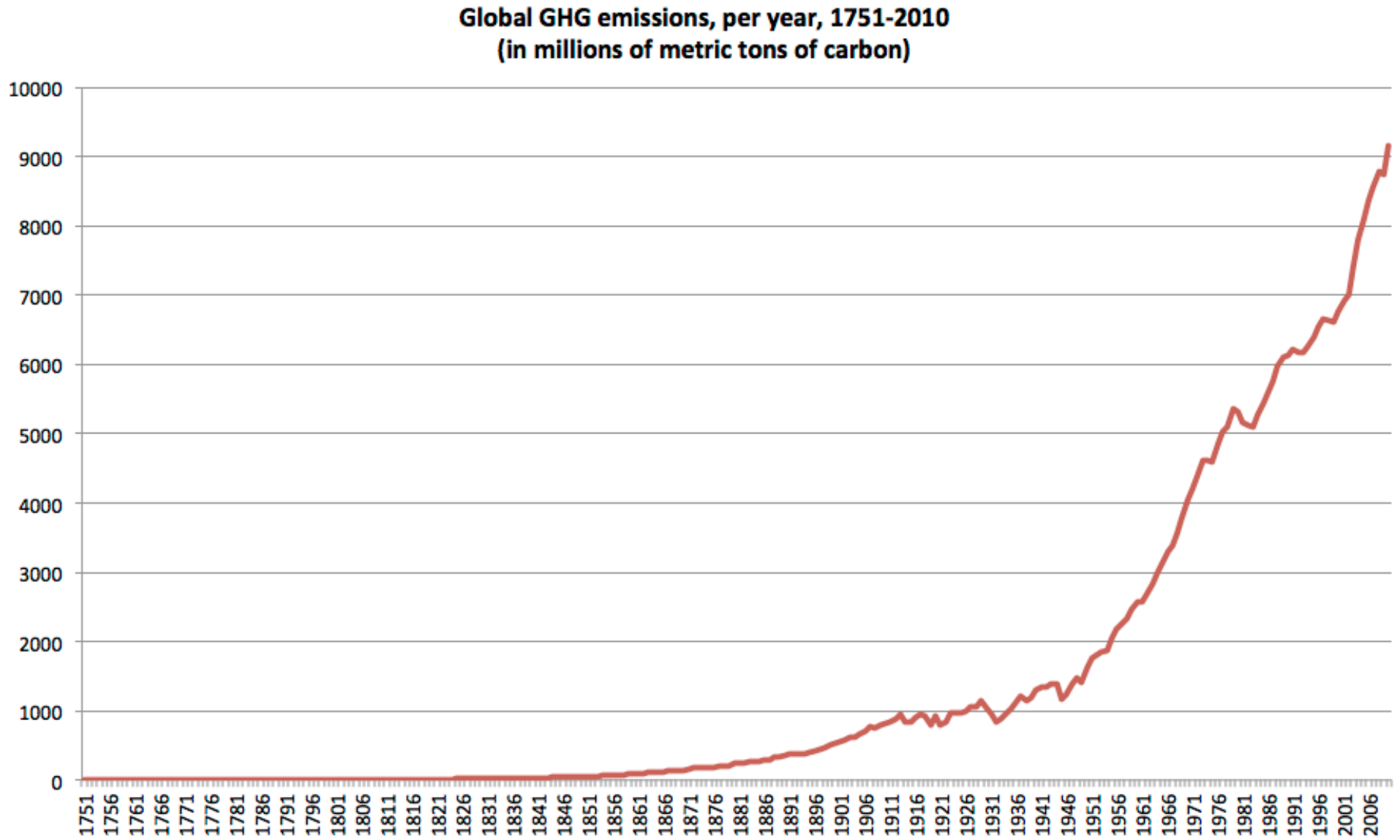
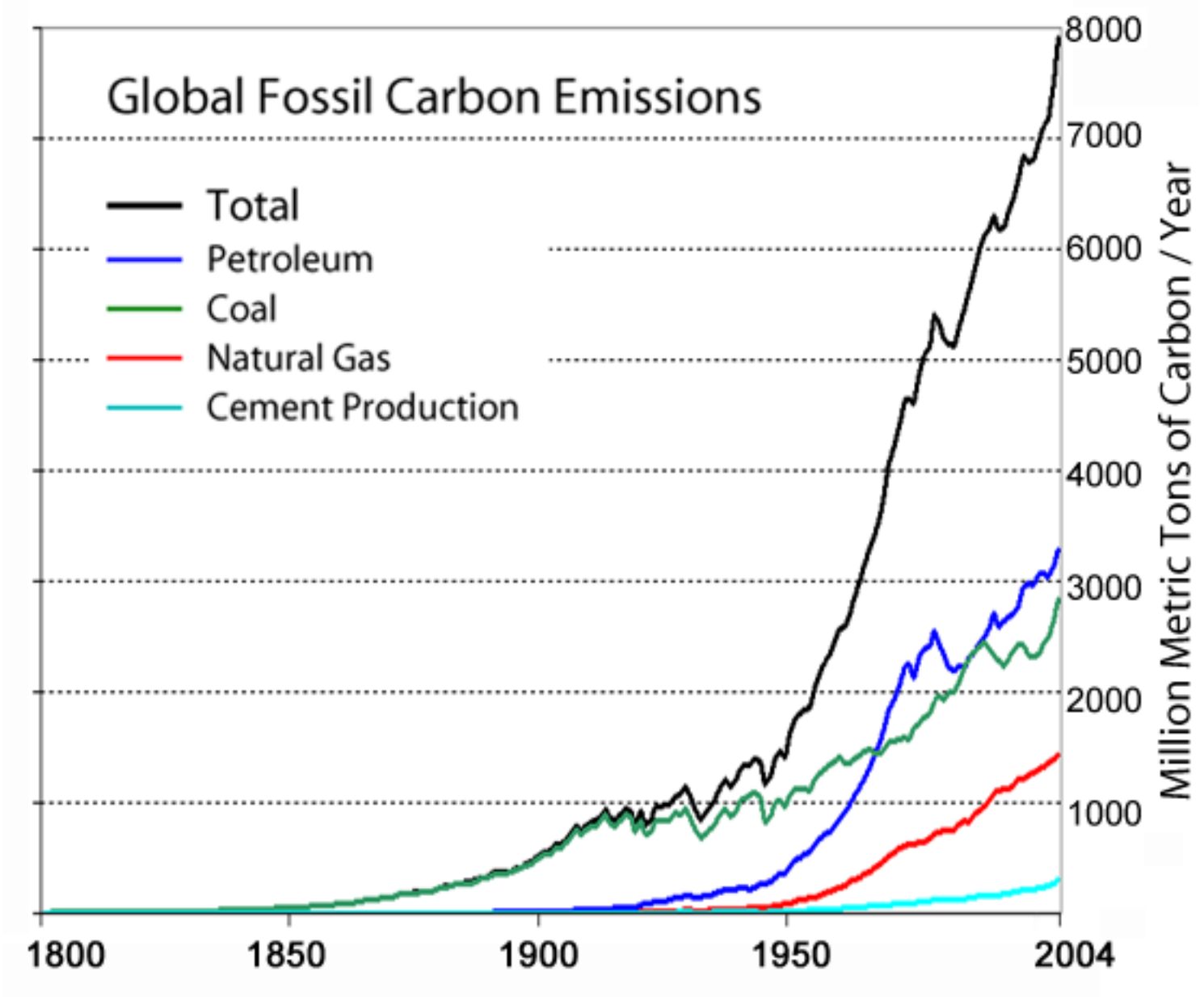
Emissions

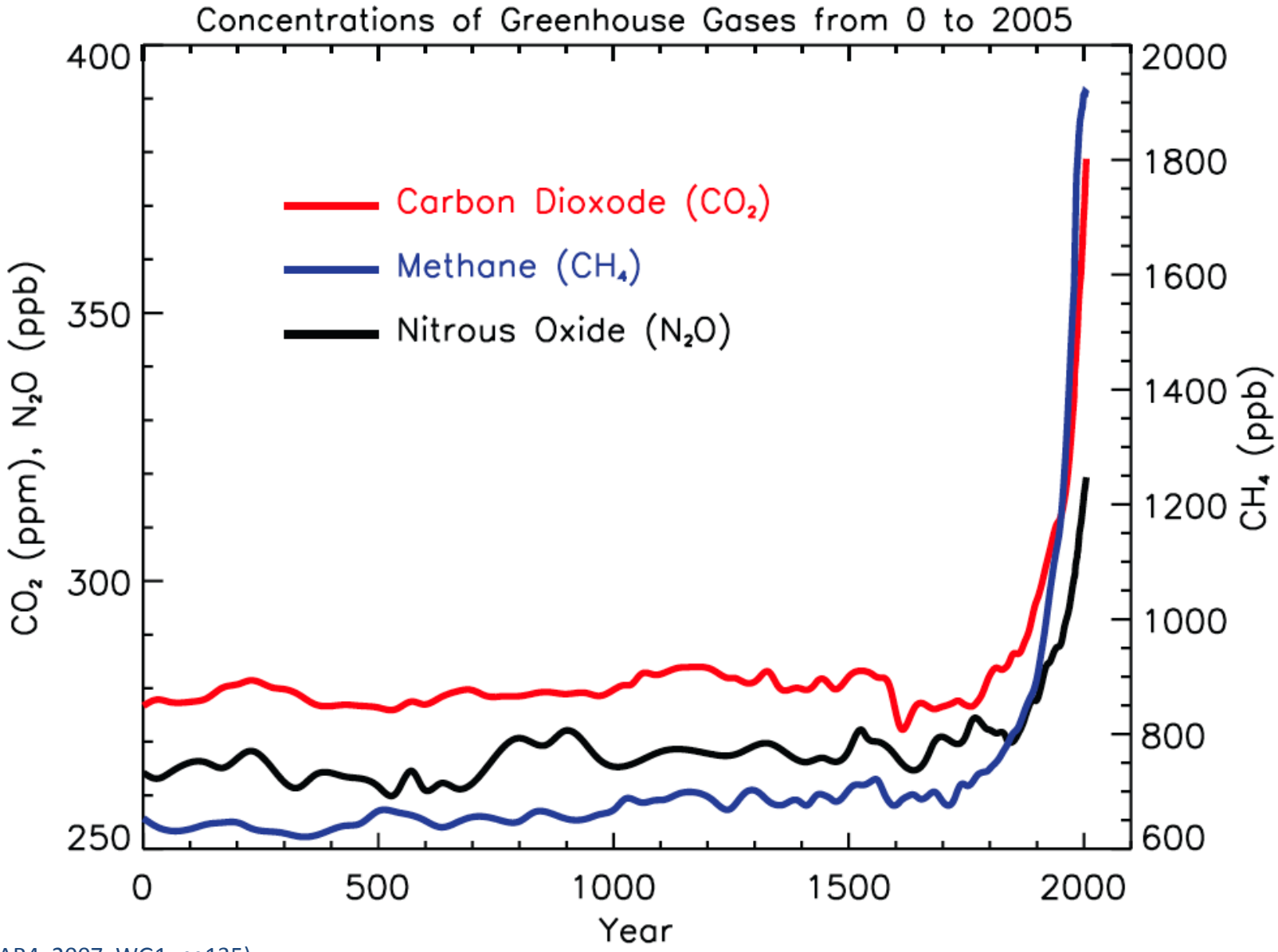

Global GHG emissions, per year, 1751-2010
(in millions of metric tons of carbon)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1751
1756
1761
1766
1771
1776
1781
1786
1791
1796
1801
1806
1811
1816
1821
1826
1831
1836
1841
1846
1851
1856
1861
1866
1871
1876
1881
1886
1891
1896
1901
1906
1911
1916
1921
1926
1931
1936
1941
1946
1951
1956
1961
1966
1971
1976
1981
1986
1991
1996
2001
2006

Where the Emissions Come From



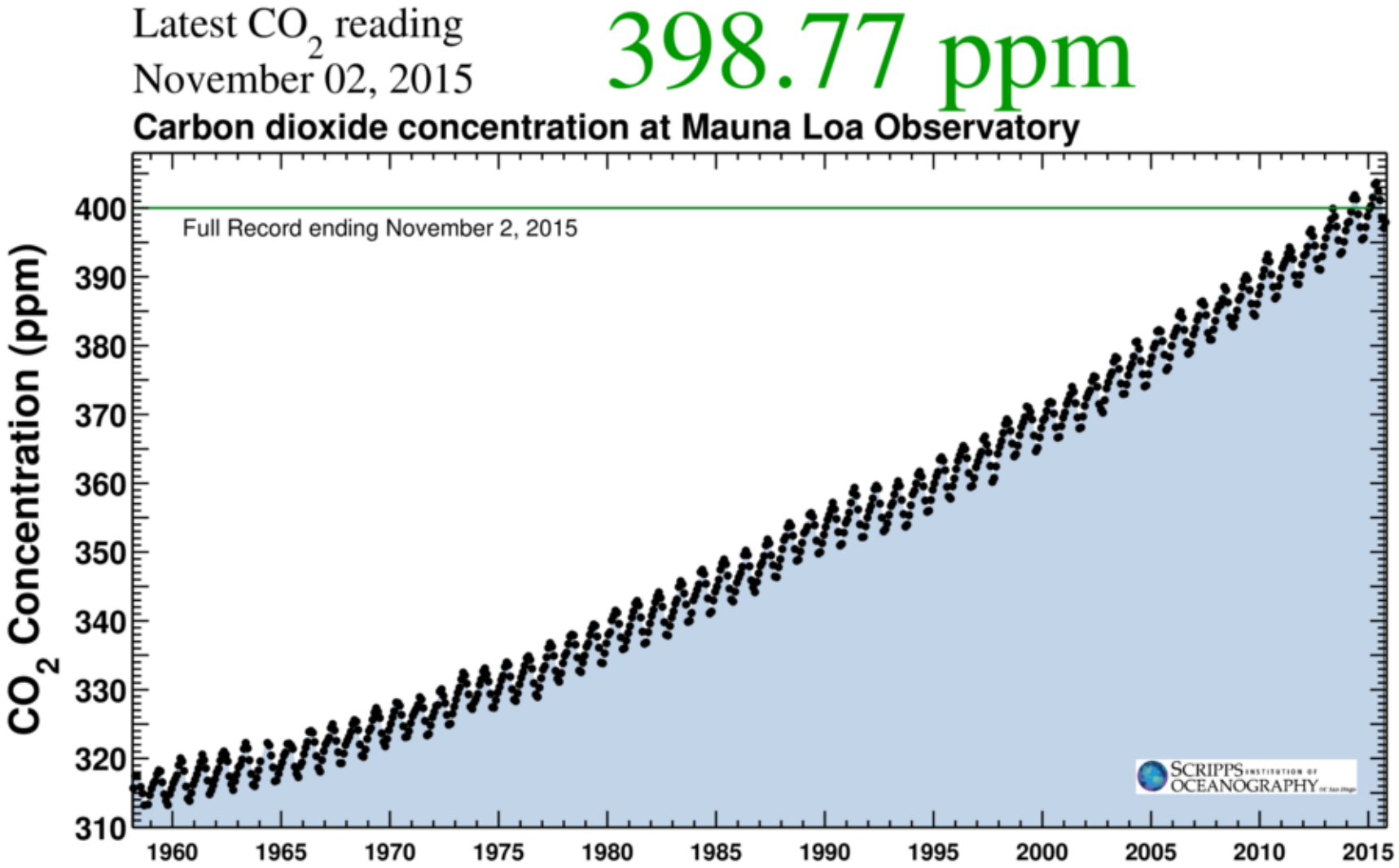
source: wikipedia

Greenhouse Gas Concentrations



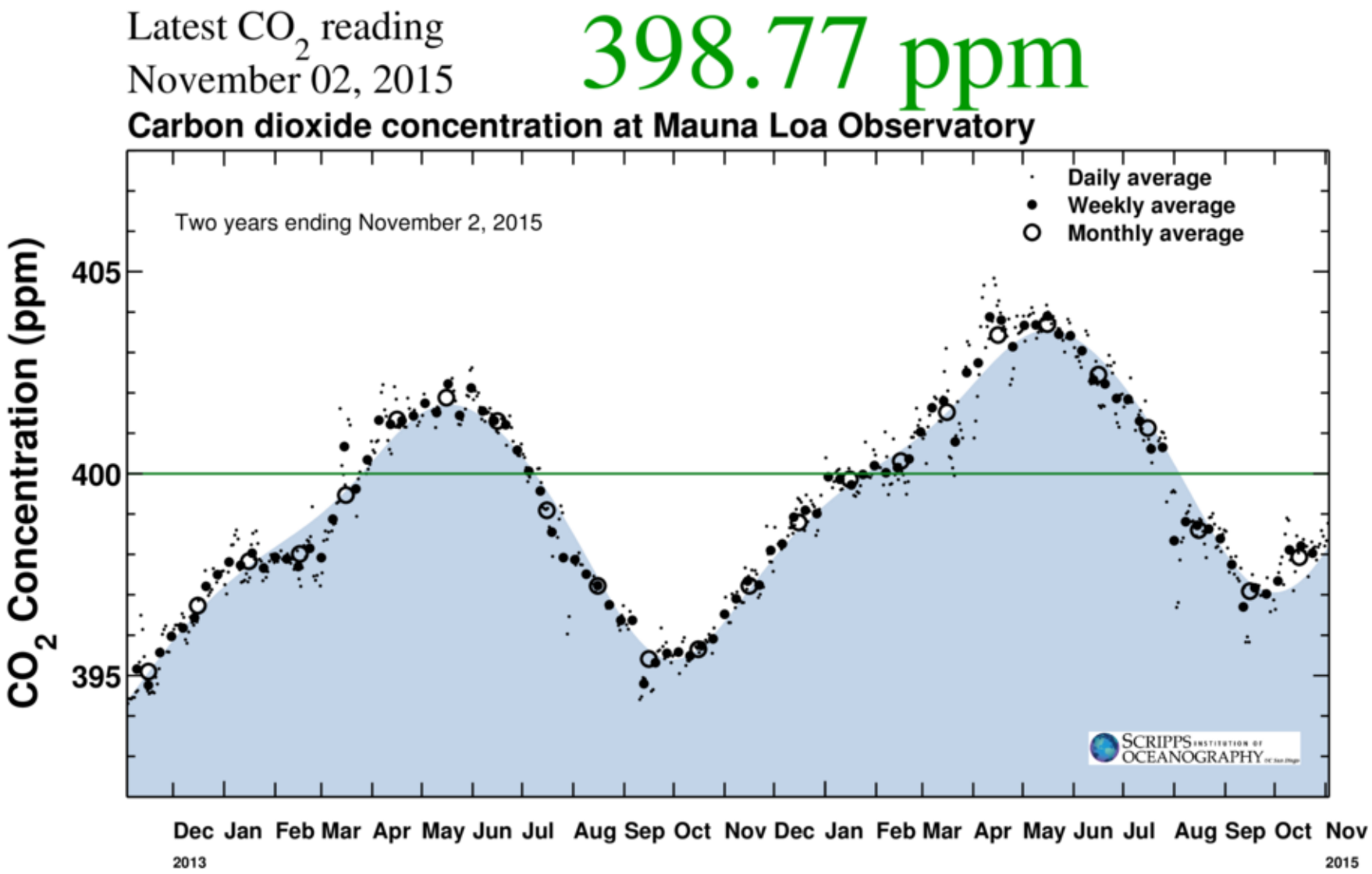
(Source: IPCC AR4, 2007, WG1, pg135)

The Keeling Curve



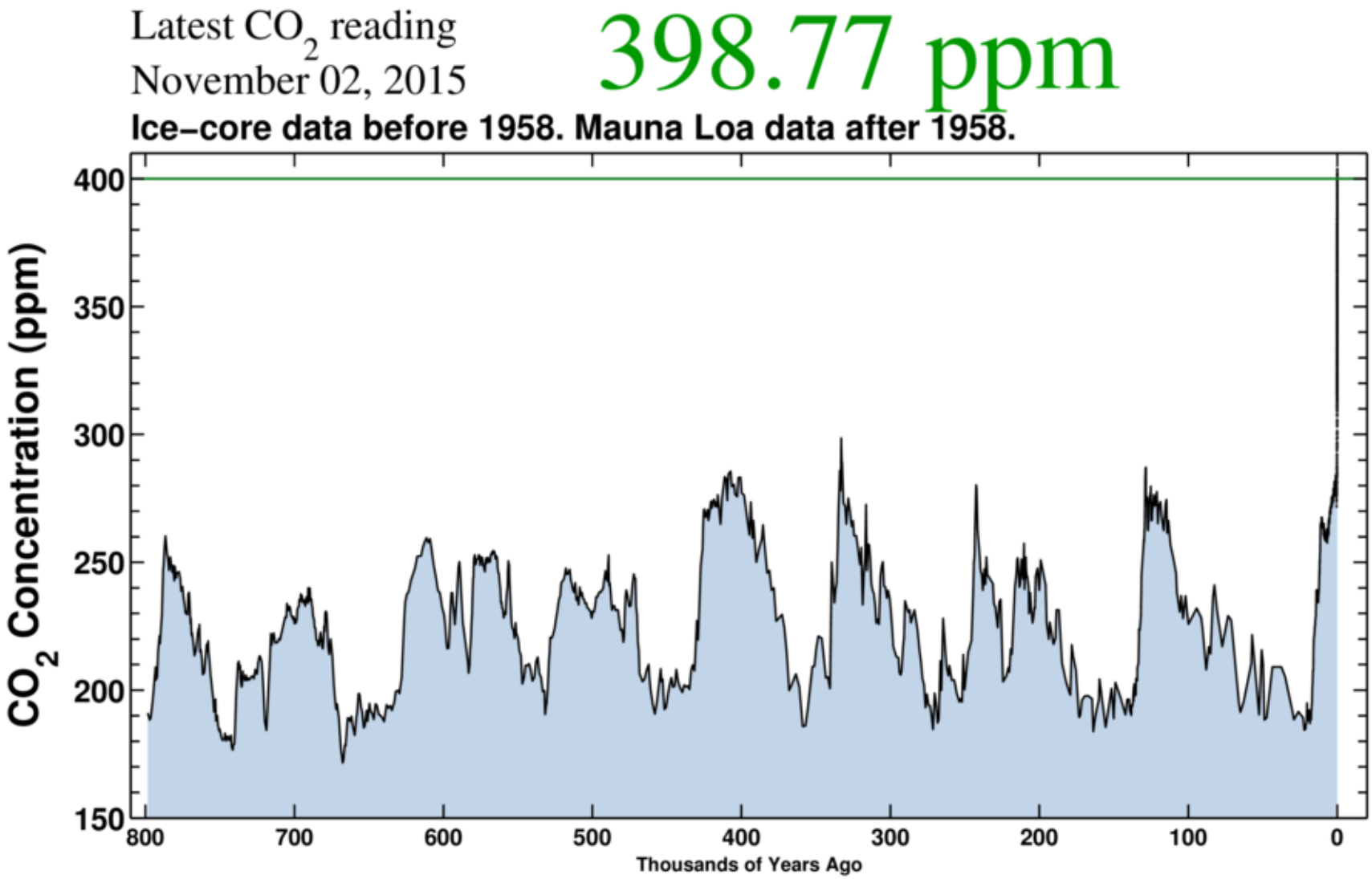
https://scripps.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-bluemoon/graphs/mlo_full_record.png

Last two years of CO2 data…



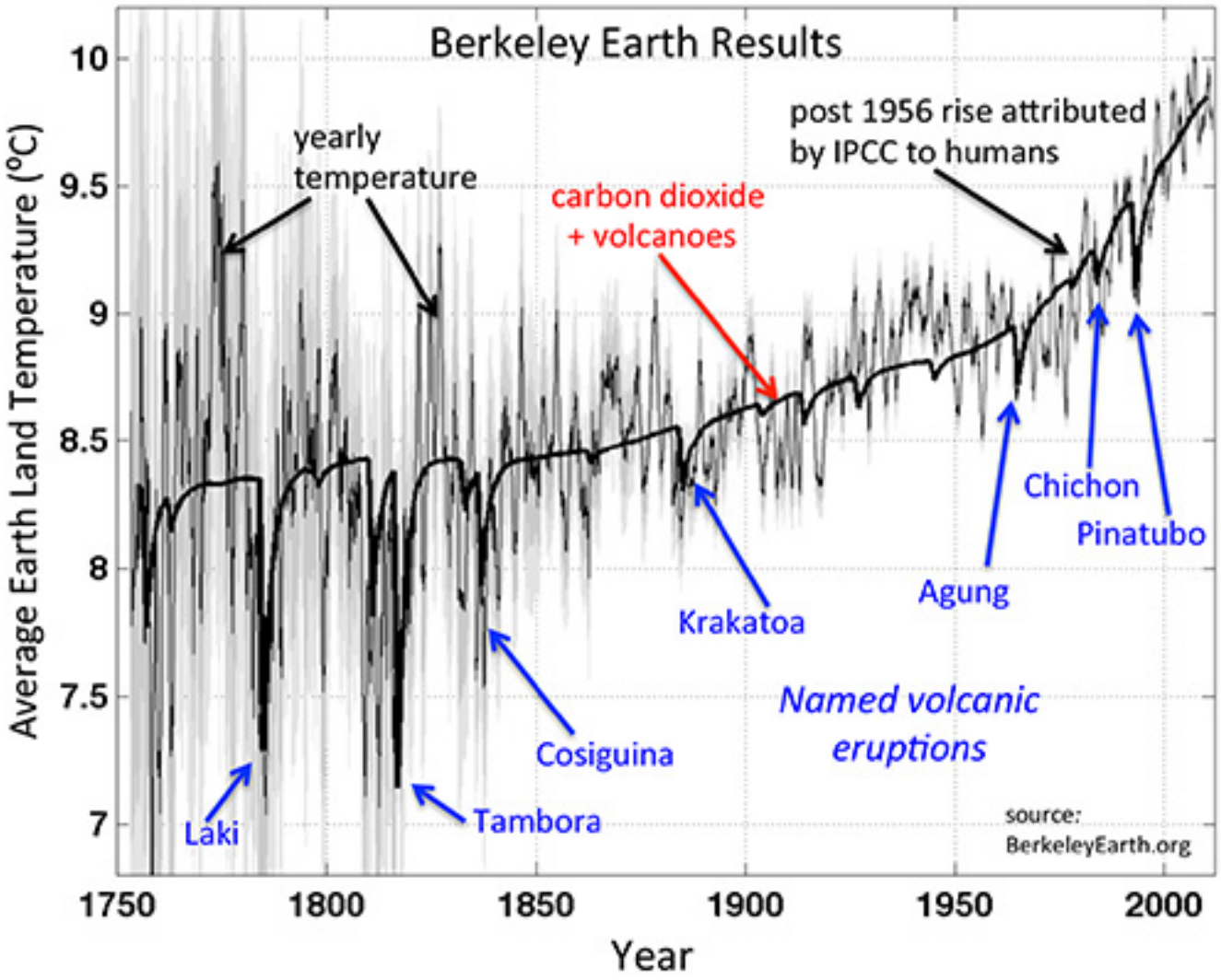
https://scripps.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-bluemoon/graphs/mlo_two_years.png

And if you zoom right out…



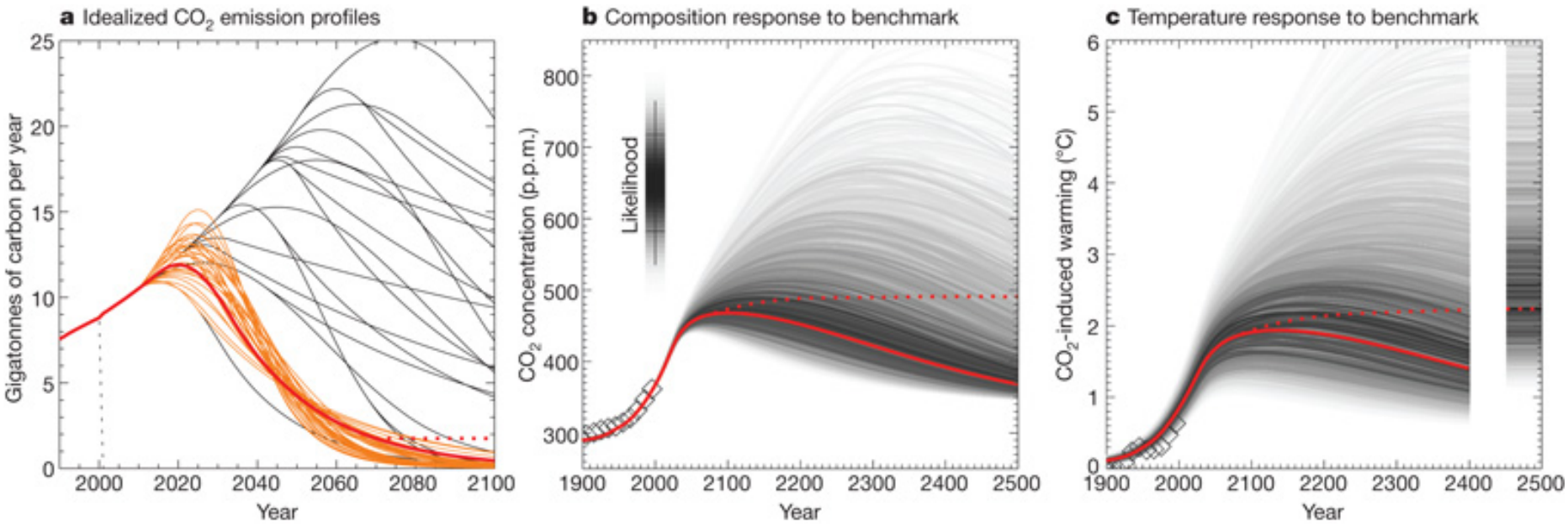
https://scripps.ucsd.edu/programs/keelingcurve/wp-content/plugins/sio-bluemoon/graphs/co2_800k.png

Surface Temperature Record



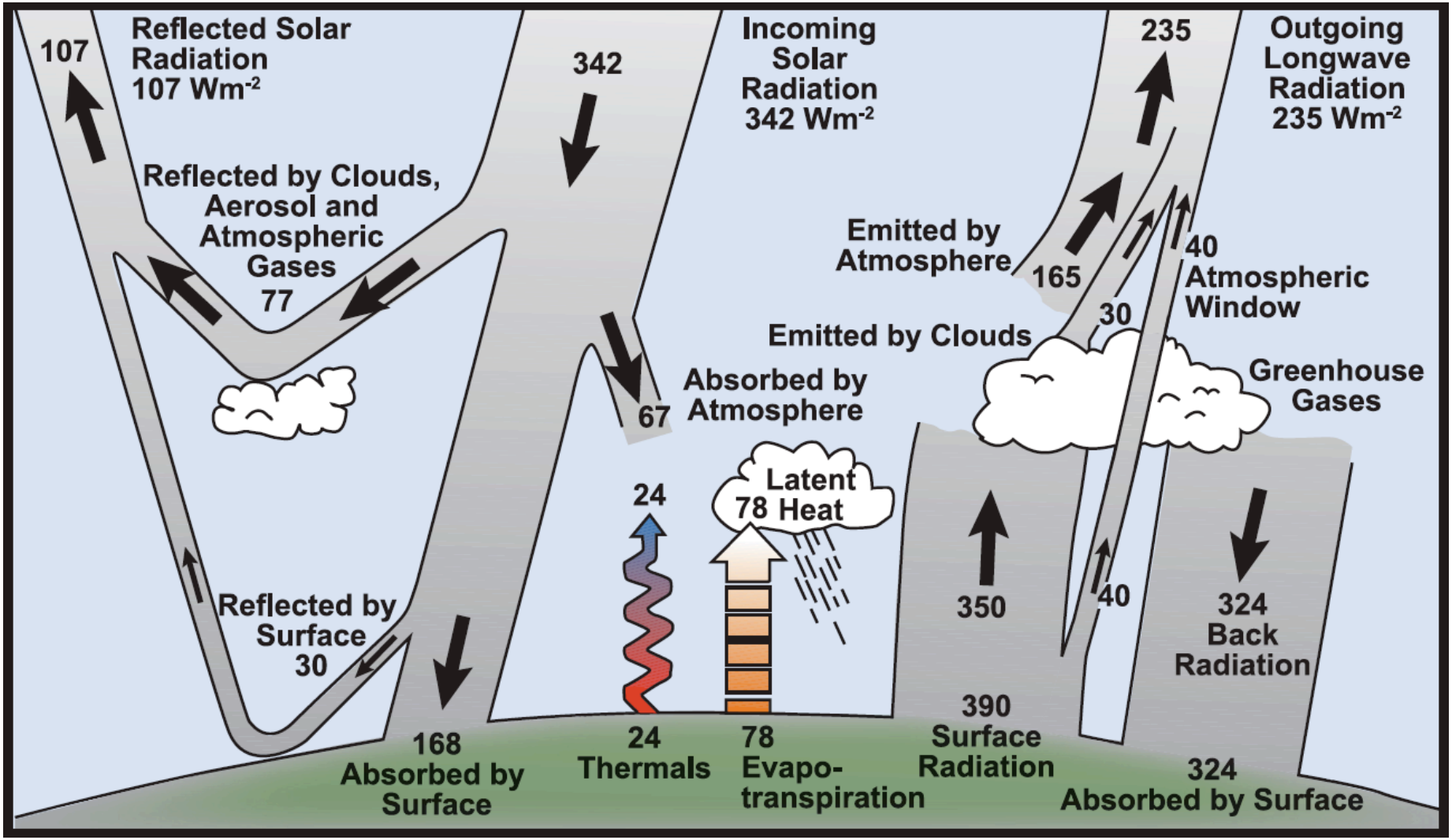
http://berkeleyearth.org/wp-content/uploads/2015/03/results-plot-volcanoes.jpg

Emissions Profile for ≤ 2ºC rise



MR Allen *et al. Nature* **458**, 1163-1166 (2009)

Basic Energy Balance Model



(Source: IPCC AR4, 2007, WG1, pg96)

Some Experiments to try…

1. Stop the rotation of the earth. What happens to the storms? Why?
2. Remove the land-masses. What happens to the gulf stream?
3. Remove the ice at the poles. What happens to polar temperatures? Why?
4. Remove all CO2 from the atmosphere. How much colder is the earth? Why? What happens if you leave it running?
5. Erupt a whole bunch of volcanoes all at once. What happens? Why?
   How long does the effect last? Does it depend on how many volcanoes?
6. Remove all human activity. How long does it take for the greenhouse gases to return to the levels they were at before the industrial revolution? Why?
7. Change the tilt of the earth's axis a bit. What happens to seasonal variability? Why? Can you induce an ice age? If so, why?
8. Move the earth a little closer to the sun. What happens to temperatures? How long do they take to stabilize? Why that long?
9. Burn all the remaining (estimated) reserves of fossil fuels all at once. What happens to temperatures? Sea levels? Polar ice?
10. Set up the earth as it was in the last ice age. How much colder are global temperatures? How much colder are the poles? Why the difference? How much colder is it where you live?
11. Melt all the ice at the poles (by whatever means you can). What happens to the coastlines near where you live? Over the rest of your continent? Which country loses the most land area?
12. Keep CO2 levels constant at the level they were at in 1900, and run a century-long simulation. What happens to temperatures? Now try keeping aerosols constant at 1900 levels instead. What happens? How do these two results compare to what actually happened?

A very simple climate model

Incoming solar radiation = Outgoing blackbody radiation

$$(1-a)S\pi r^2 = 4\pi r^2 \varepsilon \sigma T^4$$

albedo of the earth

solar radiation

radius of the earth

emissivity of the earth

Stefan-Boltzmann constant

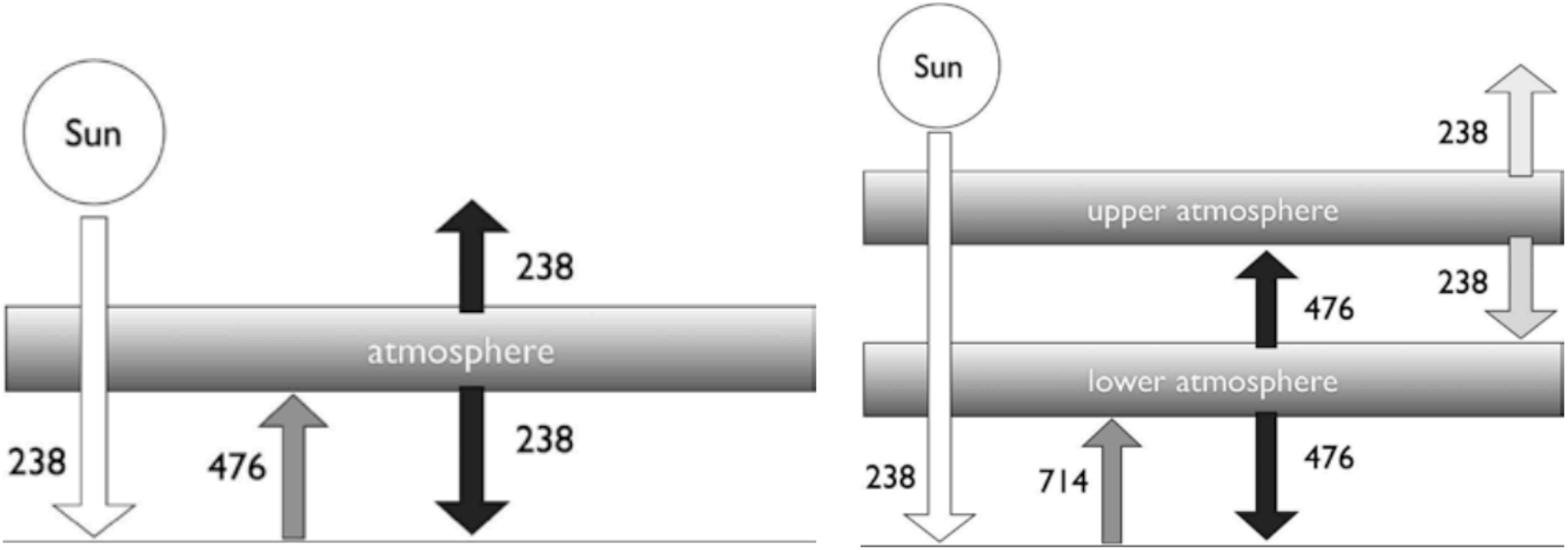
temperature of the earth's surface

Solving for temperature, you get:

$$T = \sqrt[4]{\frac{(1-a)S}{4\varepsilon\sigma}} \approx 12\,^{\circ}C$$

Source: http://en.wikipedia.org/wiki/Climate_model

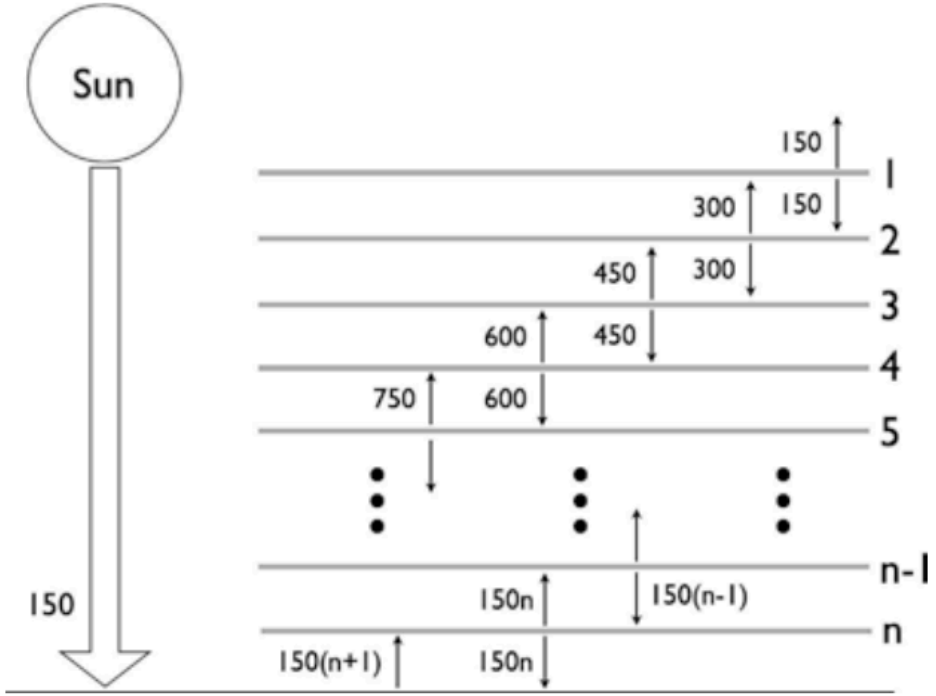
Simple 1 & 2 Layer Models



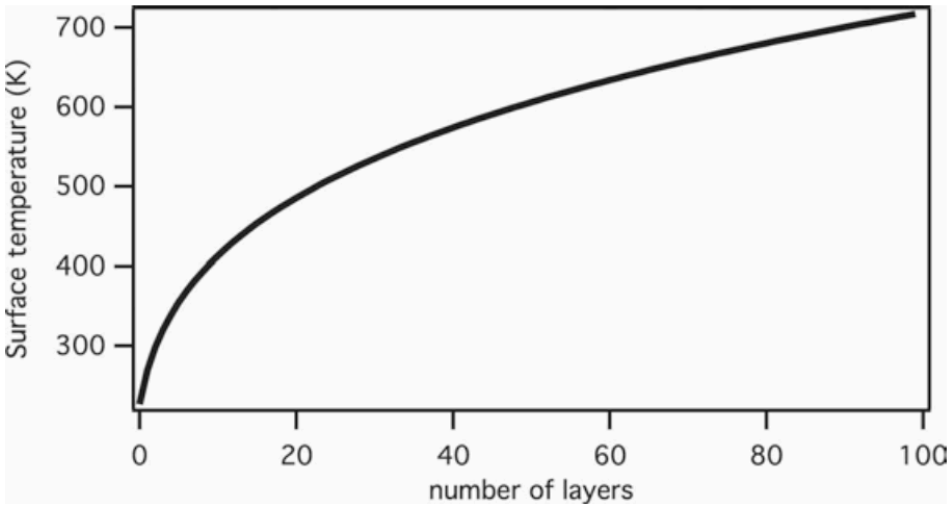
Note: Assumes “an atmosphere layer” = enough GHG to complete block all infra-red

Source: Dessler, Introduction to Modern Climate Change, chapter 4

Generalizing to more layers



$$T = \sqrt[4]{\frac{(n+1)S(1-\alpha)}{4\sigma}}$$



Source: Dessler, Introduction to Modern Climate Change, chapter 4

How well does the model work?

Table 4.1 Data on the four inner planets in our solar system

Planet	Solar constant (W/m^2)	Albedo	Observed surface temperature (K)	Inferred n
Mercury	10,000	0.1	452	0.052
Venus	2,650	0.7	735	82
Earth	1,360	0.3	289	0.65
Mars	580	0.15	227	0.22

Source: Dessler, Introduction to Modern Climate Change, chapter 4