Carbon Dioxide

The elixir of life!

Source: Watts up with That

[redacted]

Properties of Carbon Dioxide (CO_2)

- It is a colourless and odourless gas
- It is a non-condensing gas
- It is slightly toxic
- It is denser than air
- It has a density of 1.977 g/ml
- It is soluble in water, solubility decreases as temperature increases
- It forms a weak carbonic acid when dissolved in water

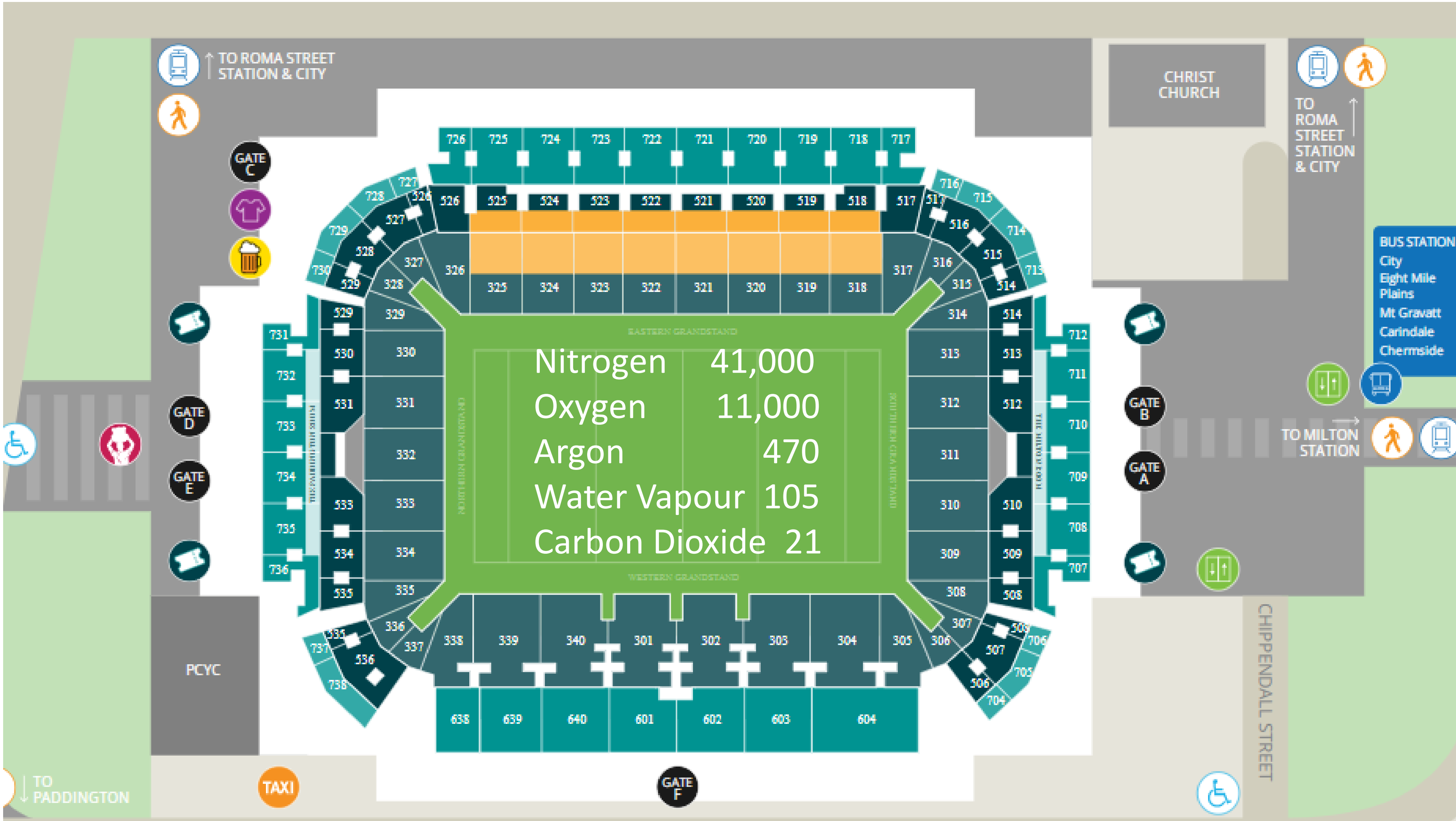
Carbon Dioxide in the Atmosphere

- composition of the atmosphere
- “greenhouse” effect
- how carbon dioxide works as a greenhouse gas
- what to expect from increasing carbon dioxide

Composition of Atmosphere

Nitrogen	78%
Oxygen	21%
Argon	0.9%
Water Vapour	0 - 3%
Carbon Dioxide	0.04%
Neon	Trace
Helium	Trace
Methane	Trace
Krypton	Trace
Ozone	Trace
Sulphur Dioxide	Trace
Nitrogen Oxides	Trace

Suncorp Stadium



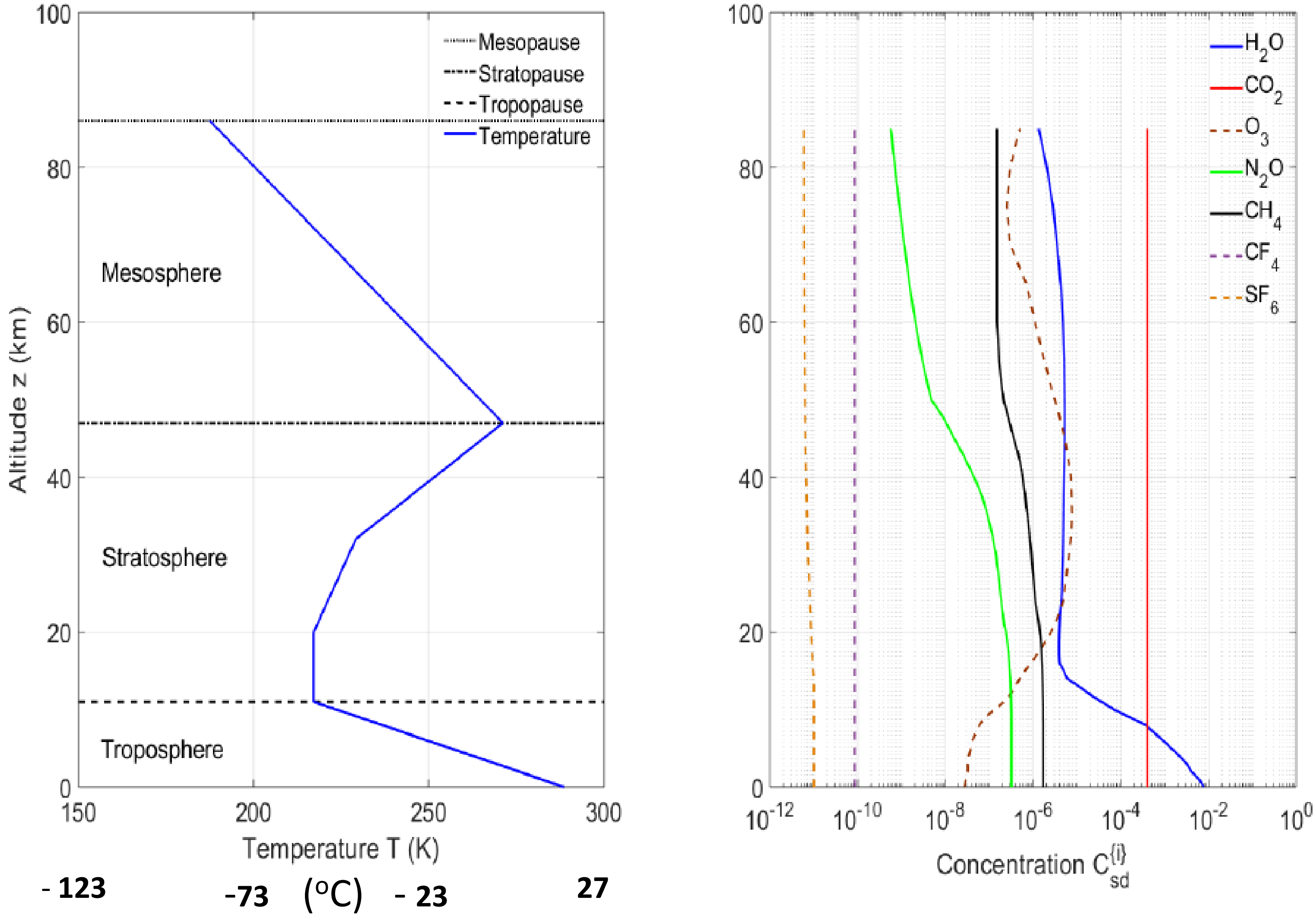
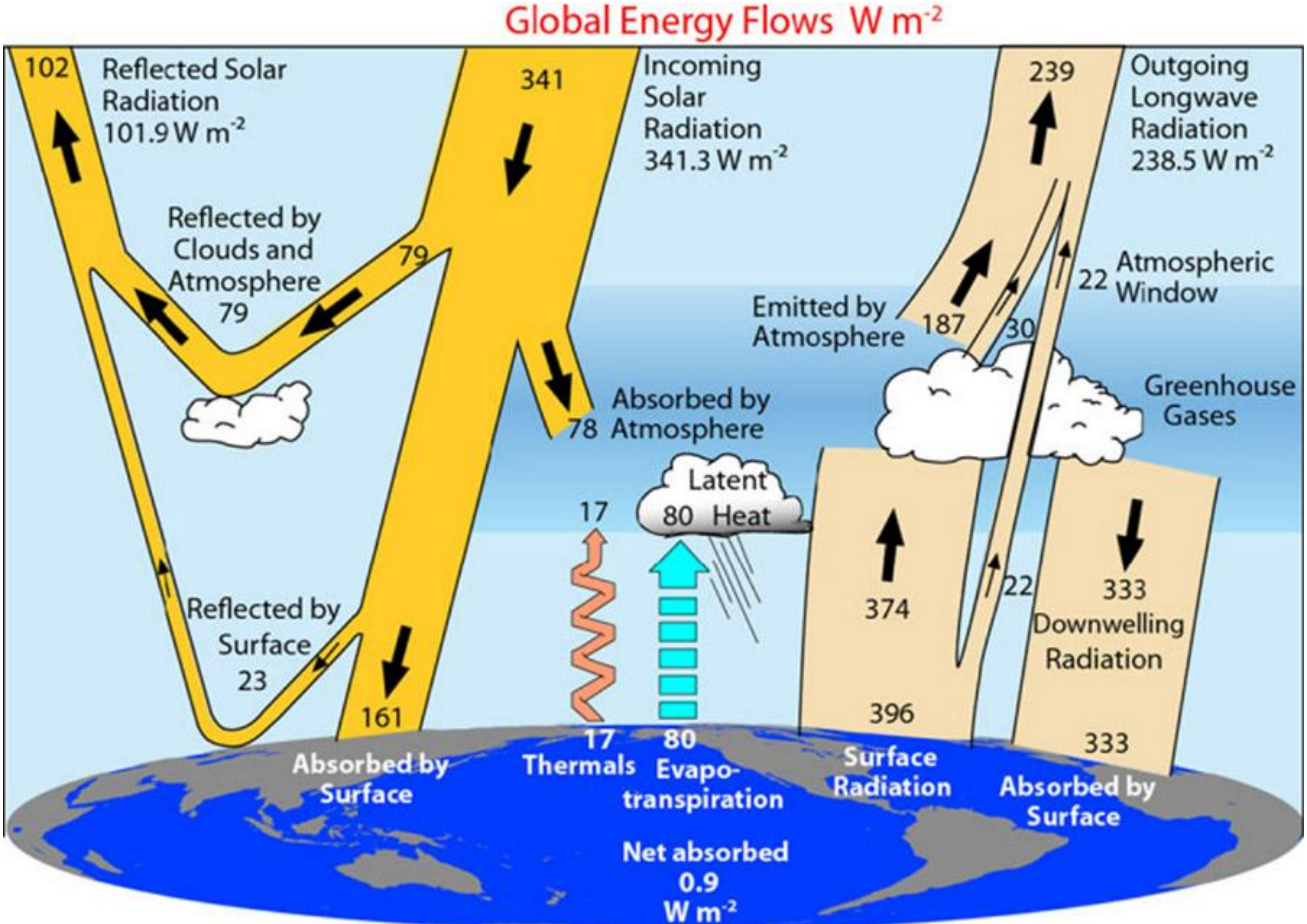
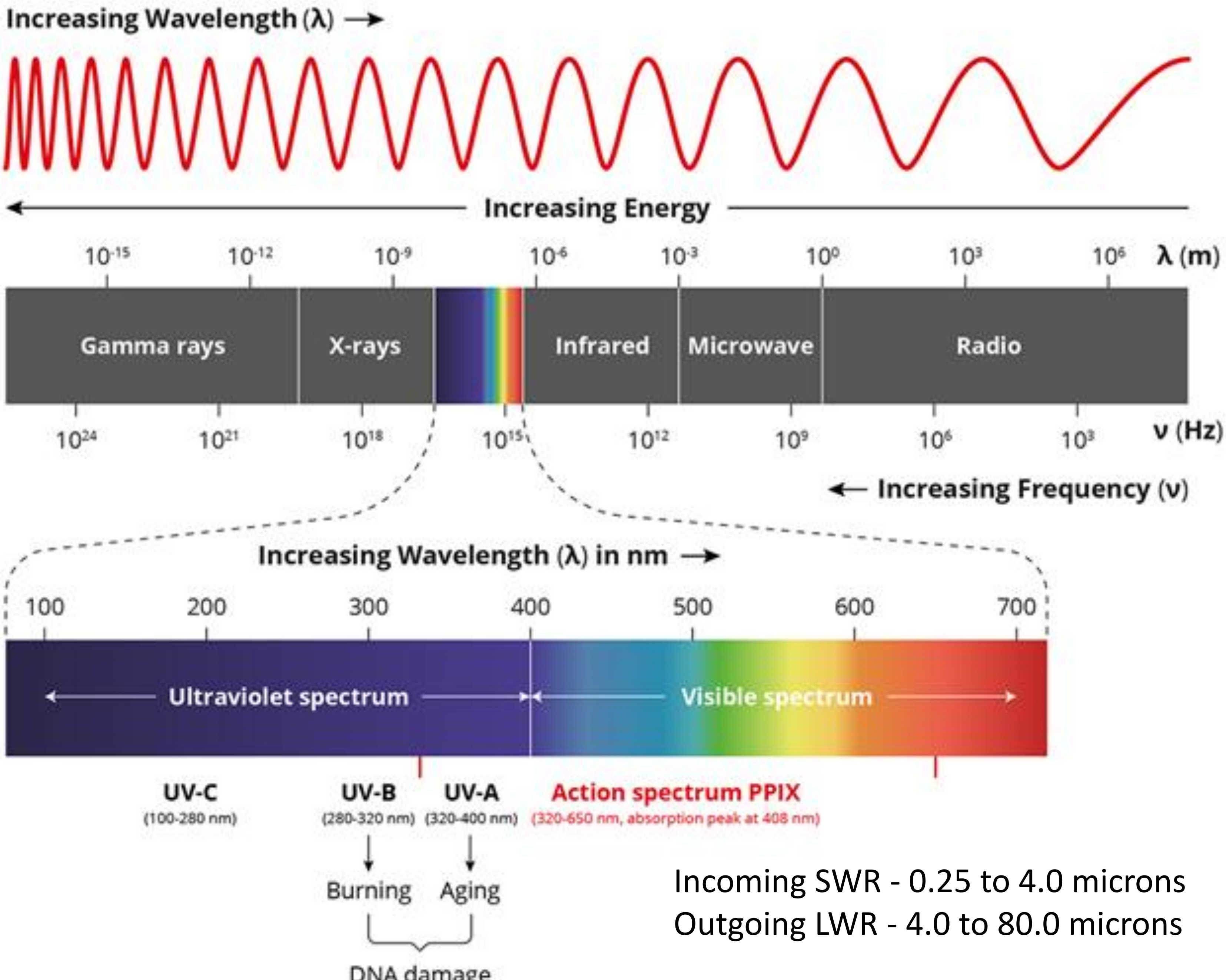


Figure 1: **Left.** A midlatitude atmospheric temperature profile, $T = T(z)$. The Earth's mean surface temperature $T(0) = 288.7$ K. **Right.** Standard observed concentrations, $C_{\mathrm{sd}}^{\{i\}}$ for greenhouse molecules versus altitude z.

Source: Winjgaarden and Happer



Source: SERC - Carleton



Source: The Secrets of the Universe

Incoming SWR - 0.25 to 4.0 microns

Outgoing LWR - 4.0 to 80.0 microns

Planck's Law of Radiation

This explains the spectral energy of radiation emitted by a black body and states:

A hypothetical body that completely absorbs all radiant energy falling upon it, reaches some equilibrium temperature and then remits that energy as quickly absorbs it but at a different frequency.

Planck assumed that the sources of radiation are atoms in a state of oscillation and that the vibrational energy of each oscillator may have any of a series of discreet values but never any value in between.

Stefan – Boltzmann Law

The thermal energy radiated by a blackbody radiator per second per unit area is proportional to the fourth power of the absolute temperature as below,

P/A = δT4 (j/m2K4) where δ=0.6703 X 10 -8 watt/ m2K4

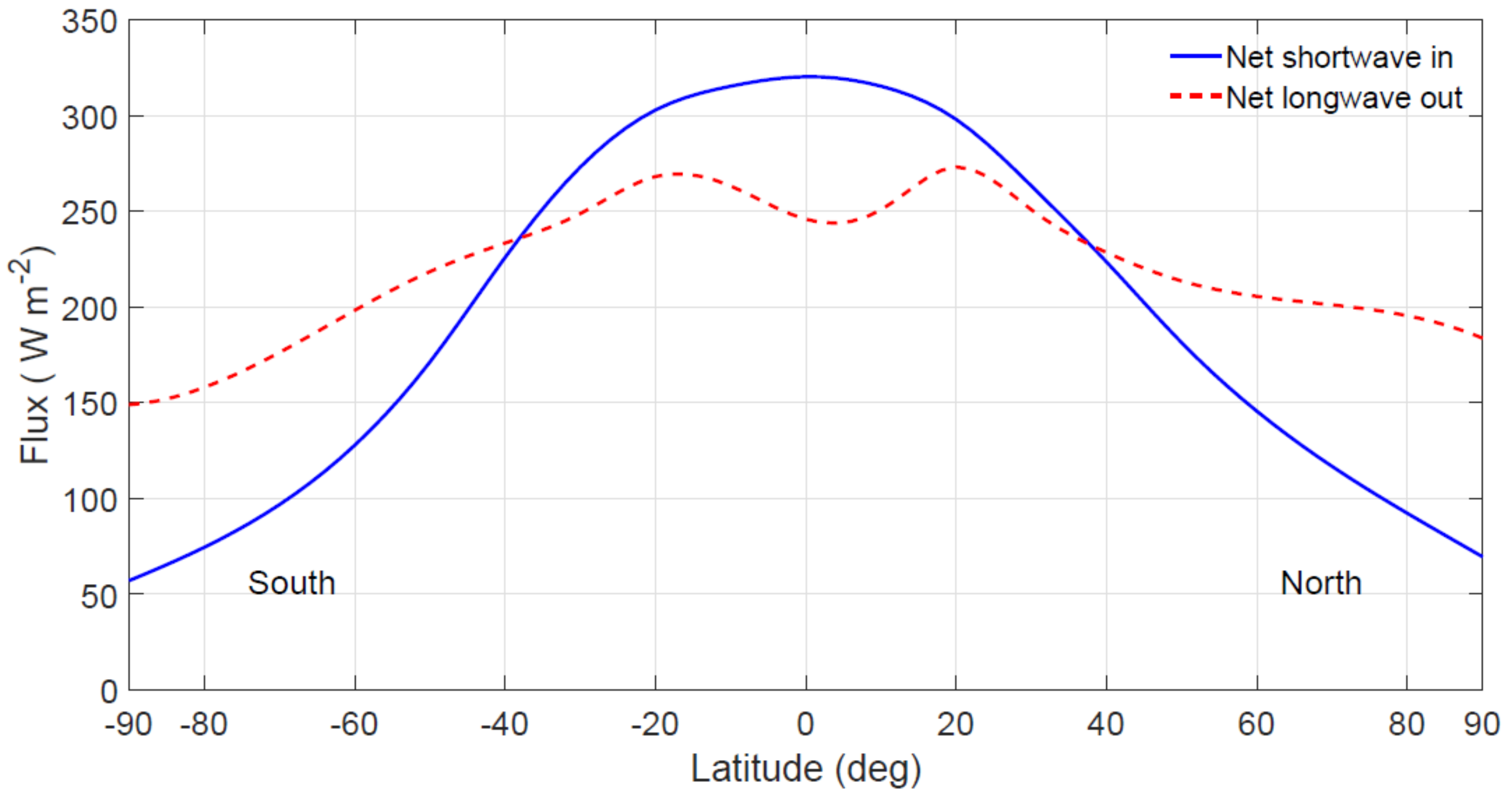
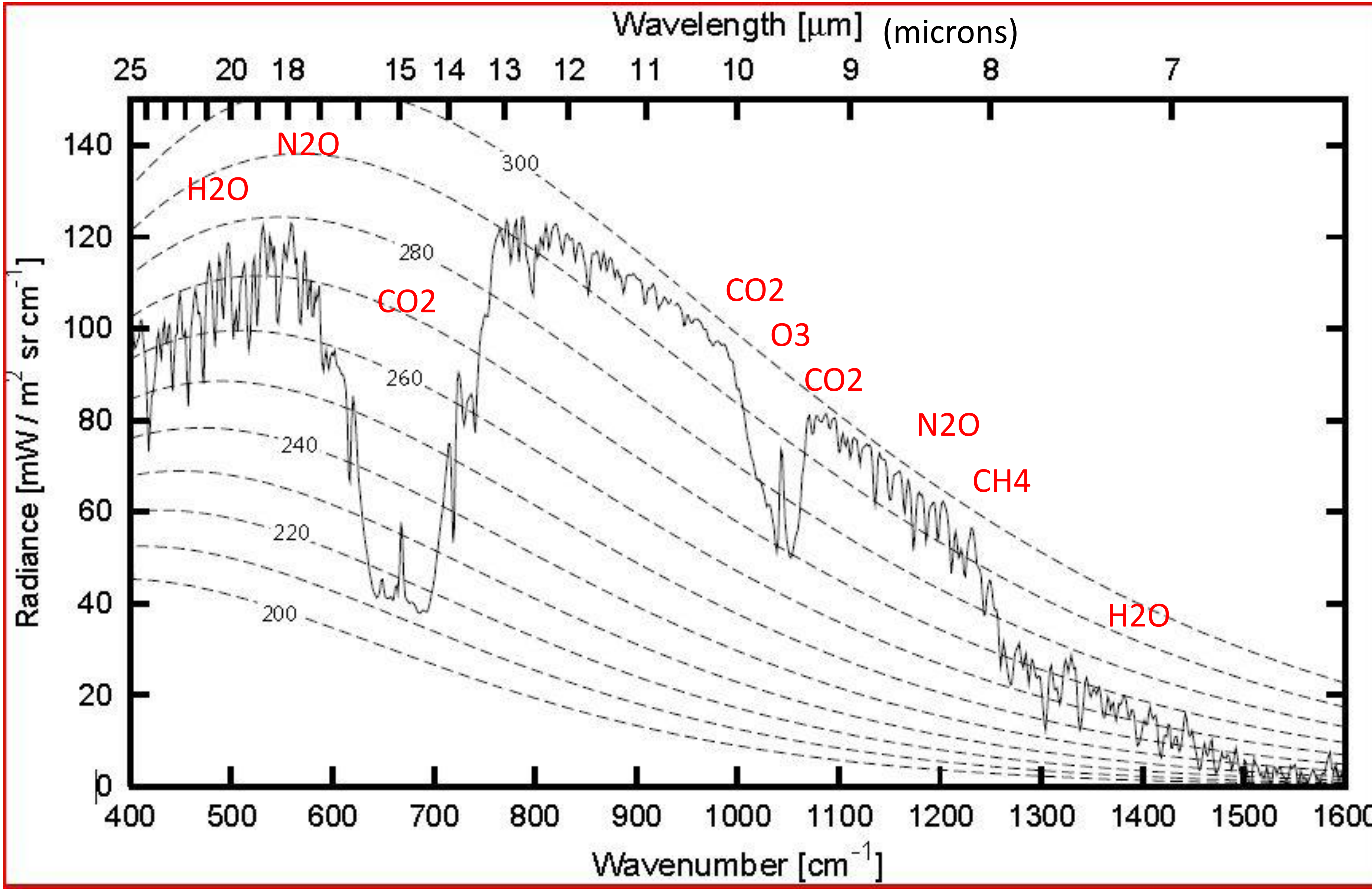
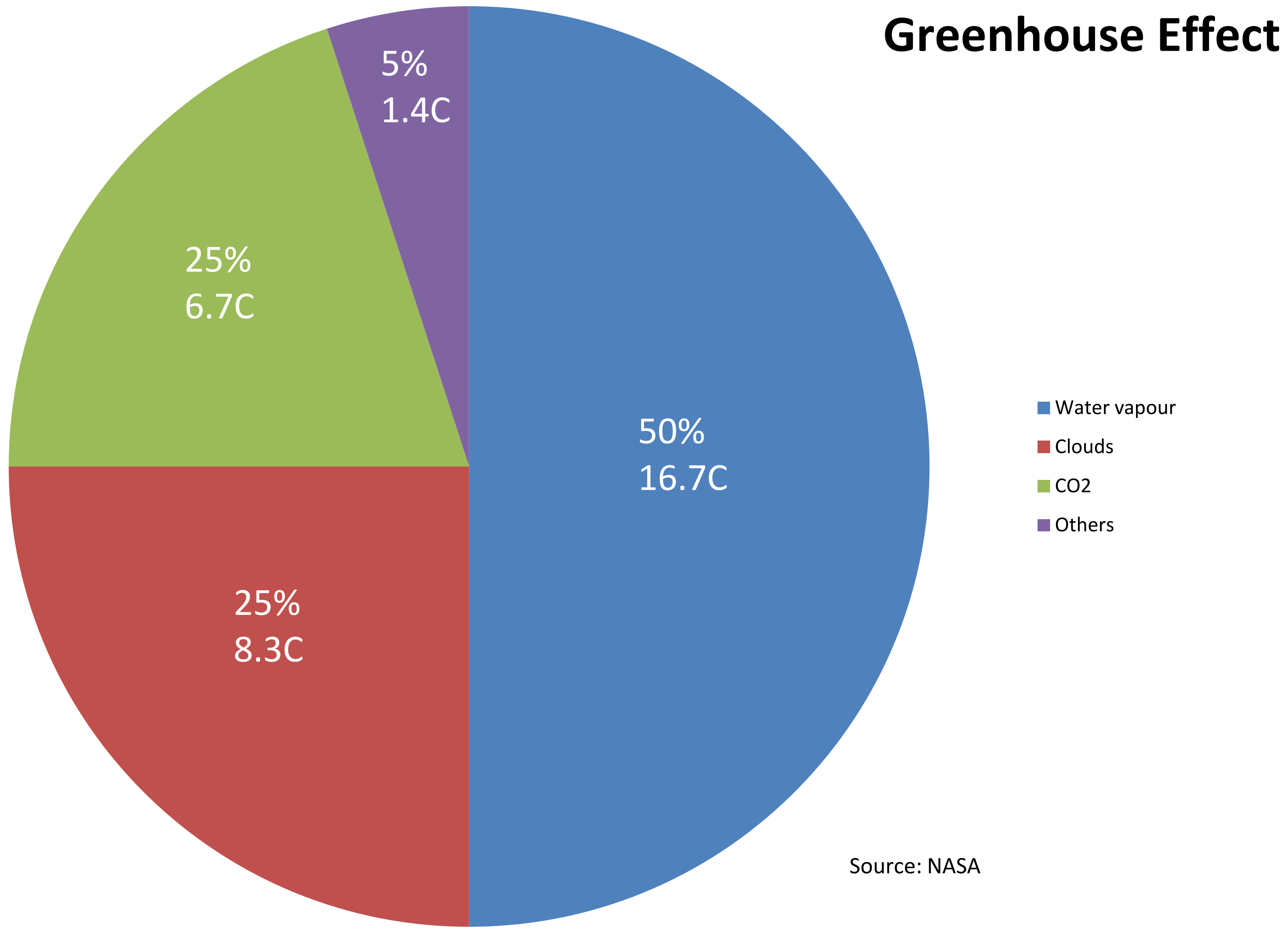


Figure 1: The continuous blue curve is the yearly average of incoming short-wave solar flux (net visible, near infrared and ultraviolet) absorbed by the Earth. The dashed red curve is the yearly average of the outgoing thermal flux (net longwave infrared) radiated to space by the Earth. Excess solar energy absorbed in the tropics is transported to the poles by mass flow in the atmosphere and oceans. The data is from satellite observations[2]. Adapted from PhysicalGeography.net [3].

Source: Infrared Forcing by Greenhouse Gases, Winjgaarden and Happer



Wavelength [μm] (microns)
25 20 18 15 14 13 12 11 10 9 8 7
140
120
100
80
60
40
20
0
Radiance [mW / m² sr cm⁻¹]
400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600
Wavenumber [cm⁻¹]
300
280
260
240
220
200
H2O
N2O
CO2
CO2
O3
CO2
N2O
CH4
H2O


Greenhouse Effect
5%
1.4C
25%
6.7C
50%
16.7C
25%
8.3C
Water vapour
Clouds
CO2
Others
Source: NASA

Chronology of CO_2 as a Greenhouse Gas

- In 1859, John Tyndall, through lab experiment found a number of gases in the atmosphere could trap heat radiated from earth. He found water vapour the most effective and CO_2 also effective.

- Arrhenius, in the 1890's, started looking at the effect of CO_2. Because water vapour varied in the atmosphere day to day but CO_2 was set in geological time by volcanos, he thought CO_2 was the regulator that determined the water vapour content and thus temperature. He calculated, in 1896, that reducing the CO_2 content by half would lower the temperature of Europe by 4 – 5 degrees C.

- Other scientists realised that coal was being "evaporated" into the atmosphere as CO_2 which might accumulate over time. Arrhenius then made a calculation that, by doubling the CO_2 in the air, the temperature would rise by 5 – 6 degree C, averaged over all latitudes. This was greeted with scepticism

- In 1931, Hulburt's calculations supported Arrhenius's estimate that doubling or halving CO_2 would bring something like a 4°C rise or fall of surface temperature, and thus "the carbon dioxide theory of the ice ages... is a possible theory." Hardly anyone noticed this paper.

- When Callendar, in 1938, compiled measurements of temperatures from the 19th century he found a warming trend was underway. He also found that over the past hundred years the concentration of CO_2 had increased by about 10%. This rise, Callendar asserted, could explain the observed warming. Callendar estimated, that a doubling of CO_2 could gradually bring a 2°C rise in some distant future. Most meteorologists gave Callendar's idea scant credence but it was mentioned in some climatology textbooks of the time.

- After WW2, research efforts resulted in new data for the absorption of infrared radiation in atmospheric gases Digital computers were now at hand for such calculations. In 1956, Plass nailed down the likelihood that adding more CO_2 would increase the interference with infrared radiation. Plass calculated that doubling the level would bring a 3-4°C rise. Assuming that emissions would continue at the current (1950s) rate, he expected that human activity would raise the average global temperature "at the rate of 1.1 degrees C per century."

- The IPCC in 2020 estimated that a doubling of CO_2 would raise the temperature by up to 4.5 degrees C.

Worlds in the making

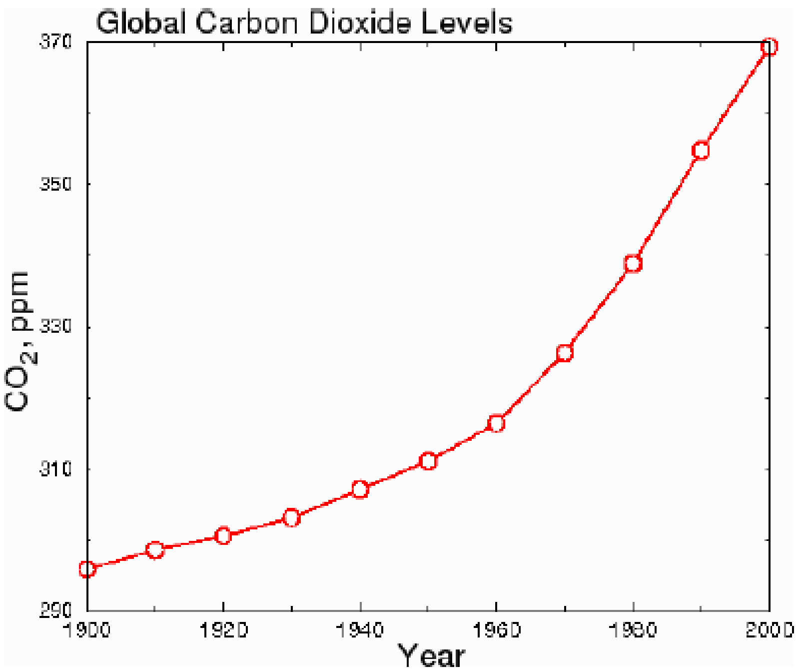
Svante Arrhenius, H. Borns

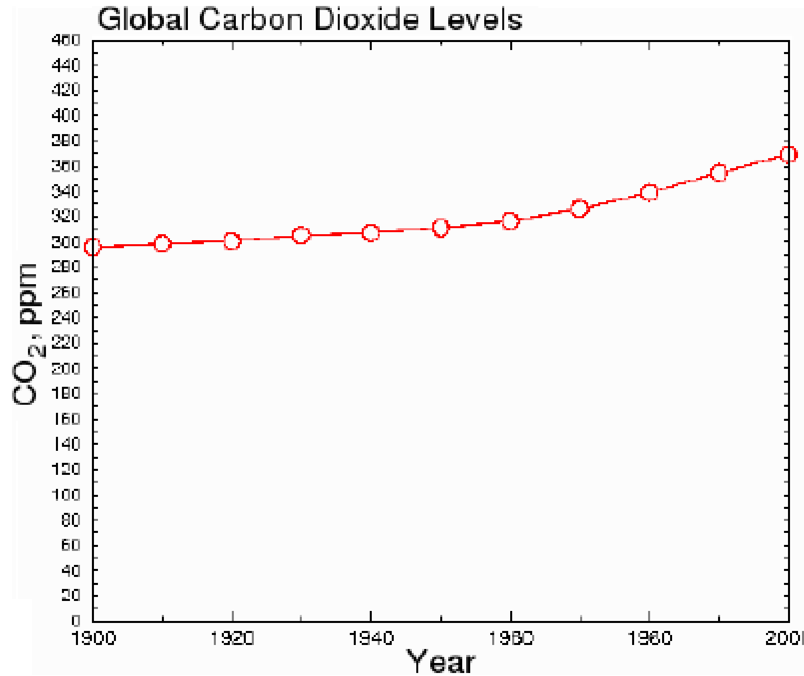
the present atmosphere. Hence the carbonic acid percentage has been increasing of late.

We often hear lamentations that the coal stored up in the earth is wasted by the present generation without any thought of the future, and we are terrified by the awful destruction of life and property which has followed the volcanic eruptions of our days. We may find a kind of consolation in the consideration that here, as in every other case, there is good mixed with the evil. By the influence of the increasing percentage of carbonic acid in the atmosphere, we may hope to enjoy ages with more equable and better climates, especially as regards the colder regions of the earth, ages when the earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind.

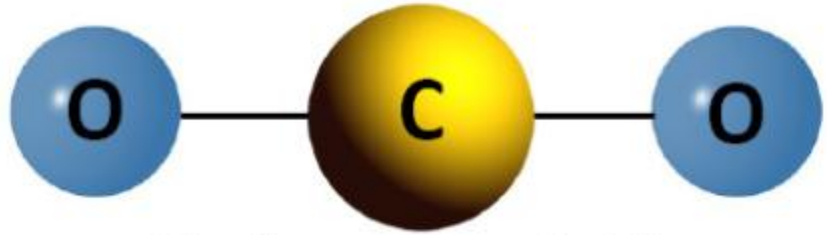
63

Svante Arrhenius, *[Worlds in the Making](), 1908*

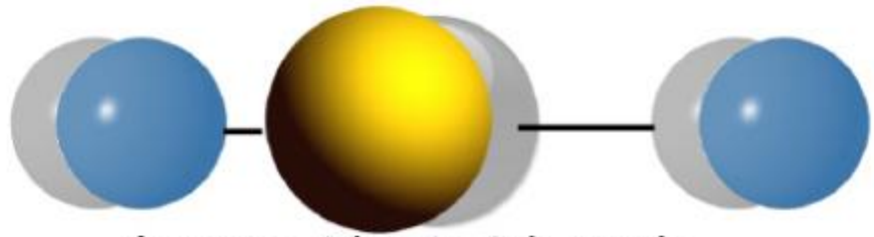


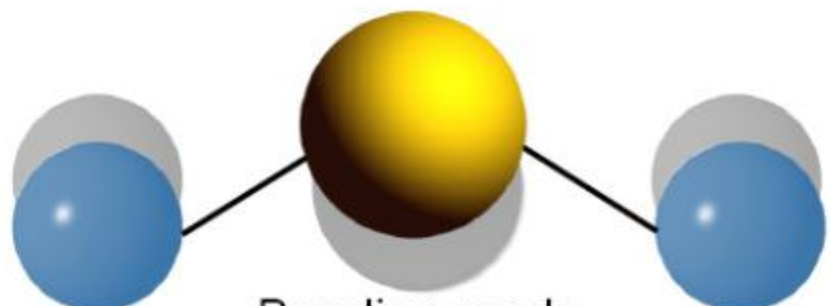


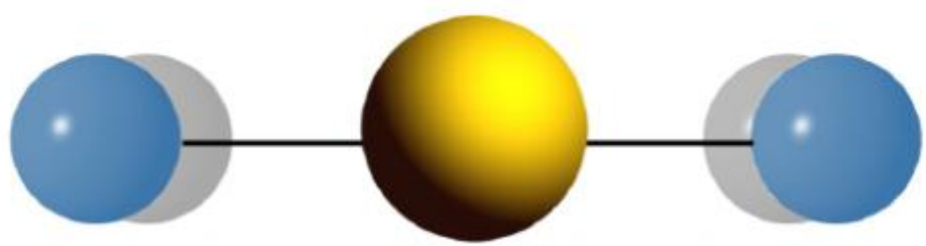
Source: Cold Facts on Global Warming



Resting or ground state


Asymmetric stretch mode


Bending mode


Symmetric stretch mode

HITRAN

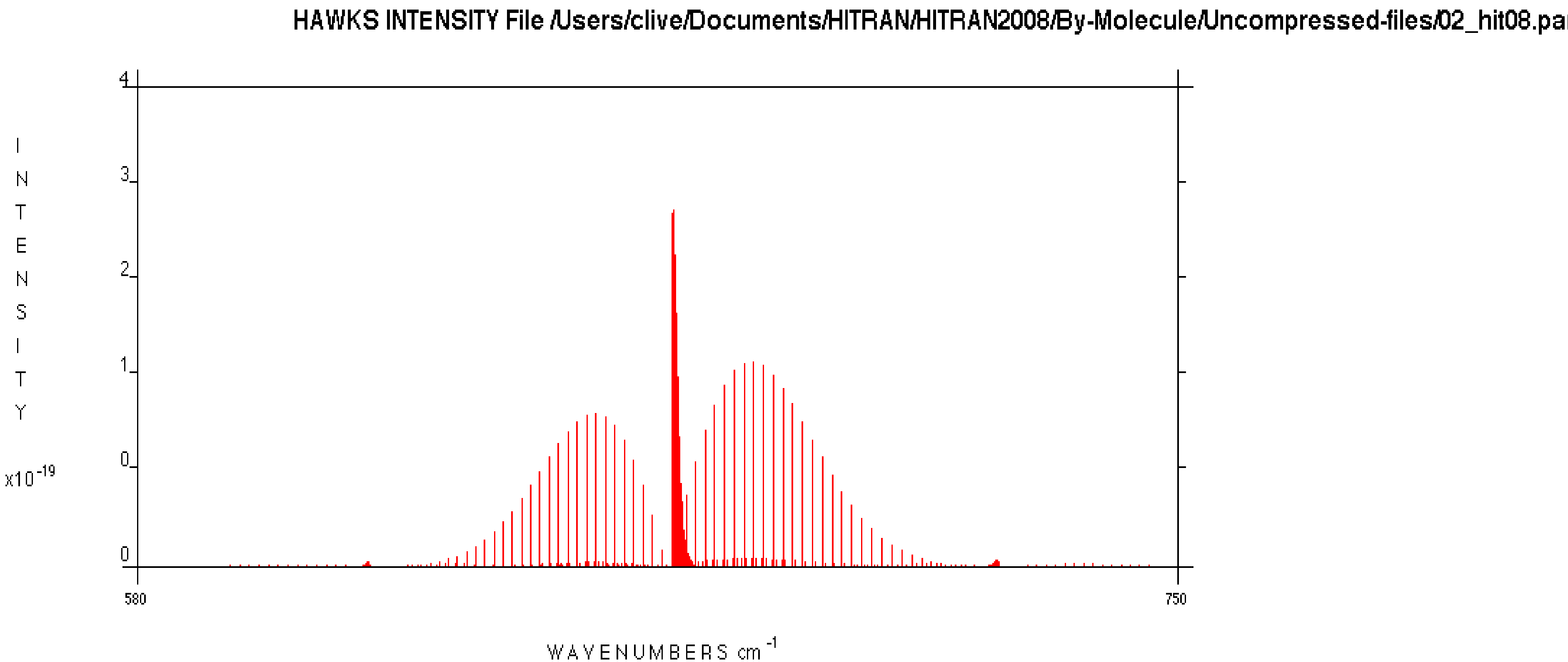
HITRAN is an acronym for *hi*gh-resolution *tran*smission molecular absorption database.

HITRAN is a compilation of spectroscopic parameters that a variety of computer codes use to predict and simulate the transmission and emission of light in the atmosphere. The original version of HITRAN was compiled by the US Air Force Cambridge Research Laboratories in the 1960s in order to enable surveillance of military aircraft detected through the terrestrial atmosphere.

One of the early applications of HITRAN was a program called Atmospheric Radiation Measurement (ARM) for the US Department of Energy. In this program spectral atmospheric measurements were made around the globe in order to better understand the balance between the radiant energy that reaches Earth from the sun and the energy that flows from Earth back out to space.

HITRAN is a free resource and is currently maintained and developed at the Harvard-Smithsonian Center for Astrophysics , Cambridge, Mass, USA

Source: HITRAN /Wikipedia

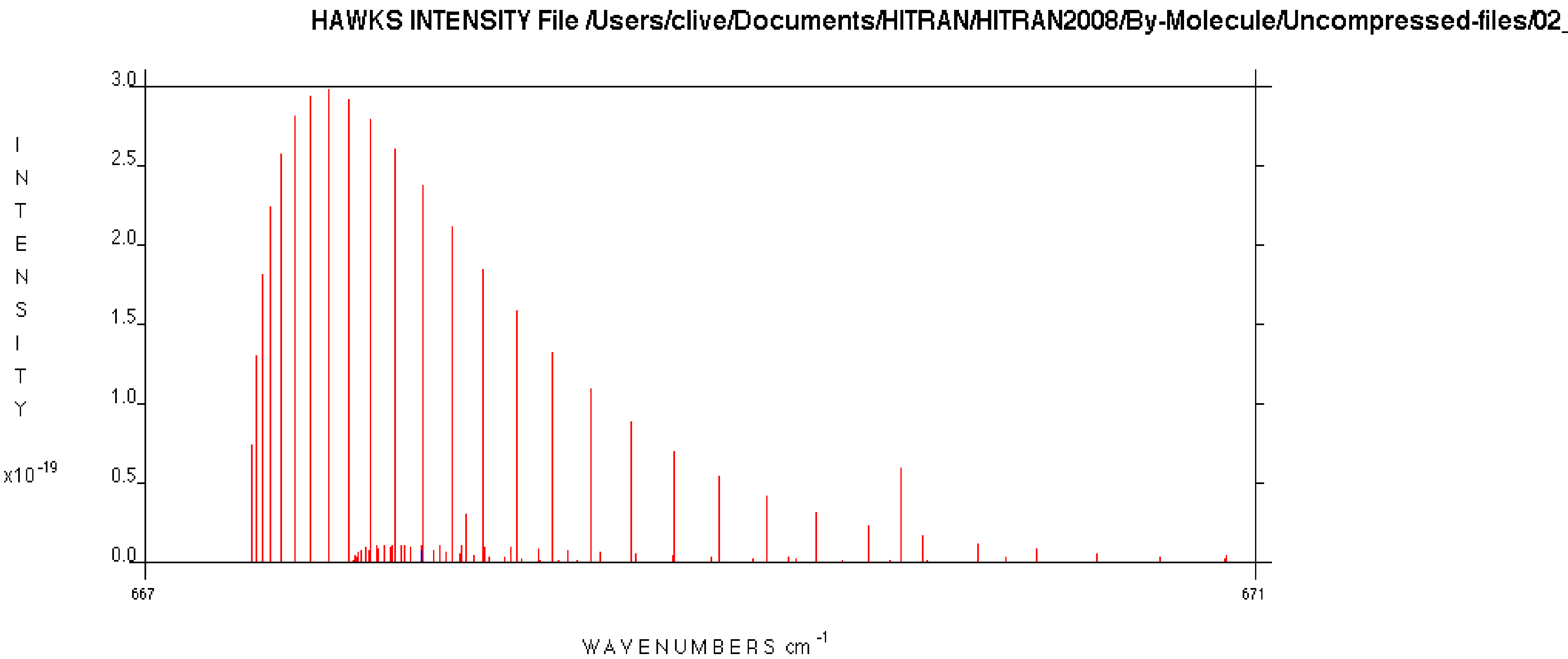


20 micron

Wavelength

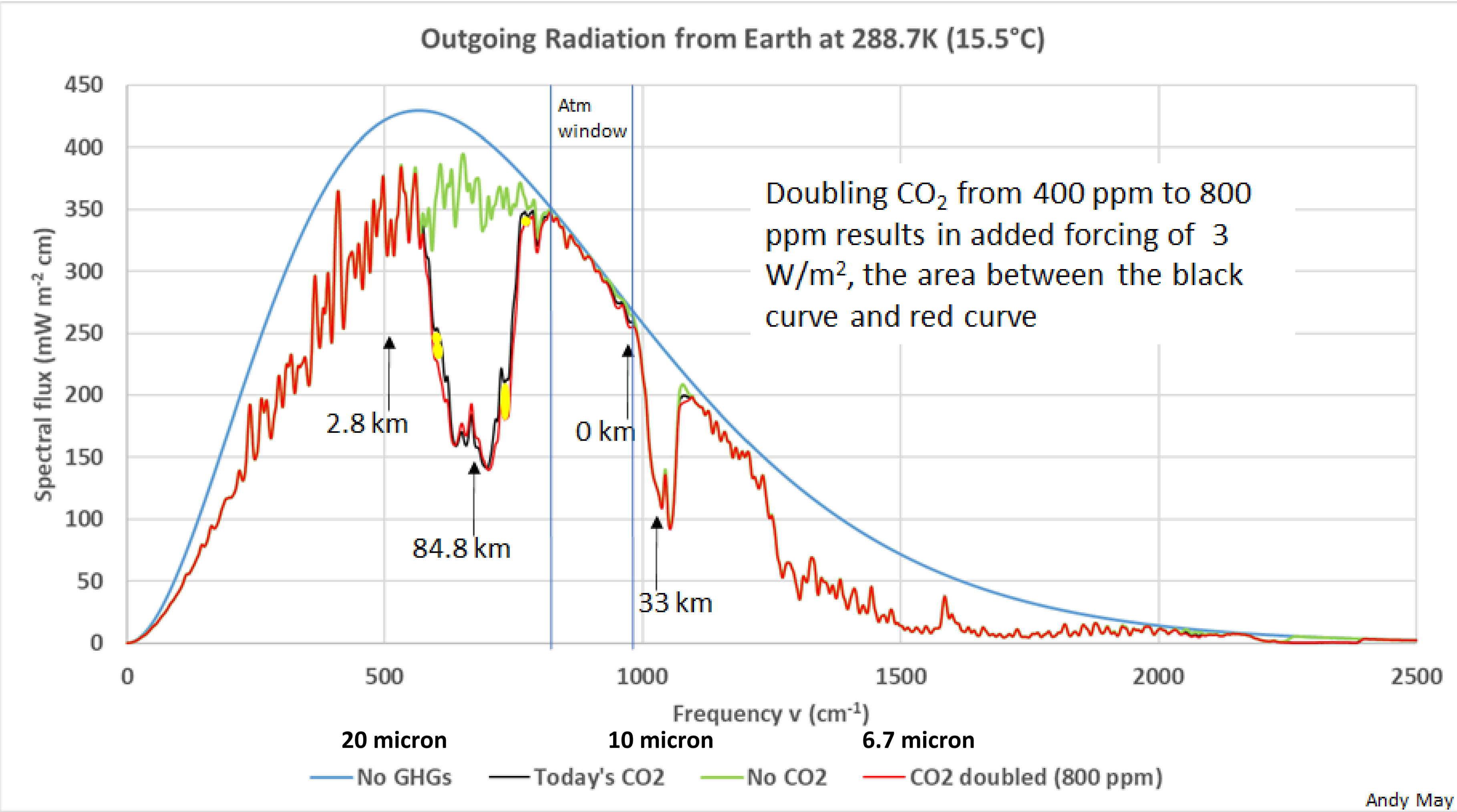
13.3 micron

Source: The CO2 GHE Demystified, Clive Best



14.99 micron **Wavelength** **14.90 micron**

Source: The CO2 GHE Demystified, Clive Best



Source: Infrared Forcing by Greenhouse Gases
W. A. van Wijngaarden and W. Happer

Additions: Andy May

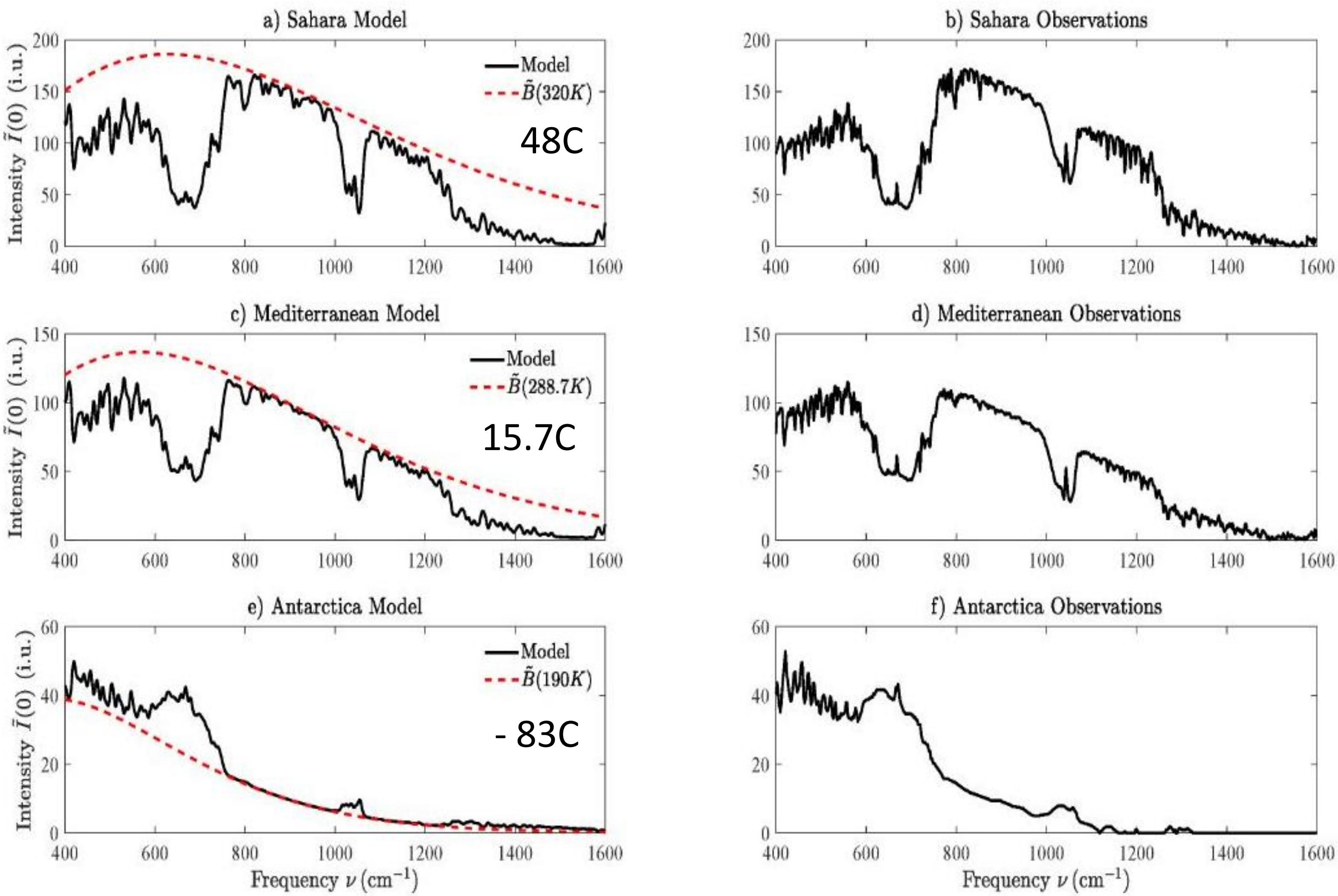
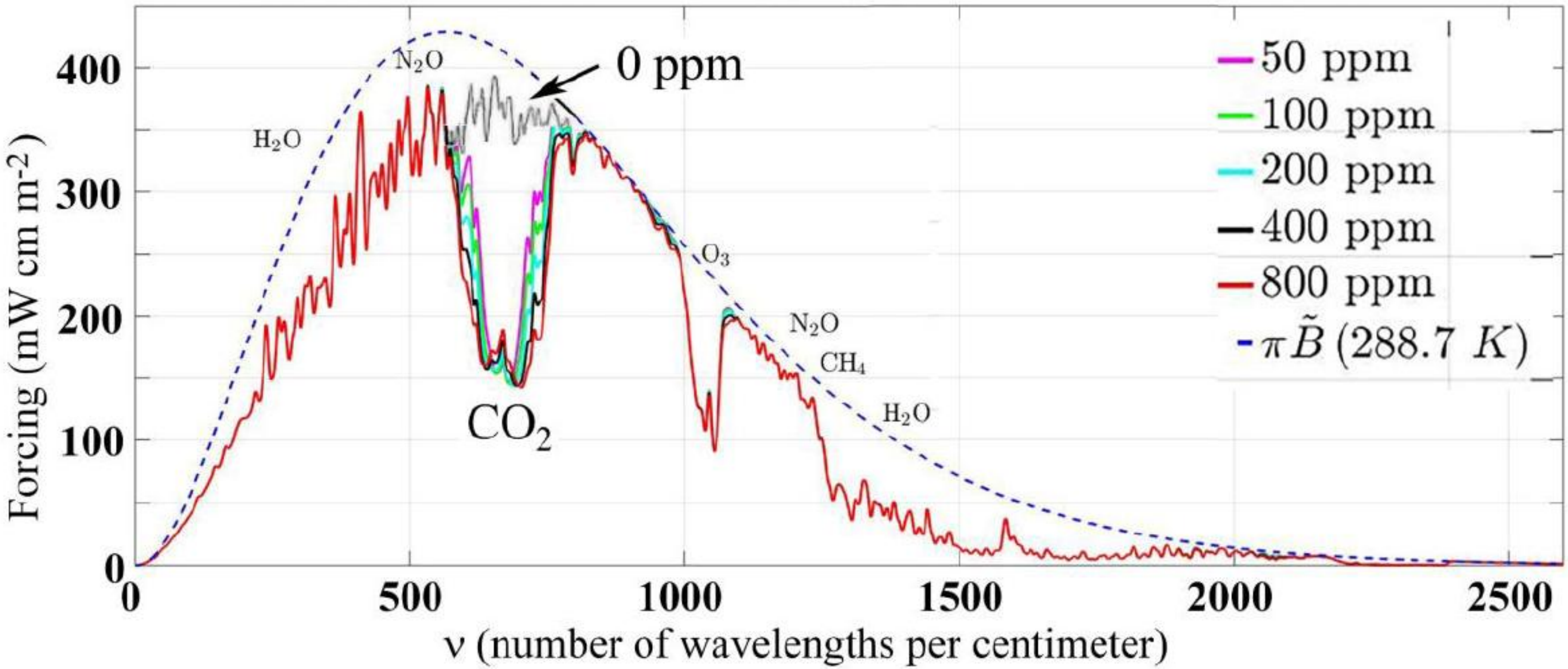


Figure 3. The W&H models on the left, compared to satellite measurements on the right. The modeled values are very similar to the measurements. Source: (Wijngaarden & Happer, 2020).

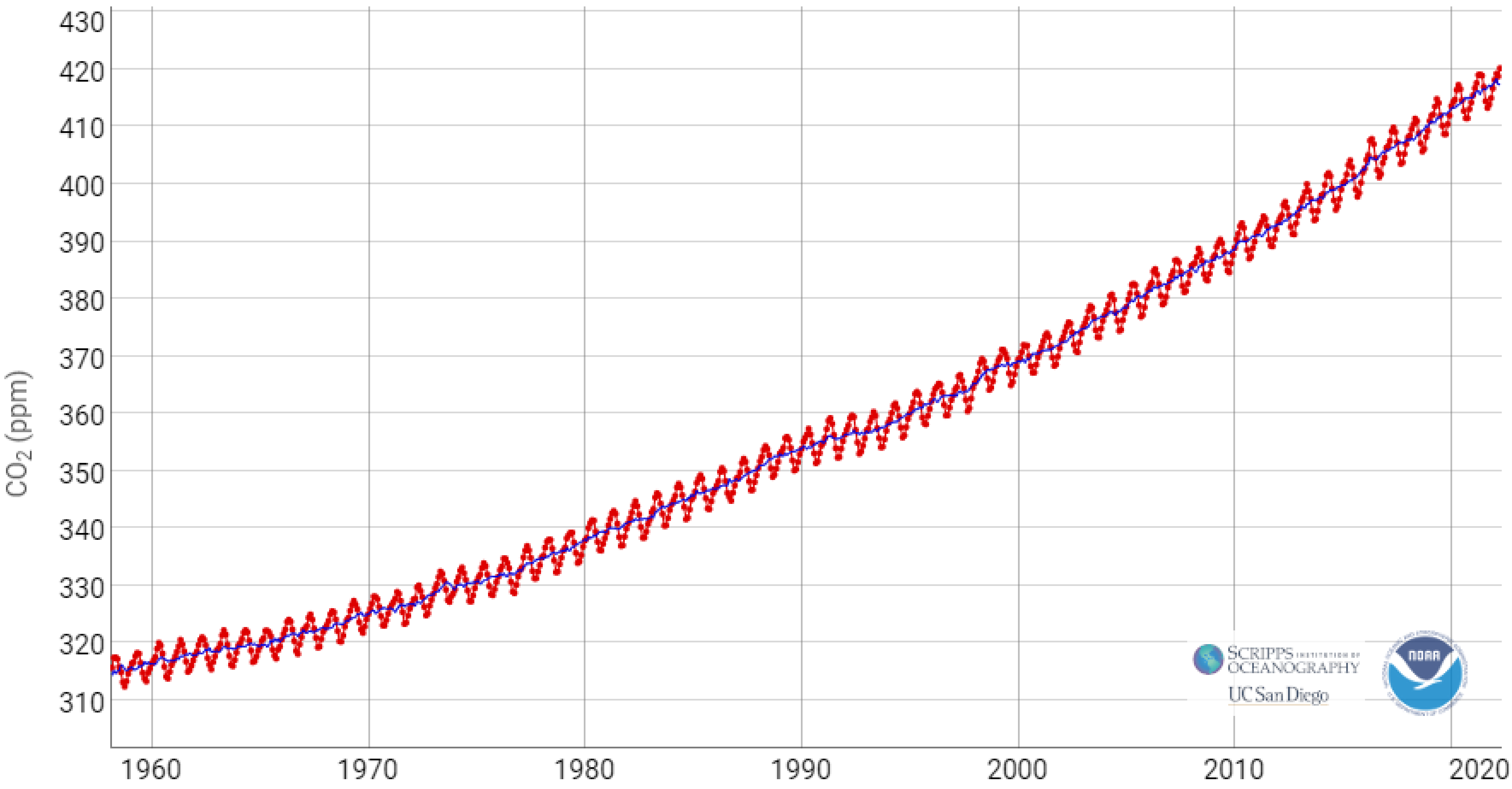


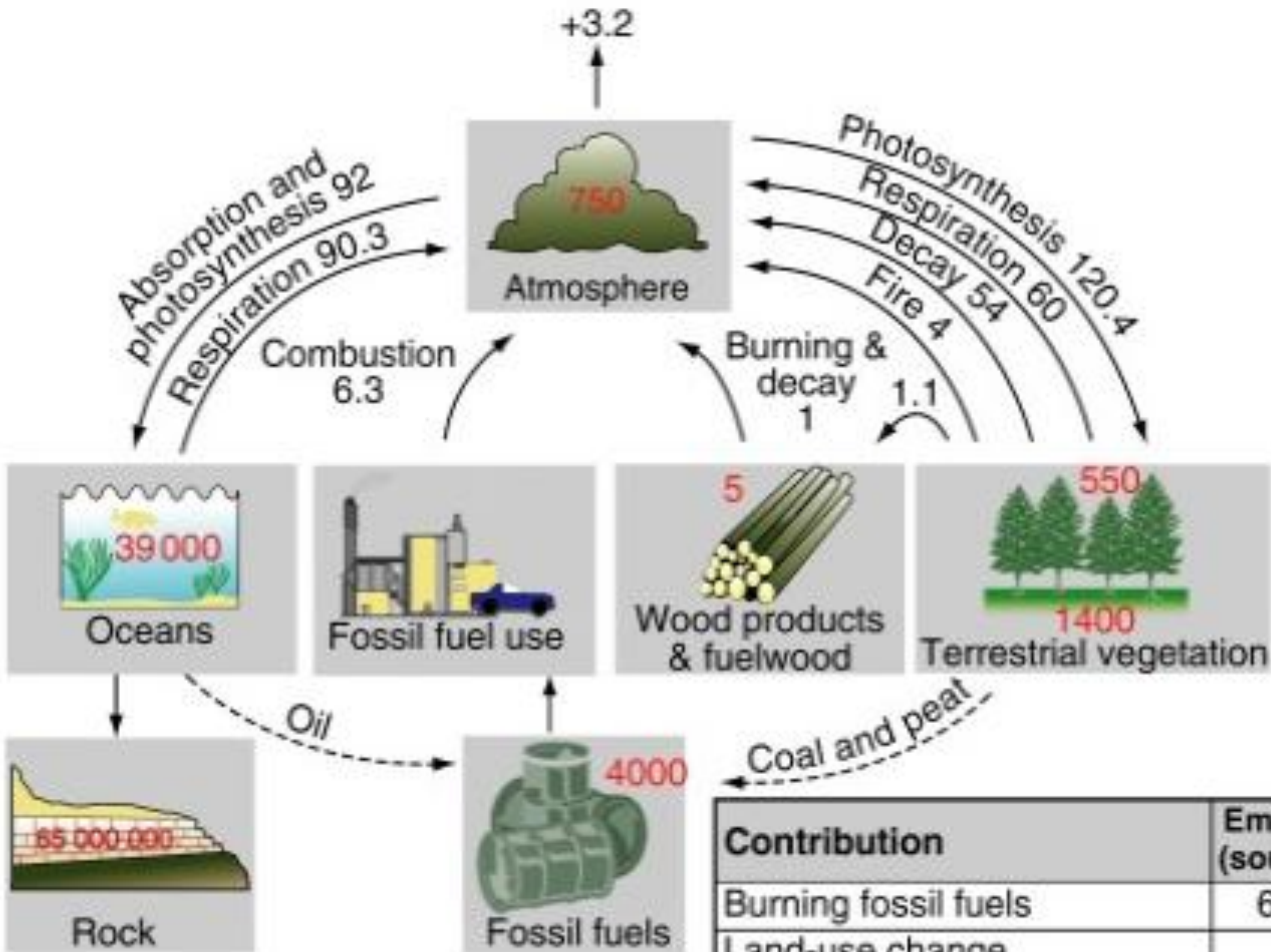
20 micron 10 micron 5 micron

Figure 3: The effect on the IR spectrum of low concentrations of CO_2.

Source: Professor Winjgaarden

Mauna Loa Monthly Averages





Contribution	Emitted (source)	Absorbed (sink)
Burning fossil fuels	6.3	
Land-use change (primarily deforestation)	1.6	
Enhanced vegetation growth		3.0
Ocean–atmosphere exchange		1.7
Total	**7.9**	**4.7**
Balance	**3.2**	

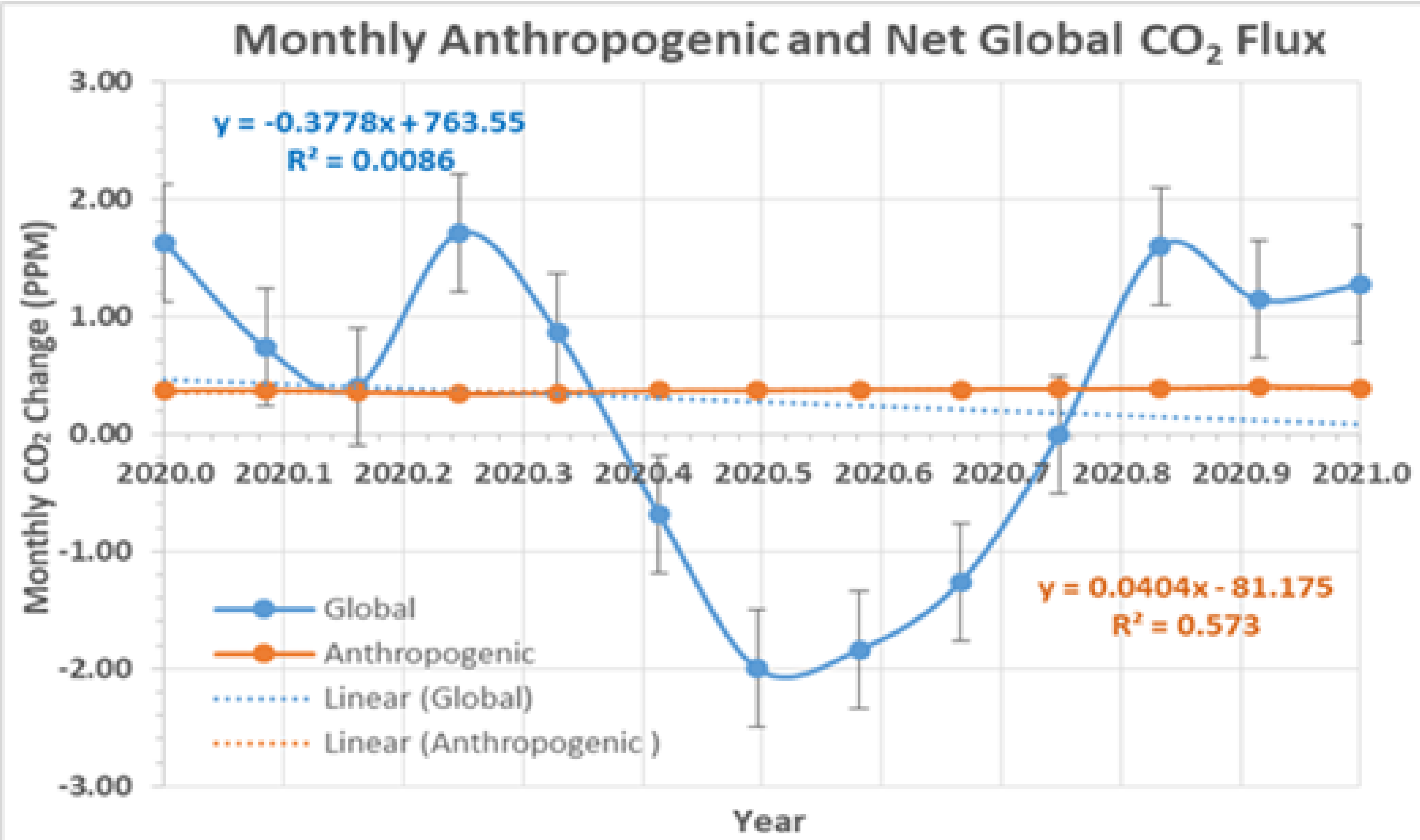
Source: Biomass: Impact on Carbon Cycle and Greenhouse Gas Emissions, Encyclopedia of Energy, 2004

CO2 Residence Time in Atmosphere

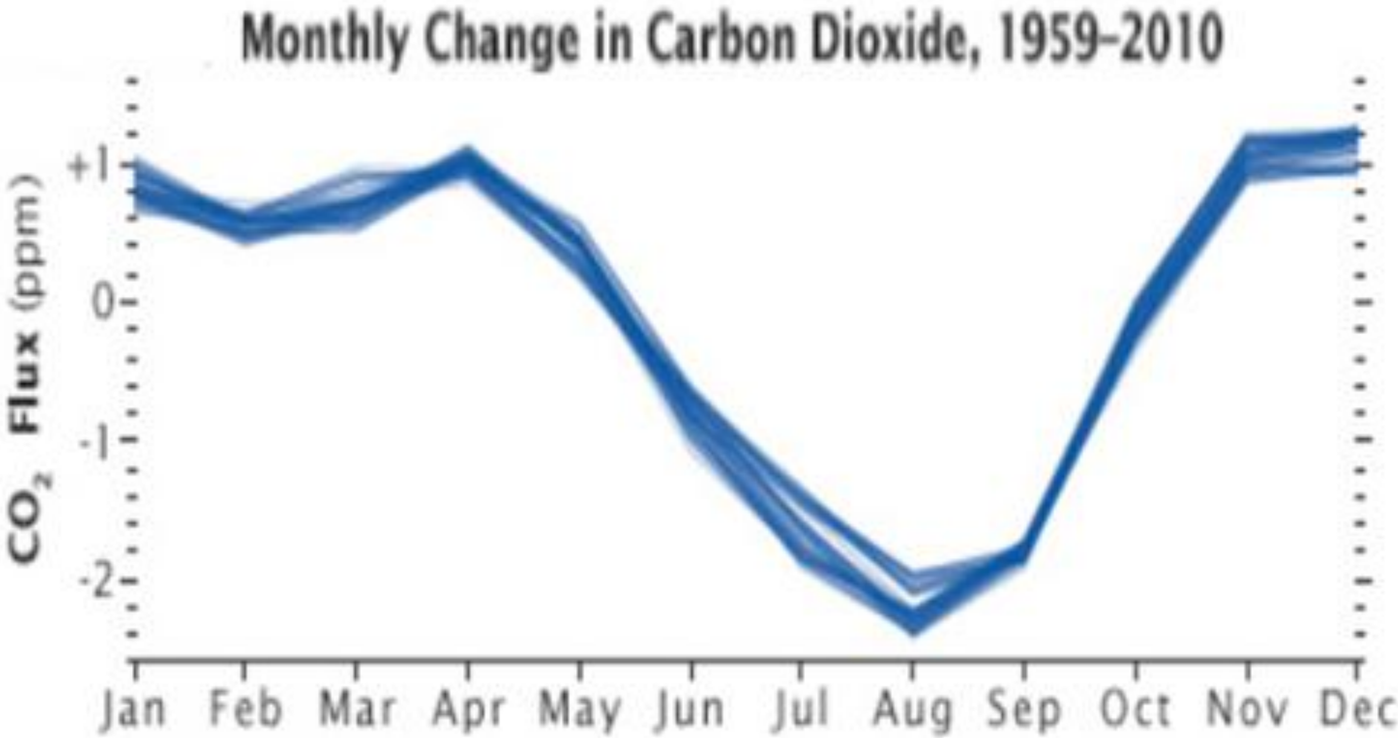
Reference	Method	Residence time
Essenhigh (2009)	IPCC Data (750/150)	5
Segalstad (1992);	Isotope C13/C12	~5
Murray (1992)	CO2 Solubility	~5
Stumm & Morgan (1970).	CO2 chemical kinetic data	~5
Revelle & Suess (1957)	Isotope C14 data	~16
Solomon *et al*. (2009)*	Climate models	+ 1000

* Lead author IPCC

Source : Tom V. Segalstad
Associate Professor of Resource and
Environmental Geology
The University of Oslo, Norway



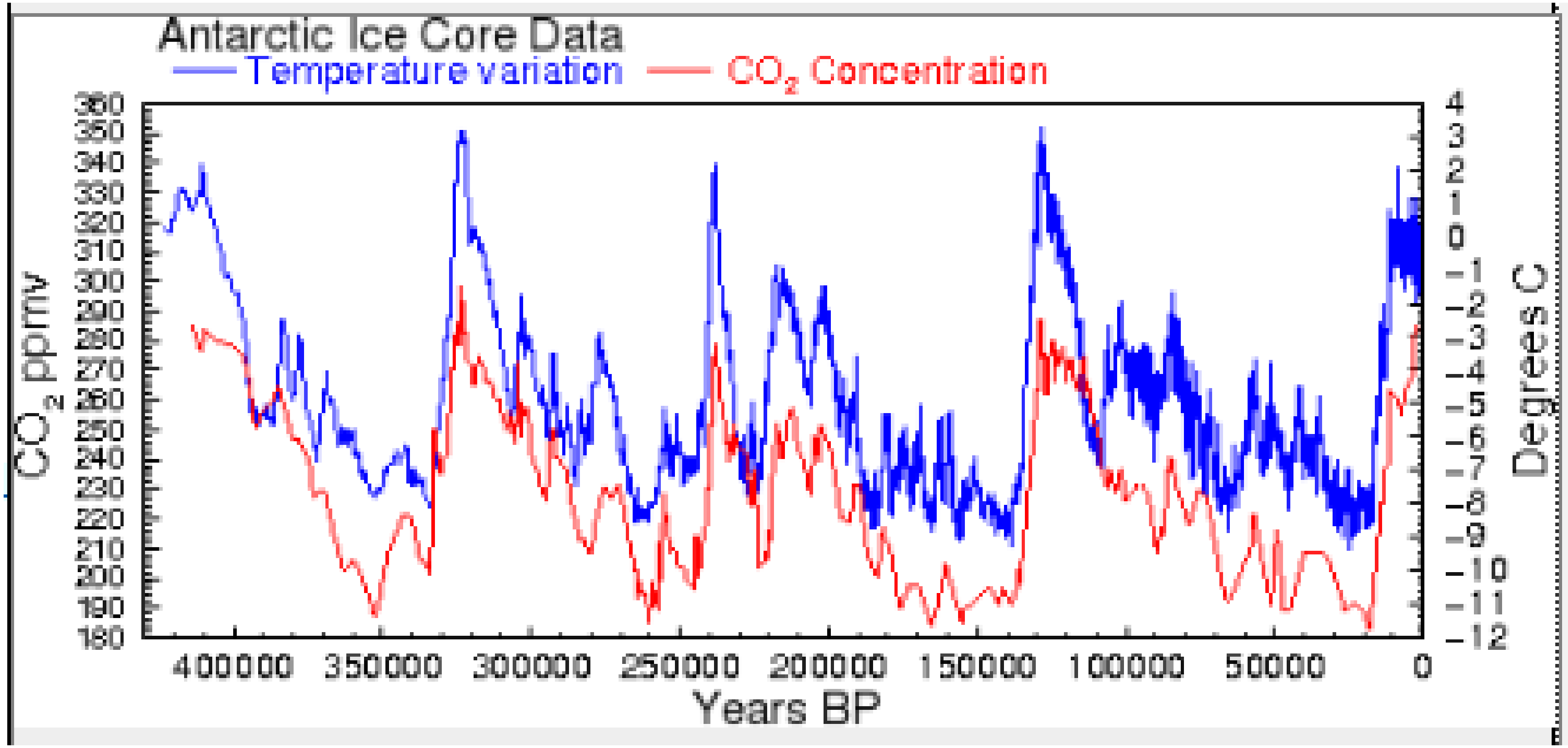
Source: Anthropogenic CO2 and the Expected Results from Eliminating It, Clyde Spencer, WUWT

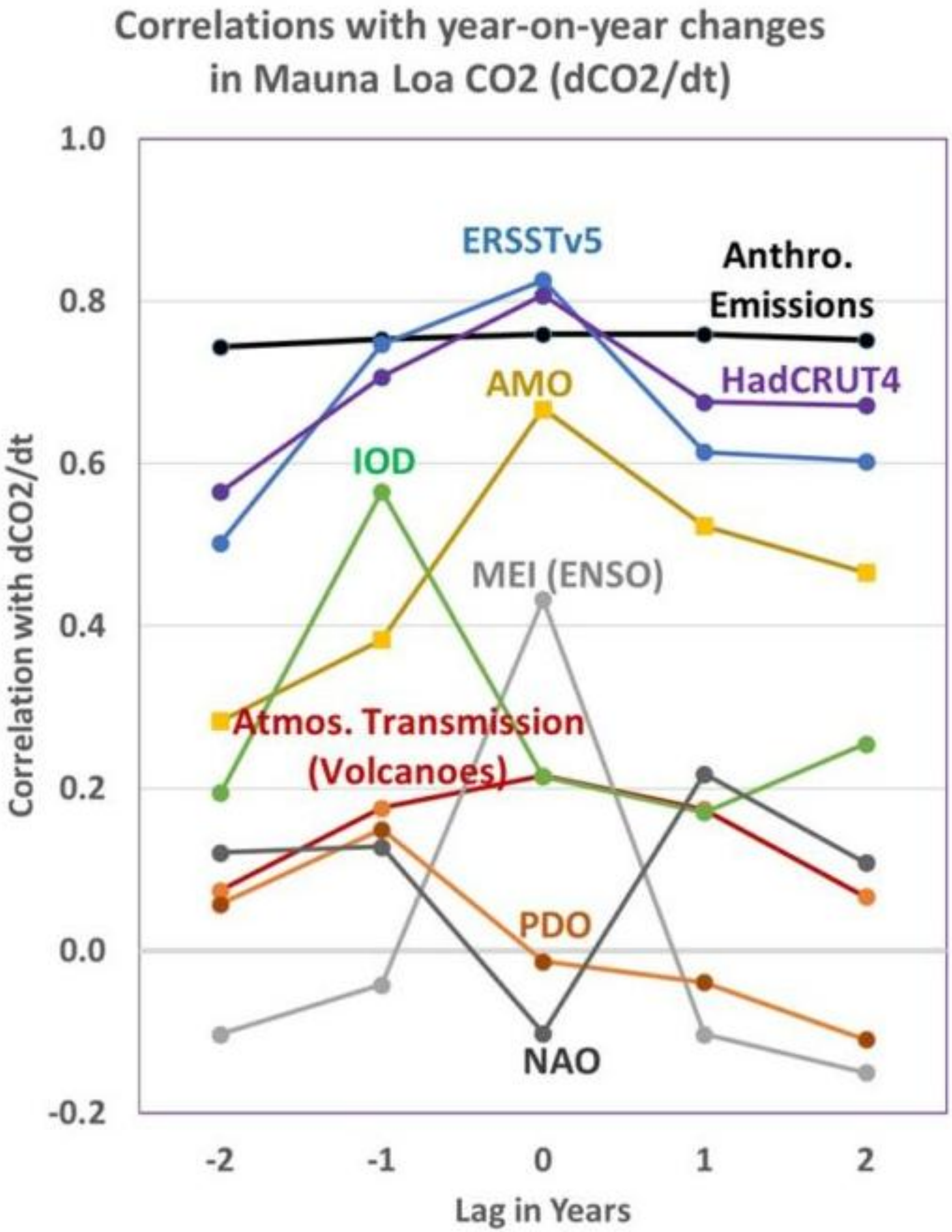


Source: Anthropogenic CO2 and the Expected Results from Eliminating It, Clyde Spencer, WUWT

The Chicken and the Egg Conundrum

Which comes first the increase in CO2 or the increase in temperature ?





Source: Explaining Mauna Loa CO2 Increases with Anthropogenic and Natural Influence, Roy Spencer, WUWT

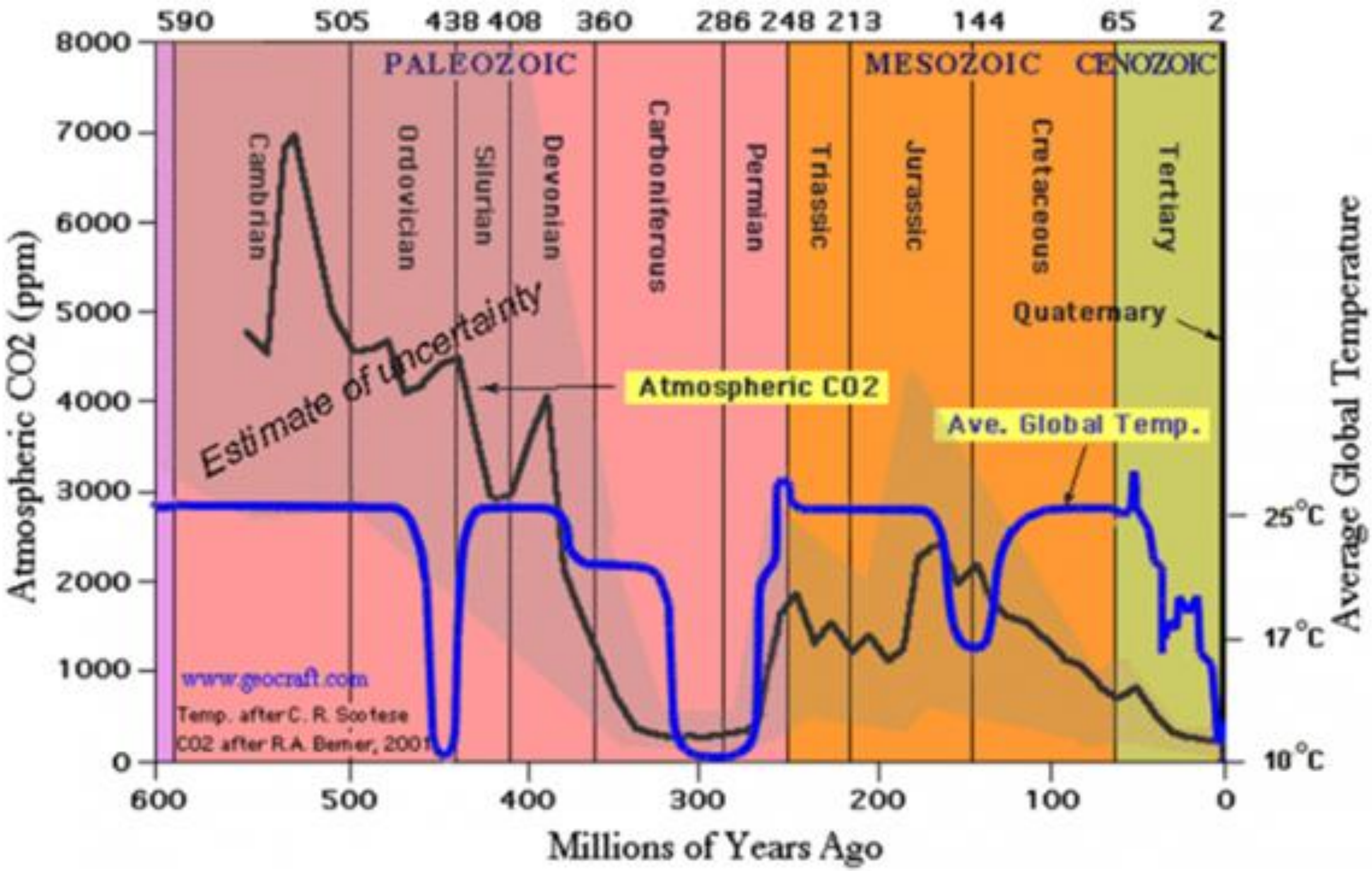
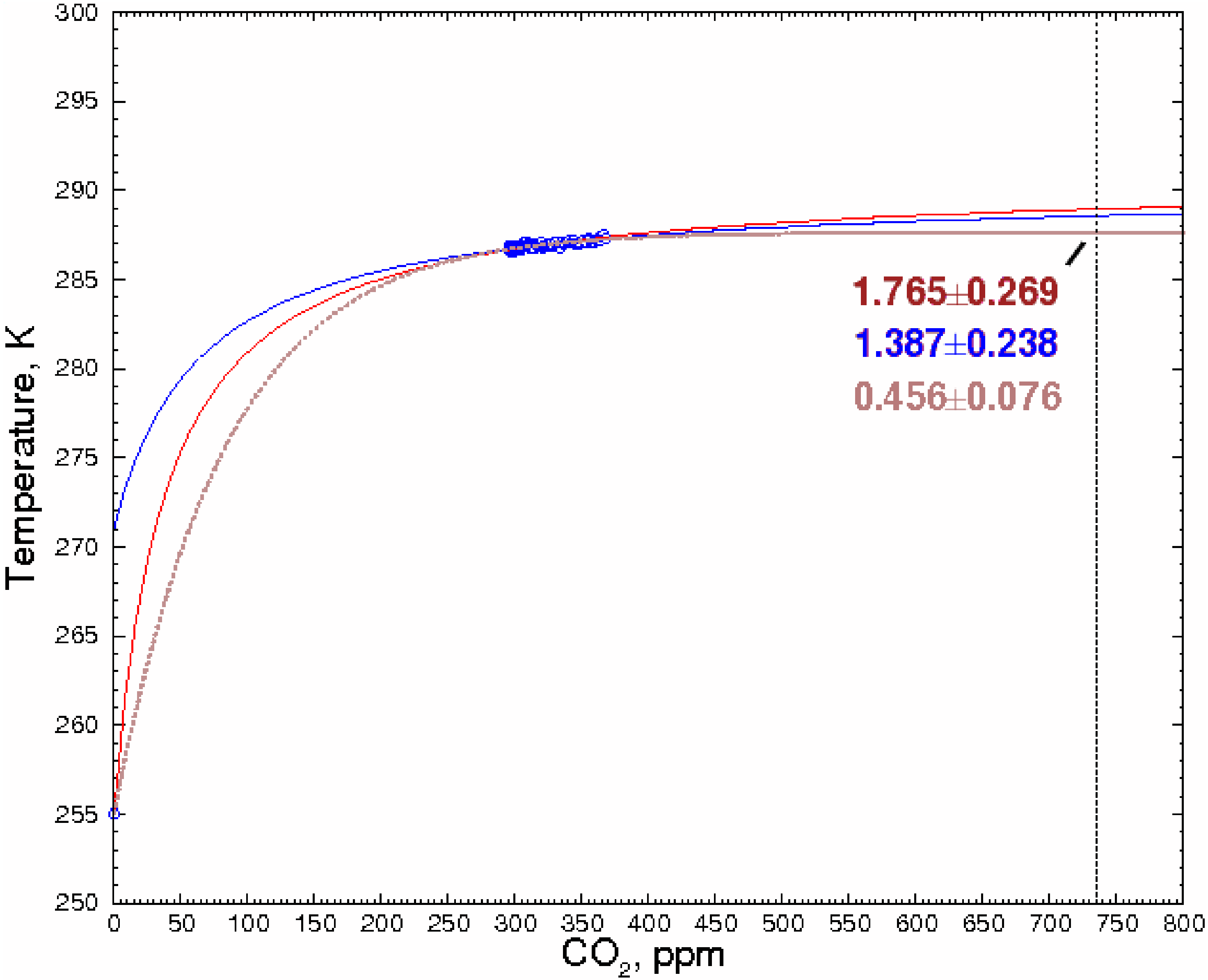


Figure 5. *Prehistoric CO_2 levels and temperatures since the Cambrian period (500-590 million years B.P.) Graphic: www.geocraft.com* [4]

Source	Year	ECS (degree K)	Methodology
Arrhenius	1896	5.0 - 6.0	Numerical computation
Callendan	1938	2	Extrapolation of 19th Century data
Plass	1956	3.0 - 4.0	Radiation transmission calc.
IPCC	2021	1.8 - 4.5	IPCC 6 - GCM Models
Lindzen & Choi	2011	0.5 - 1.5	Data ERBE/CERES/SST
Lewis and Curry	2018	1.5	Energy budget Data IPCC AR5
Wijngaarden & Happer	2019	1.3 – 2.2	HITRAN data/Radiation transfer calc.
Smirnov	2021	0.4	HITRAN data/Radiation transfer calc.
Coe et al	2021	0.5	HITRAN data/Radiation transfer calc.

Note: As of January 2022, 137 published papers have detailed an ECS much lower than the IPCC estimate

ECS from Curve Fitting Method



Source: Cold Facts on Global Warming, T J Nelson

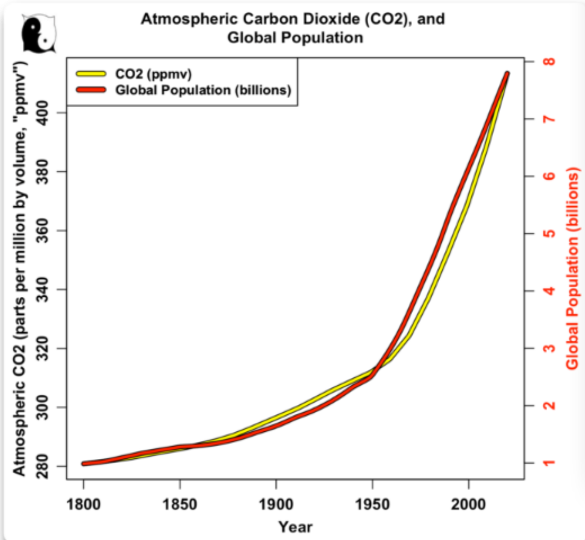


Figure 1. Atmospheric CO2 levels, and population growth, 1800 – 2020

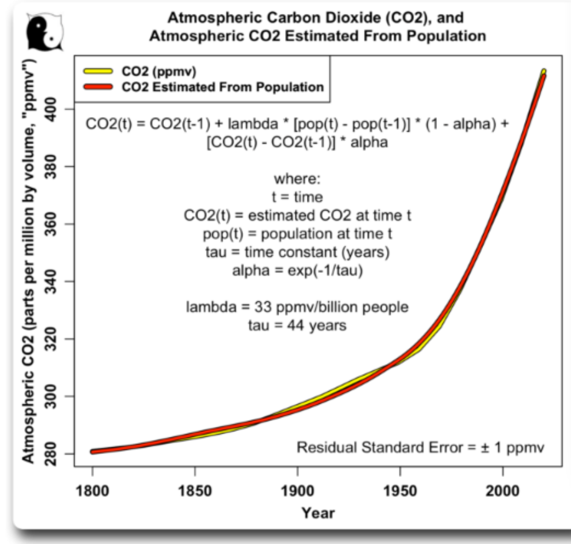


Figure 2. Atmospheric CO2 levels as calculated as a lagged and resized version of the population growth.

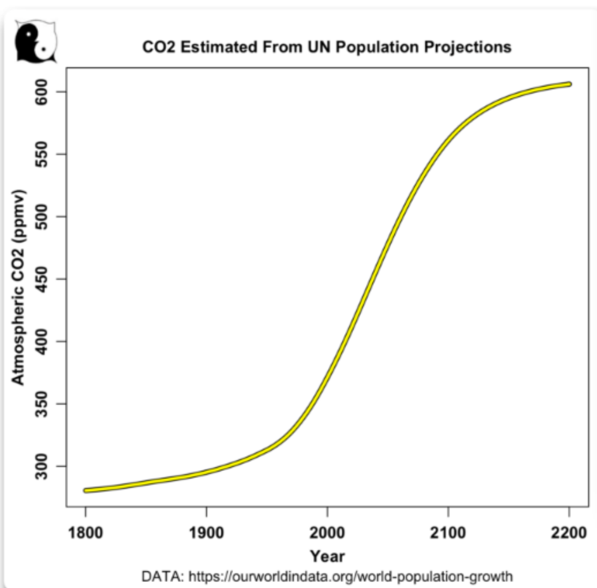


Figure 4. CO2 projection to 2200, using the method of Figure 2 with the same tau and lambda values.

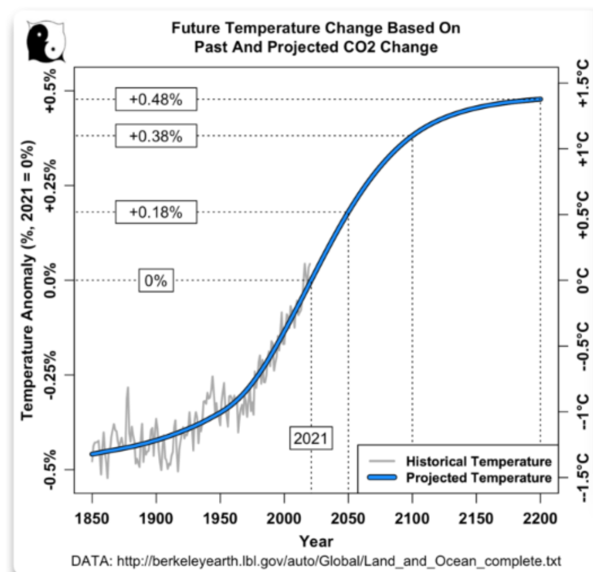


Figure 5. Past and future temperature anomalies based on the CO2 projections in Figure 4. Please be clear that I do **not** think that global average surface temperature is a function of CO2 levels, so this is done purely as a theoretical exercise.

Source: WUWT, Humanoids and CO2 Levels, Willis Eschenbach

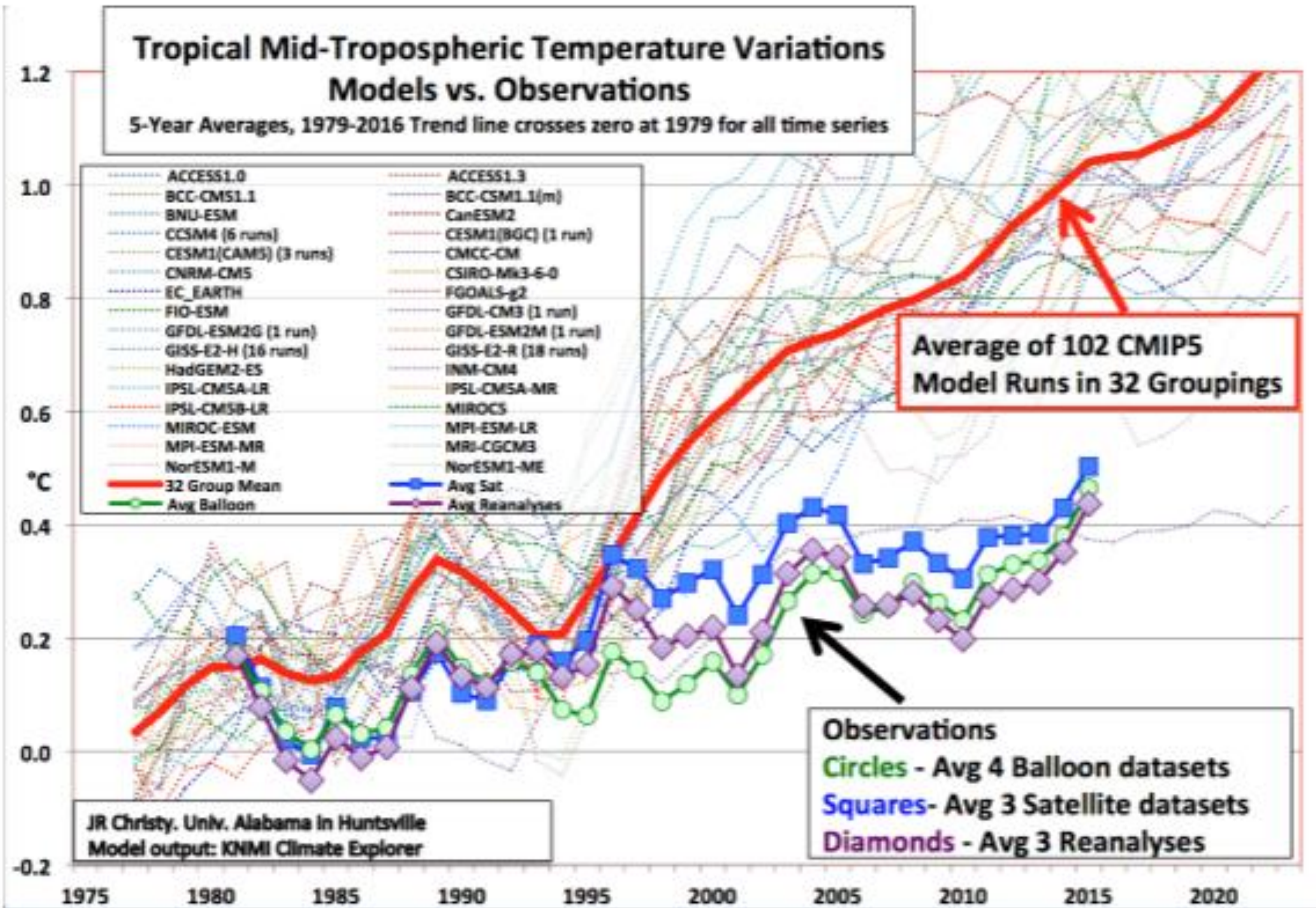


Figure 2: Five-year averaged values of annual mean (1979-2016) tropical bulk T_{MT} as depicted by the average of 102 IPCC CMIP5 climate models (red) in 32 institutional groups (dotted lines). The 1979-2016 linear trend of all time series intersects at zero in 1979. Observations are displayed with symbols: Green circles - average of 4 balloon datasets, blue squares - 3 satellite datasets and purple diamonds - 3 reanalyses. See text for observational datasets utilized. The last observational point at 2015 is the average of 2013-2016 only, while all other points are centered, 5-year averages.

Atmospheric Carbon Dioxide and the Oceans

Henry’s Law

Henry's law is one of the gas laws formulated by William Henry in 1803 and states: "At a constant temperature, the amount of a given gas that dissolves in a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid." An equivalent way of stating the law is that the solubility of a gas in a liquid is directly proportional to the partial pressure of the gas above the liquid:

$$C=kPgas$$

Calcium carbonate, or calcite

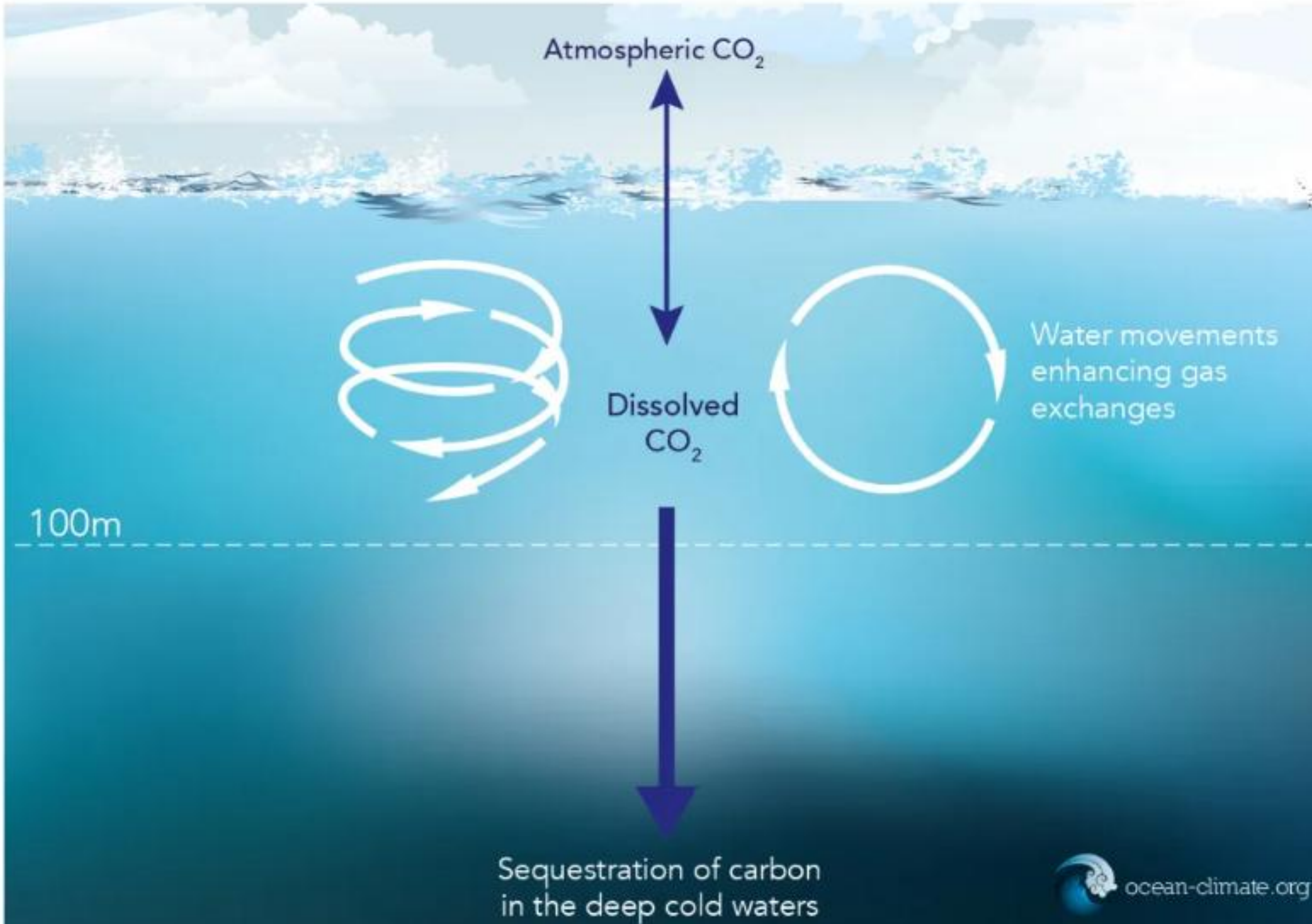
Bicarbonate ions

$$H_2O + CO_2 + \boxed{CaCO_3} \;=>\; Ca^{2+} + \boxed{2HCO_3^-}$$

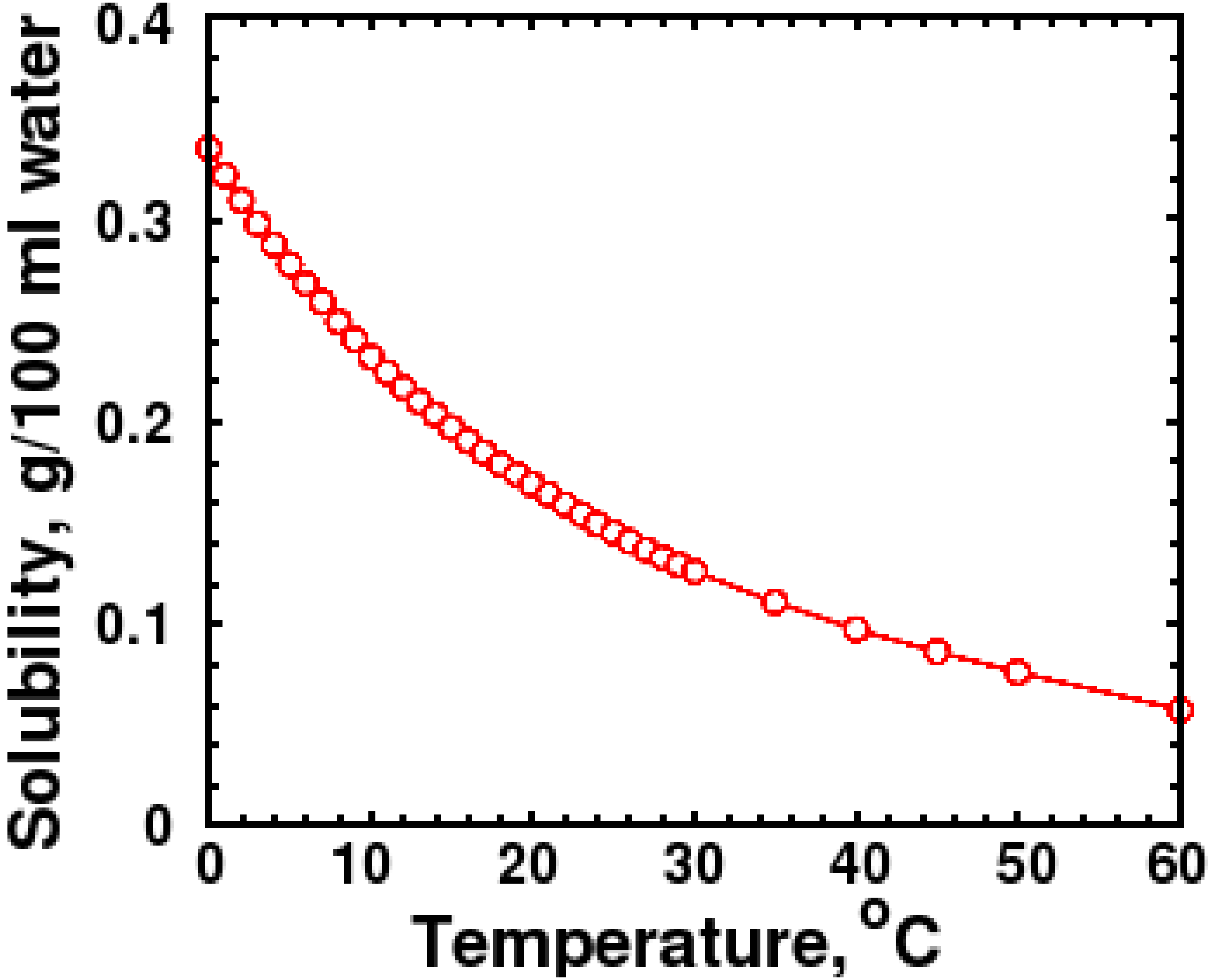
Dissolution of calcite adds additional bicarbonate ions and hydrogen ions to seawater

$$CO_2 + H_2O \;<=>\; \boxed{H_2CO_3} \;\mathbf{<=}\; \boxed{H^+} + \boxed{HCO_3^-} \;<=>\; 2H^+ + CO_3^{2-}$$

Reaction is buffered by producing more carbonic acid



Physical carbon pump



Solubility, g/100 ml water
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
Temperature, °C

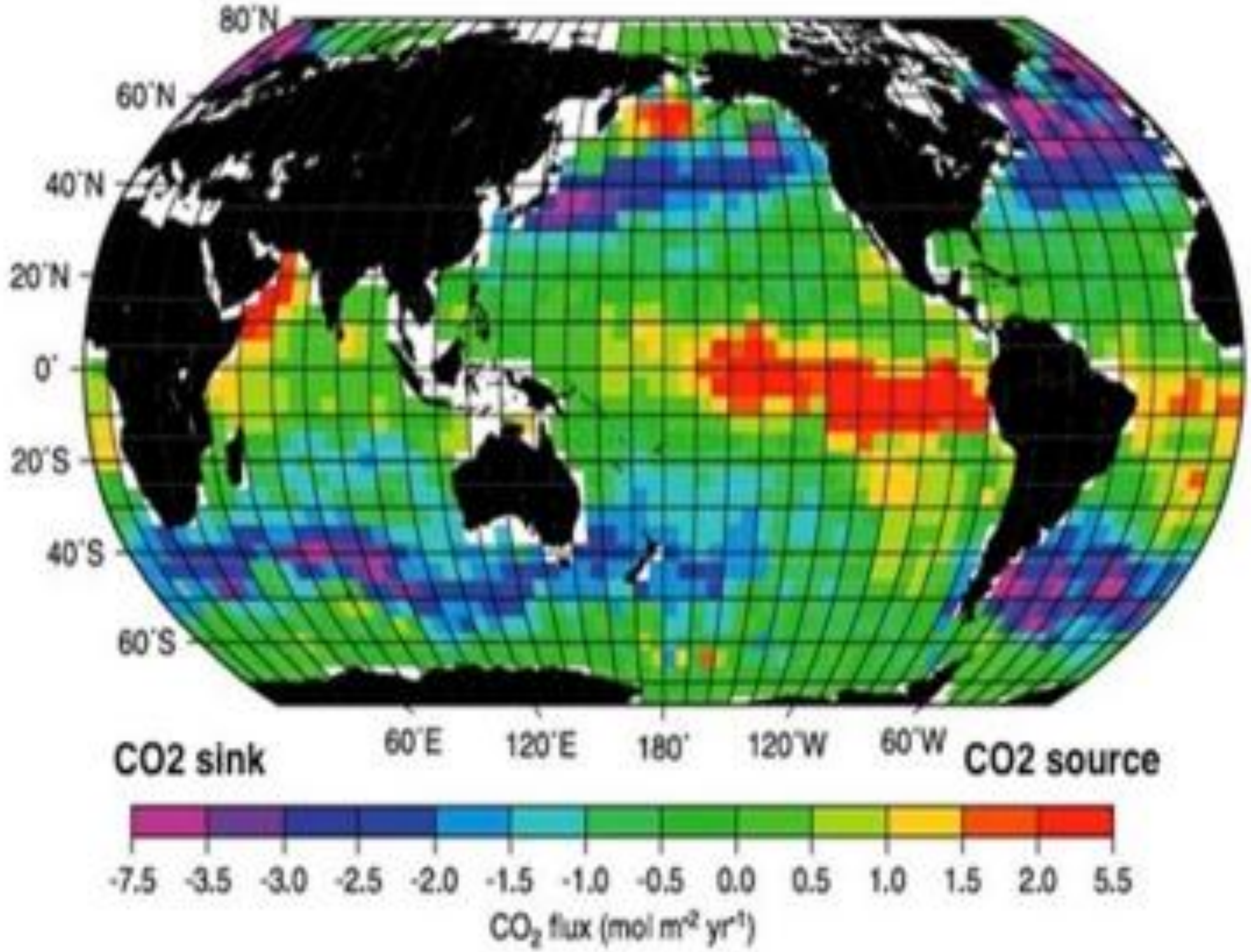
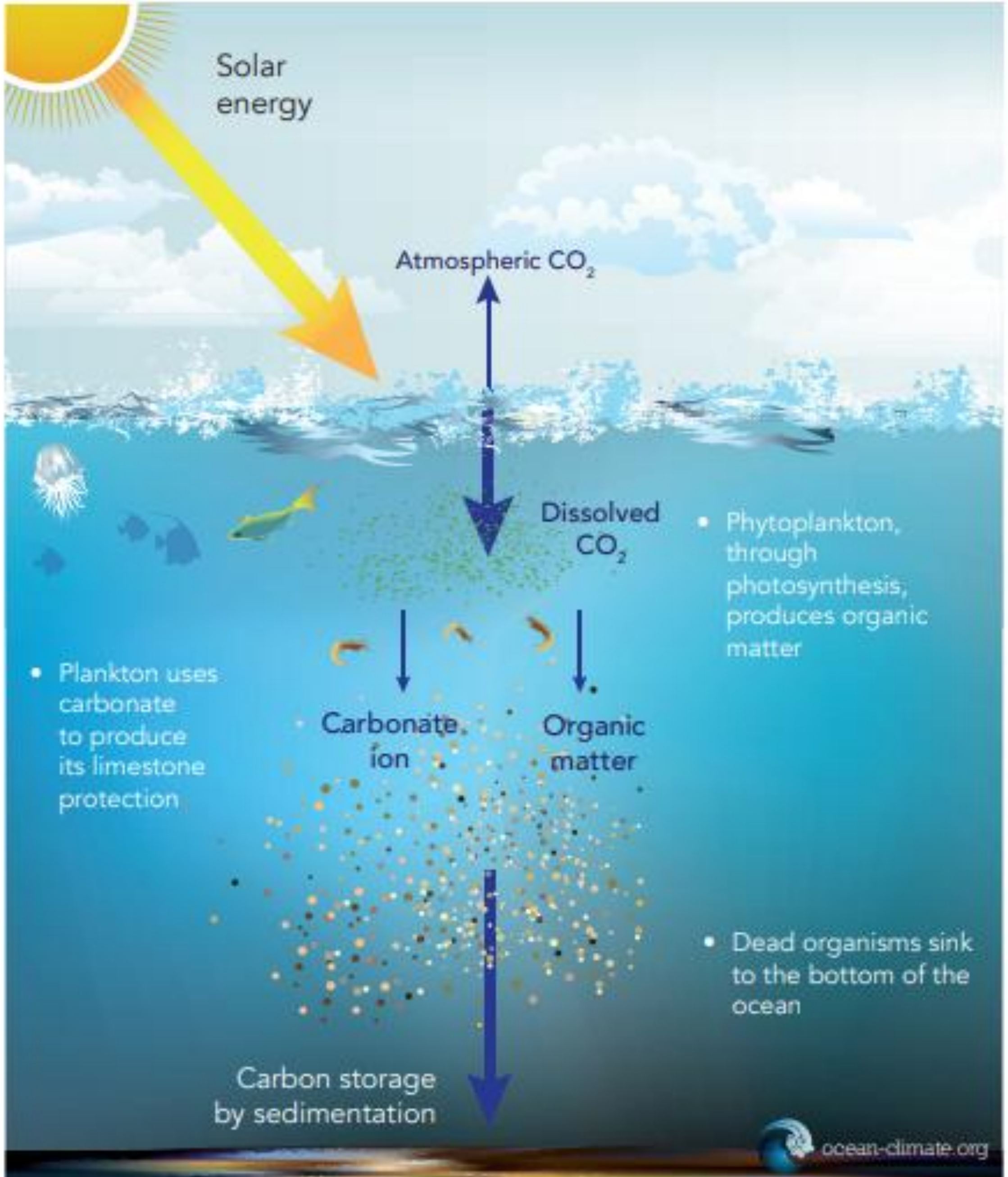


Figure 3: Map of total sea-air CO2 flux (NOAA[10])



Biological carbon pump

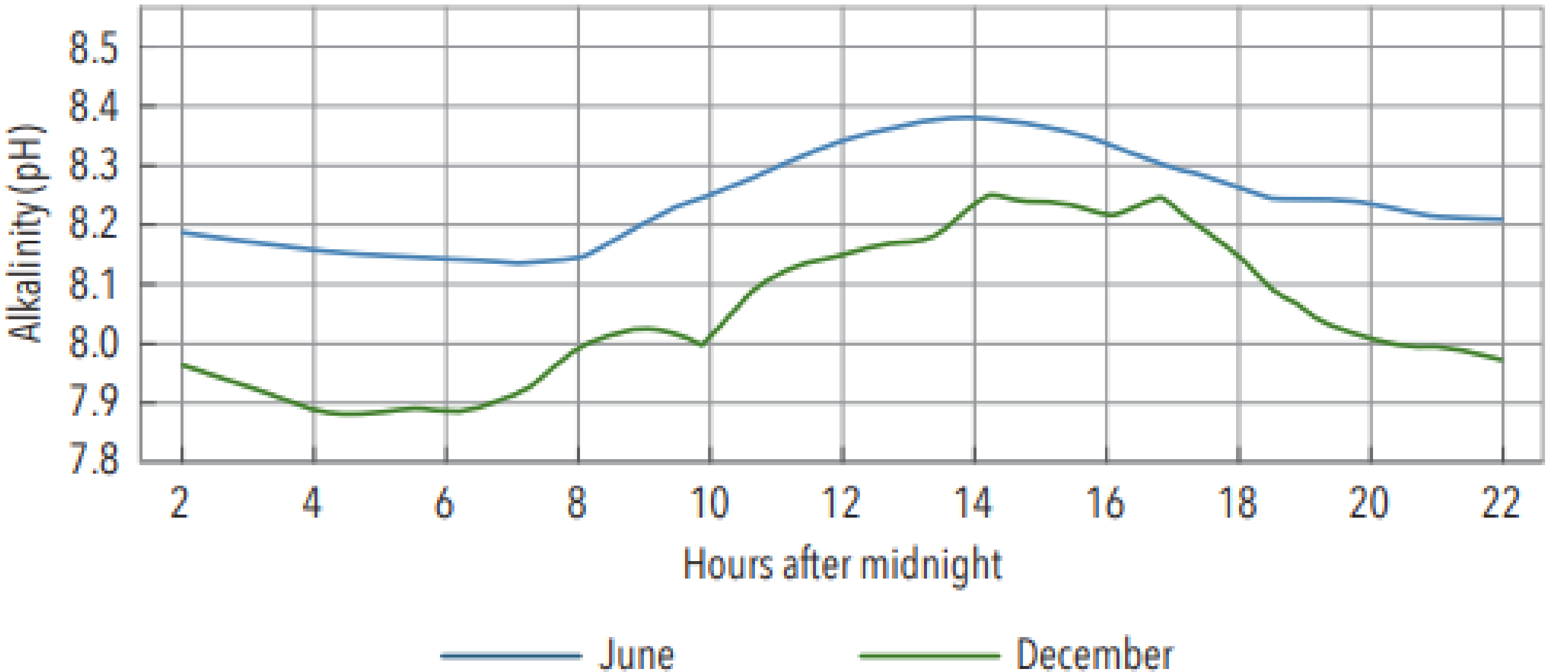
The ocean plays a critical role in carbon sequestration. Phytoplankton, which live on the warm, light-filled surface, suck carbon dioxide out of the atmosphere for food. They also need nutrients such as phosphorus and nitrogen from colder, heavier, saltier water that upwells into warmer layers. When phytoplankton die, they sink, bringing some of the carbon and other nutrients they consumed with them back to the ocean depths.

Key to this circular process, known as the ocean's biological carbon pump, is the vertical mixing of the surface and deeper water layers, which occurs through such mechanisms as currents, winds, and tides. However, because higher ocean temperatures cause greater stratification of these layers, traditional scientific models have long predicted that as the planet warms, this process would be disrupted, phytoplankton would be unable to thrive, and the ocean would sequester less carbon.

Now, two studies have shown the limits of such models. One found evidence that phytoplankton may become more efficient as the ocean warms. The other reported the discovery of a new, widely distributed ocean microbe species that also has the potential to sequester carbon.

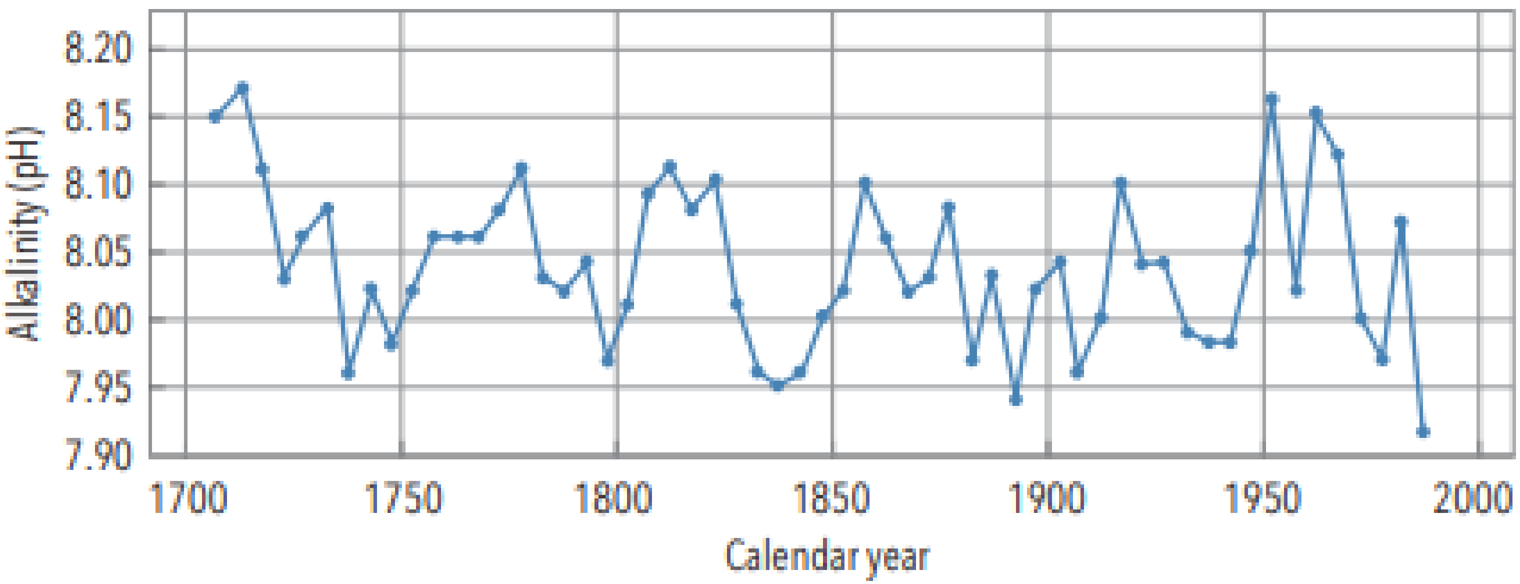
Source : The Ocean Is Still Sucking Up Carbon—Maybe More Than We Think
Nancy Averett, WUWT, May 2022

Figure 2.2 Variation in daily pH



Source: Adapted with permission from Kline, DI et al., 'Six month *in situ* high-resolution carbonate chemistry and temperature study on a coral reef flat reveals asynchronous pH and temperature anomalies,' *PLoS ONE*, vol. 10, no. 6, e0127648, copyright 2015.

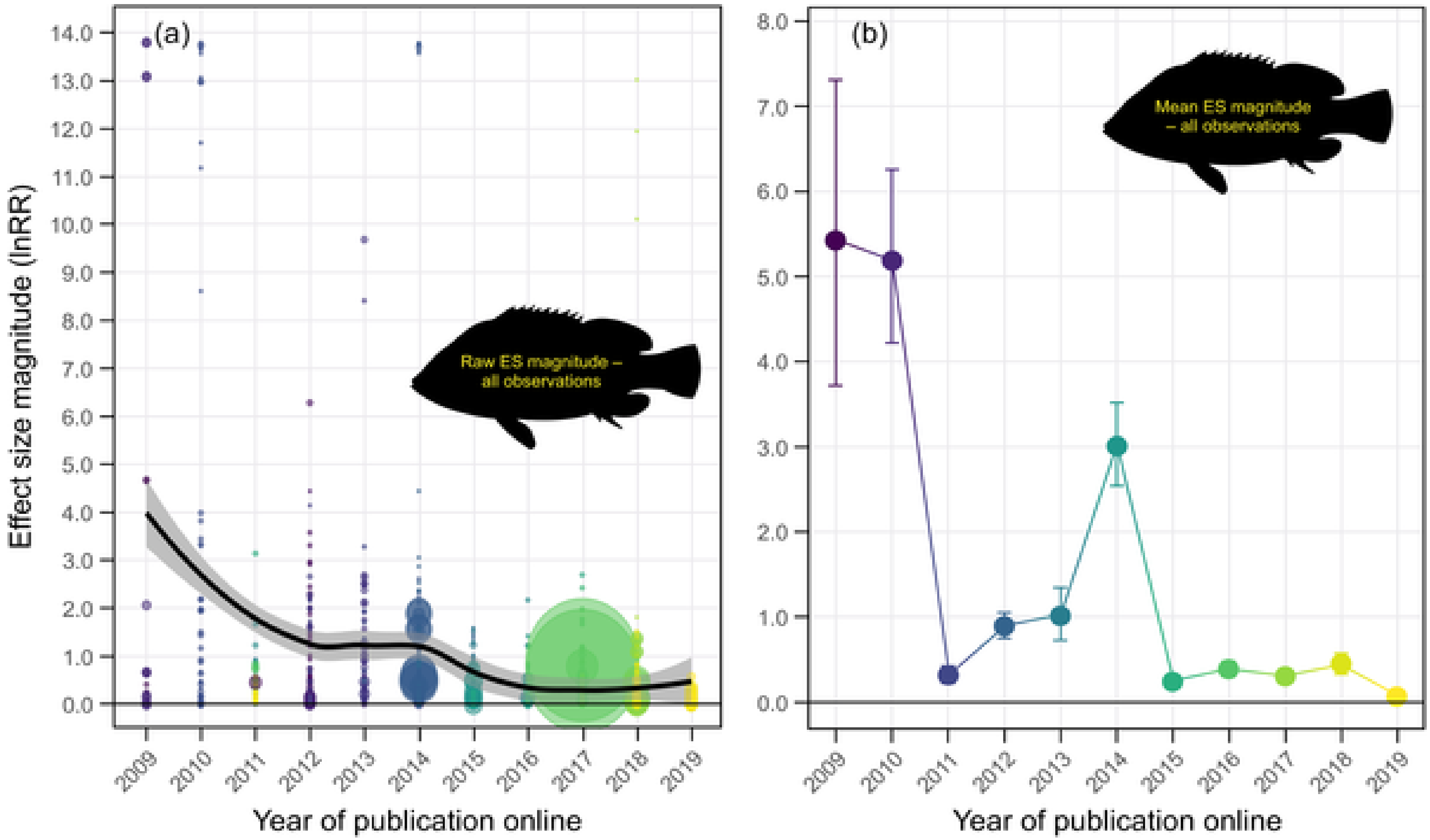
Figure 2.4 Changes in pH over decadal time scales



Variations in pH at Flinders Reef reconstructed from boron isotopes in coral.

Source: Adapted by permission from The American Association for the Advancement of Science – Pelejero, C et al., 'Preindustrial to modern interdecadal variability in coral reef pH', Science, vol. 309, no. 5744, pp. 2204-2207, copyright 2005.

Fig 1. The decline effect in ocean acidification research on fish behavior.



Clements JC, Sundin J, Clark TD, Jutfelt F (2022) Meta-analysis reveals an extreme “decline effect” in the impacts of ocean acidification on fish behavior. PLOS Biology 20(2): e3001511. https://doi.org/10.1371/journal.pbio.3001511
https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.3001511

Acidification in context

The concept of ocean acidification, and human-caused global warming more generally, has been described as containing a grain of truth embedded in a mountain of nonsense (Lawson 2008; Carter 2010). Indeed, the projected large increase in atmospheric CO_2 will at most cause a small reduction in pH – it will not turn the ocean acidic. Yet this is what is implied by the term ocean acidification. True acidification would require average pH to be reduced below 7.0, at which point shells would indeed begin to dissolve. This is an impossible scenario, however, because of the ocean's effectively limitless buffering capacity

CLIMATE CHANGE: THE FACTS 2017

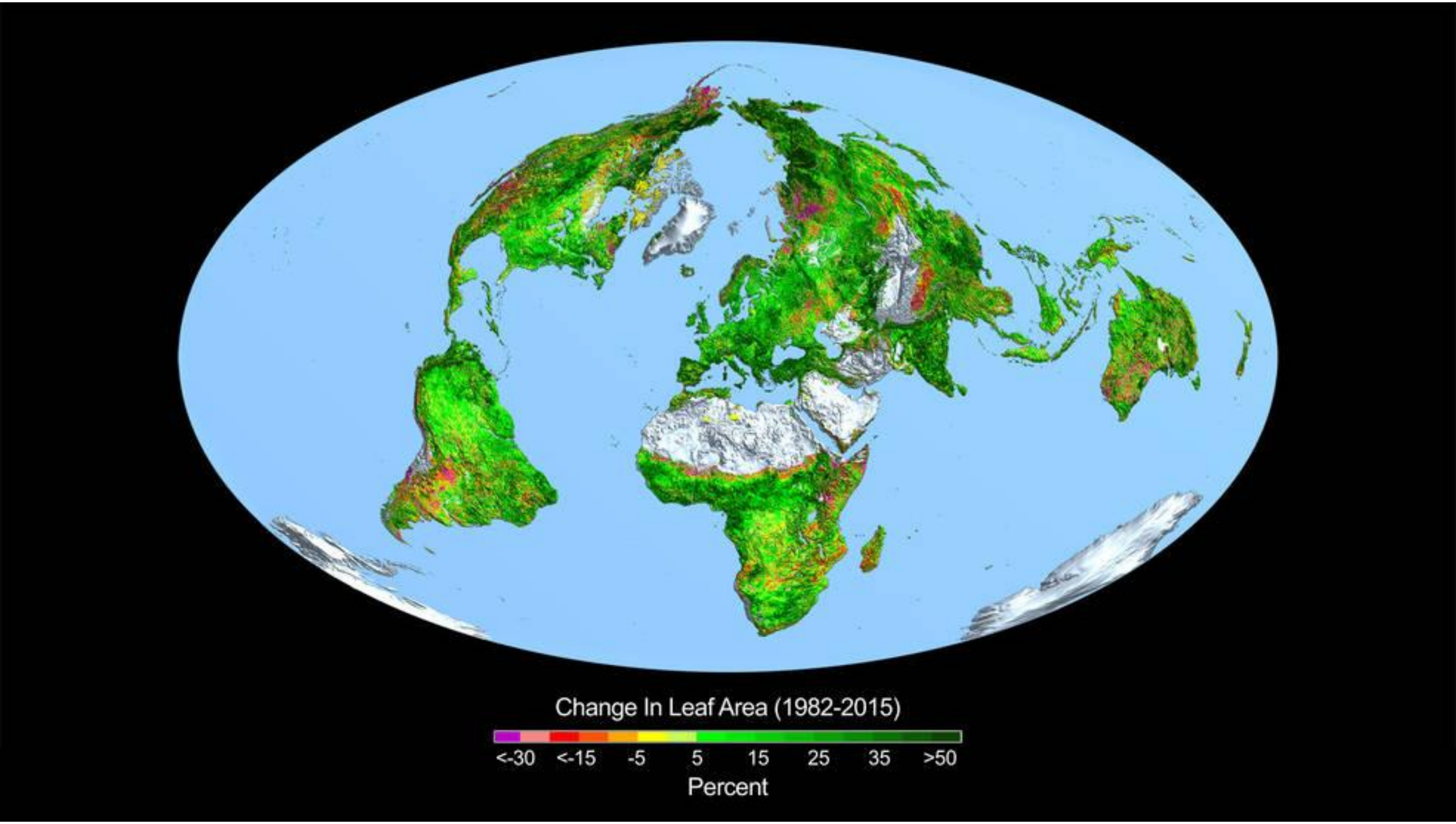
Ocean Acidification: Not Yet a Catastrophe for the Great Barrier Reef

Dr John Abbot & Dr Jennifer Marohasy

***Figure 6**. The enormous limestone masses of the Swiss Jura mountain chain have been built by corals and other shell-secreting marine creatures (Photo: private)*

Carbon Dioxide as Plant Fertiliser

- overall global effect
- effect on tree growth
- effect on food crops
- beneficial effect on usage of water



This image shows the change in leaf area across the globe from 1982-2015.
Credits: Boston University/R. Myneni

***Figure 2**. Eldarica pine trees grown at the U.S. Water Conservation Laboratory in the mid-1980s by Dr. Sherwood Idso under ambient CO_2 air and air enriched with an extra 150, 300 and 400 ppm of atmospheric CO_2. Photo copyright and courtesy of the author.*

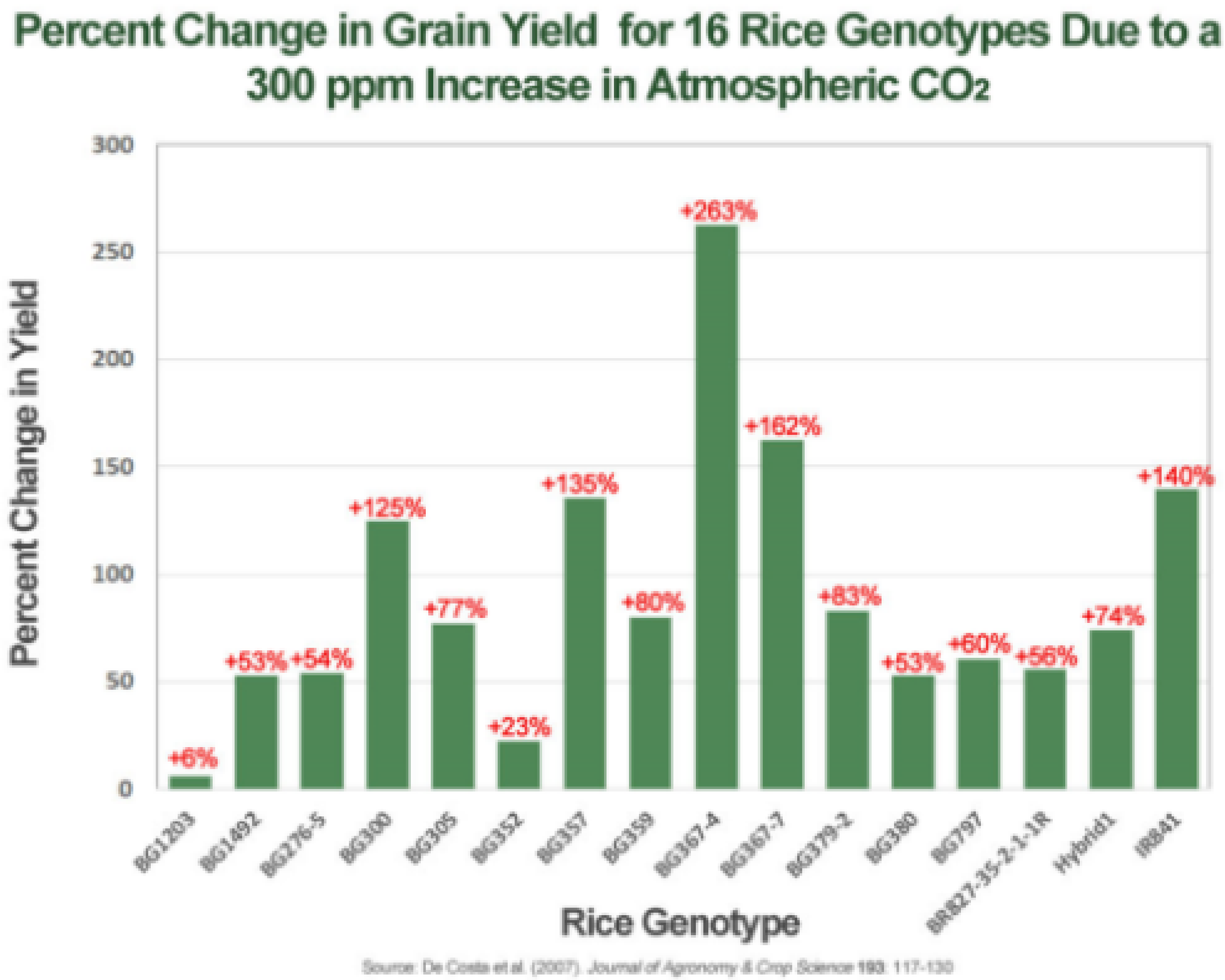


***Figure 3**. Percent change in grain yield for 16 different rice genotypes in response to a 300 ppm increase in atmospheric CO_2. Source: Decosta et al. (2007).*

Plant Dry Weight (Biomass) Responses to Atmospheric CO2 Enrichment

Plant Name	**300 ppm**			**600 ppm**			**900 ppm**		
	Studies #	Mean	Std Error	Studies #	Mean	Std Error	Studies #	Mean	Std Error
Wheat Common (*Triticum aestivum*)	490	38.50%	1.50%	17	63.30%	12.80%	12	33.80%	7.20%
Wheat Durum (*Triticum durum*)	12	54.50%	8.50%	2	61%	0.70%			
Corn (*Zea mavs*)	60	32.10%	5.40%	16	27.60%	3.70%			
Cotton (*Gossypium hirsutum*)	43	56.50%	7.50%	1	27%				

Source: CO2 Science

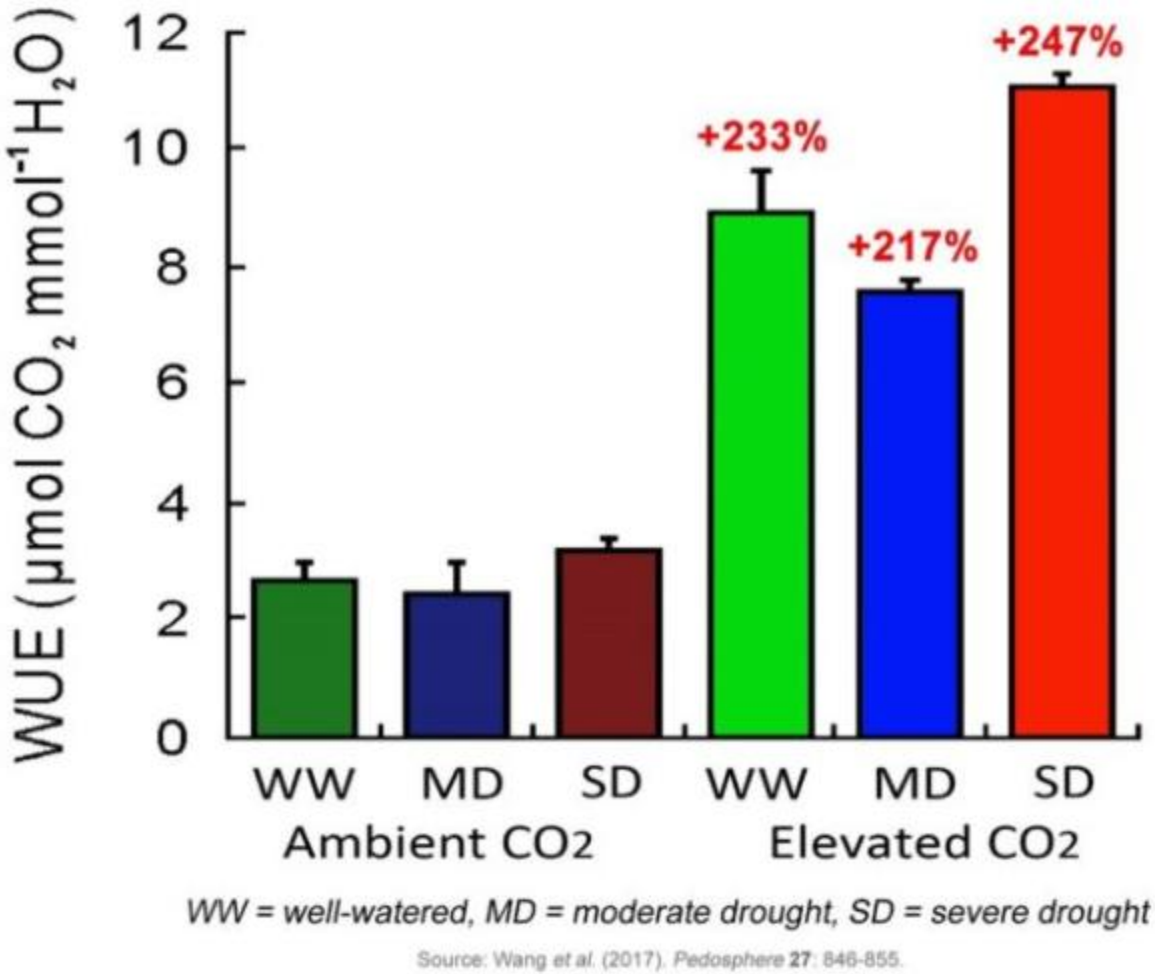


***Figure 1**. Water use efficiency (WUE) of soybean plants grown for 40 days under various water-supply treatments (WW = well-watered; MD = moderate drought; SD = severe drought) and atmospheric CO_2 (ambient and elevated, elevated = twice ambient). The numbers in red text indicate the percent enhancement of plant WUE under elevated CO_2 for a given water supply treatment. Source: Wang et al. (2017).*

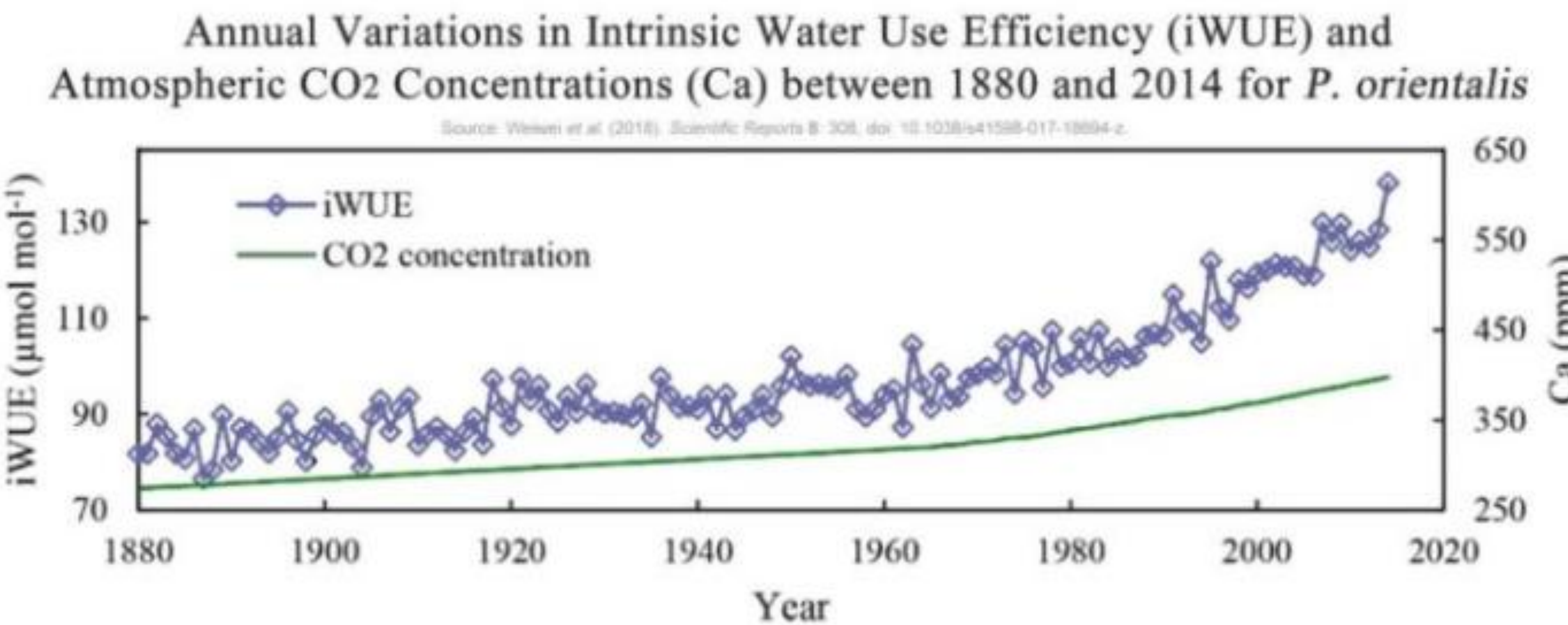


***Figure 2**. Annual variations in tree-ring averaged intrinsic water use efficiency (iWUE) and atmospheric CO_2 concentrations (Ca) between 1880 and 2014 for P. orientalis. Source: Weiwei et al. (2018).*

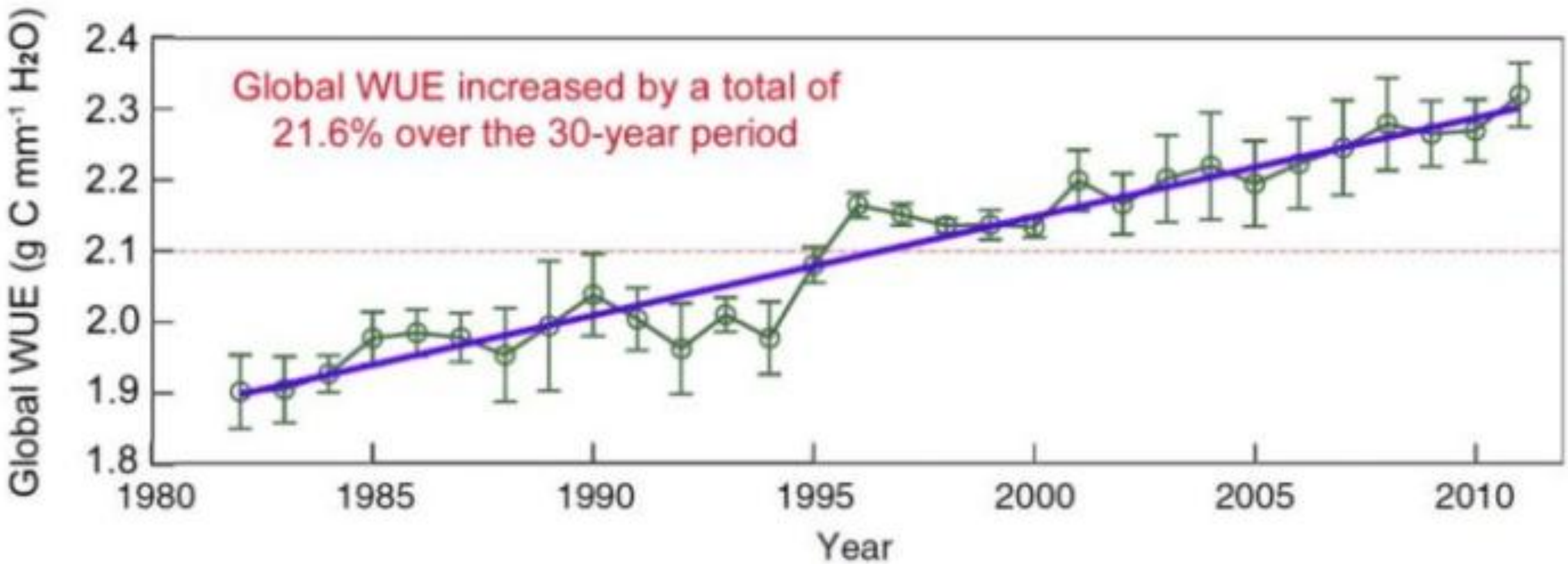


Figure 3. *Estimated trends in global water use efficiency (WUE) over 1982-2011. Annual mean anomalies (with linear trend line) are presented along with associated standard deviations of global WUE. Source: Cheng et al. (2017).*

Yes, the **real** science is definitely settled, **increasing** carbon dioxide in the atmosphere is **good** for mother Earth!