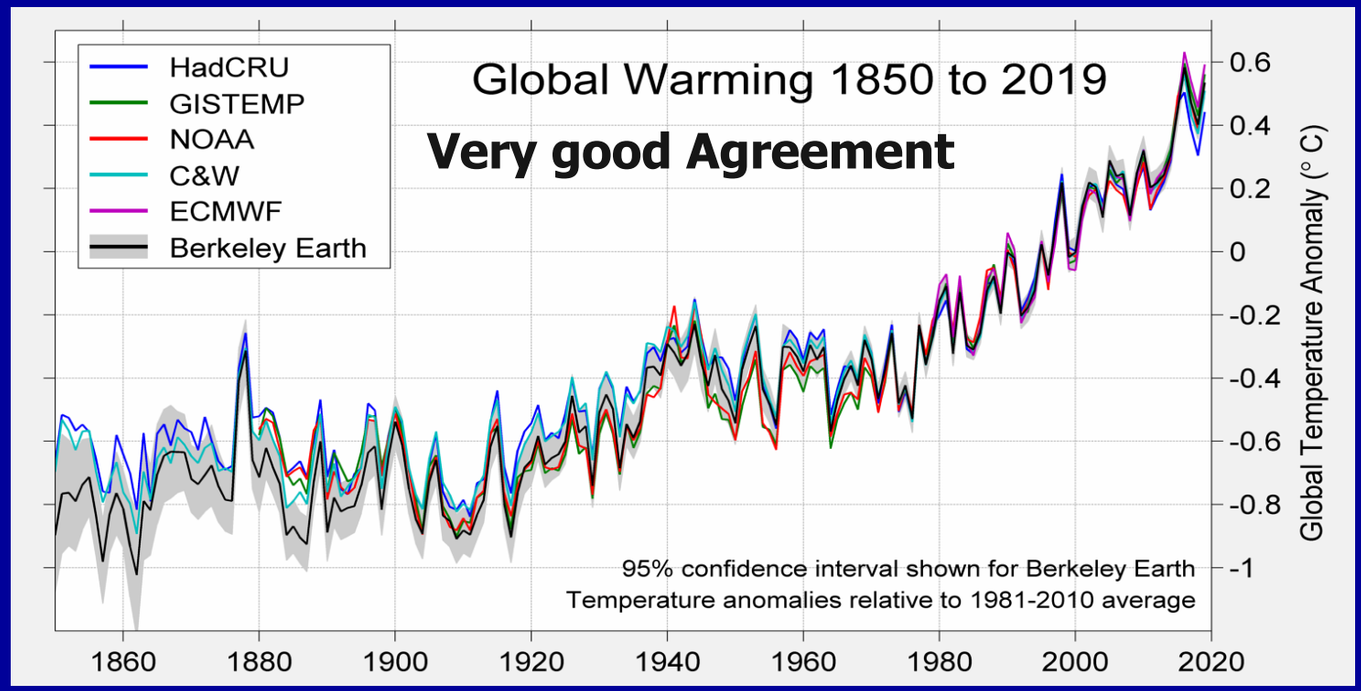


1000 years



2000 years

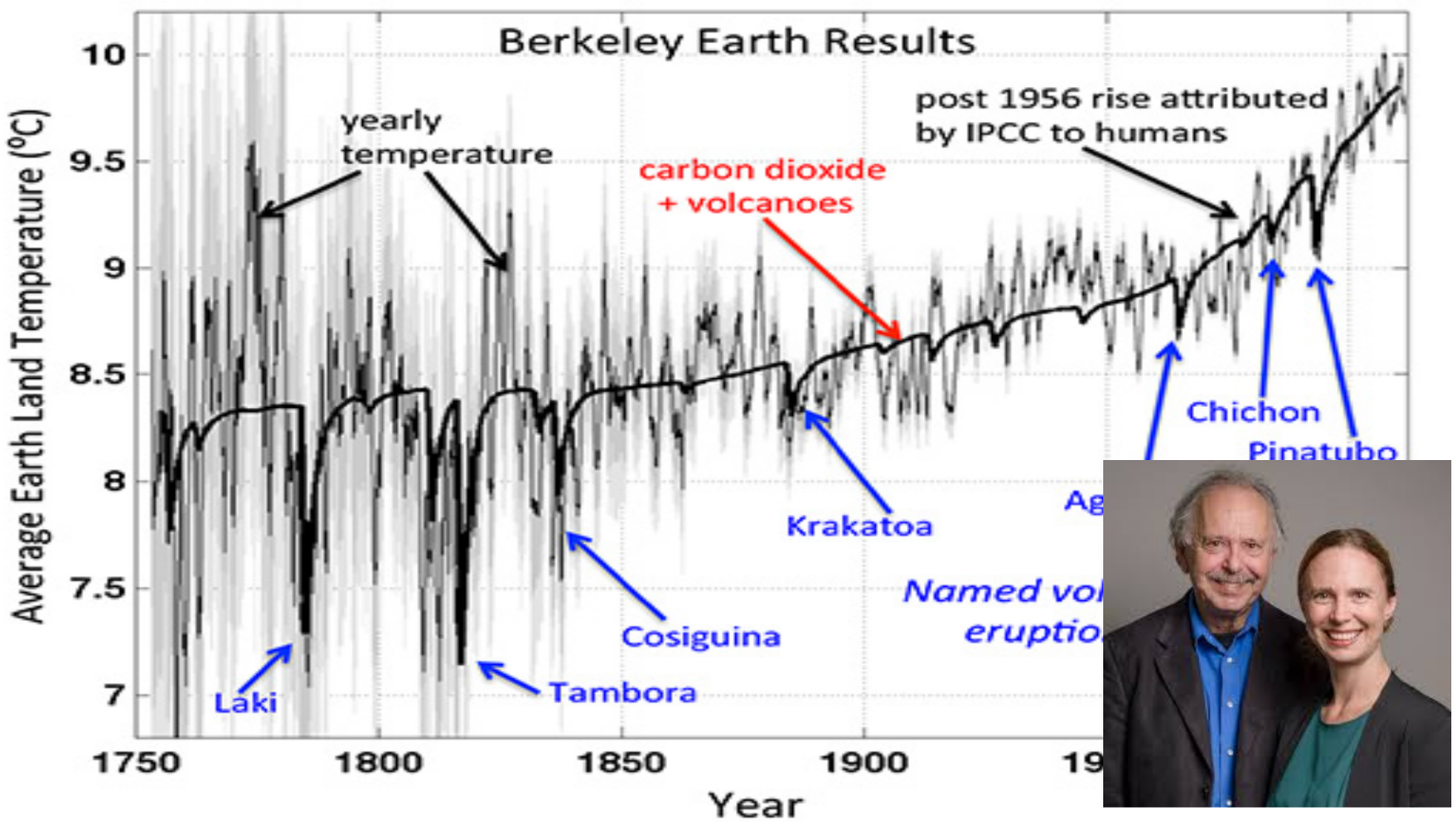




Volcanos by "Berkeley Earth"

T_{avg} fit by function f(Ln(CO_2) - 1.5 x mVS (Tg))

mVS (Tg)= Mass of Volcanic Sulfates in Tera-grams (10^6 tons)



Weather or Climate

Federal Budgets

Big numbers: start with the familiar

- Taxes: 10s of thousands
- NASA Research grants: 100 thousands to few million (10^6)
- "A billion here, a billion there, pretty soon you're talkin' real money." (10^9)
  - Everett Dirksen
- Stimulus bills Trillion (10^{12})

Energy: Joule = Watt/s

- Raise an apple by 1 m: 1 Joule
- Drive a car 1 mile: 1 kilo(10^3)-Joule
- Run a 100 W Lightbulb for a year: 3 Giga(10^9)-Joules
- Power a city of 100,000 for a year: 2 Tera(10^{12})-Joules
- Hiroshima bomb: 63 Tera(10^{12})-Joules
- Power plant annual energy output: 4 Peta(10^{15})-Joules
- To keep 7.67B humans alive a year: 30 Exa(10^{18})-Joules
- Annual energy usage in the USA: 94 Exa(10^{18})-Joules
- Global energy consumption/year: 0.5 Zetta(10^{21})-Joules
- Incident solar energy annually: 200 Zetta(10^{21})-Joules
- Energy to heat all Earth's water 1^{o}C: 1 Yotta(10^{24})-Joule

Infrared radiation we feel as heat

You know about heat radiation. Scientists call it infrared radiation.

Cloudless night

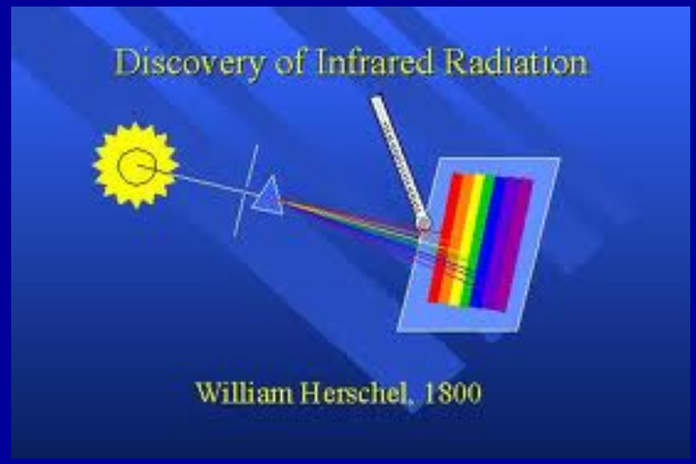
What happens? It gets cold. Cold desert night!

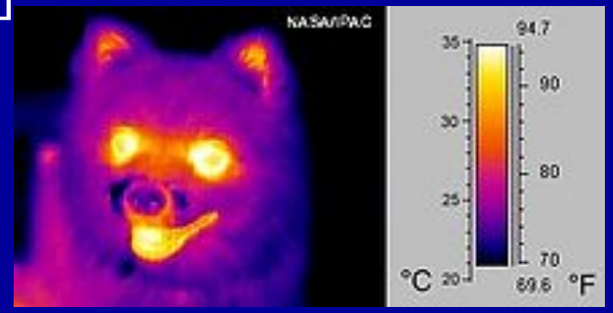
Earth cools by radiation!

How was thermal radiation discovered?

- William Herschel
  - also discovered the first new planet since antiquity (Uranus) and studied sunspots,
- In an 1800 experiment, Herschel used a glass prism to spread sunlight into a rainbow of colors.
  - measured the temperature of each color of visible light and noted differences.
  - readings when the thermometer bulb was placed just beyond the red portion of the visible spectrum.

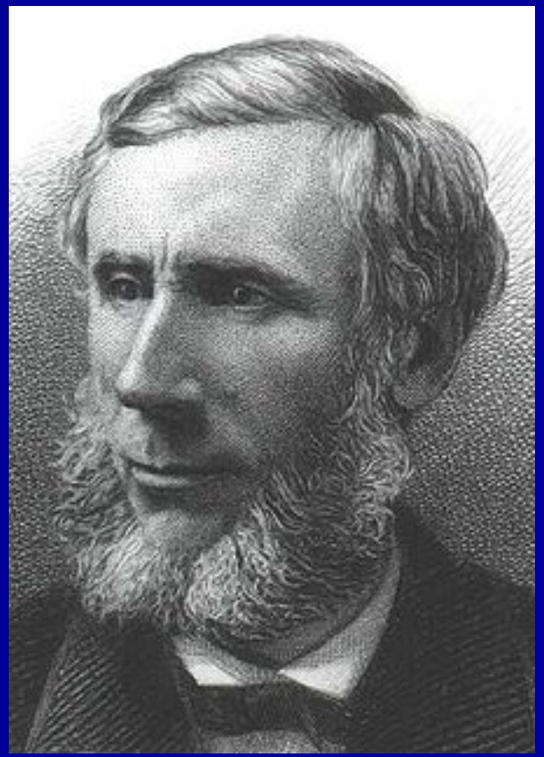
• He had discovered thermal radiation, which has come to be known as infrared. [The prefix "infra" means "below."]





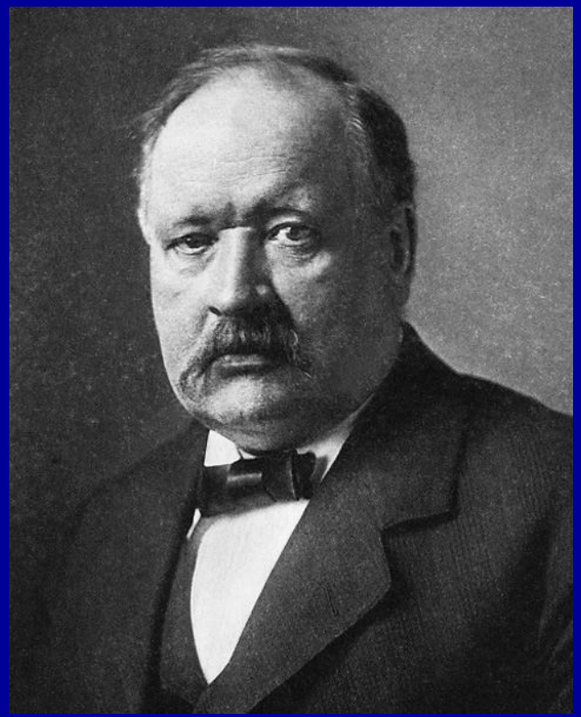
Greenhouse gases keep the planet warm

Joseph Fourier computed that the Earth should be much colder than it is (1824, 1827)



John Tyndall, January 1863

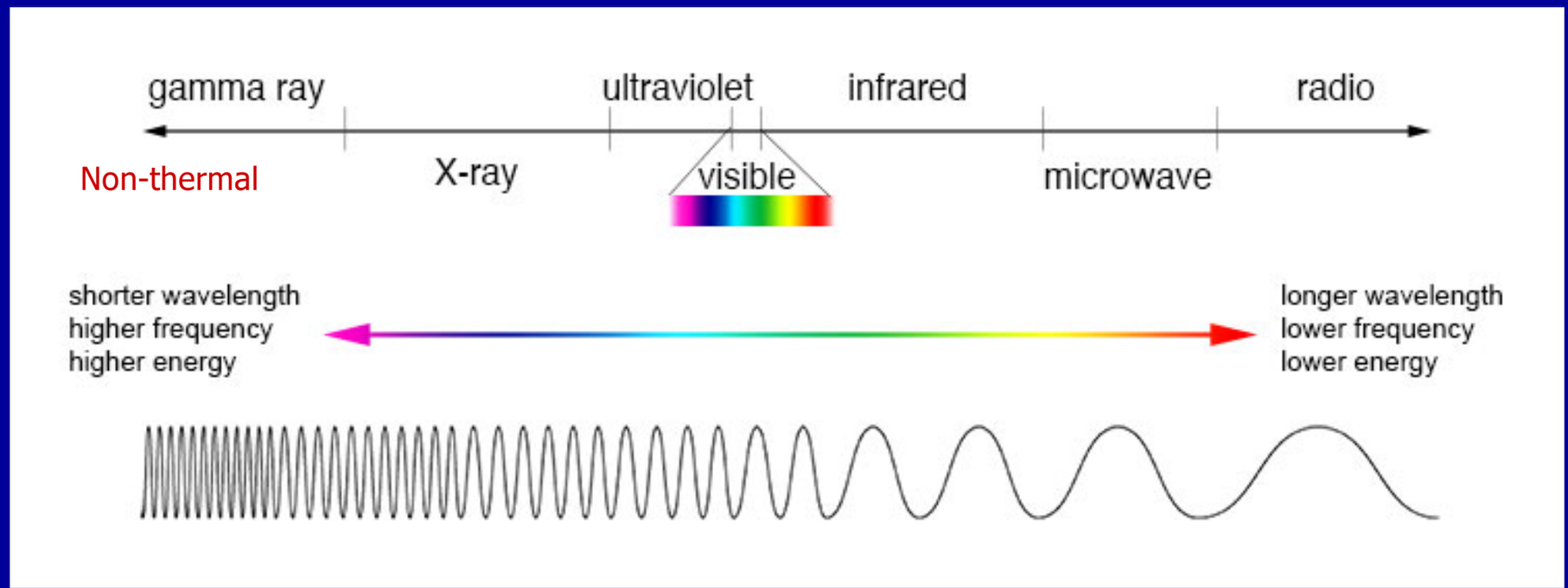
Measured the absorption and emission of heat radiation by CO_2 in air (made the measurements of the physics.)

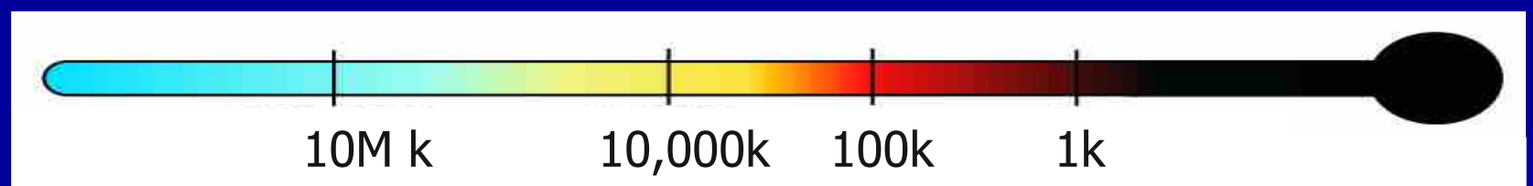


Svante Arrhenius, 1896

Calculated in detail effect of CO_2 on Earth's temperature.

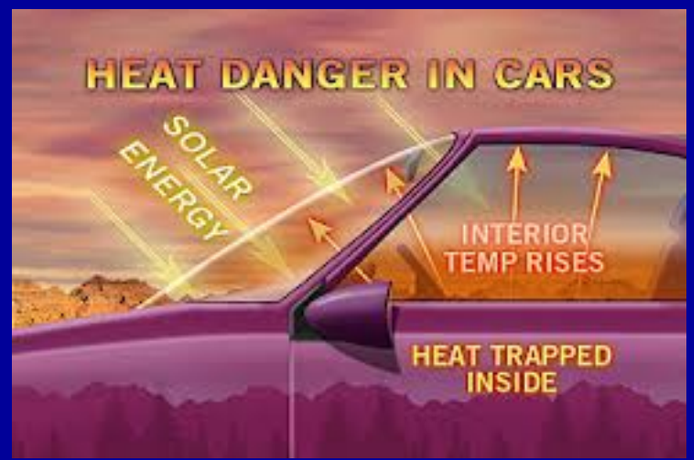
The electromagnetic spectrum





The Greenhouse Effect

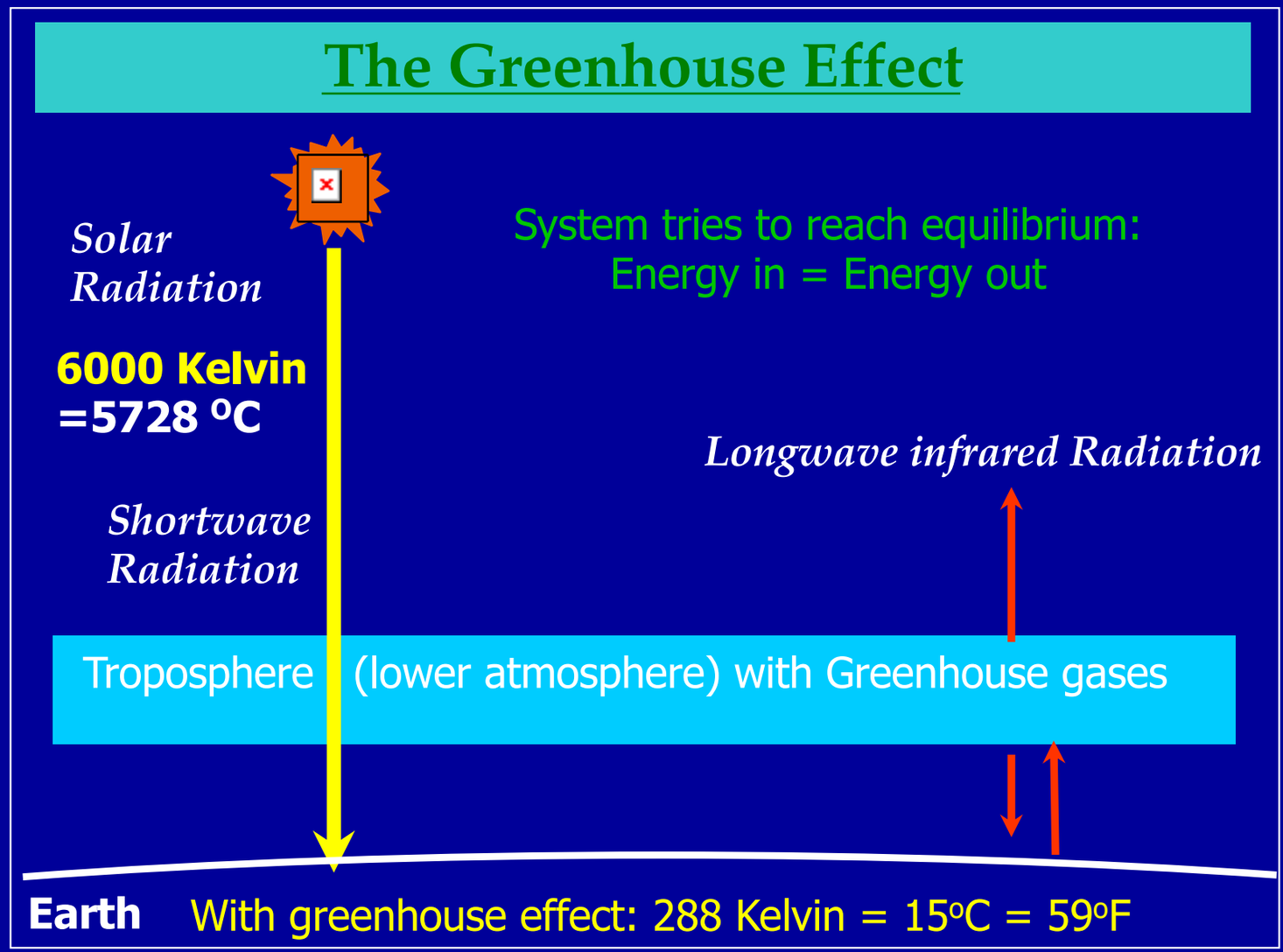
aka Arrhenius Effect



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

140 °F = 60 °C

Earth' is 59°F (33°C) warmer than it would be without the current greenhouse effect.



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

Heat seeking missiles were developed in the early 1950s by the military.

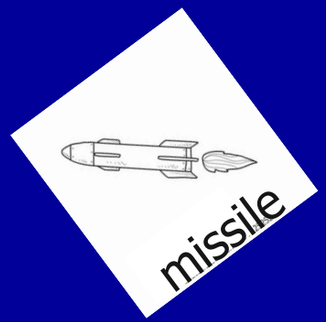
They learned all about the absorption of infrared by atmospheric CO_2.

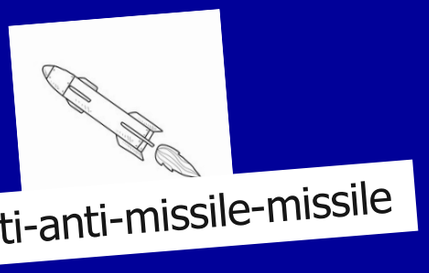
Raising the alarm on CO_2 for climate began in the late 1950s.
The first articles were by Gilbert Plass:

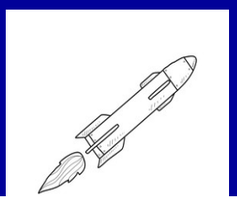
Plass, G.N., 1956, Carbon Dioxide and the Climate, American Scientist **44**, p. 302-16.
Plass, G.N., 1956, Effect of Carbon Dioxide Variations on Climate, American J. Physics **24**, p. 376-87.
Plass, G.N., 1956, The Carbon Dioxide Theory of Climatic Change, Tellus VIII, **2**. (1956), p. 140-154.

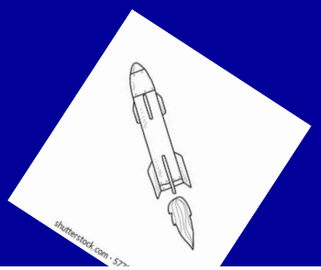
Your airplane in the ir

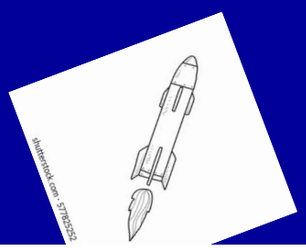
Anti-missile: heat seeking



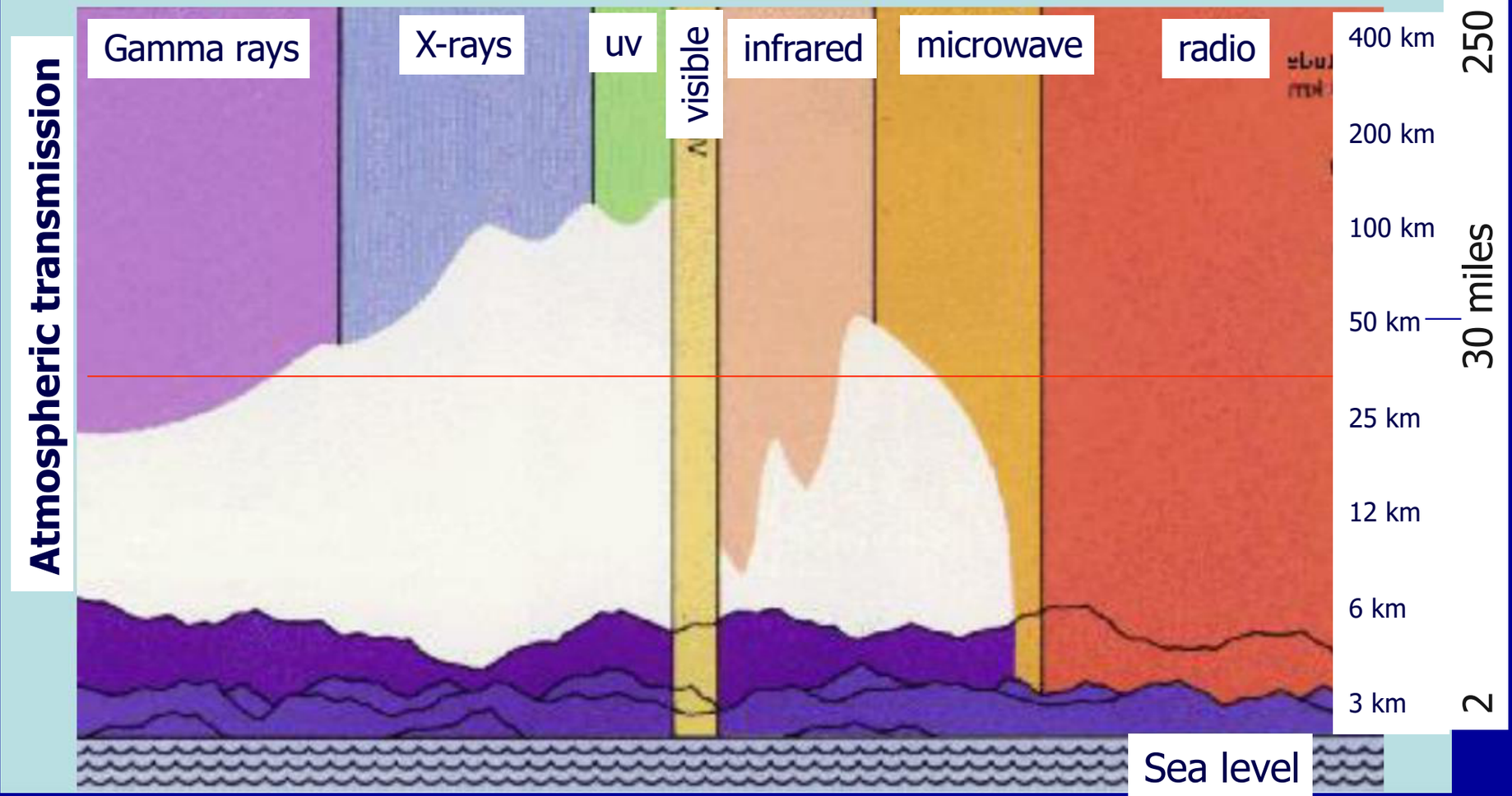

Anti-anti-missile-missile

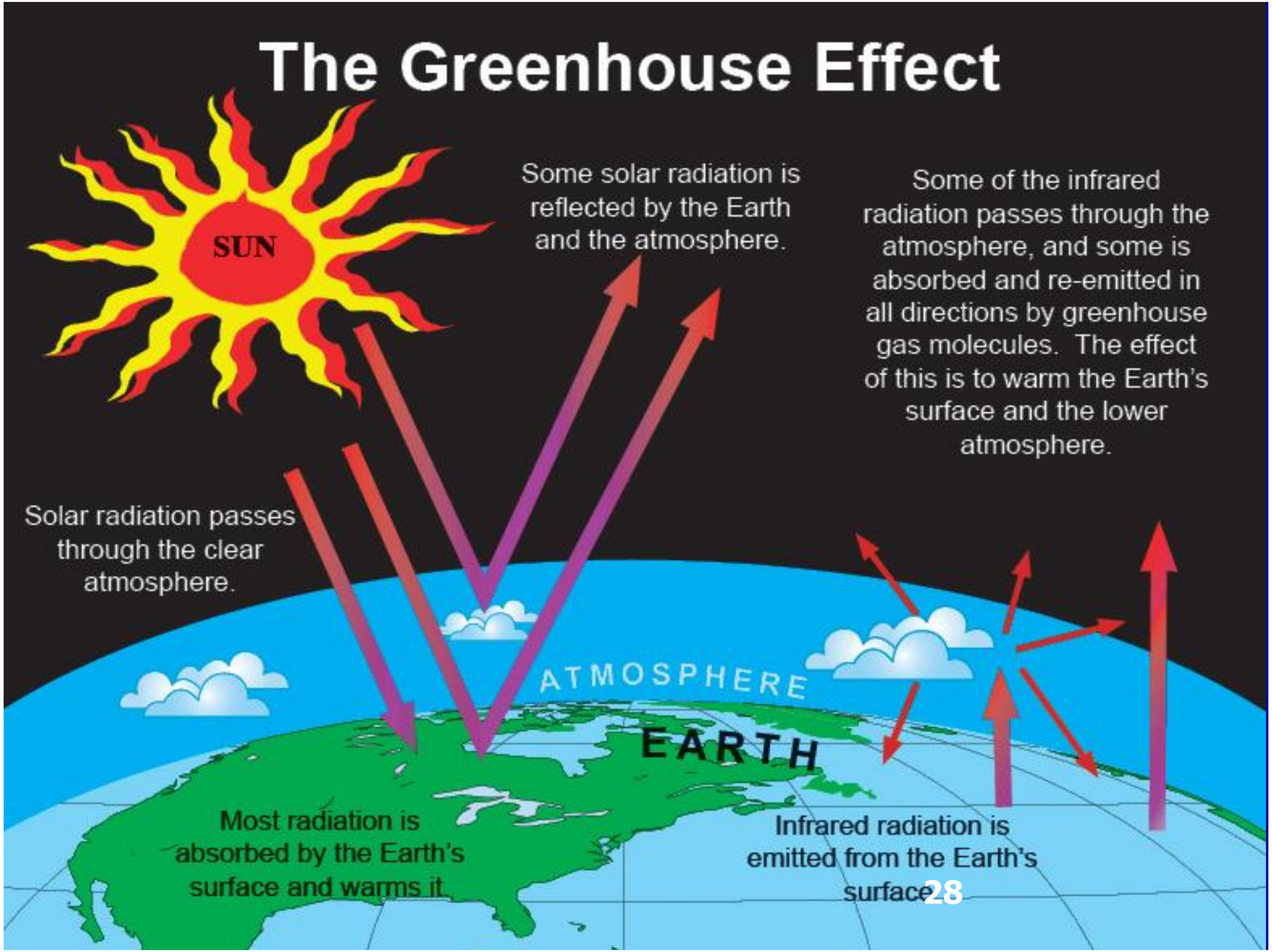

Anti-anti-anti-missile-missile-missile


Anti-anti-anti-anti-missile-missile-missile-missile


Anti-anti-anti-anti-anti-missile-missile-missile-missile-missile

Penetration of different wavelengths of light through the atmosphere

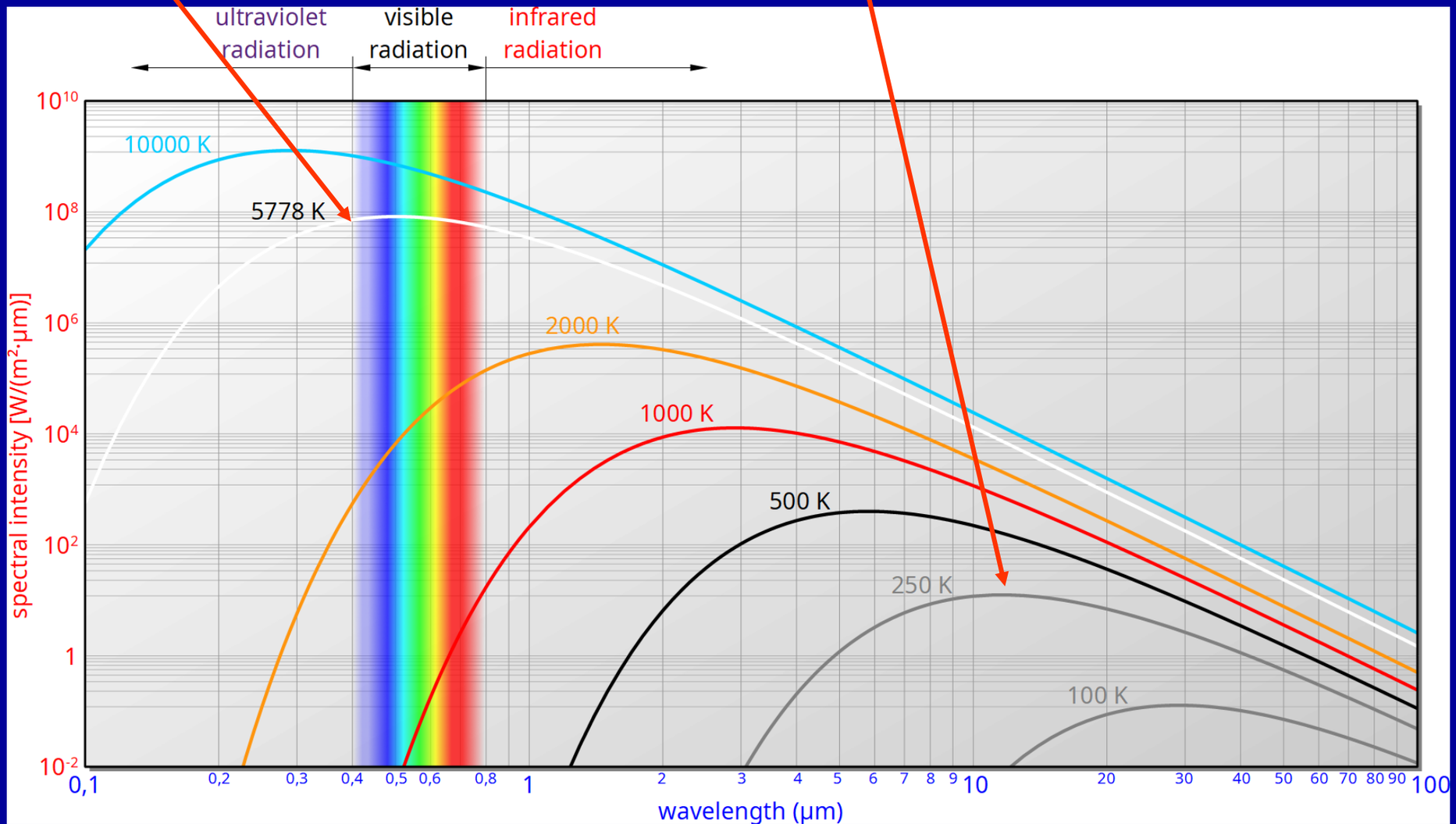


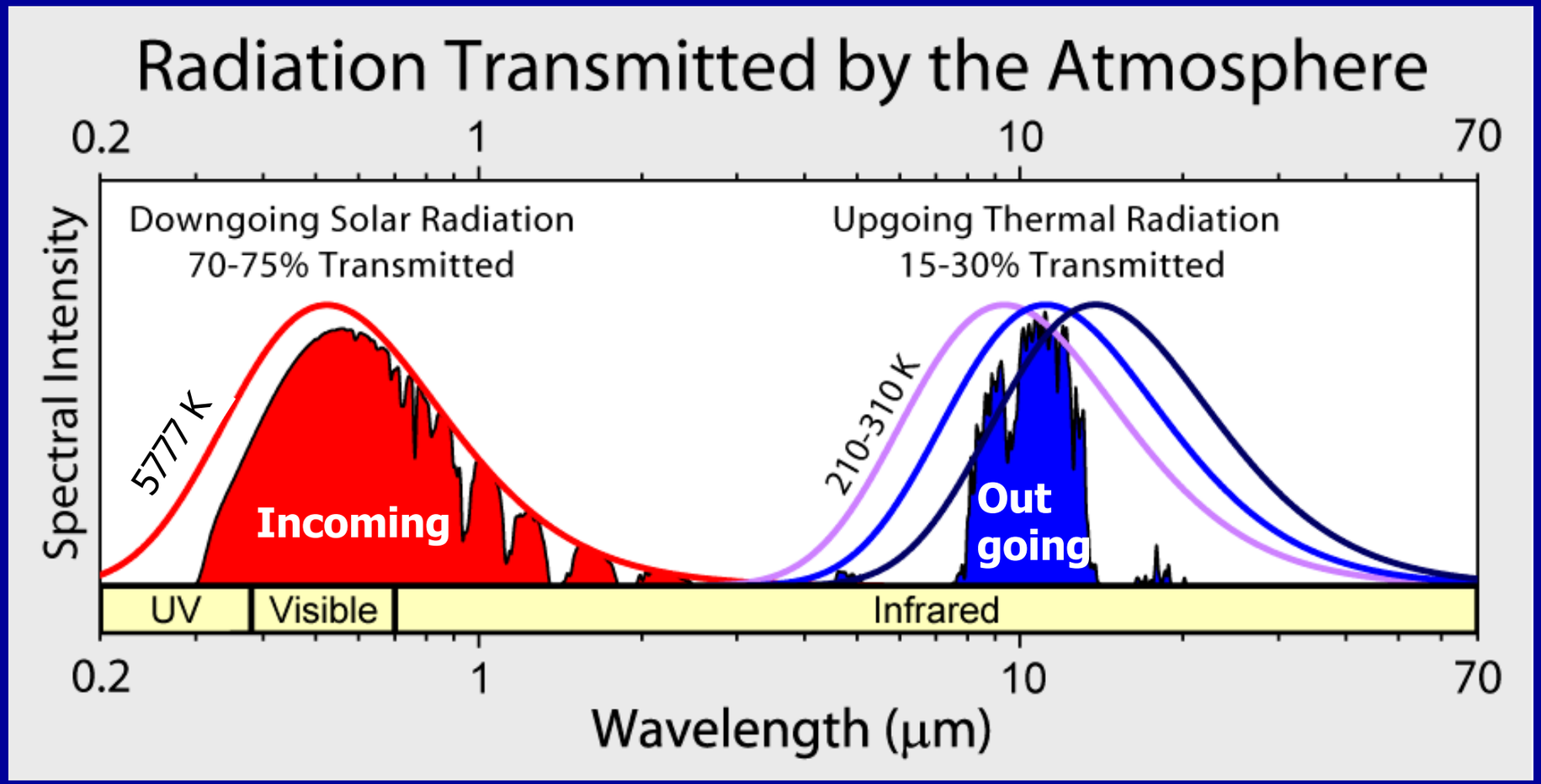

The Greenhouse Effect
SUN
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower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

Blackbody spectrum

White curve 5778 K emission by sun

Grey curve 288 K emission by Earth





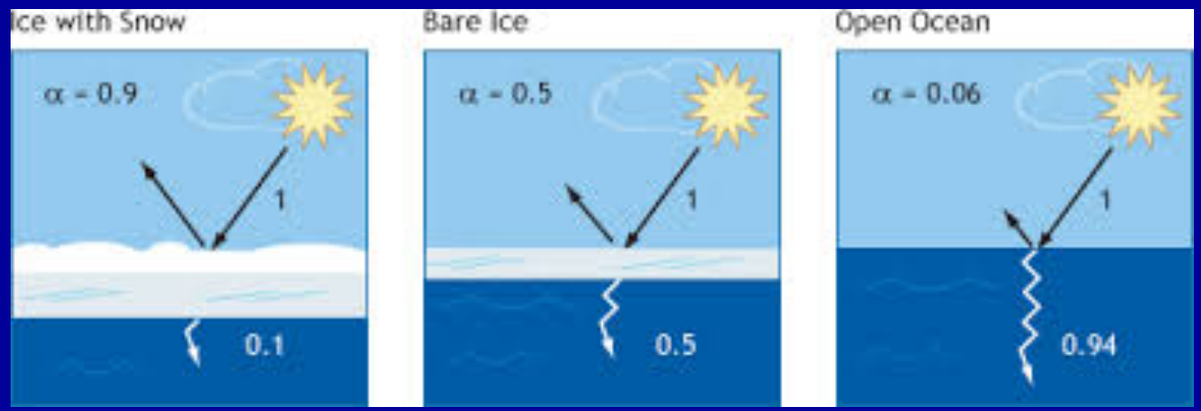
red λs come in

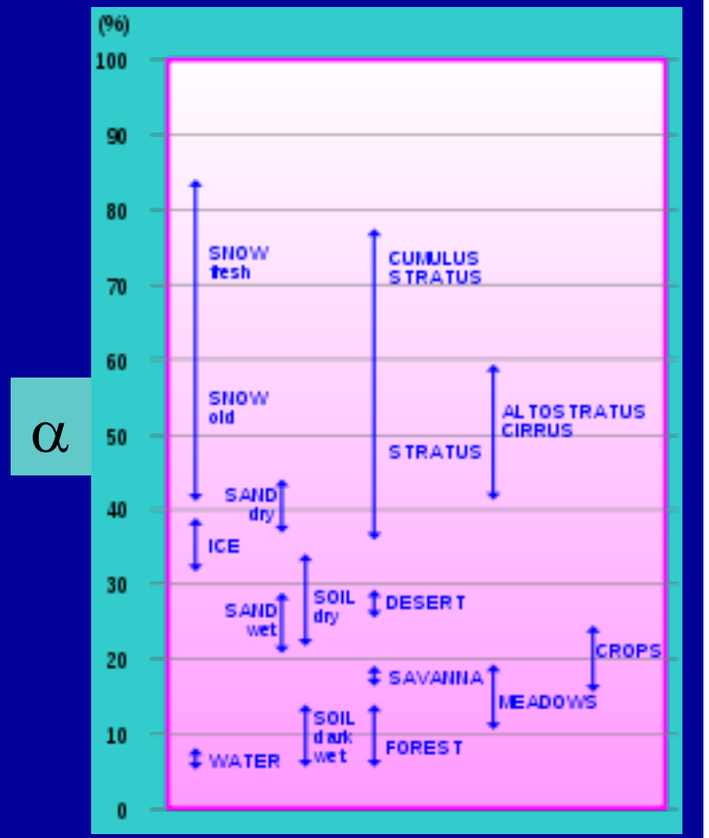
blue λs go out

We call it "albedo", but it is really the measure (coefficient) of reflectivity

Albedo, α, is the ratio of $\frac{\text{reflected radiation from the surface}}{\text{incident radiation upon it.}}$ to the

The word comes from the Latin word albedo (whiteness).

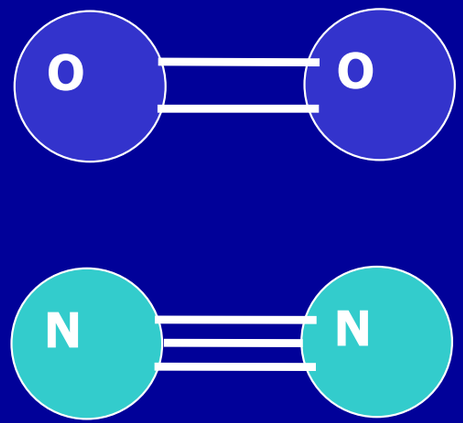




Global spatial and temporal average
α = 0.31 for the Earth

Dancing Molecules and Heat Rays!

- Nearly all of the air is made of oxygen (O_2) and nitrogen (N_2).



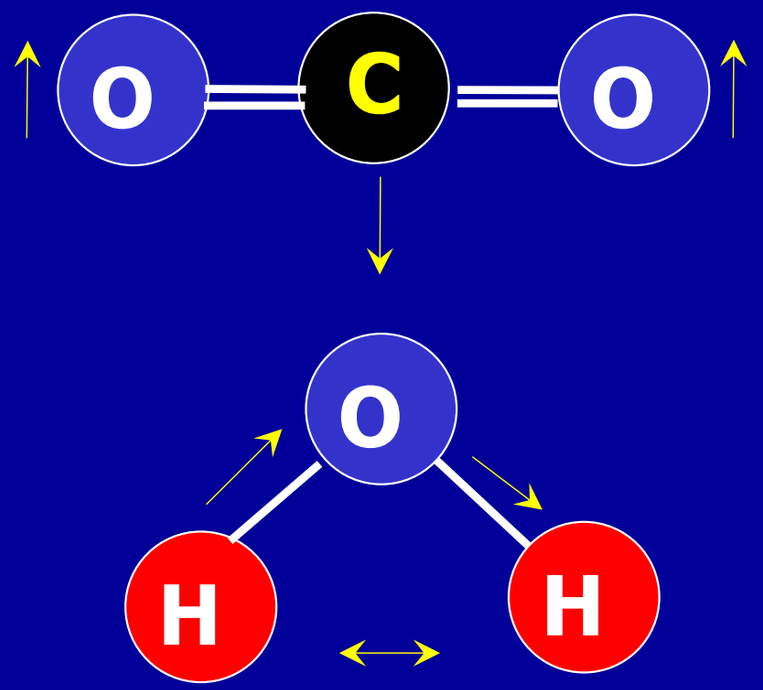
- Very little infrared (heat) energy radiated up from the surface can be absorbed by these molecules.

Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical

Dancing Molecules and Heat Rays!

- Carbon dioxide (CO_2) and water vapor (H_2O) are different!

- They have many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation.



Molecules that have many ways to wiggle are called "Greenhouse" molecules

The absorption spectrum of CO_2 was measured by John Tyndall in 1863.


The COMET Program
The COMET Program
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The COMET Program
The COMET Program
The COMET Program
The COMET Program

Prof. Scott Denning, CSU

NOVA program S47 Ep15
"*Can we cool the planet*?"

Movie of greenhouse gases
https://scied.ucar.edu/video/greenhouse-effect-video-scott-denning

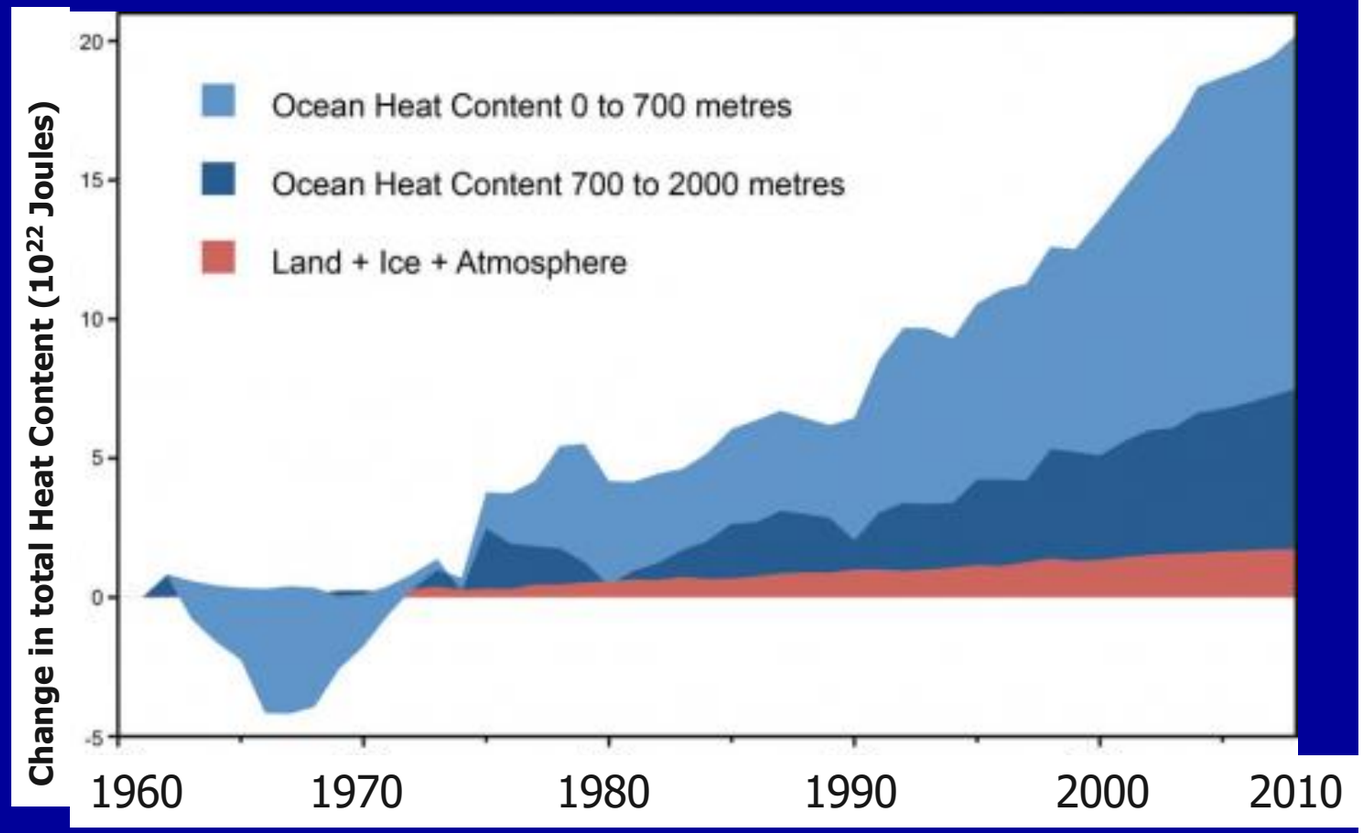
That CO_2 traps energy is unequivocal

- It is straightforward well understood physics
- Tremendous amount of energy
  - >2.2 billion Hiroshima bombs since 1998
    - 130 Zetta-Joules
- Temperature should be rising faster
- Trenberth, Kevin U of Colorado in 2010
  - Energy is going into the oceans

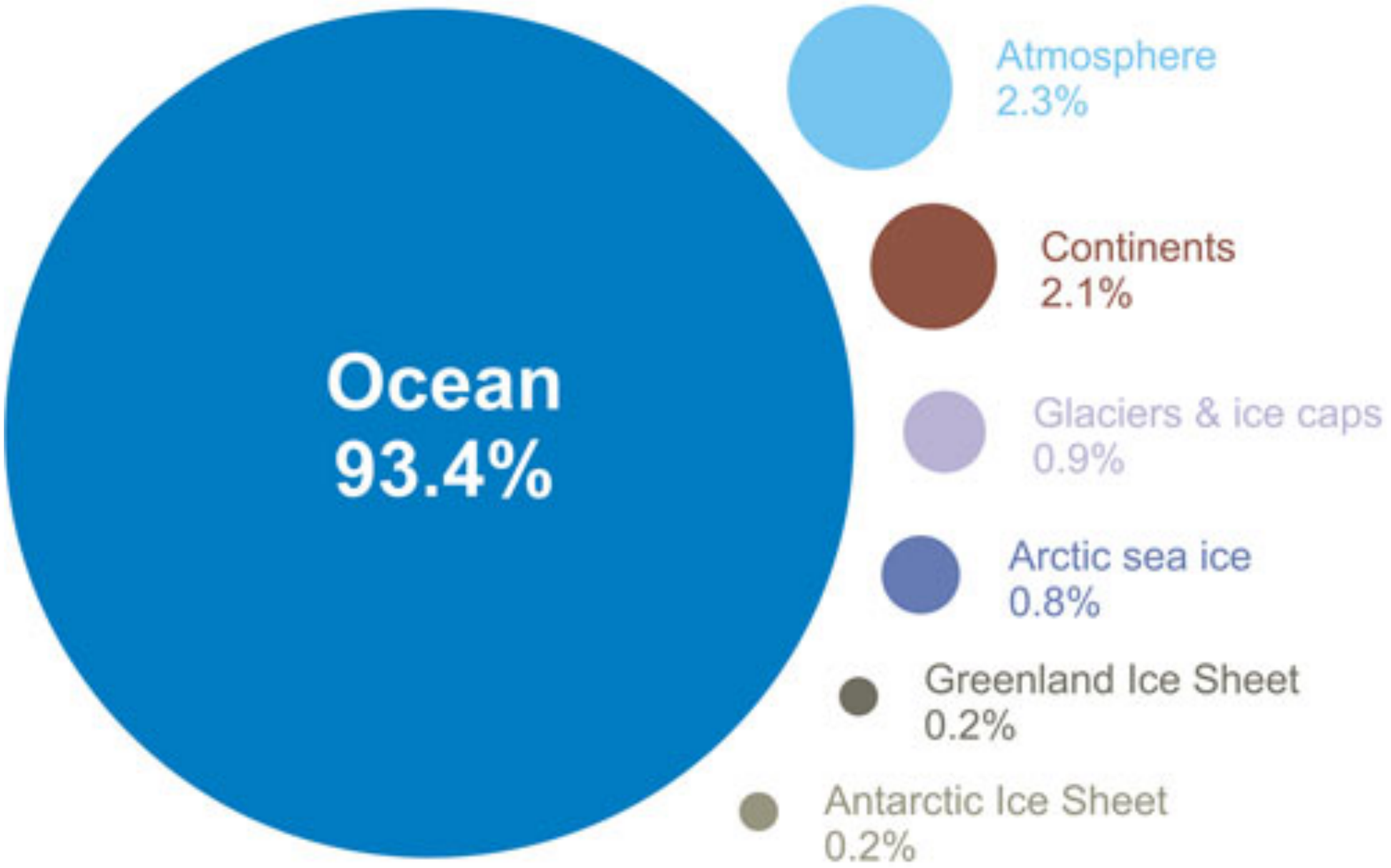
Excess heat is prodigious

Earth is accumulating 400,000 Hiroshima atomic bombs (24 Exa(10^{18})-Joules) worth of extra heat every day, 365 days per year. That's 4.6 Hiroshima bombs per sec.

93% of the energy is going to heat the oceans; the rest heats the land and air.

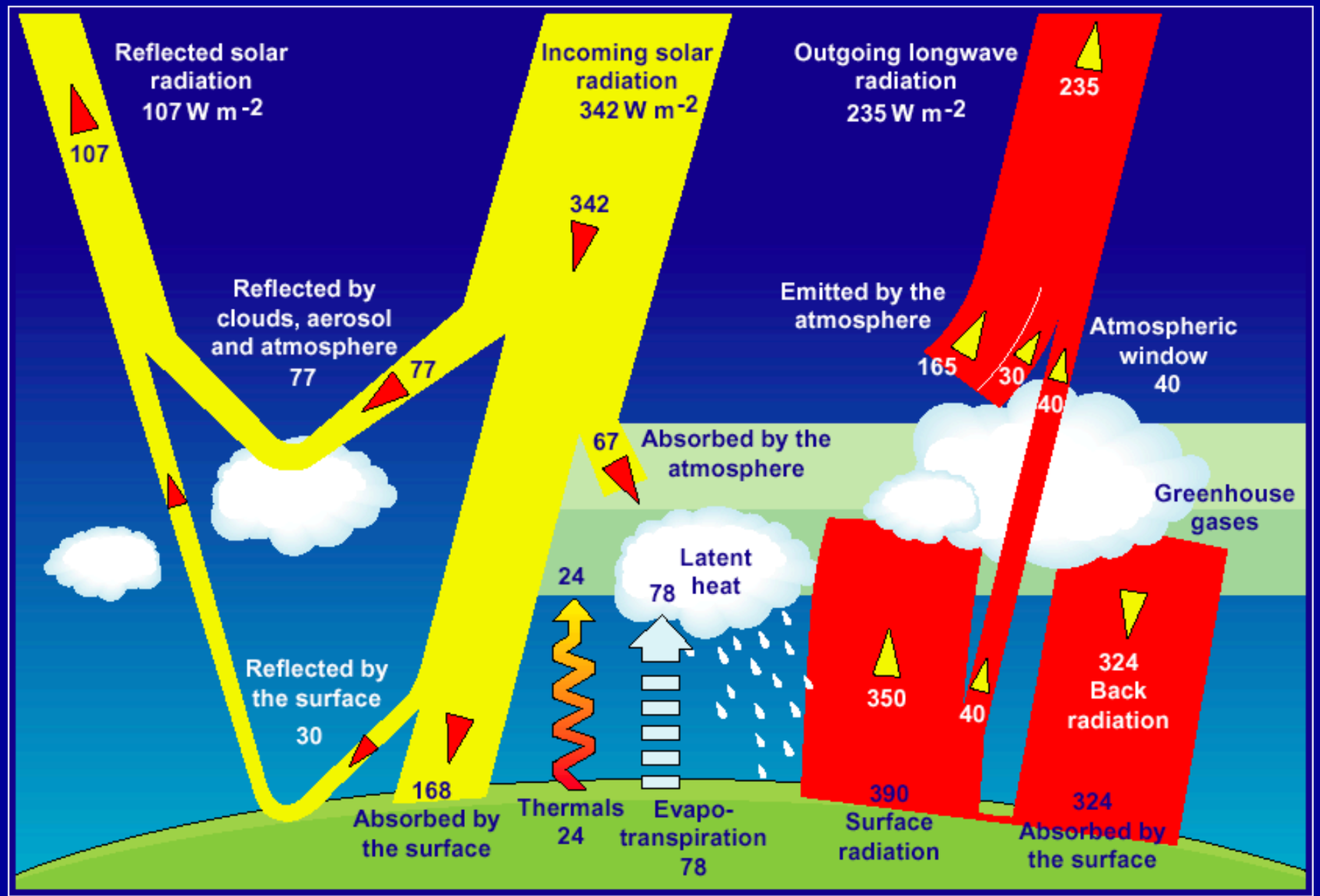


Where is global warming going?



Global Radiation Budget

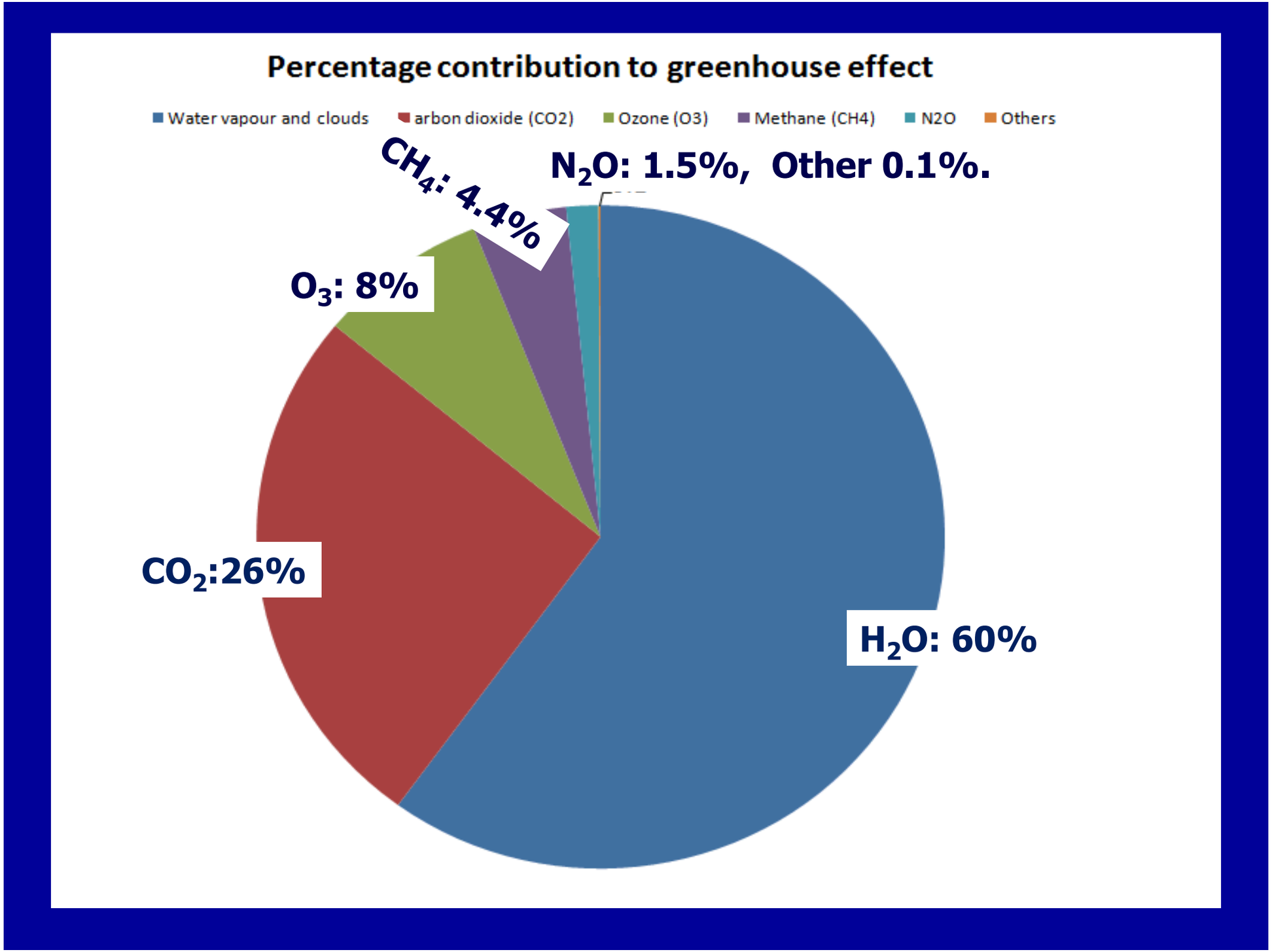
342-107 W m^{-2}
=235 W m^{-2}



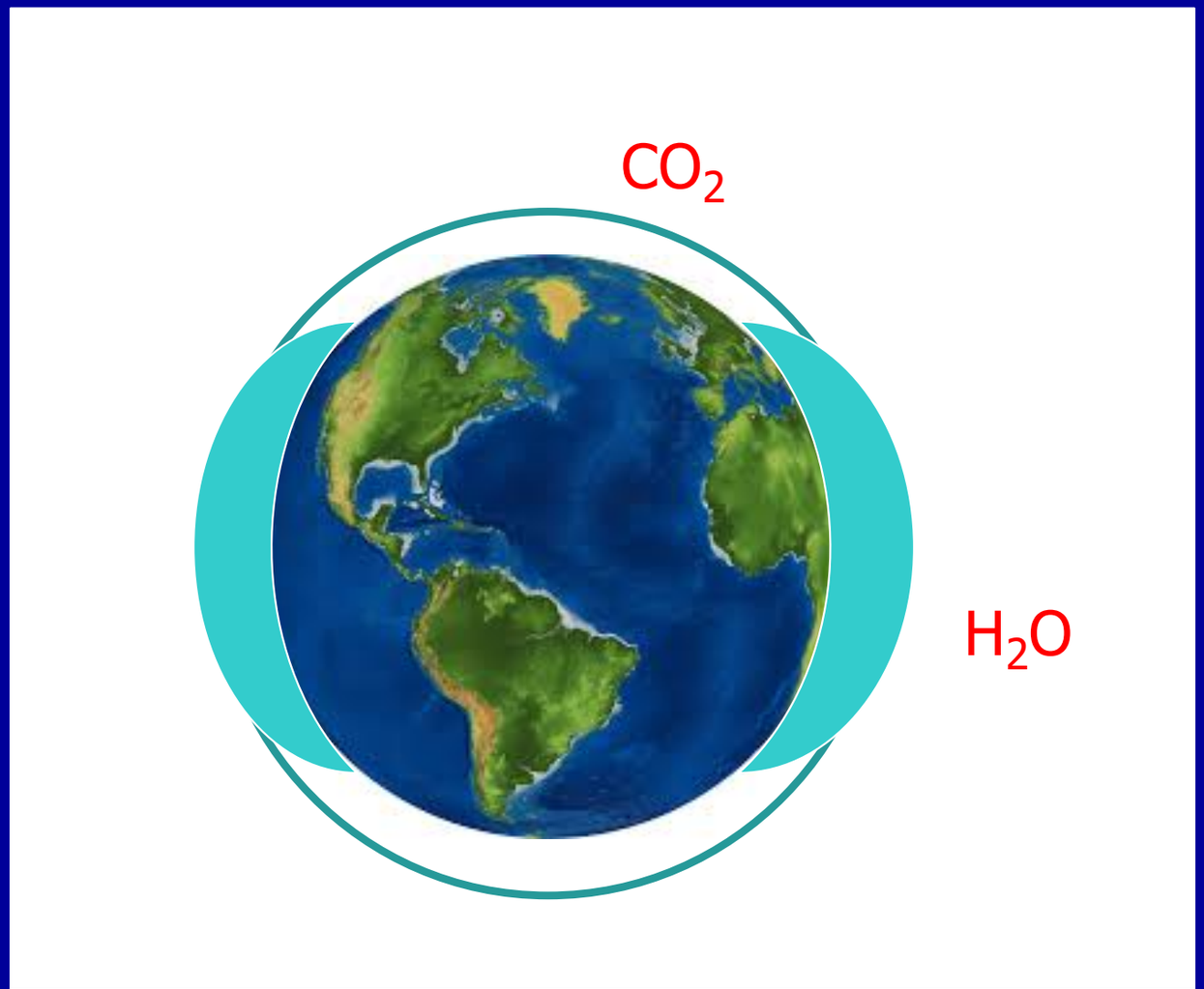
Climate changes with changes in the radiation balance

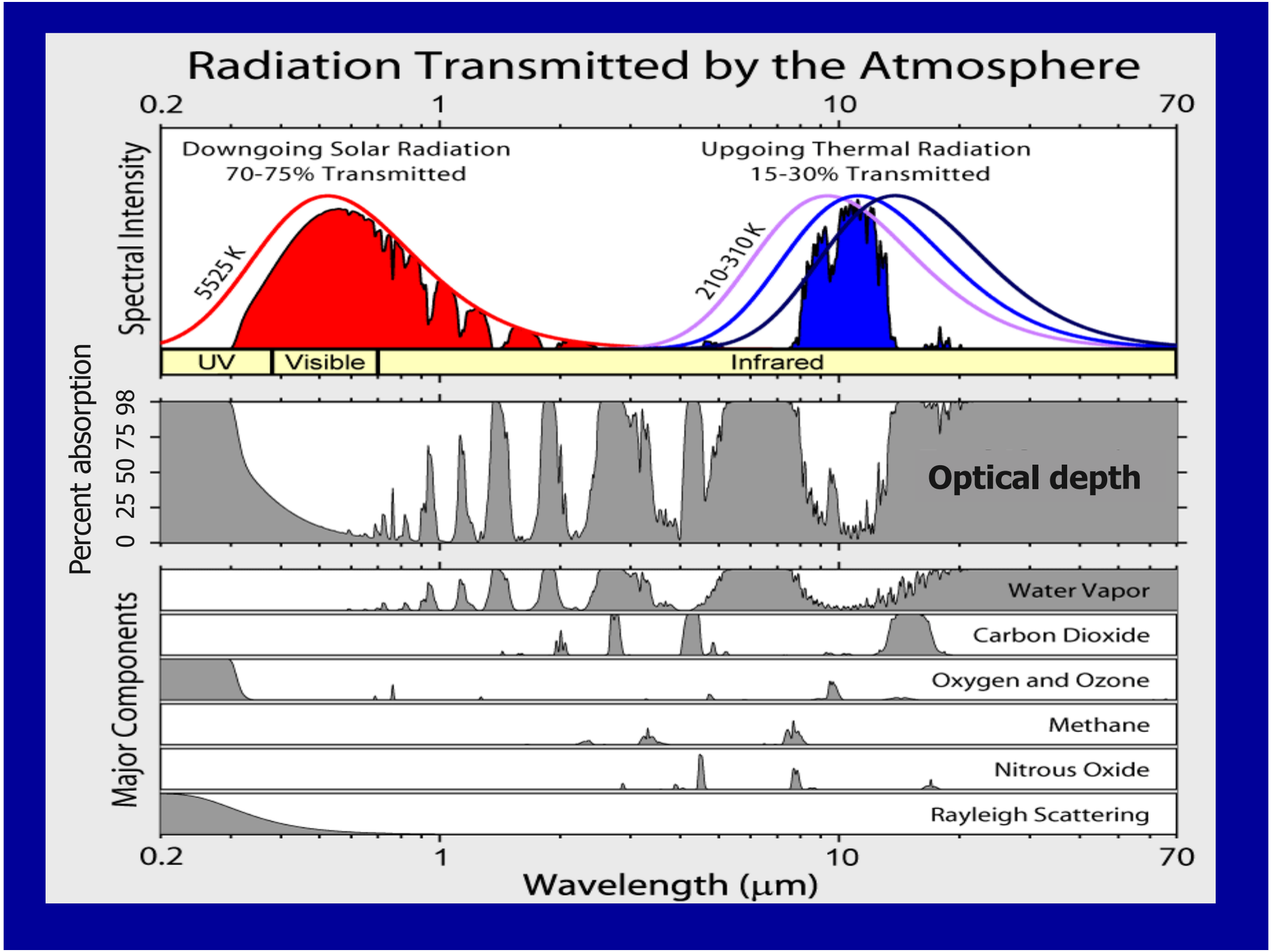
1. changing the incoming solar radiation
   - by changes in the Earth's orbit or in the Sun itself
   - will discuss when we talk about ice cores
2. changing the reflected fraction of solar radiation
   - the albedo can be changed, for example, by changes in ice coverage, aerosols or land cover
3. altering the heat energy radiated to space
   - by changes in greenhouse gas concentration
   - People or paleo

Local climate also depends on how heat is distributed by winds and ocean currents. All of these factors have played a role in past climate changes.


Percentage contribution to greenhouse effect
Water vapour and clouds
arbon dioxide (CO2)
Ozone (O3)
Methane (CH4)
N2O
Others
CH4: 4.4%
N2O: 1.5%, Other 0.1%.
O3: 8%
CO2:26%
H2O: 60%

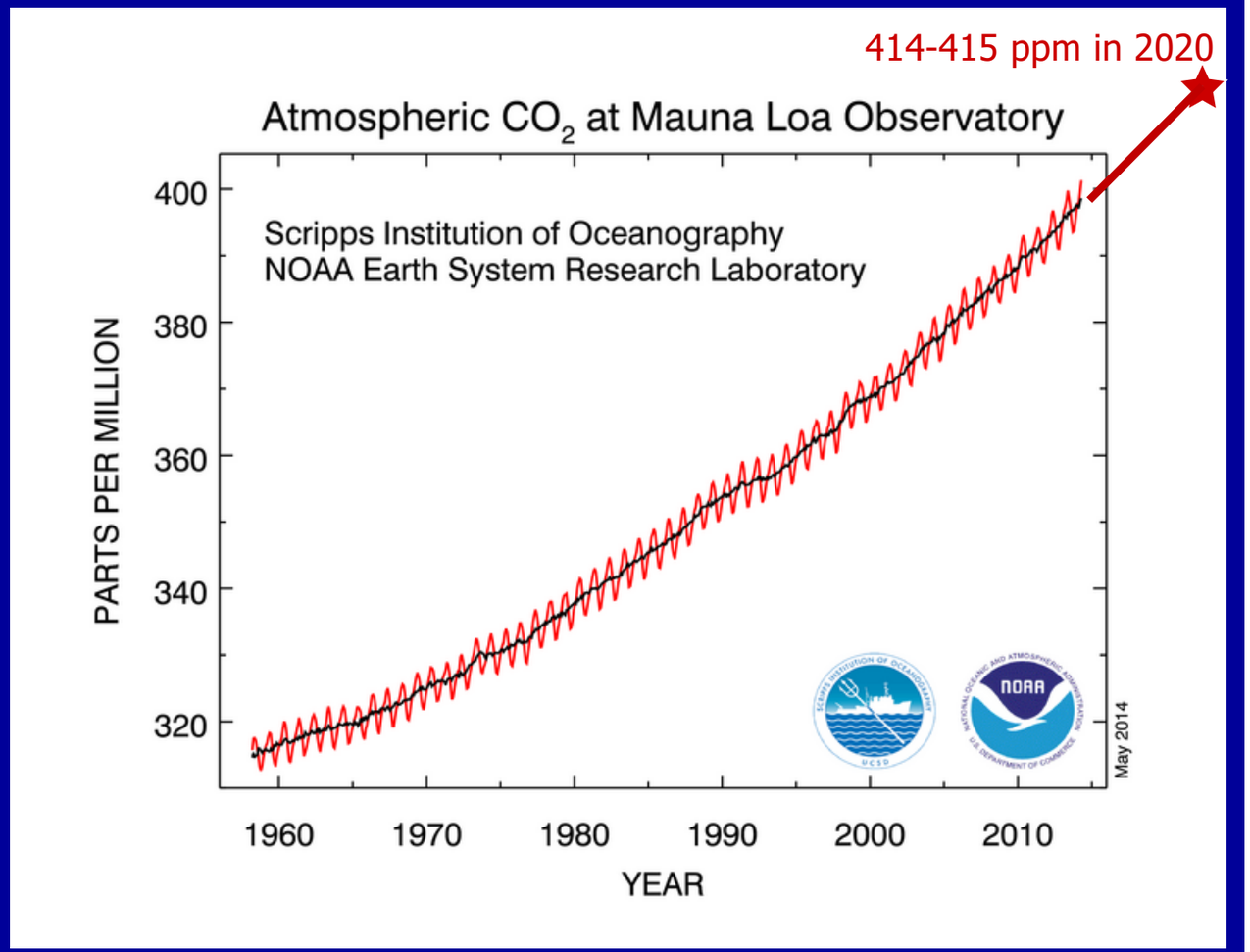
Distributions of Greenhouse gases



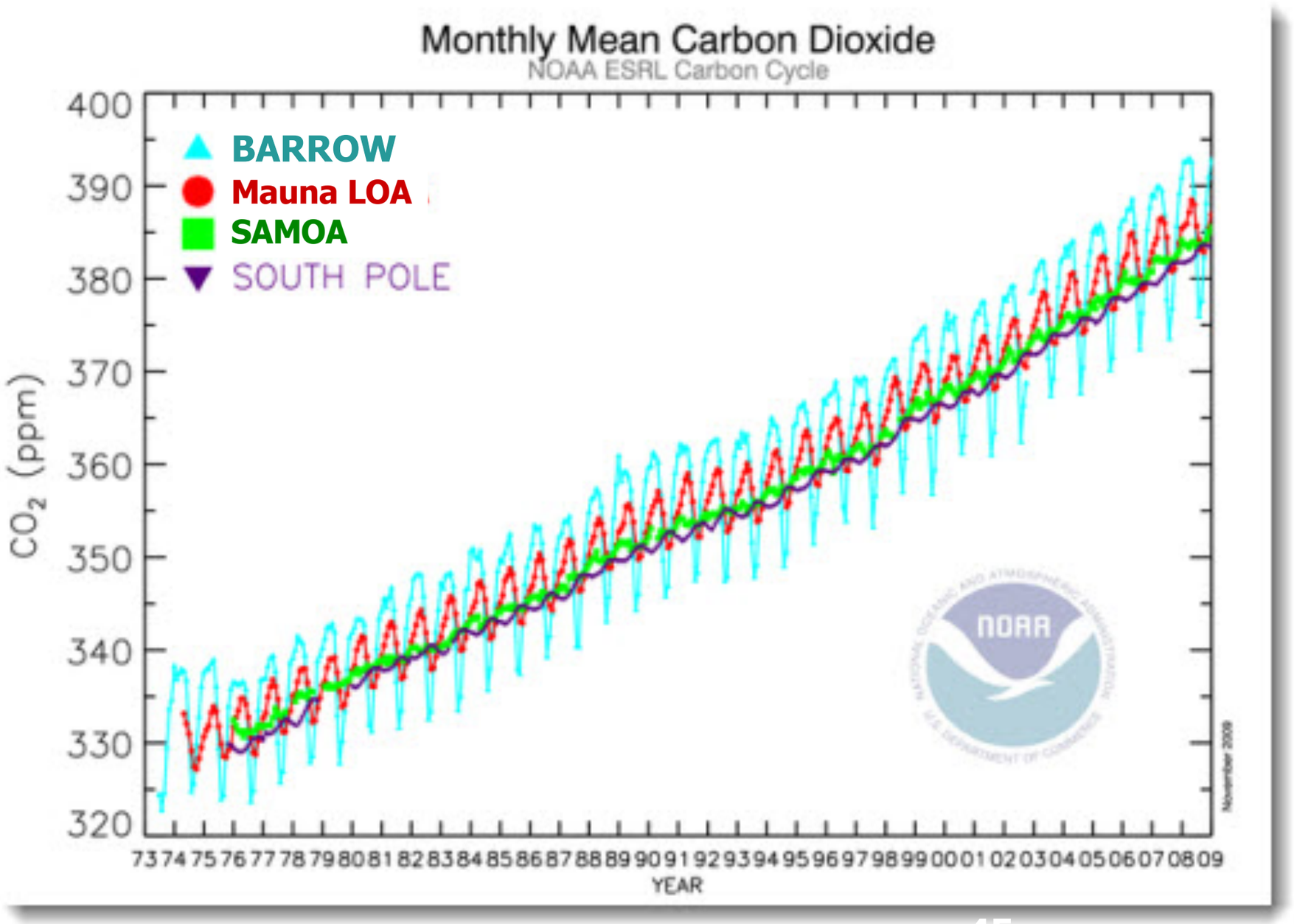

Radiation Transmitted by the Atmosphere
0.2
1
10
70
Spectral Intensity
Downgoing Solar Radiation
70-75% Transmitted
Upgoing Thermal Radiation
15-30% Transmitted
5525 K
210-310 K
UV
Visible
Infrared
Percent absorption
0 25 50 75 98
Optical depth
Major Components
Water Vapor
Carbon Dioxide
Oxygen and Ozone
Methane
Nitrous Oxide
Rayleigh Scattering
0.2
1
10
70
Wavelength (μm)

The Keeling curve

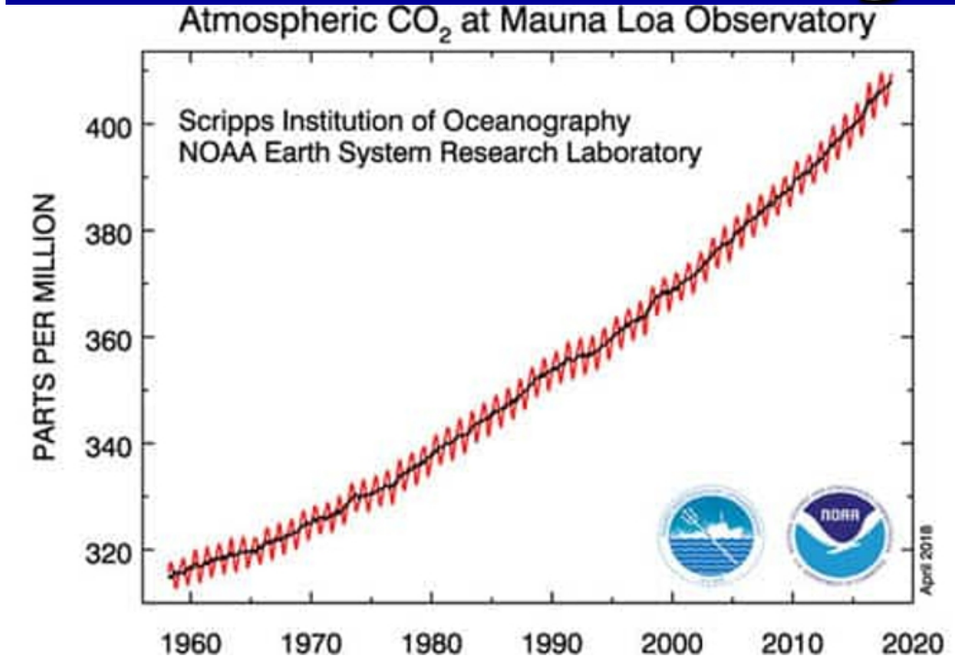
Charles David Keeling

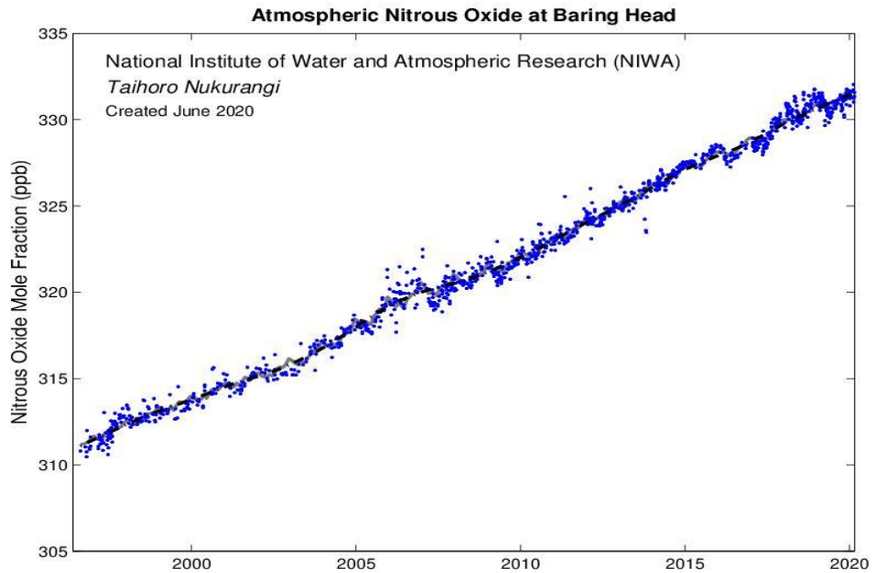


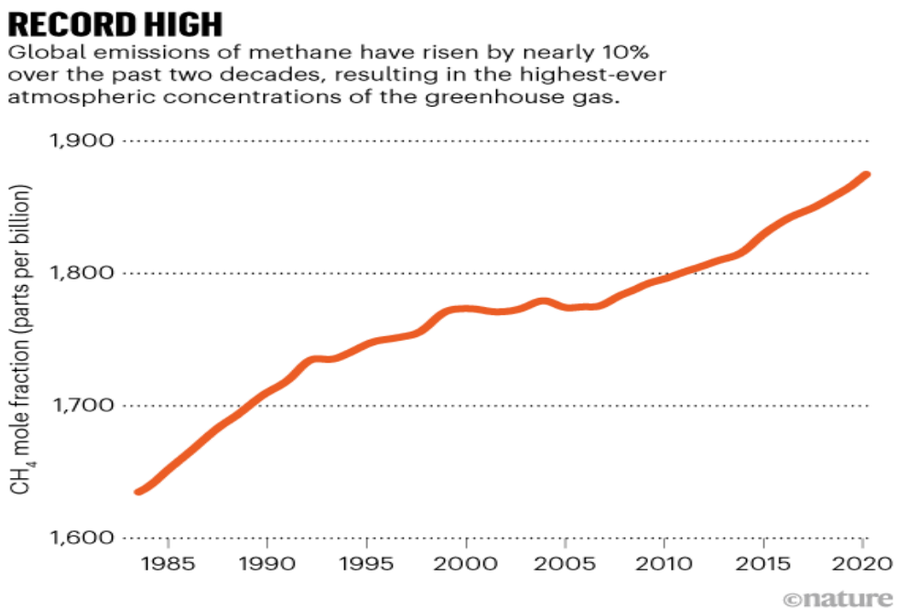
https://www.esrl.noaa.gov/gmd/ccgg/trends/

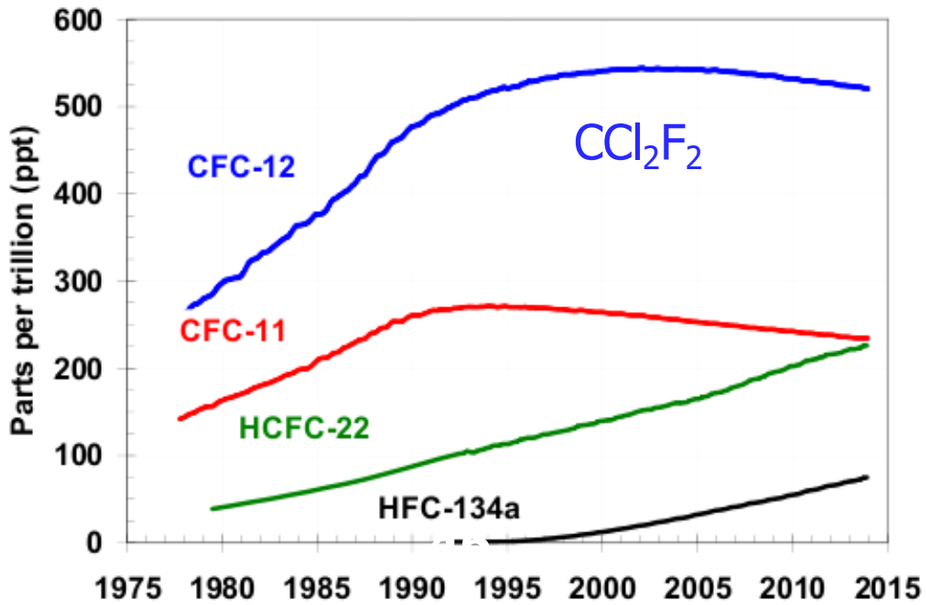

Monthly Mean Carbon Dioxide
NOAA ESRL Carbon Cycle
BARROW
Mauna LOA
SAMOA
SOUTH POLE
CO2 (ppm)
400
390
380
370
360
350
340
330
320
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09
YEAR
NOAA
November 2009

Greenhouse gas (GHG) trends










Making aerosols

Airborne Aerosols

Understanding anthropogenic effects on climate means understanding aerosols.

- Aerosols are micron scale particles consisting at least in part of solid material.
- Density of an aerosol particle: 1.0 g/cm^3 (for soot) to 2.6 g/cm^3 (for minerals).
- Natural aerosols:
  - salt (from seawater), natural terrestrial biomass burning, volcanic eruptions, windblown dust
- Man-made aerosols:
  - pollution from industrial production, engine exhaust, burning trash, etc.
- Density of aerosol particles varies a lot:
  - continent 2,300/cm^3 (windless desert), 3,000/cm^3 (clean air),
  - 50,000/cm^3 (polluted), 160,000/cm^3 (urban)
  - sea 1,000/cm^3 (clean), 300-600/cm^3 (cleanest)
  - Arctic 6,600/cm^3 (mostly soot); Antarctic desert 43/cm^3 (sulfate)

Airborne Aerosols

Where are they found?

In the air over oceans, deserts, mountains, forests, ice,
and every ecosystem in between

A billion tons of dust from the Sahara each year.

Small light particles stay in the atmosphere up to two weeks.

Volcanic ashes (small aerosols) rise in the atmosphere and can stay for 2 years.

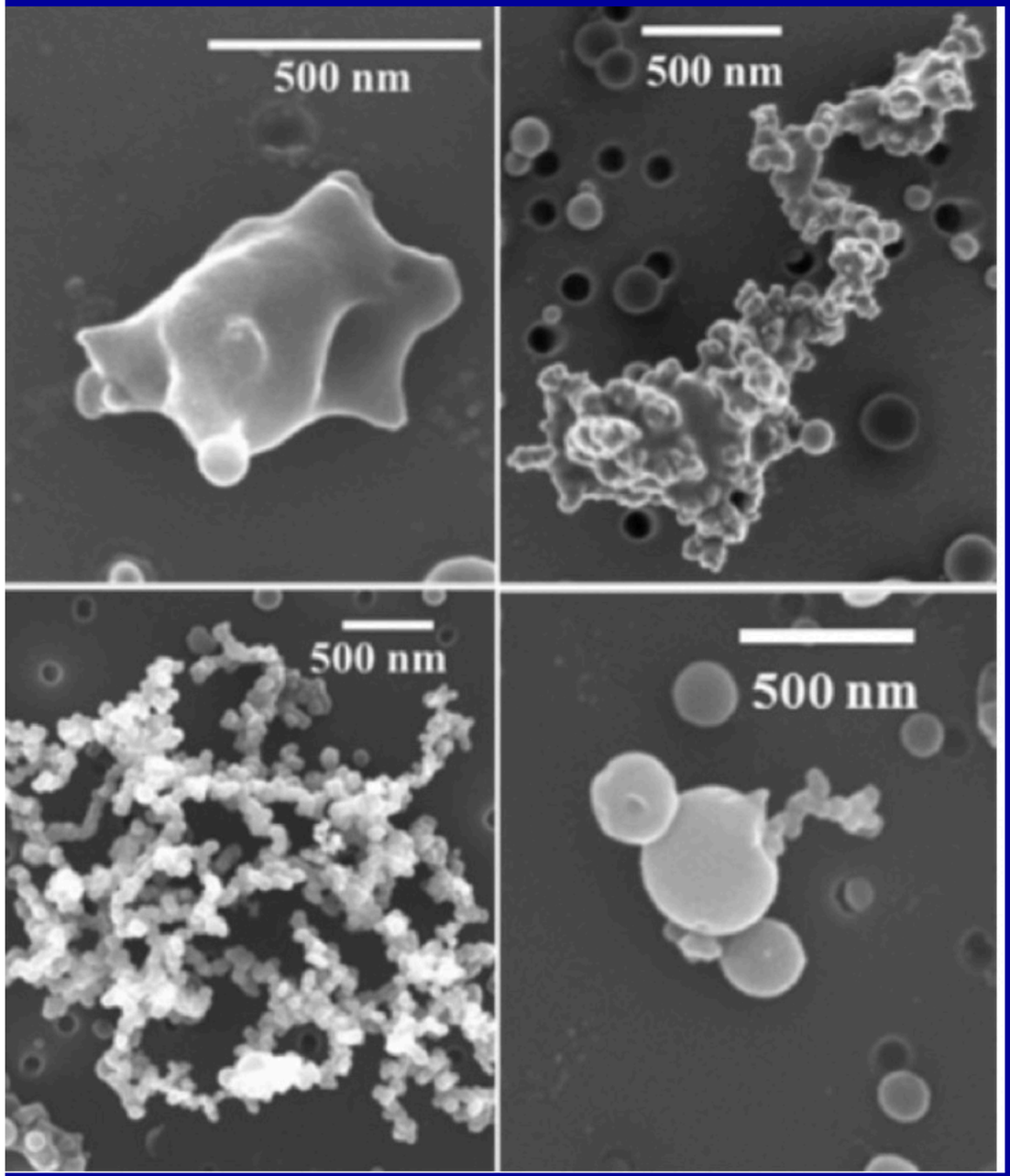
Some aerosols block sunlight & cause cooling (by decreasing surface sunlight)

Volcanic emissions
Black soot absorbs solar radiation causing warming

Anthropogenic sources now overwhelm natural sources over much of the globe

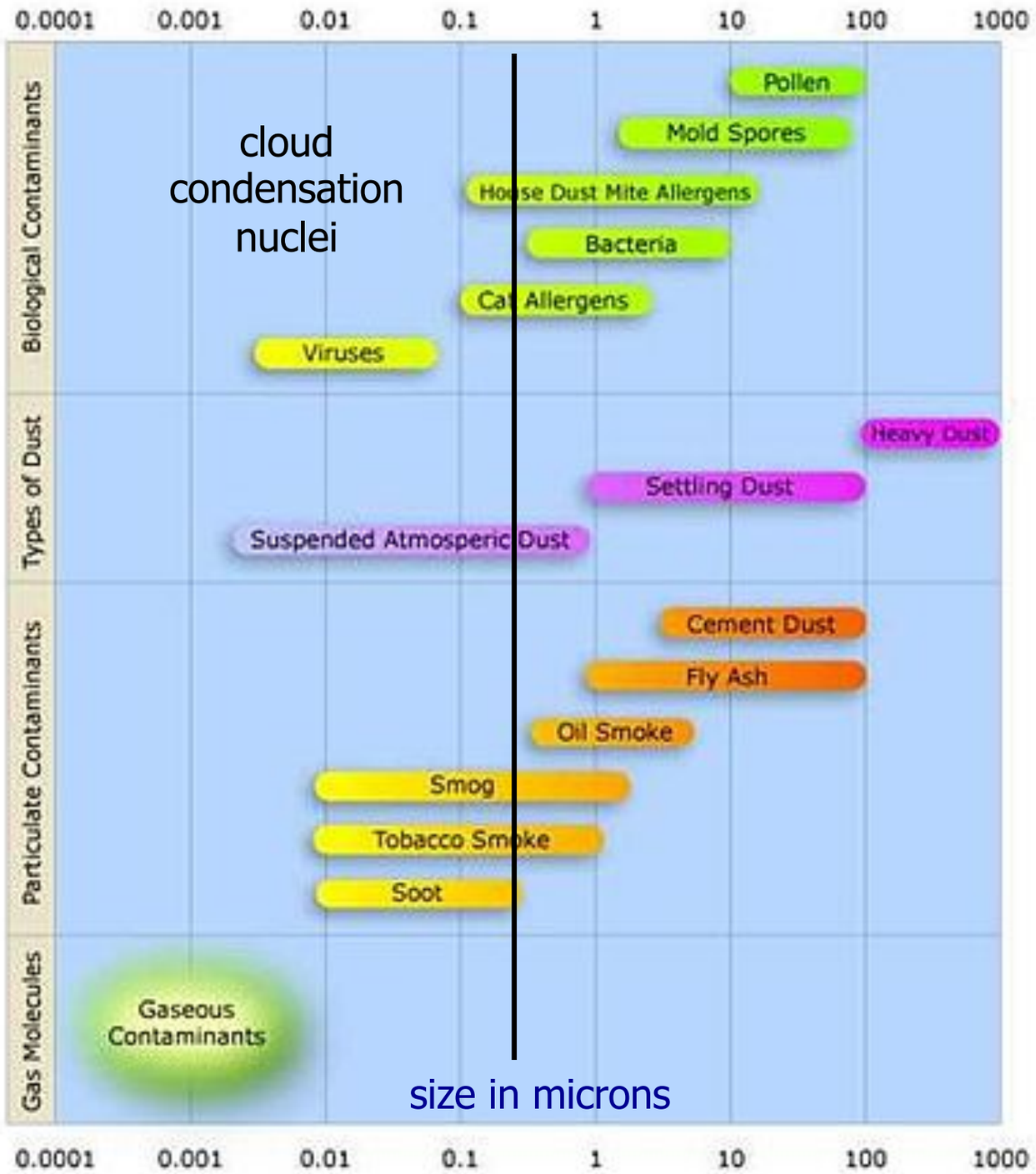
Some aerosols are important in nucleating raindrops

Other aerosols nucleate water droplets causing “shallow” / thin clouds or haze.



The enormous variety of aerosol shapes and chemical compositions is maddening to modelers

- These are soot particles, tarballs, etc. from a 2011 New Mexico fire



Aerosols

Cloud condensation nuclei <0.2 microns -> rain

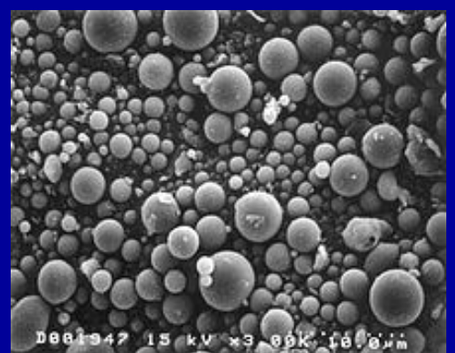
sea salt, dust, soot and, yes, viruses

Anthropogenic sources now overwhelm natural sources over much of the globe

Some cool (T down), some warm (T up); not well understood

Other examples

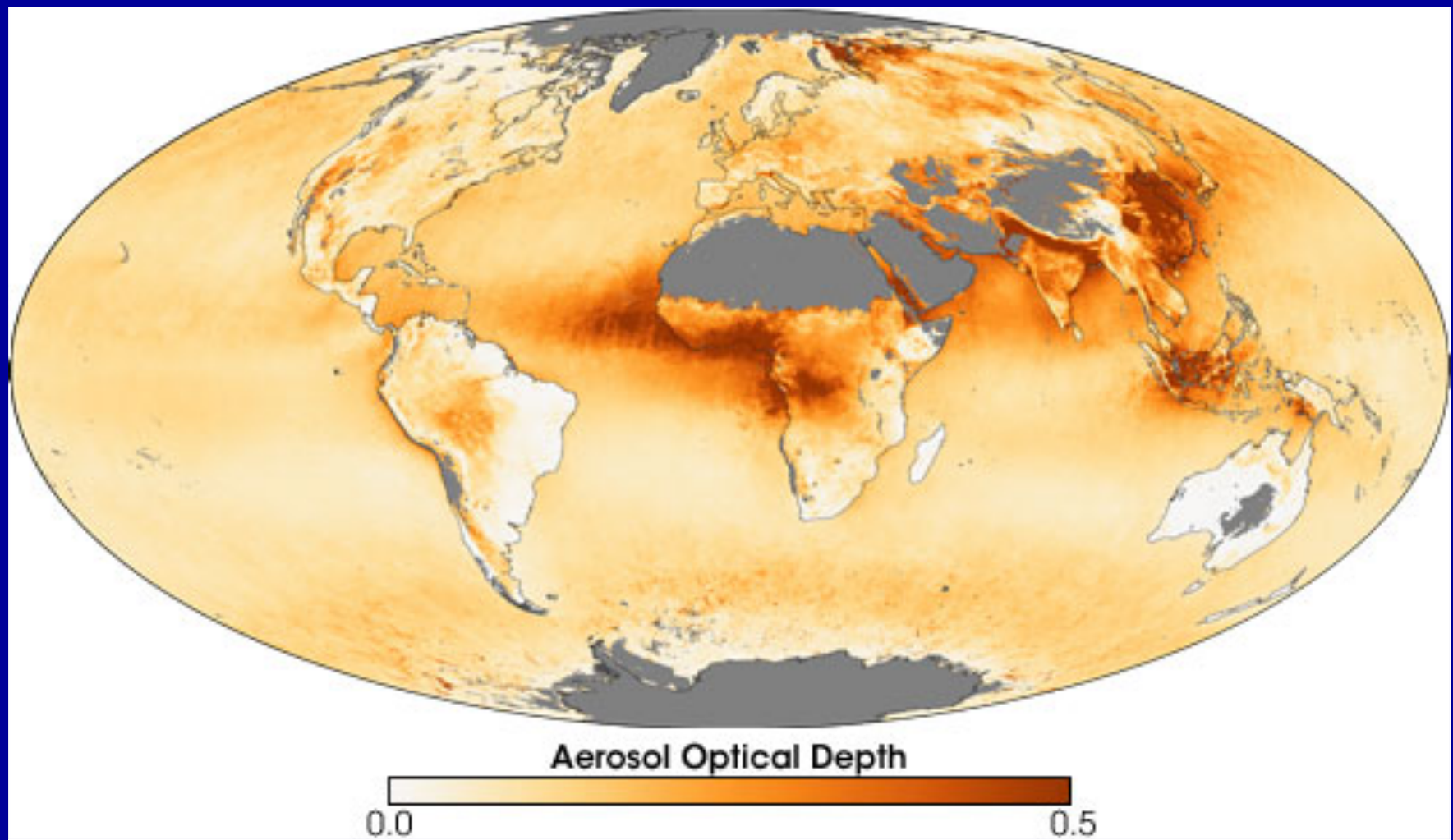
Mist and clouds are aerosols



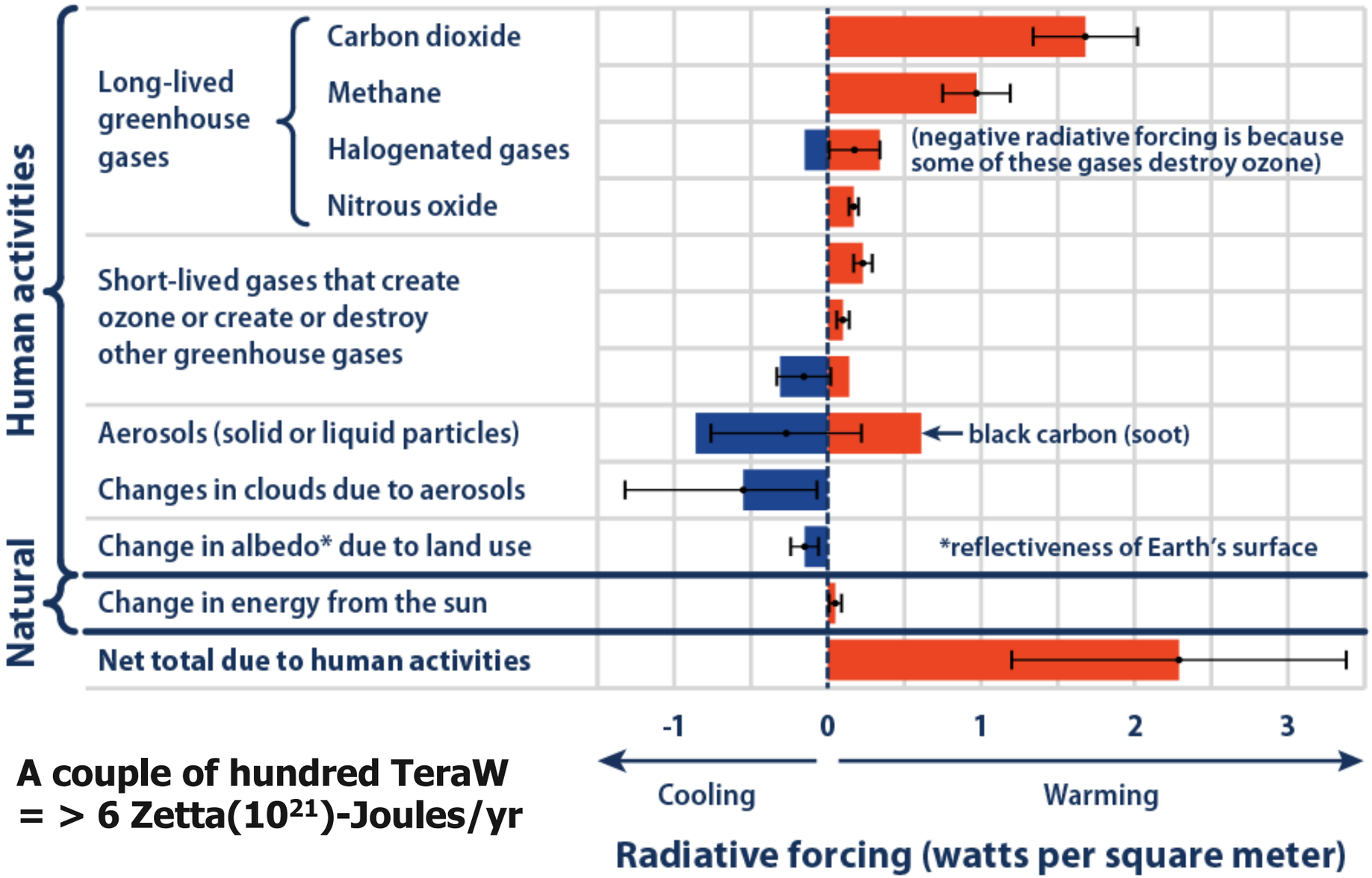
Fly ash from coal combustion.

Dust that quickly settles to the ground is not considered an aerosol.

Annual mean aerosol optical depth, 2006



τ = 1 => 63% transmittance; τ = 0.5 => 40% transmittance



A couple of hundred TeraW
= > 6 Zetta(10^{21})-Joules/yr

Conclusions

- Tracking temperature alone is only diagnostic (is the patient/planet sick?)
- Tracking CO_2 is getting closer to the cause
- H_2O stays the same; CO_2 is the big driver
- Aerosols and clouds limit our understanding and are the largest sources of error in modeling the climate.

What I discussed today

- Temperature in perspective
  - Like taking a patient's temperature
- Energy and heat (infrared radiation)
- Trapping of heat by the atmosphere
  - How the disease works
- Greenhouse gases, especially CO_2 & H_2O
  - CO_2 is kind of like the viral load
- Aerosols, clouds and other climate drivers
  - Doctor's tools