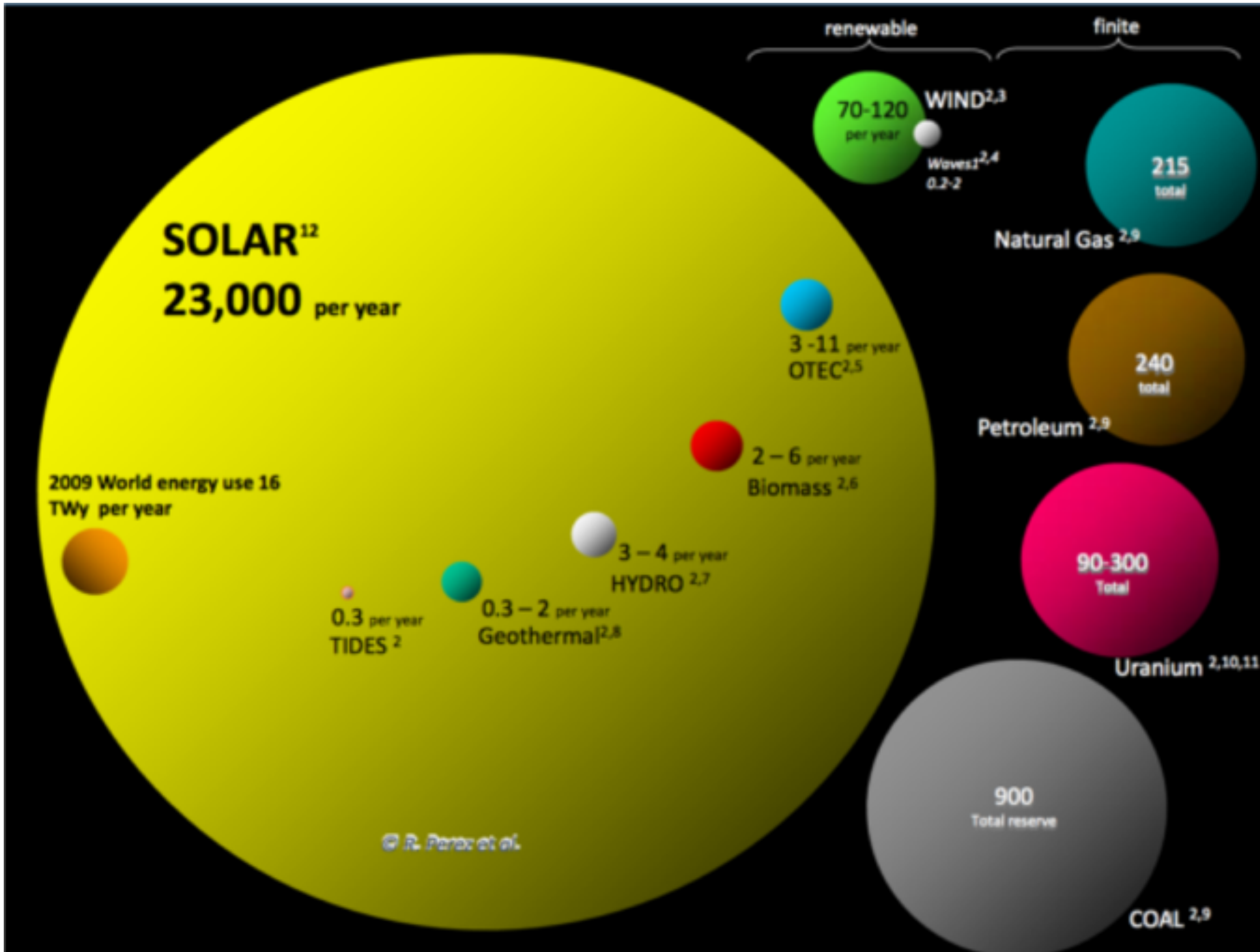
Thermodynamics of Energy Conversion

3. Resources, Carbon, Climate

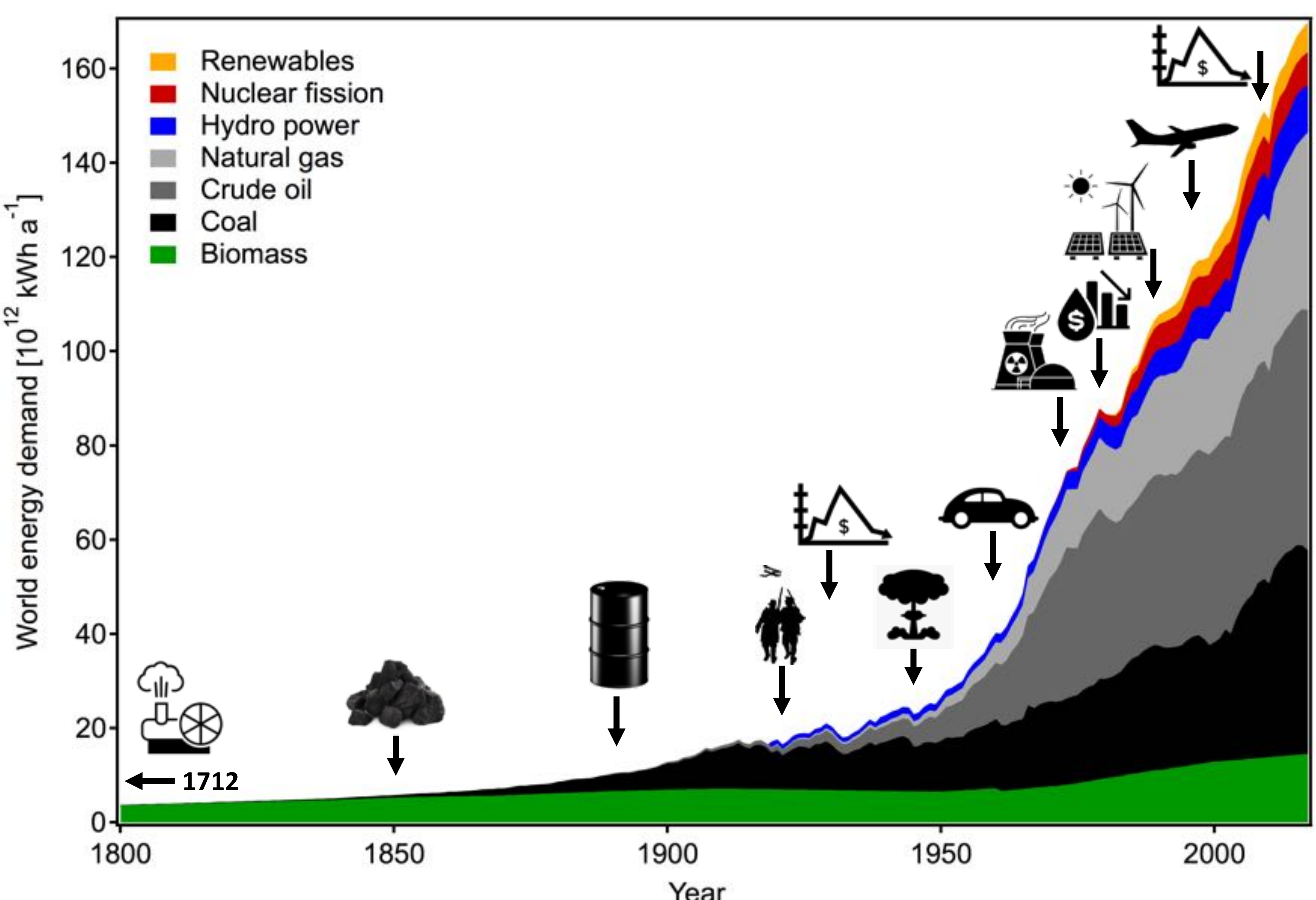


3) RESOURCES & CLIMAT

3) Resources

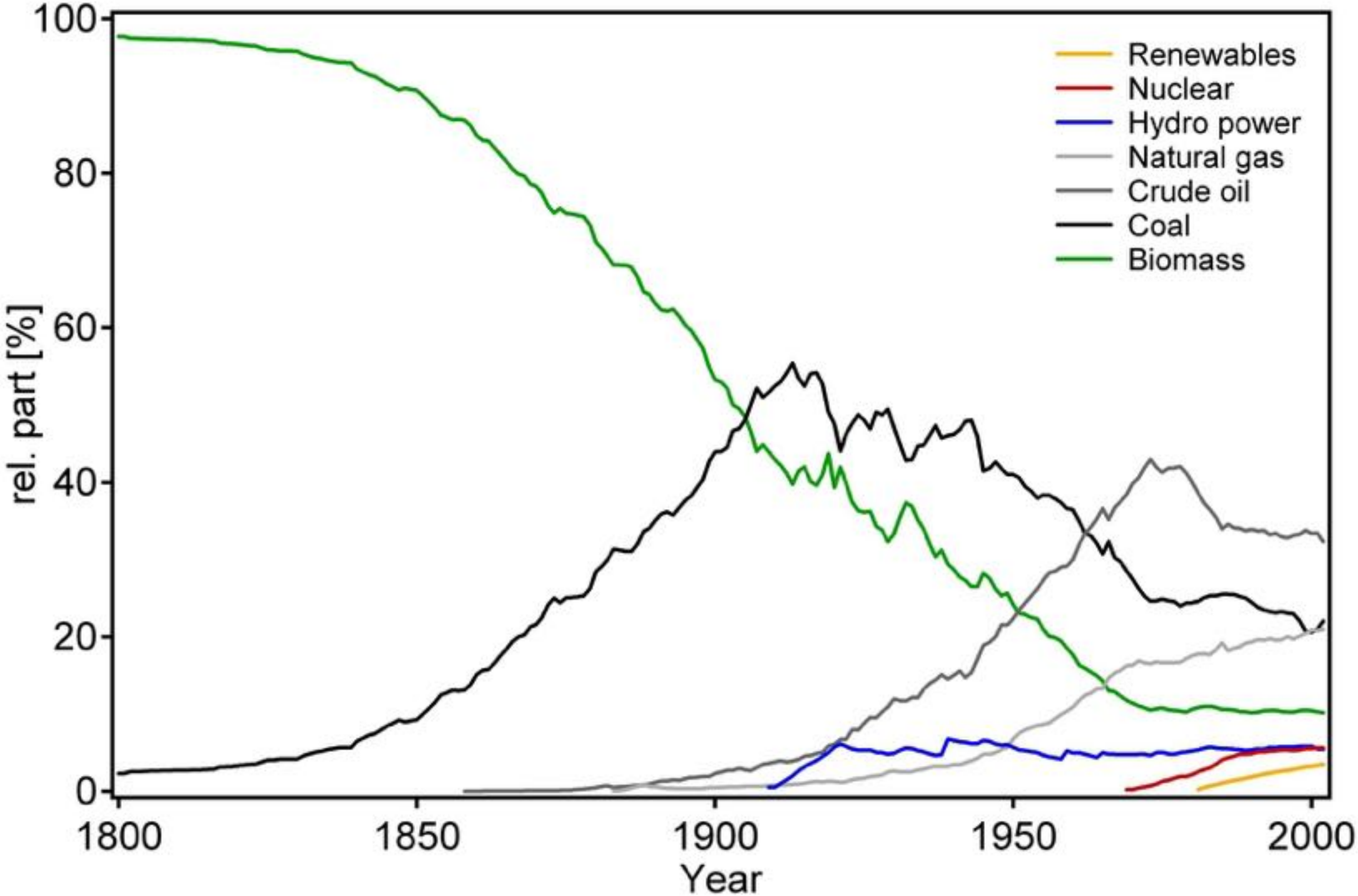
3) Resources

3.1. World resource use

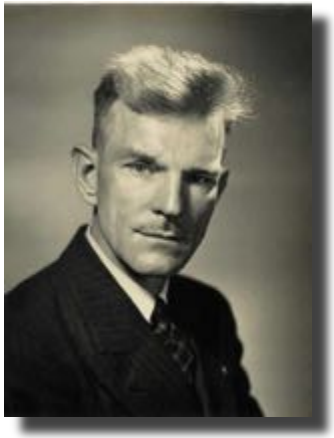


Ref.: Jean-Marie Martin-Amouroux, IEPE, Grenoble, France

3.1.1. Contribution of the energy carriers

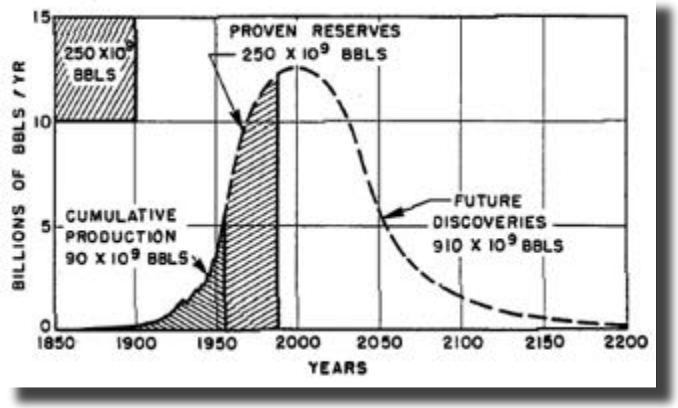


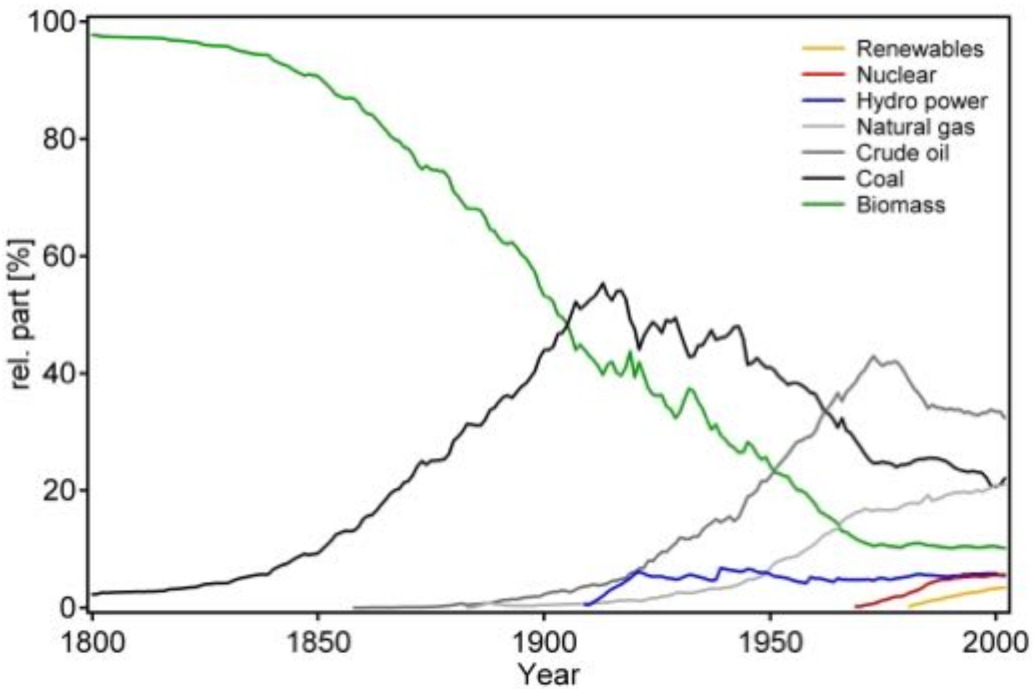
3.1.2. Peak oil

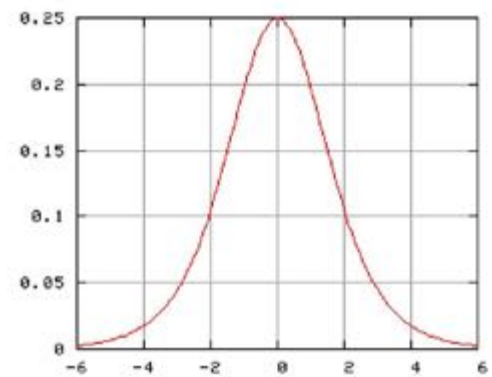


M. King Hubbert
October 5th, 1903 -- October 11th, 1989

"Our ignorance is not so vast as our failure to use what we know."



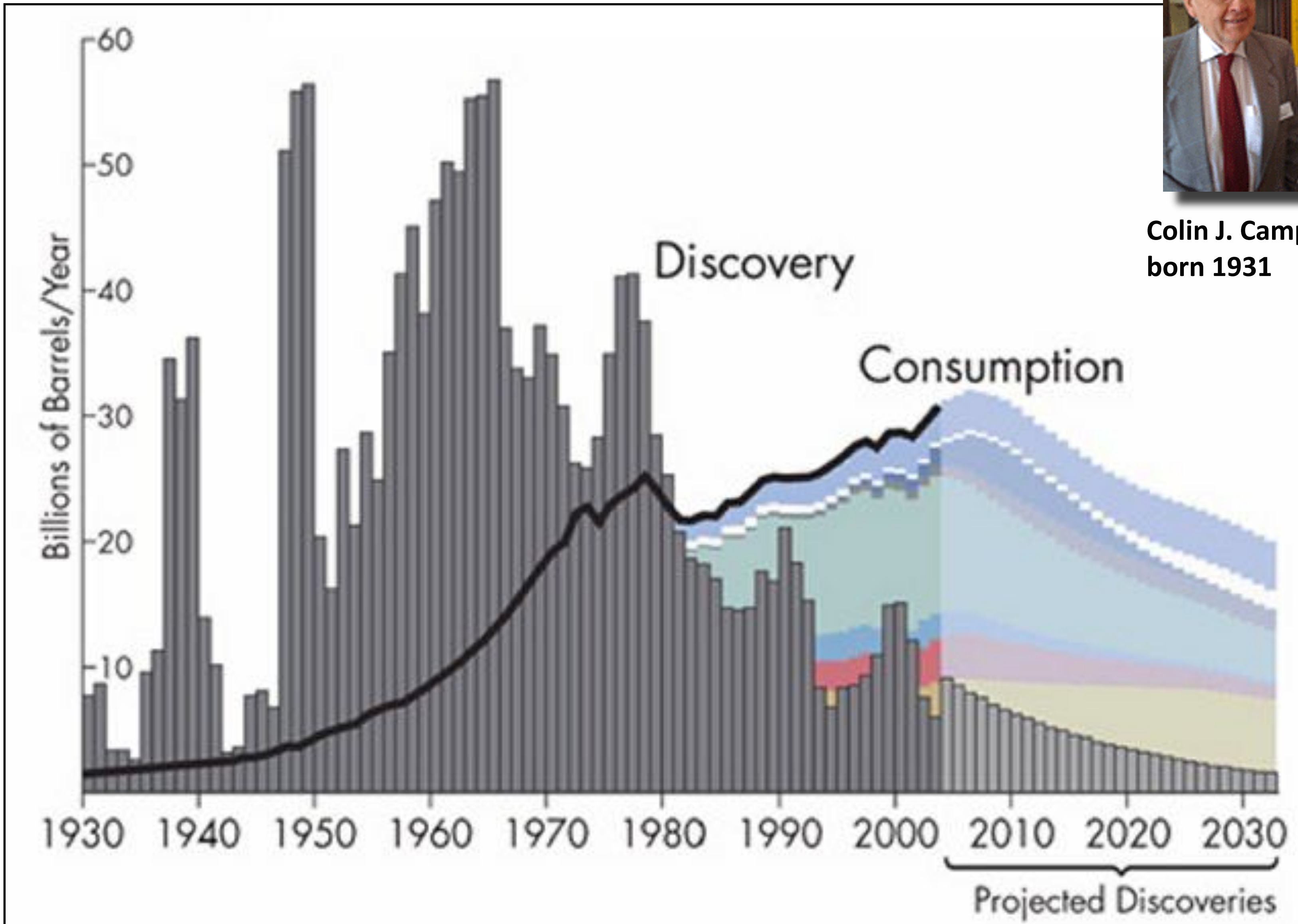




$$x = \frac{e^{-t}}{(1+e^{-t})^2} = \frac{1}{2+2\cosh t}$$

after M. King Hubbert, “Nuclear energy and the fossil fuels”, Drilling and Production Practice (1956)

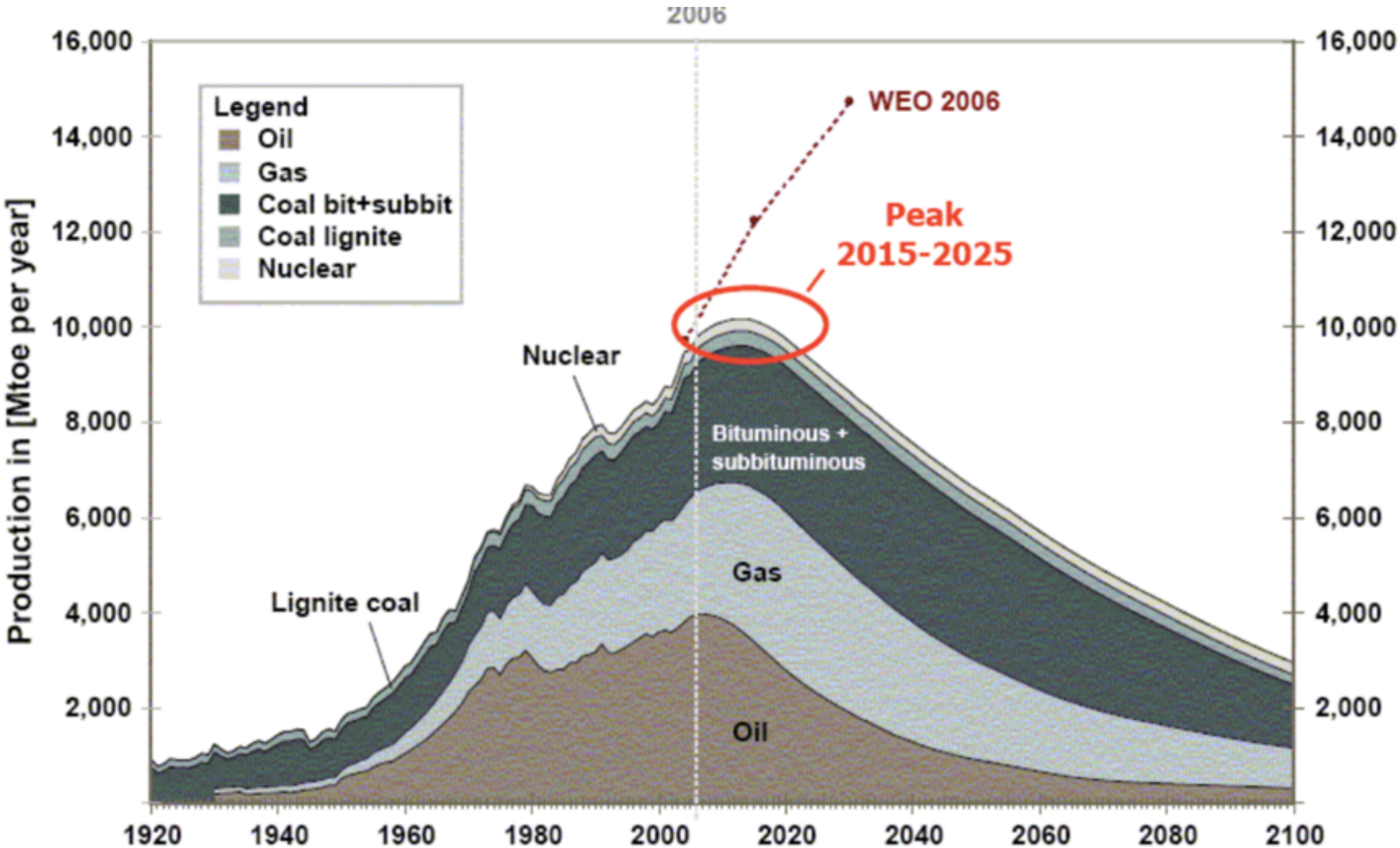
3.1.3. The growing gap



Colin J. Campbell
born 1931

Ref.: Colin J. Campbell , Oil Depletion Analysis Centre ("ODAC")

3.1.4. Peak fossil energy



Ref.: Jörg Schindler· Patrick Schmidt· Martin Zerta· Werner Zittel, (all from Ludwig-Bölkow-Systemtechnik GmbH ·Ottobrunn), “Woher kommt der Wasserstoff? Eine Analyse der globalen Energiesituation”, FVS-Workshop· Wasserstoff aus Erneuerbaren Energien, WBZU, Ulm, 21. - 22. Mai 2007

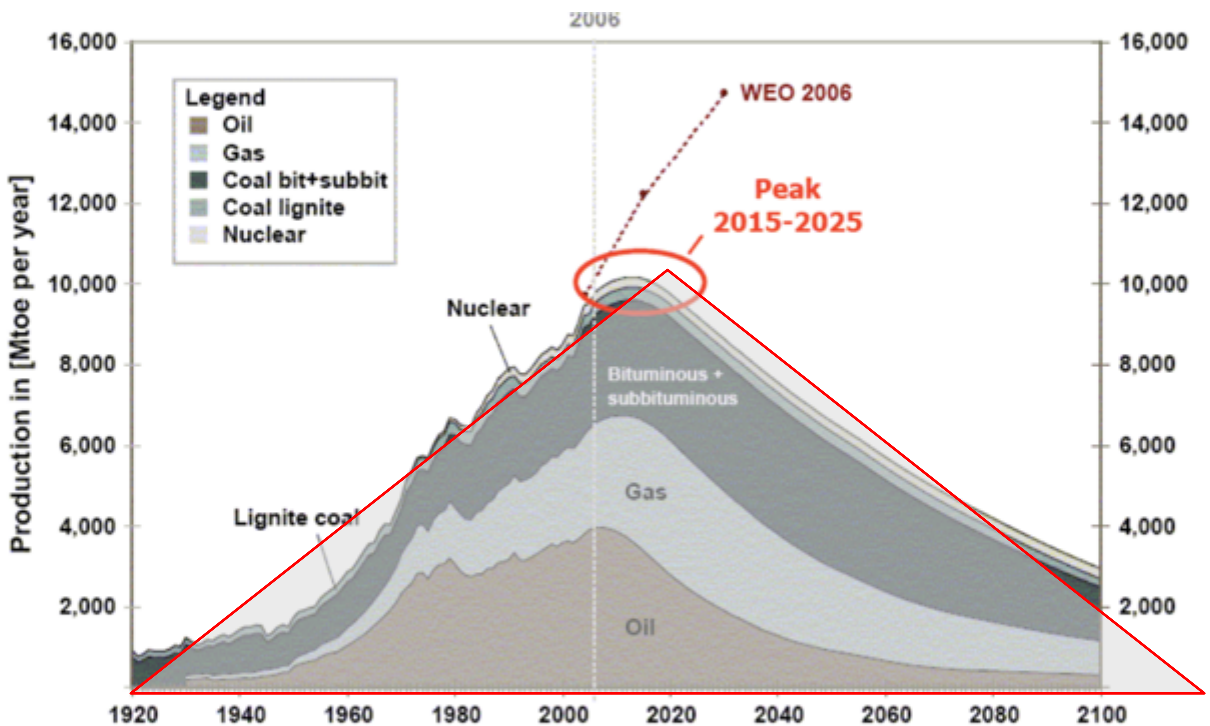
QUESTION

Estimate from the Figure on the previous slide how much fossil energy carriers were already used and how much is left?

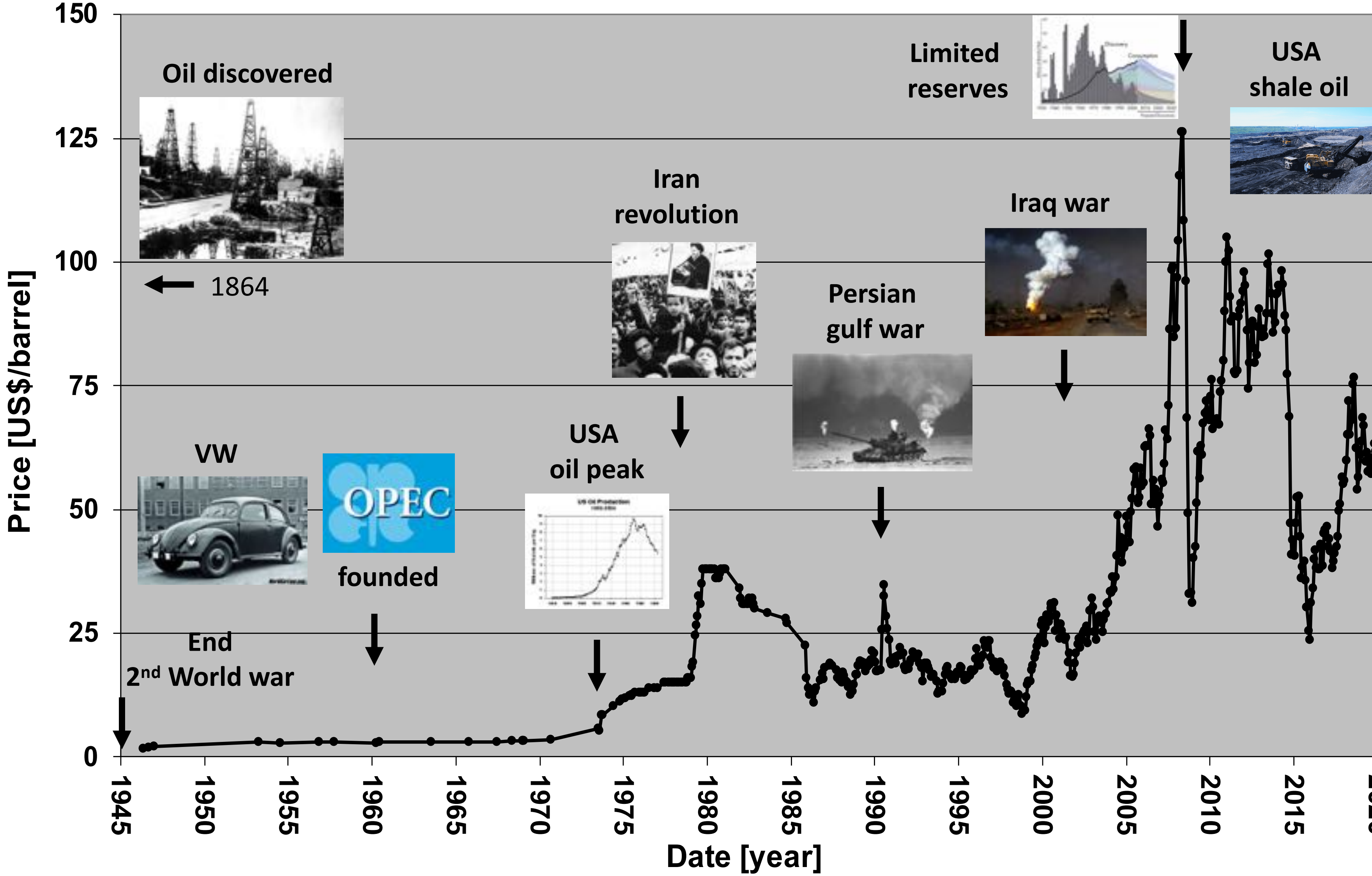
SOLUTION

Estimate from the Figure on the previous slide how much fossil energy carriers were already used and how much is left?

Approximation with a triangle: 200 years/2·10'000 Mtoe/year = 1000 Gtoe = **735 Gt C**
370 Gt C already used 365 Gt C reserves = $1.163 \cdot 10^{13}$ kWh · 365 Gt C = $4.2 \cdot 10^{15}$ kWh
Approx. 1/3 is oil 170 Gt C = $905 \cdot 10^{9}$ barrels

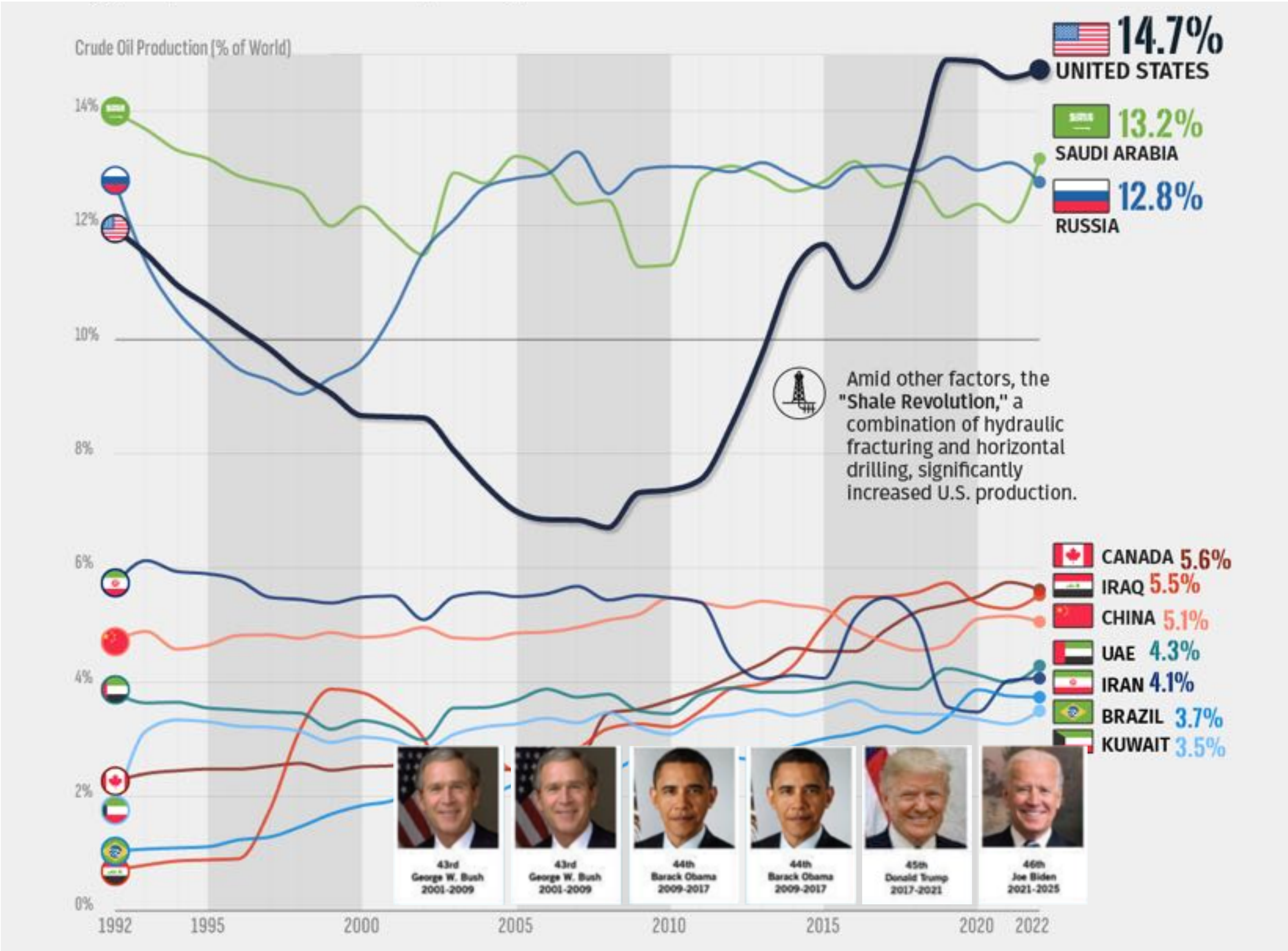


3.1.5. Global oil price

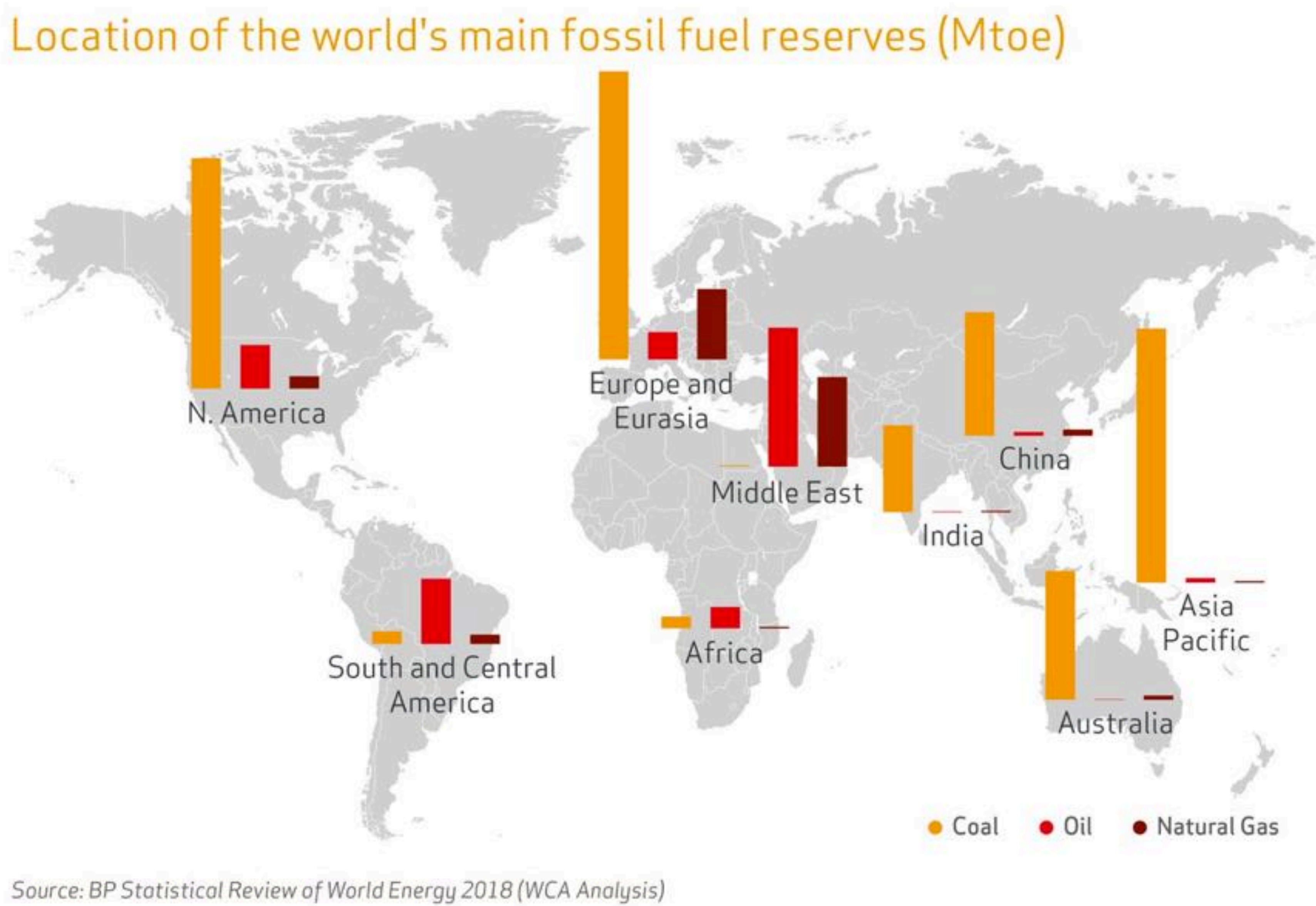


Ref.: https://www.indexmundi.com/commodities/?commodity=crude-oil&months=60;
http://www.tradingeconomics.com/commodity/crude-oil

3.1.6. Oil producing countries (50% of global)

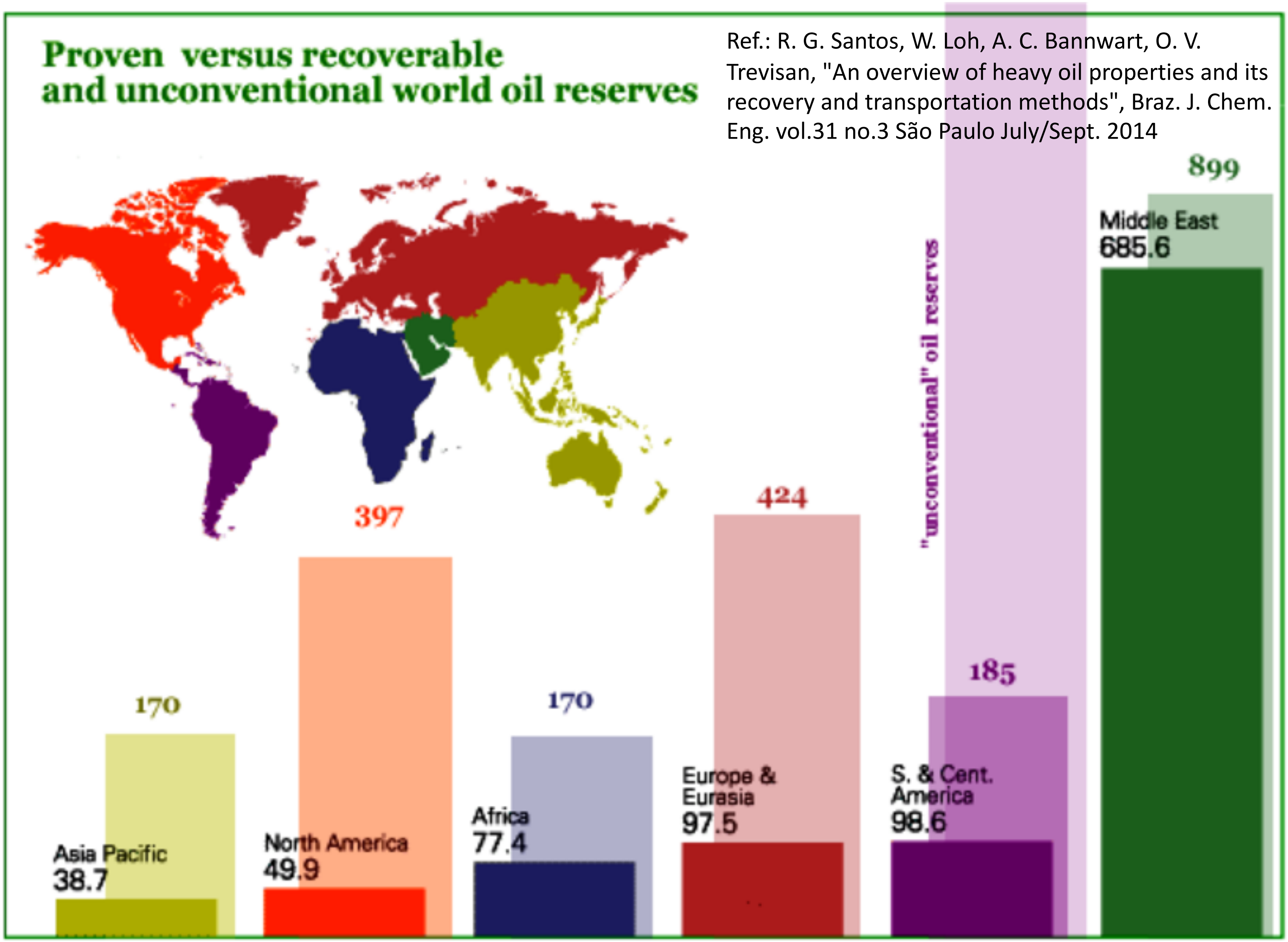


3.2. World reserves



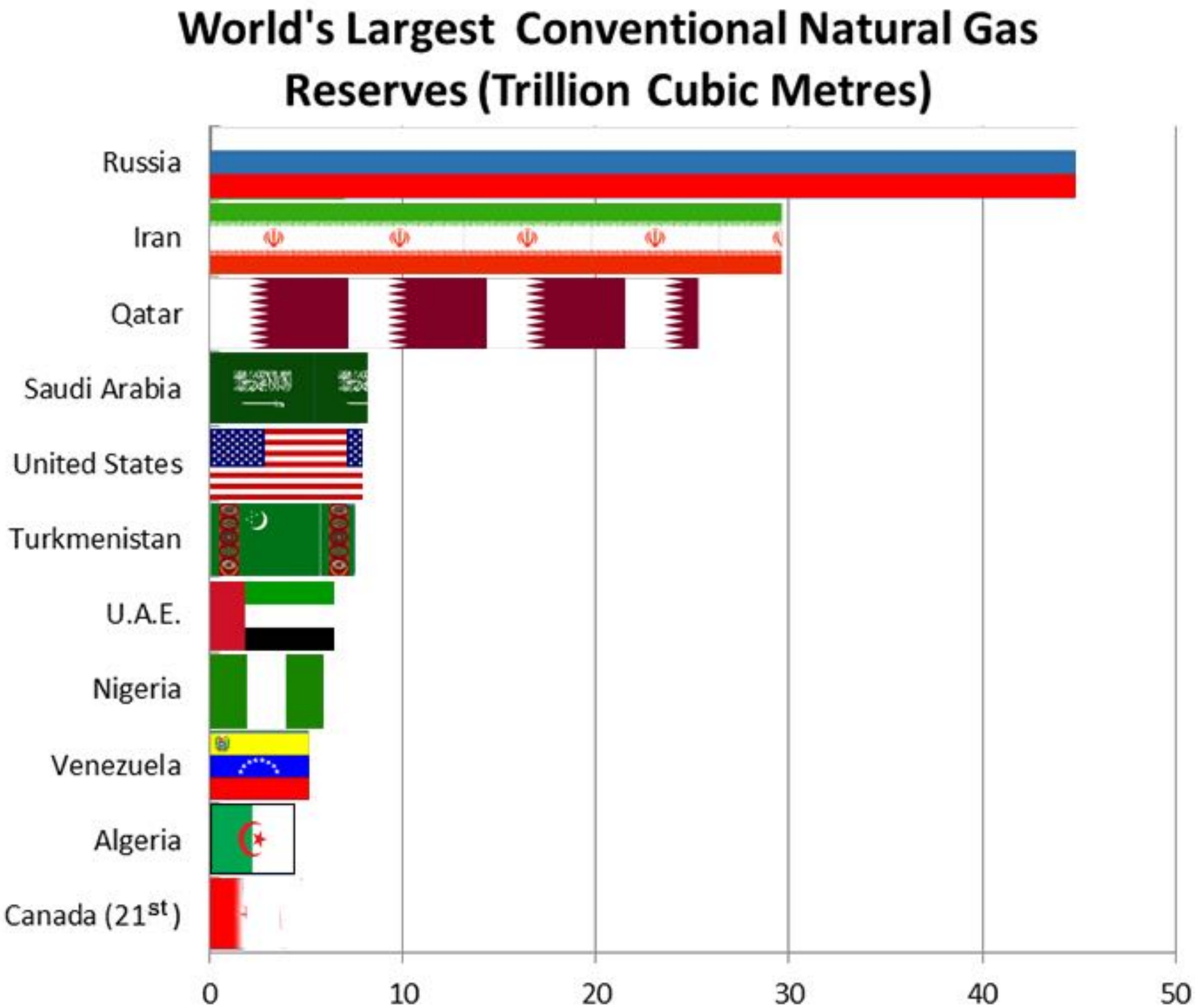
3.2.1. World oil reserves

Total 1’040·10^9 barrels



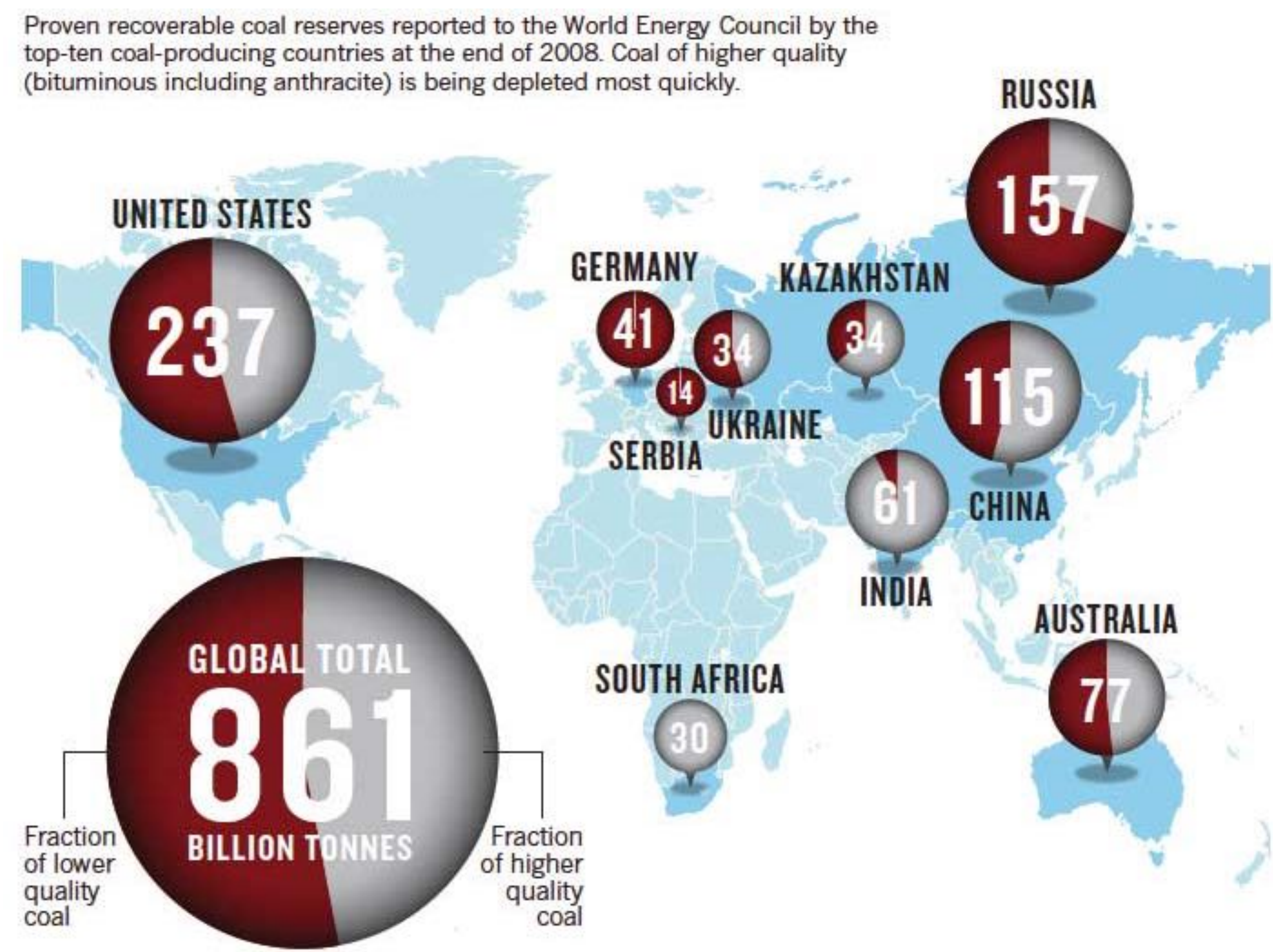
3.2.2. World gas reserves

Total $143 \cdot 10^{12}$ m^3



3.2.3. World coal reserves

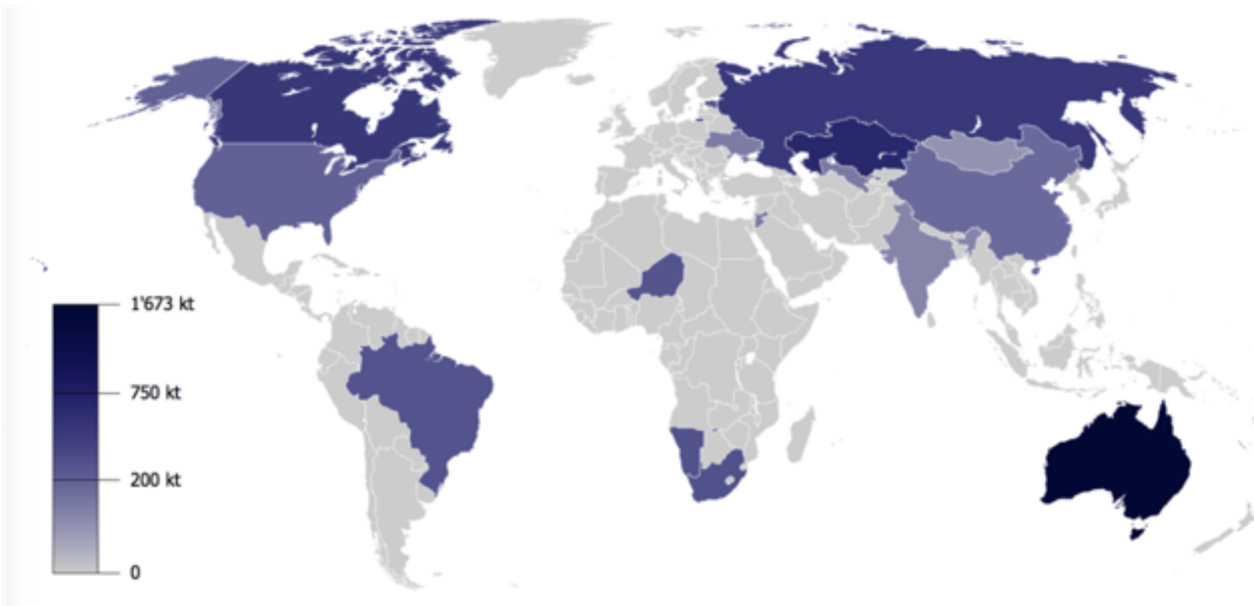
Total $861 \cdot 10^{12}$ kg



3.2.4. Uranium demand & reserves

Uranium demand, mining production and deficit[22]

Country	Uranium required 2006-08[129]	% of world demand	Indigenous mining production 2006[130]	Deficit (-surplus)
United States	18,918 tonnes (42 × 10^6 lb)	29.3%	2,000 tonnes (4.4 × 10^6 lb)	16,918 tonnes (37 × 10^6 lb)
France	10,527 tonnes (23 × 10^6 lb)	16.3%	0	10,527 tonnes (23 × 10^6 lb)
Japan	7,659 tonnes (17 × 10^6 lb)	11.8%	0	7,659 tonnes (17 × 10^6 lb)
Russia	3,365 tonnes (7.4 × 10^6 lb)	5.2%	4,009 tonnes (8.8 × 10^6 lb)	−644 tonnes (−1.4 × 10^6 lb)
Germany	3,332 tonnes (7.3 × 10^6 lb)	5.2%	68.03 tonnes (0.1500 × 10^6 lb)	3,264 tonnes (7.2 × 10^6 lb)
South Korea	3,109 tonnes (6.9 × 10^6 lb)	4.8%	0	3,109 tonnes (6.9 × 10^6 lb)
United Kingdom	2,199 tonnes (4.8 × 10^6 lb)	3.4%	0	2,199 tonnes (4.8 × 10^6 lb)
Rest of the World	15,506 tonnes (34 × 10^6 lb)	24.0%	40,327 tonnes (89 × 10^6 lb)	−24,821 tonnes (−55 × 10^6 lb)
Total	**64,615 tonnes (140 × 10^6 lb)**	**100.0%**	**46,403 tonnes (100 × 10^6 lb)**	**18,211 tonnes (40 × 10^6 lb)**



Identified resources recoverable (reasonably assured resources plus inferred resources), to US$ 130/kg U, 1/1/17, from OECD NEA & IAEA, Uranium 2018: Resources, Production and Demand ('Red Book'). The total recoverable identified resources to US$ 260/kg U is 7.989 million tonnes U. Identified resources in situ to US$ 130/kg U are 8.122 Mt, and to US$ 260/kg U, 10.653 Mt. * IAEA estimate.

Uranium availability

Table 2: Uranium resources by country in 2017

	tonnes U	percentage of world
Australia	1,818,300	30%
Kazakhstan	842,200	14%
Canada	514,400	8%
Russia	485,600	8%
Namibia	442,100*	7%
South Africa	322,400	5%
China	290,400	5%
Niger	280,000*	5%
Brazil	276,800	5%
Uzbekistan	139,200*	2%
Ukraine	114,100	2%
Mongolia	113,500	2%
Botswana	73,500*	1%
Tanzania	58,200*	1%
USA	47,200	1%
Jordan	43,500	1%
Other	280,600	4%
World total	**6,142,600**	

QUESTION

Convert the volume [m^3] of the World gas reserves into mass [kg].

SOLUTION

Convert the volume [m^3] of the World gas reserves into mass [kg].

ideal gas law: $p \cdot V = n \cdot R \cdot T$

$p \cdot V \cdot M = m \cdot R \cdot T$ and therefore $m = (p \cdot V \cdot M)/(R \cdot T)$

$m = (p \cdot V \cdot M)/(R \cdot T) = 1.013 \cdot 10^5 Pa \cdot 130 \cdot 10^{12} m^3 \cdot 16 g \cdot mol^{-1} \cdot (8.314\ J \cdot mol^{-1} \cdot K^{-1} \cdot 273.15 K)^{-1}$
$m = 92 \cdot 10^{12} kg$

3.2.5. Proven reserves of fossil fuels

YEAR	1980	1985	1990	1995	2000	2005	2010	2017	
Oil	684	802	1027	1125	1300	1377	1642	1728	10^9 barrel
Natural gas	71	83	109	121	139	157	179	196	10^{12} Nm^3
Coal	...	...	...	...	...	...	807	1035	10^{12} kg
Uranium	10.5	...	...	...	...	4.0	7.0	7.6	10^9 kg

Ref.: BP Statistical Review of World Energy - Main Indicators: https://knoema.com/BPWES2017/bp-statistical-review-of-world-energy-main-indicators

calculated mass of C from table above

Oil	91	106	136	149	172	183	218	229	Gt = 10^{12} kg C
Natural gas	51	59	78	86	99	112	128	140	Gt
Coal							807	1035	Gt
Total								1404	Gt

Geological estimations:

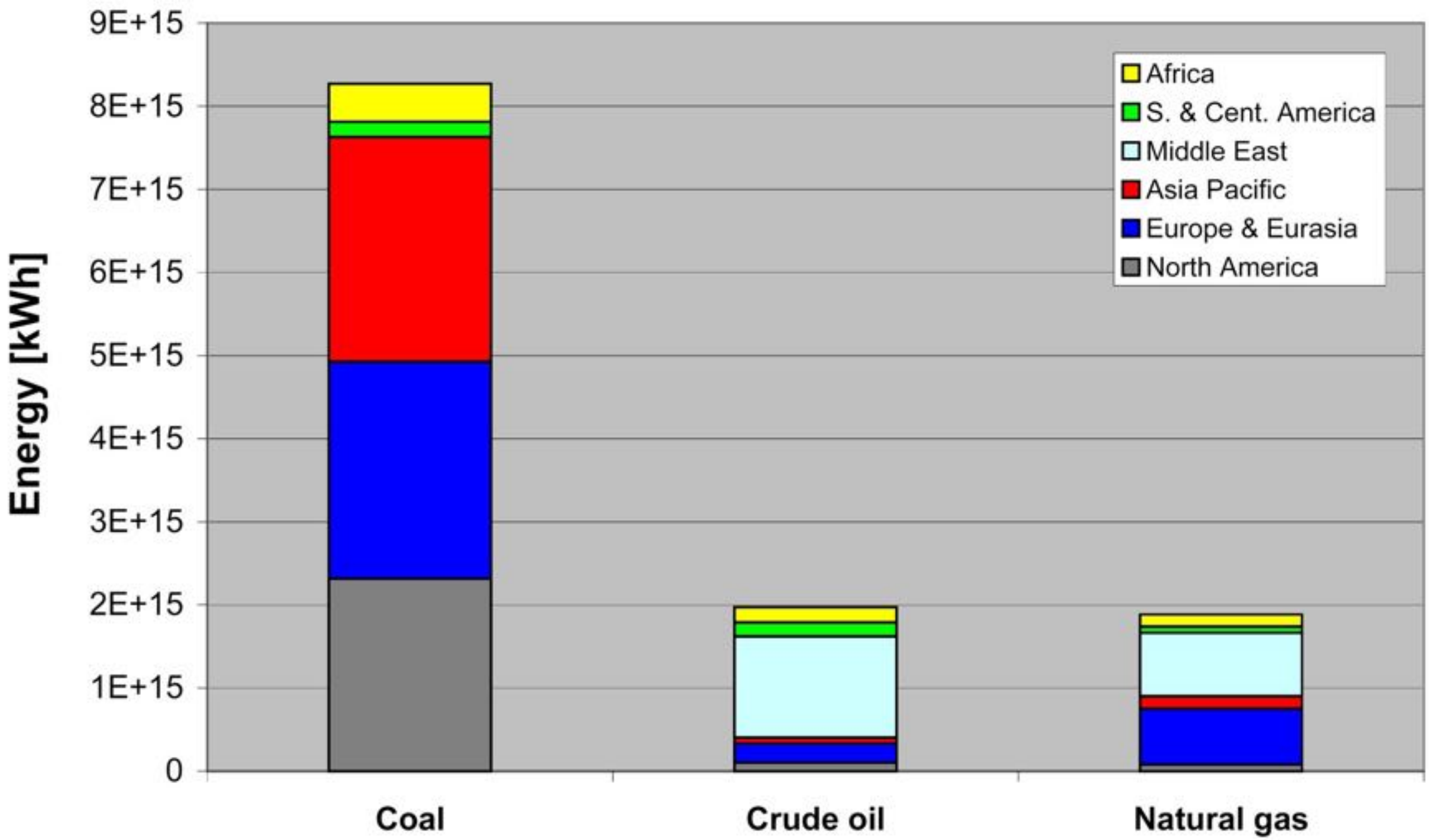
$11'000 \cdot 10^{12}$ kg CO_2 = $3500 \cdot 10^{12}$ kg C

Ref.: Michael Jakob & Jérôme Hilaire, "Unburnable fossil-fuel reserves", Nature 517 (2015), pp. 150–152

$10'000 \cdot 10^{12}$ kg C

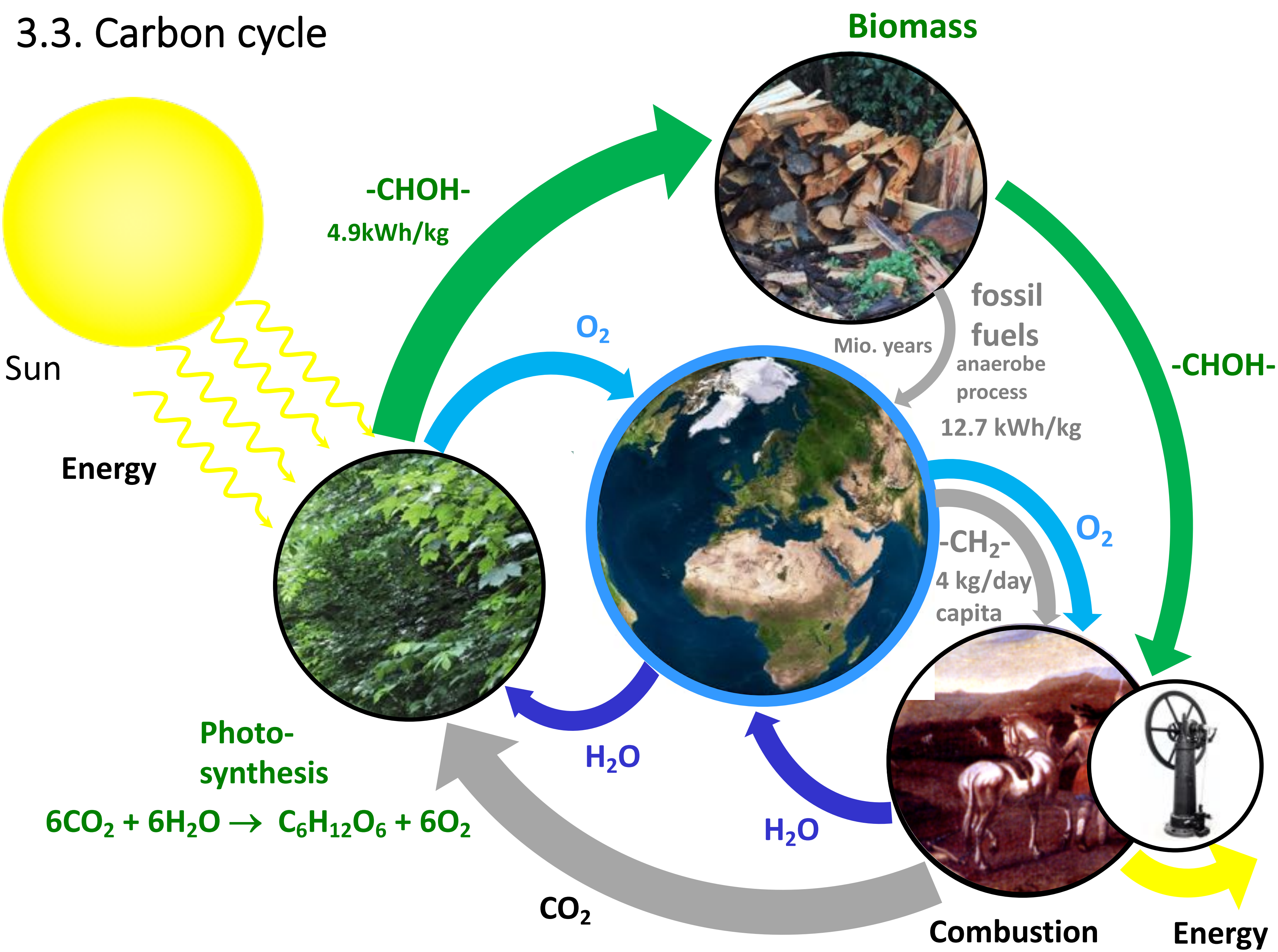
Ref.: Siegenthaler, U. and Sarmiento, J.L., "Atmospheric Carbon Dioxide and the Ocean", Nature, 365 (1993), 119-125.

3.2.6. Estimated world energy reserves



Ref.: ENERGY, ECOLOGY & ECONOMICS–PART III, By Mary Odum, originally published by A Prosperous Way Down

3.3. Carbon cycle



3.3.1. Formation of crude oil

BIOMASS

Cellulose/Starch	$[C_6(H_2O)_5]_n$
Hemi-cellulose	$[C_5(H_2O)_4]_n$
Hemi-cellulose	$[C_{10}(H_{12}O)_3]_n$
Terpenes	$C_{10}H_{16}$
Triacylglycerols	$[C_xH_yO_6]$, x ≈ 50 – 60
Other organics	[C,O,N,S]; Nucleotides; Phospholipides [C,O,P] ...
Inorganics	K, Se, Si, Mg, Ca, Fe, S ...

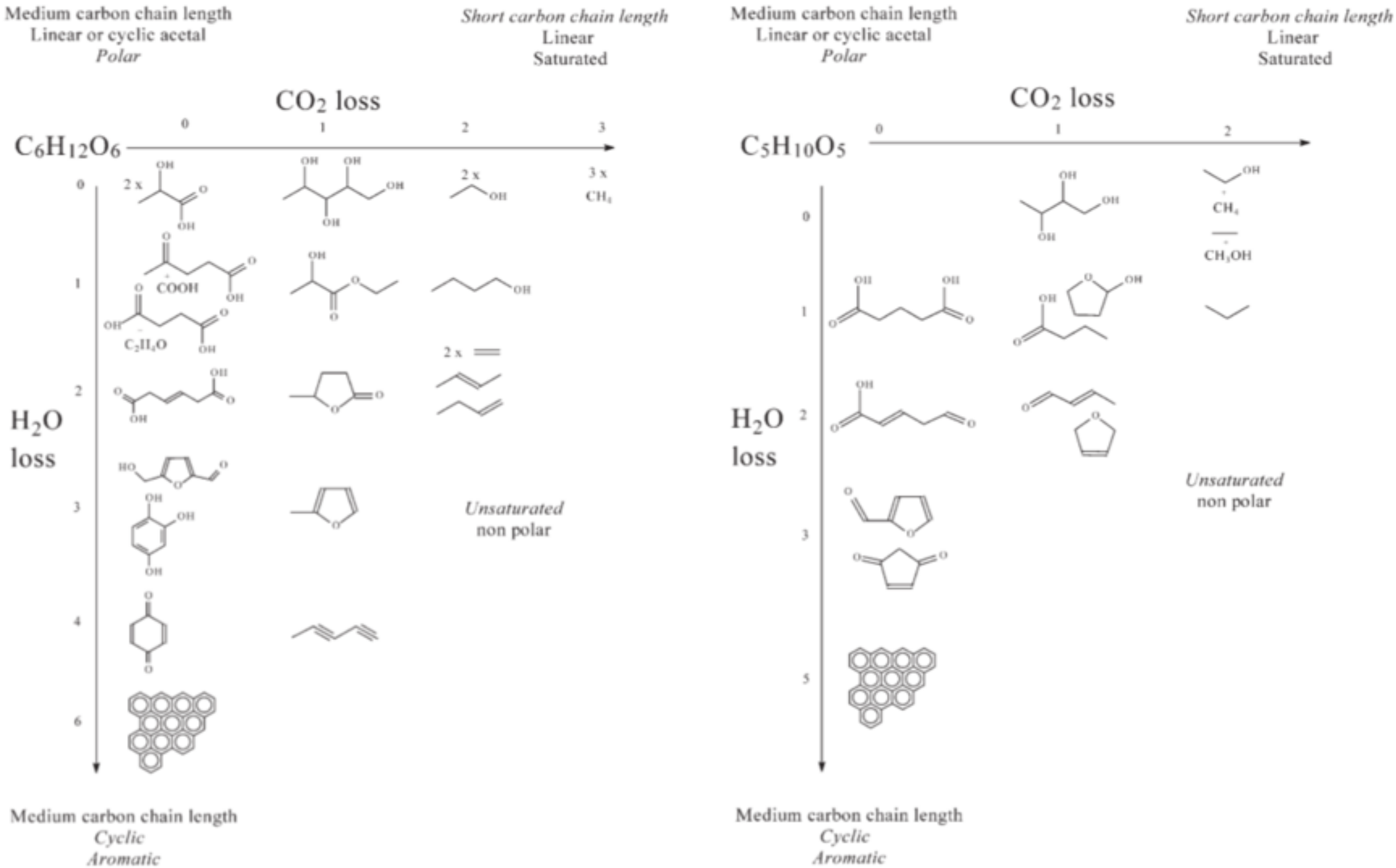
CaAl-, MgAl-Silicate + NaCl reacts to NaAl-Silicate finally NaOH
Elimination of all oxygen [O] as: CO_2, H_2O, CO

$C_6(H_{12}O_6) \rightleftarrows 3\,CO_2 + \mathbf{[C_3H_{12}]}$ Splits: 3 CH_4 (Biogas)
$C_6(H_{12}O_6) \rightleftarrows 6\,H_2O + \mathbf{6\,[C]}$ Charcoal
$C_6(H_{12}O_6) \rightleftarrows \mathbf{6\,CO} + \mathbf{6\,H_2}$ Synthesis gas

Mineralöle und verwandte Produkte: Ein Handbuch für das Laboratorium, 29. Juli 2013, Springer-Verlag, Carl ZERBE, Chap.: Erdöl und Erdölprodukte. A. Allgemeines über Erdöl. Von DipL-Ing. K. K. RUMPF, Hamburg, p. 226
Leo Petrus and Minke A. Noordermeer, “Biomass to biofuels, a chemical perspective”, Green Chem. 8 (2006), pp. 861–867

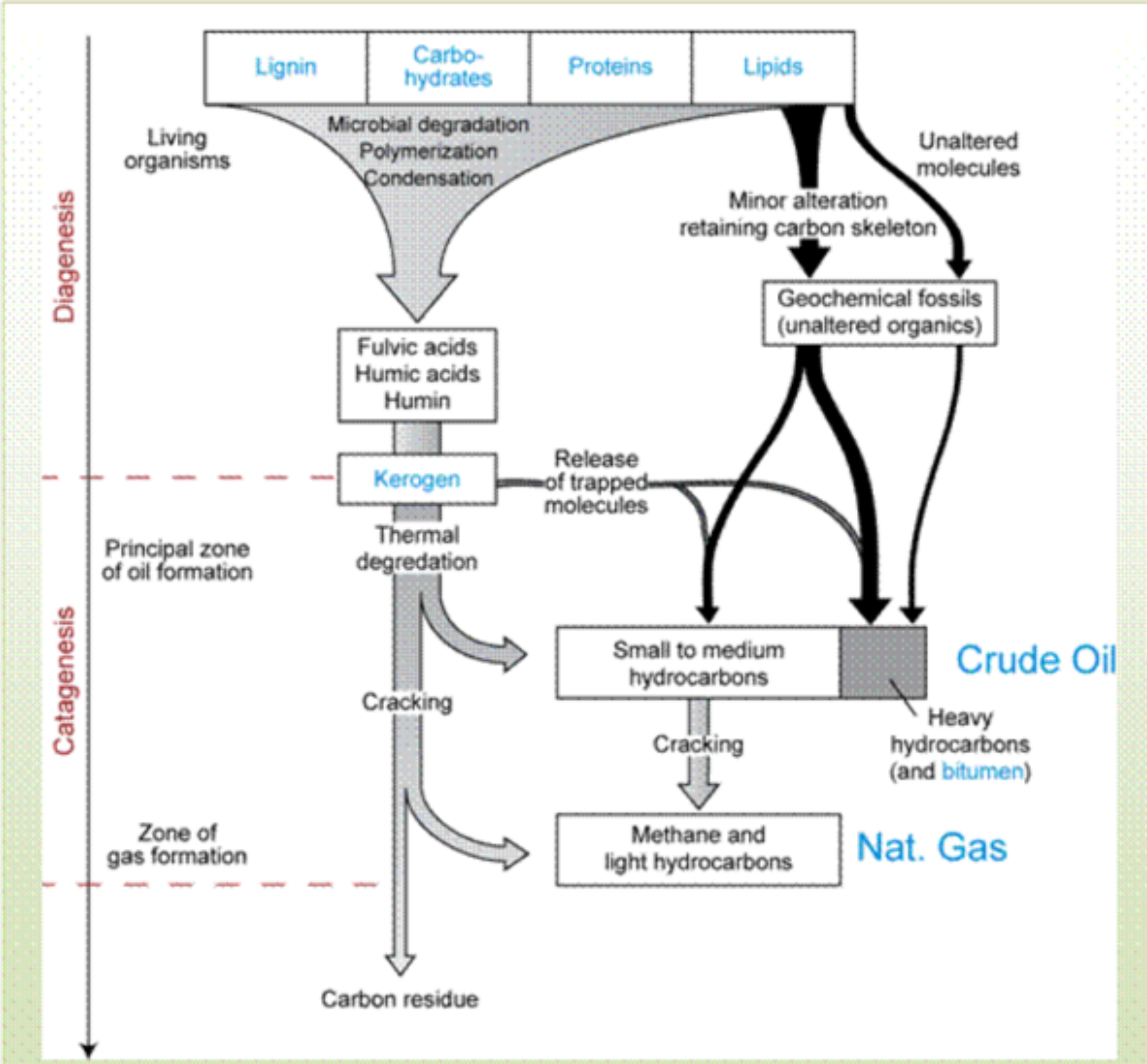
3.3.2. Decarboxylation and dehydration

of C_6- and C_5-carbohydrates, over- view scheme.



Ref.: Leo Petrus and Minke A. Noordermeer, "Biomass to biofuels, a chemical perspective", Green Chem. 8 (2006), pp. 861–867

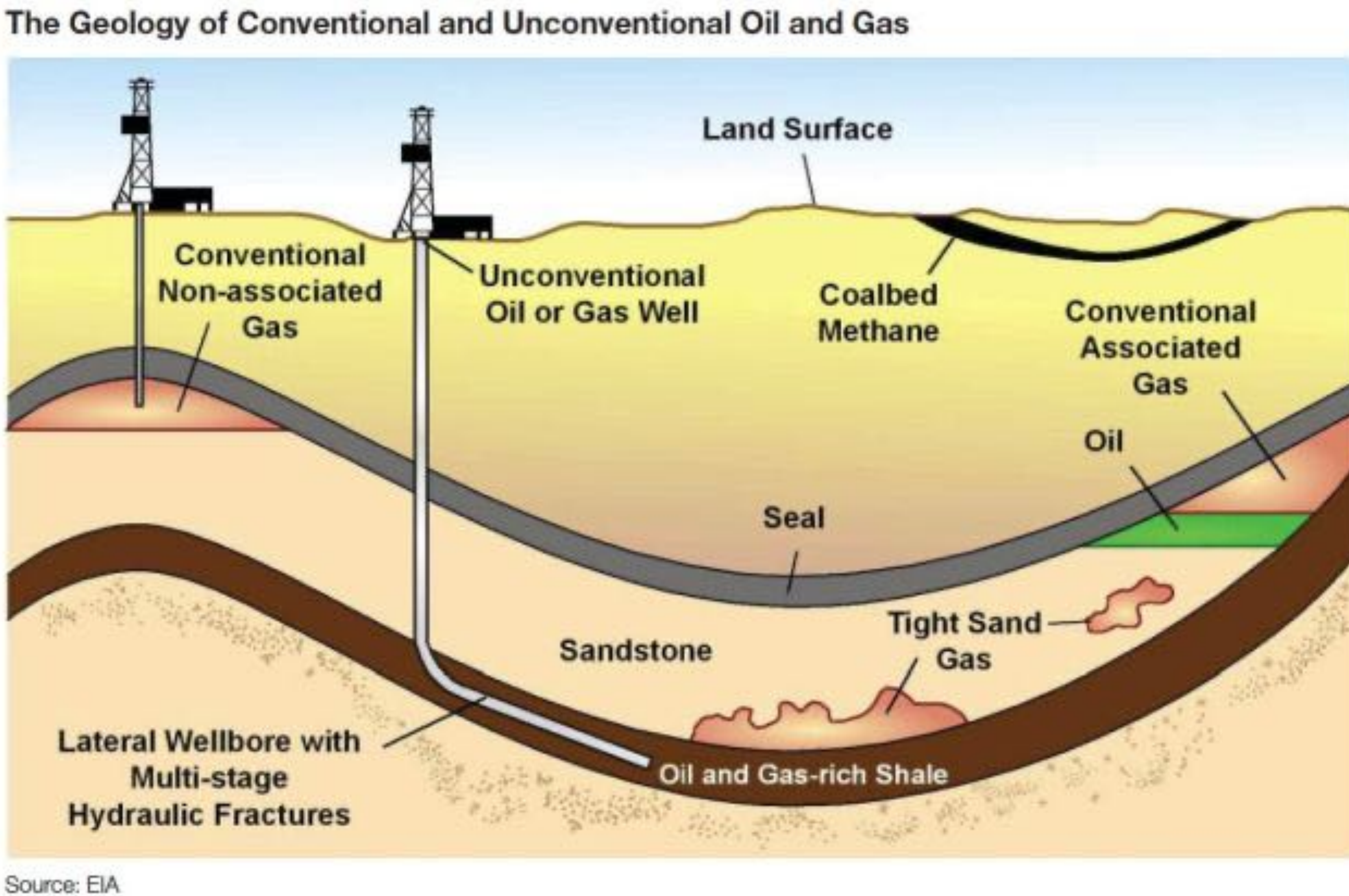
3.3.3. Diagenesis and catagenesis



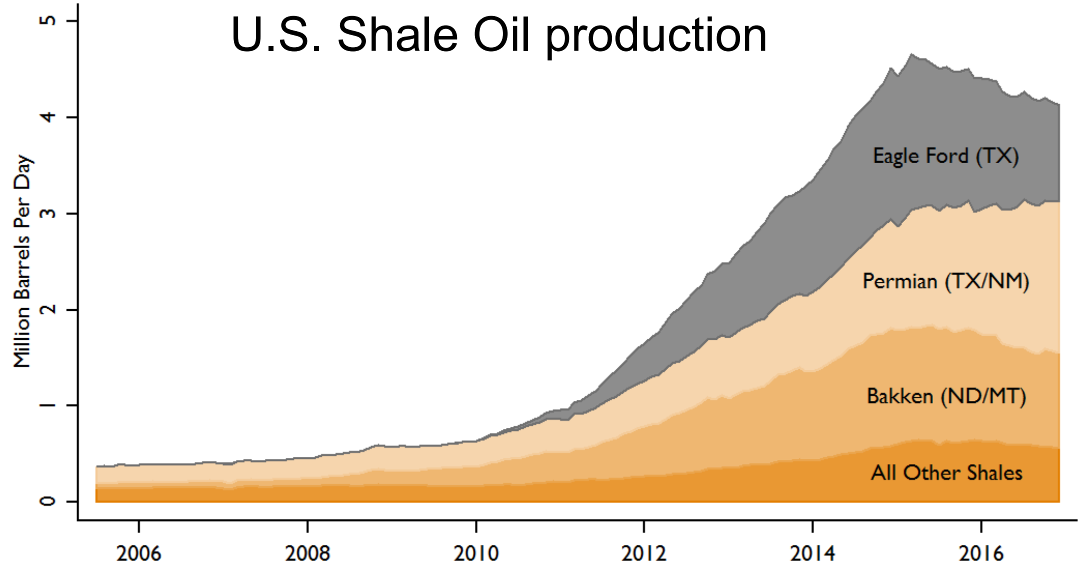
Modified from Tissot and Welte, 1984. *Petroleum formation and occurrence*, Springer –Verlag, 699 pp.
Summary of the oil formation process

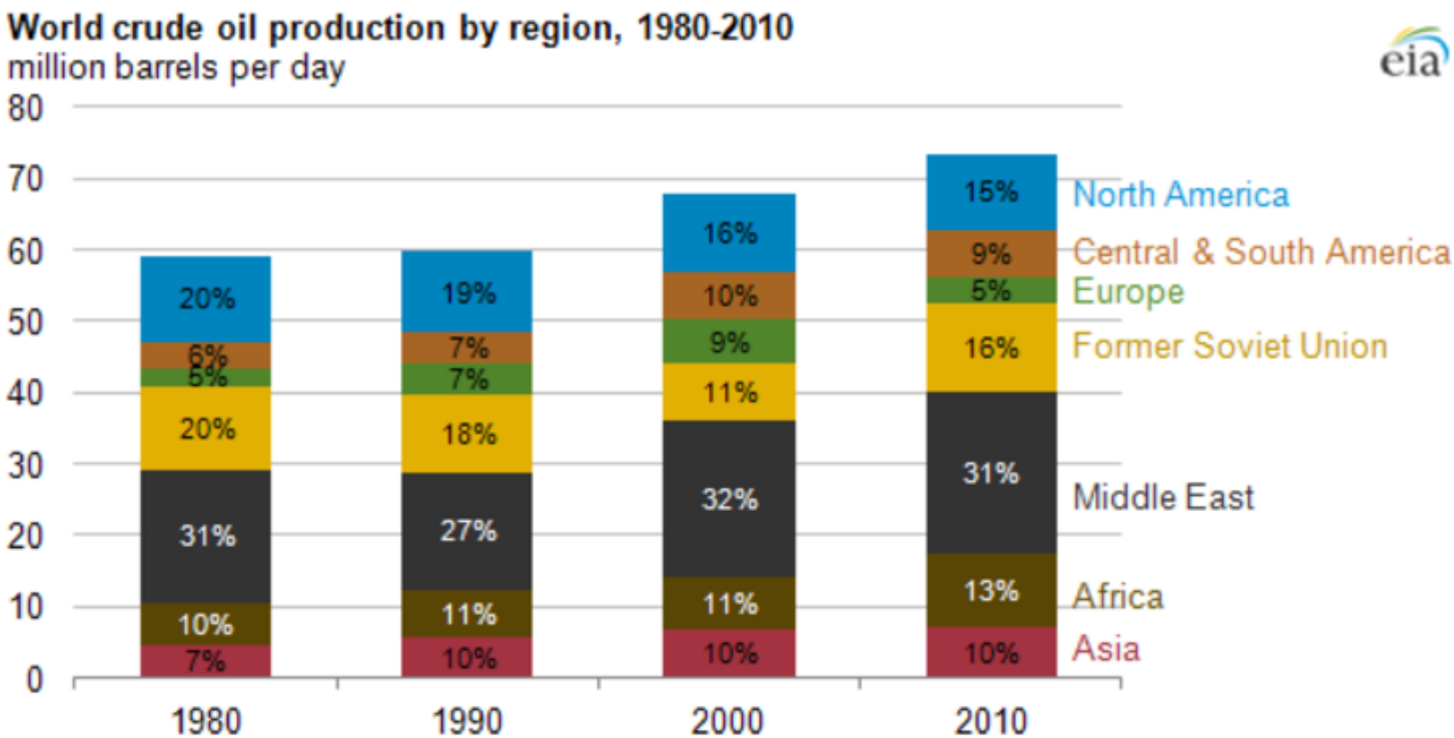
J.D. Brooks, J.W. Smith, "The diagenesis of plant lipids during the formation of coal, petroleum and natural gas—II. Coalification and the formation of oil and gas in the Gippsland Basin", Geochimica et Cosmochimica Acta, Volume 33, Issue 10, October 1969, pp. 1183-1194

3.3.4. Shale oil



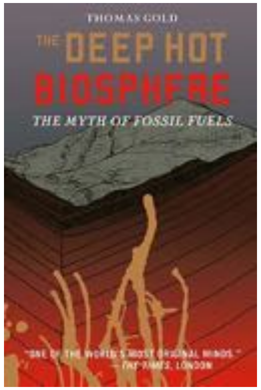
3.3.5. Global oil production

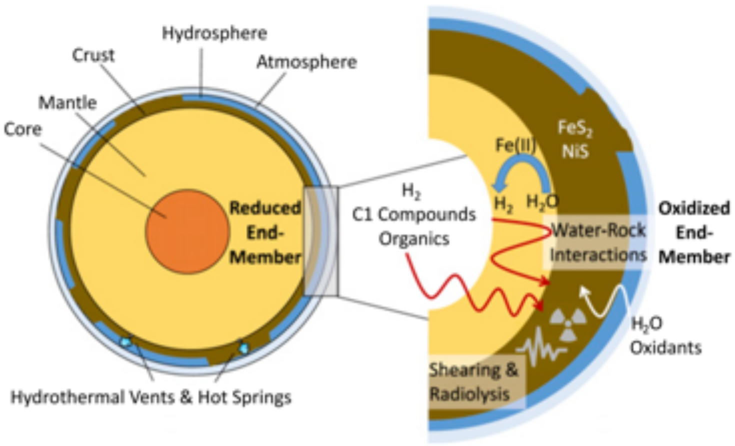




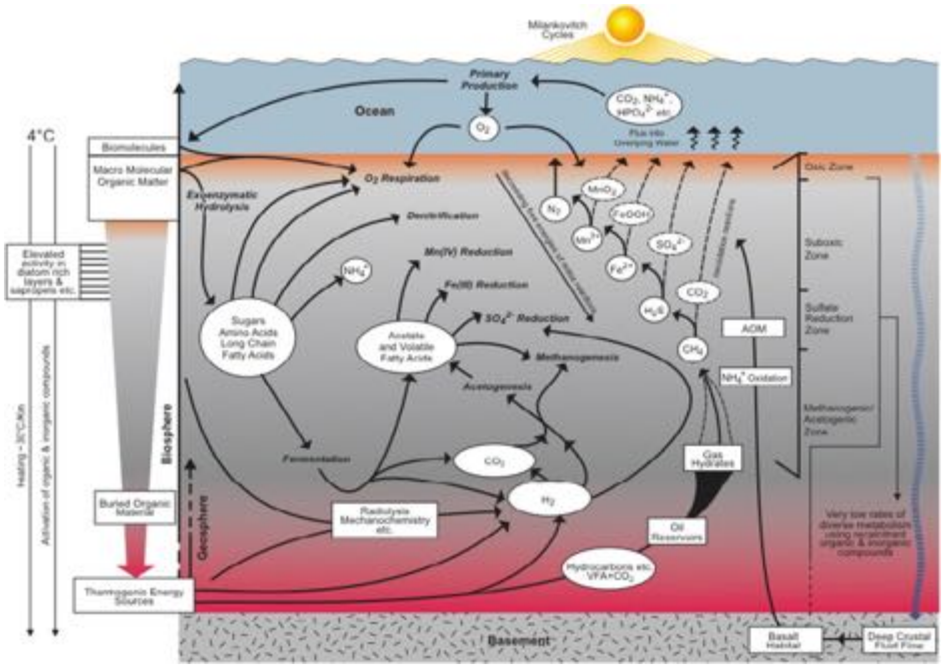
3.3.6. Geological oil production

Thomas Gold





Generalized schematic of the subsurface crustal environment and interacting forces that produce habitable conditions in the subsurface. Inset shows a magnified view of the interactions occurring at the surface–subsurface interface, and mechanisms of H_2 production in the subsurface that are discussed in the text are highlighted.



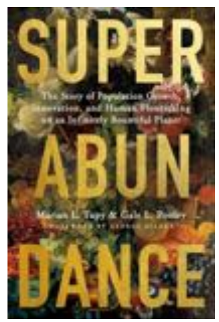
Schematic drawing representing the role of the deep biosphere in the global carbon cycle. Parts of the organic carbon deposited on the seafloor are re-mineralized and cycled back to the water column. Some inorganic carbon is buried as diagenetic carbonate. The latter is mainly induced by additional alkalinity from anaerobic metabolisms and is decoupled from sedimentary carbonate induced by alkalinity from continental weathering. Most carbon is stored in the rock record, but the deep biosphere has a significant effect on what goes into this reservoir.

Ref.: Daniel R. Colmana, Saroj Poudela, Blake W. Stampsb, Eric S. Boyda, and John R. Spear, "The deep, hot biosphere: Twenty-five years of retrospection", PNAS 114:27 (2017), pp. 6895–6903

3.3.7. Superabundance

Population resource abundance over time: the Basic 50 commodities (1980 – 2018)

Gale L. Pooley



Marian L. Tupy

Compound annual growth rate in population resource abundance: **4.84%**

Years to double population resource abundance: **14.66**

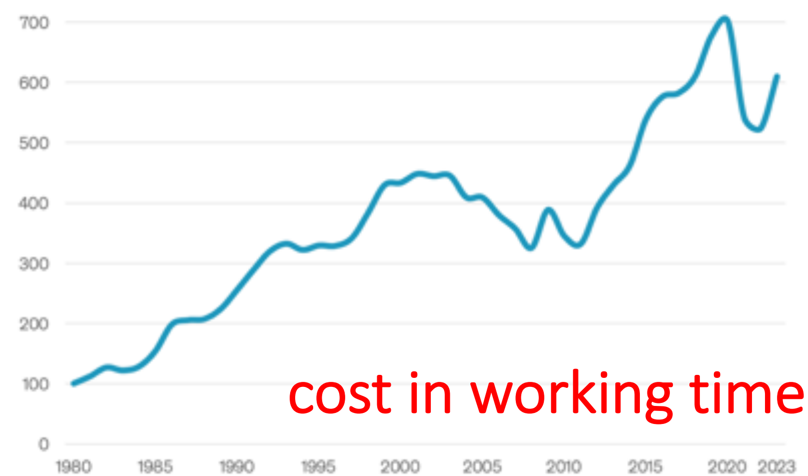
Julian SIMON
1932 – 1998
Economist

The Simon–Ehrlich wager: Simon challenged Ehrlich to choose any raw material he wanted and a date more than a year away, and he would wager on the inflation-adjusted prices decreasing as opposed to increasing.

Paul R. EHRLICH
1932 –
Biologist

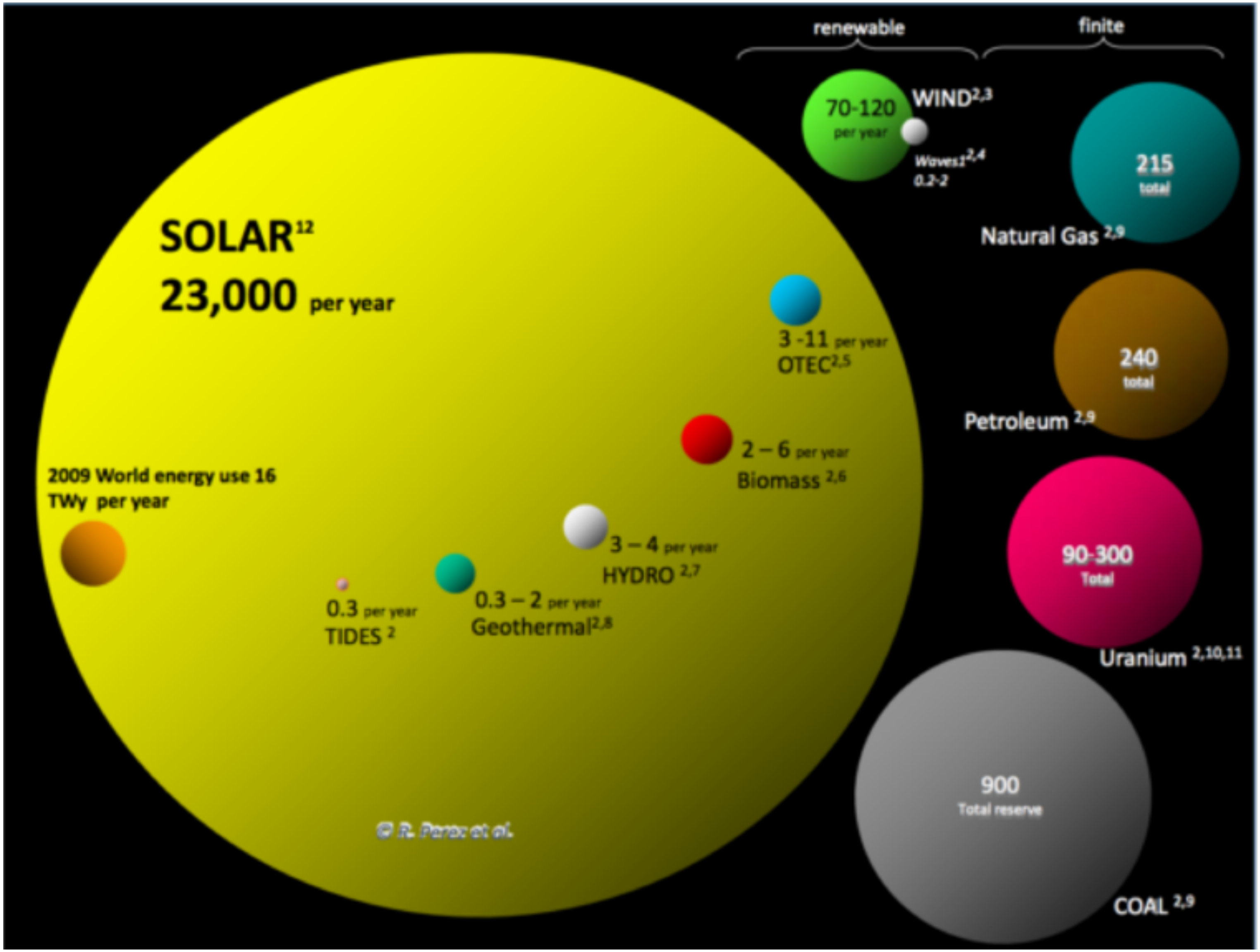
Ehrlich chose copper, chromium, nickel, tin, and tungsten. The bet was formalized on September 29, 1980, with September 29, 1990, as the payoff date. Ehrlich lost the bet, as all five commodities that were bet on declined in price from 1980 through 1990, the wager period.

The Simon Abundance Index 1980 – 2023 (1980 = 100)



Ref.: Marian L. Tupy, Gale L. Pooley, “Superabundance: The Story of Population Growth, Innovation, and Human Flourishing on an Infinitely Bountiful Planet”, (2022), George Gilder (Foreword)

3.4. Primary energy “Sources and reserves”

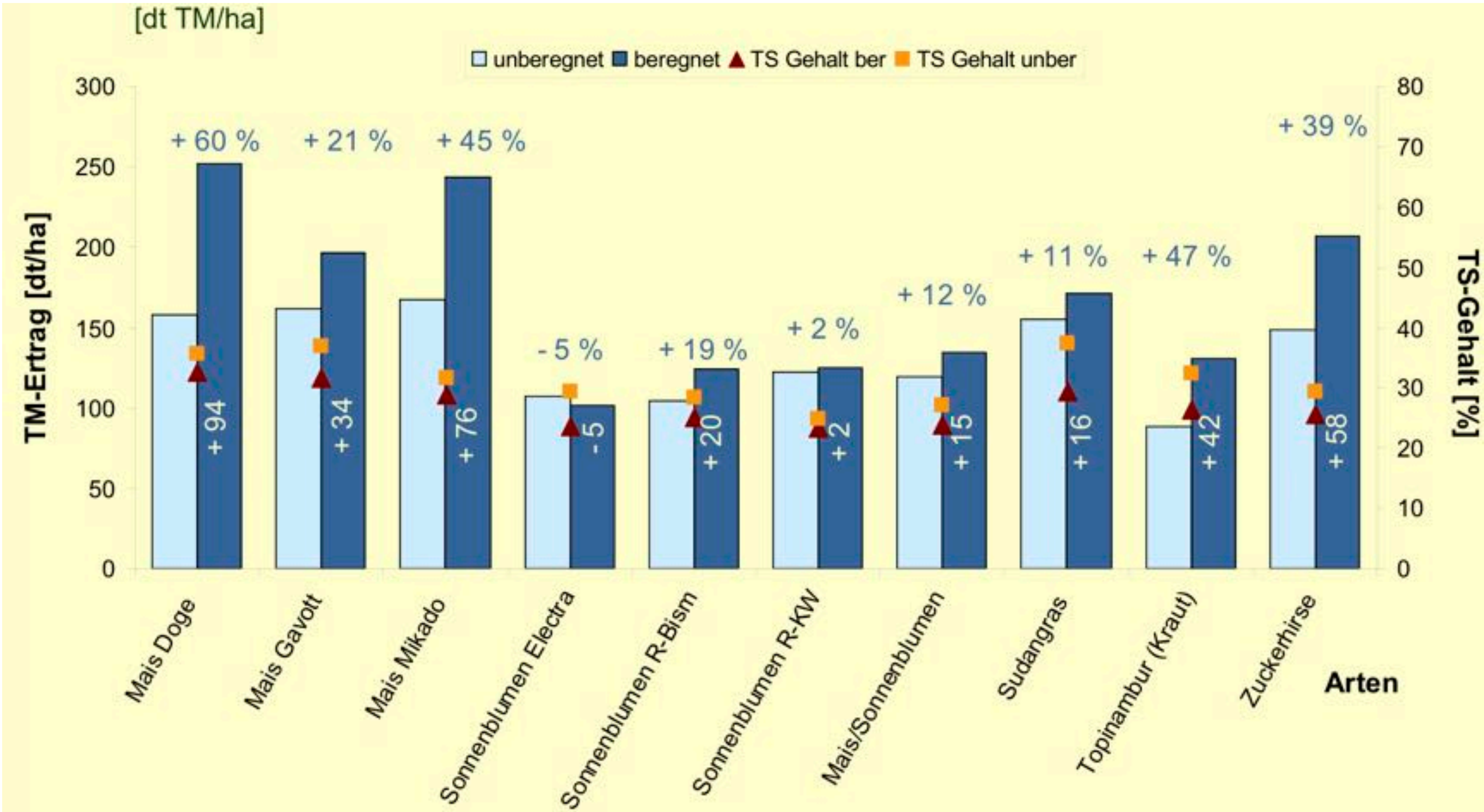


Ref.: http://cleantechnica.com/2016/08/17/10-solar-energy-facts-charts-everyone-know/

3.4.1. Biomass Production

1 dt/ha = 100 kg/10'000m²

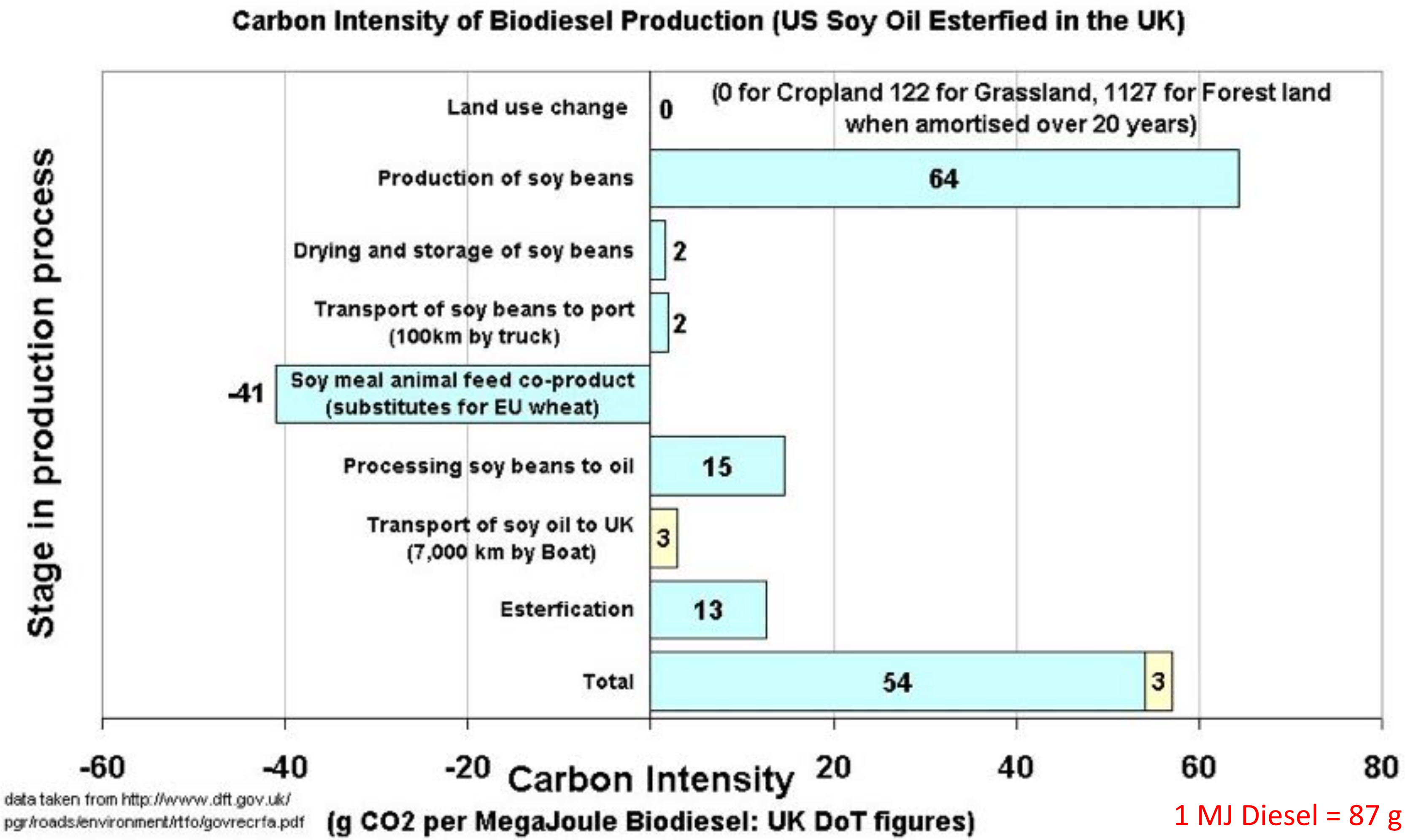
2009



Corn (7150kJ/kg): 25t/10'000m^2 = 2.5kg·m^2·2kWh·kg^{-1} = 5 kWh·m^{-2}

Ref.: Dr. Sandra KRUSE, Landwirtschaftliches Technologiezentrum Augustenberg, Hochburg, 8. 2. 2010

3.4.2. CO_2 Emission for biodiesel production



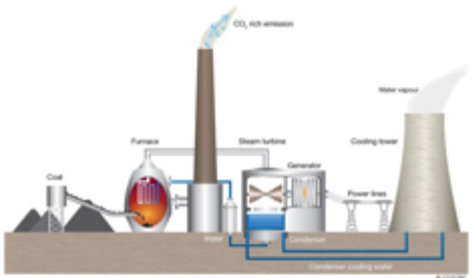
1 MJ Diesel = 87 g CO_2

Ref.: Carbon and Sustainability Reporting Within the Renewable Transport Fuel Obligation". UK Department for Transport. January 2008.

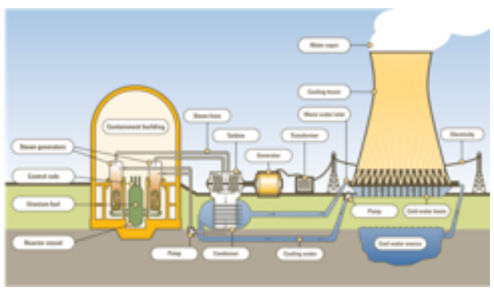
3.5. World energy demand 19 TW

Electricity **6.9 TW**

2100 GW **3.3 $TW_{el.}$**



290 GW

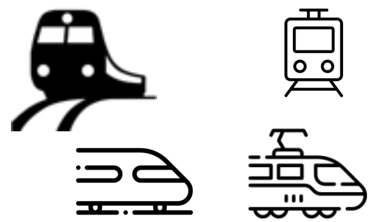


480 GW + 420 GW

Mobility **2.0 TW**

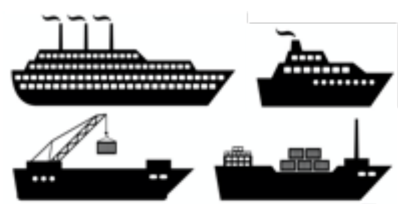
1350 GW

24 GW



380 GW

240 GW



Residential & Industry **7.7 TW**

1200 GW

1800 GW

3000 GW

1700 GW

3.6. Combustion of fossil fuels

IUPAC has changed the definition of standard temperature and pressure (STP) in 1982: [1]

Until 1982, STP was defined as a temperature of 273.15 K (0°C, 32°F) and an absolute pressure of exactly 1 atm (1.01325·10^5 Pa).
Since 1982, STP is defined as a temperature of 273.15 K (0°C, 32°F) and an absolute pressure of exactly 10^5 Pa (100 kPa, 1 bar).

STP should not be confused with the standard state commonly used in thermodynamic evaluations of the Gibbs energy of a reaction.

NIST uses a temperature of 20°C (293.15 K, 68 °F) and an absolute pressure of 1 atm (14.696 psi, 101.325 kPa). This standard is also called normal temperature and pressure (abbreviated as NTP).

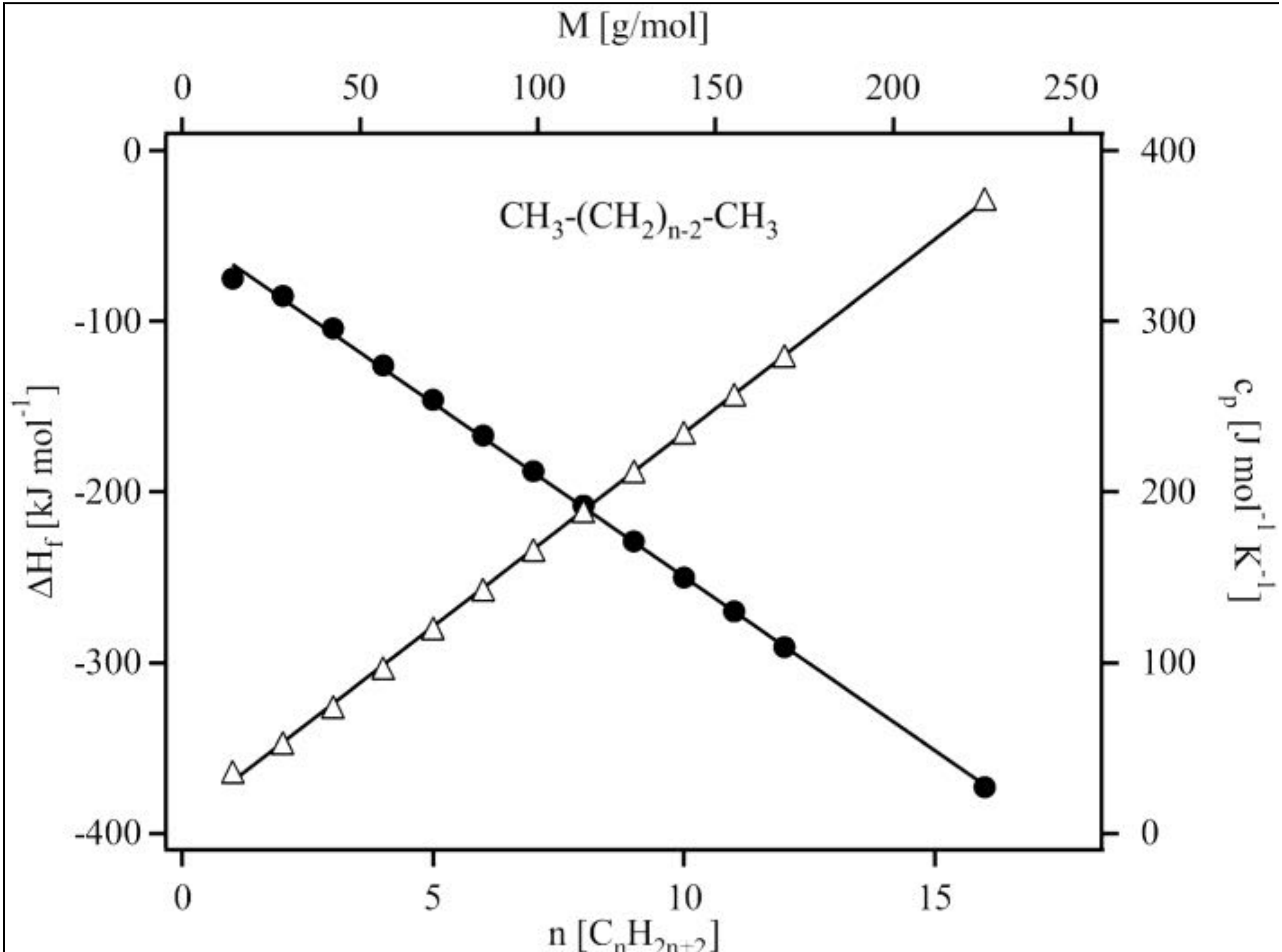
[1] A. D. McNaught and A. Wilkinson (1997). IUPAC. Compendium of Chemical Terminology (2nd ed.). Oxford: Blackwell Scientific Publications. ISBN 0-9678550-9-8. Standard conditions for gases: ... and pressure of 10^5 pascals. The previous standard absolute pressure of 1 atm (equivalent to 1.01325·10^5 Pa) was changed to 100 kPa in 1982. IUPAC recommends that the former pressure should be discontinued.

Enthalpy & Entropy of formation

Product	n in C_nH_{2n+2}	ΔH_f [kJ·mol^{-1}]	S^0 [J·mol^{-1}K^{-1}]	c_p [J/Kmol]
Methan	1	-74.8	186.2	36
Ethan	2	-84.7	229.5	53
Propan	3	-103.8	269.9	74
Butan	4	-126	310.227	97
Pentan	5	-146		120
Hexan	6	-167		143
Heptan	7	-188		166
Octan	8	-208	360.896	189
Nonan	9	-229		212
Decan	10	-250		235
Undecan	11	-270		257
Dodecan	12	-291	622.5	280
Hexadecan	16	-373		372
C		0	5.7	9
H_2		0	130.6	29
O_2		0	205	29
N_2		0	191.5	29
H_2O liq.		-285.830	69.9	75
H_2O gas		--241.826	188.7	34
CO		-110.53	197.6	
CO_2		-393.51	213.6	37

at standard temperature (273.15K) and pressure (STP = 10^5 Pa)

3.6.1. Enthalpy of formation of hydrocarbons



3.6.2. Enthalpy of the combustion reaction

$C_8H_{18} + 12.5\ O_2 \rightarrow 8\ CO_2 + 9H_2O$

$\Delta H_R = 9 \cdot \Delta H_f(H_2O) + 8 \cdot \Delta H_f(CO_2) - 12.5 \cdot \Delta H_f(O_2) - \Delta H_f(C_8H_{18})$

$\Delta H_R = 9\text{mol} \cdot (-241.826\text{kJ/mol}) + 8\text{mol} \cdot (-393.51\text{kJ/mol})$
$\quad - 12.5\text{mol} \cdot 0 - 1\text{mol} \cdot (-208\text{kJ/mol})$

$\Delta H_R = -5116.5\ \text{kJ}\ (H_2O)_{gas}$ and $\Delta H_R = -5512.5\ \text{kJ}\ (H_2O)_{liq}$

$M(C_8H_{18}) = 114\ \text{g/mol}$

$\Delta H_R = -44.88\ \text{kJ/g} = -44.88\ \text{MJ/kg} = -12.4\ \text{kWh/kg}$

3.6.3. Entropy of the combustion reaction

$C_8H_{18} + 12.5\ O_2 \rightarrow 8\ CO_2 + 9H_2O$

$\Delta S_R = 9 \cdot S^0(H_2O) + 8 \cdot S^0(CO_2) - 12.5 \cdot S^0(O_2) - S^0(C_8H_{18})$

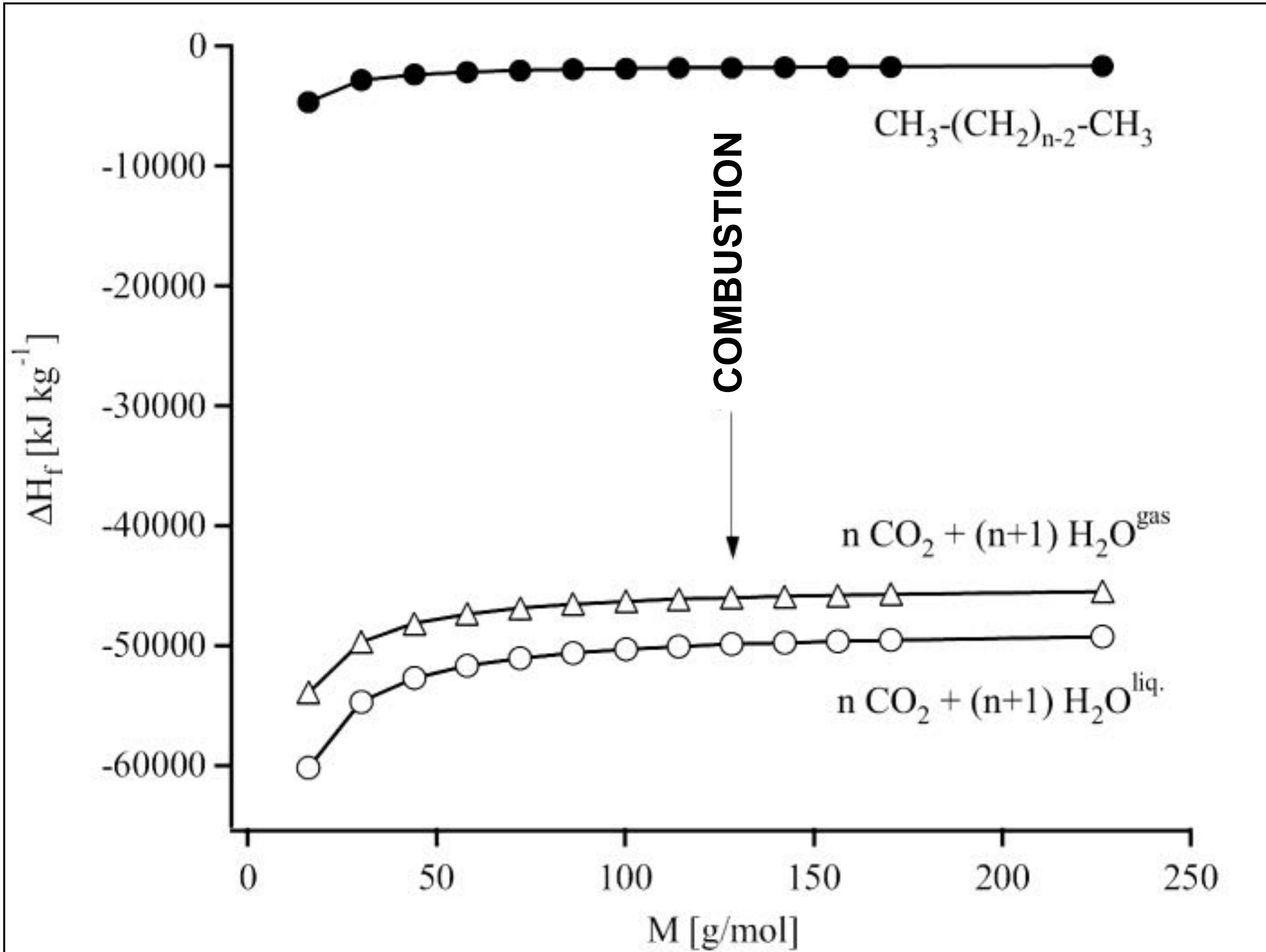
$\Delta S_R = 9mol \cdot (188.7\ J/mol \cdot K) + 8mol \cdot (213.6\ J/mol \cdot K)$
$- 12.5mol \cdot (205\ J/mol \cdot K) - 1mol \cdot (360.8\ J/mol \cdot K)$

$\Delta S_R = 483.8\ J/mol \cdot K\ (H_2O)_{gas}$

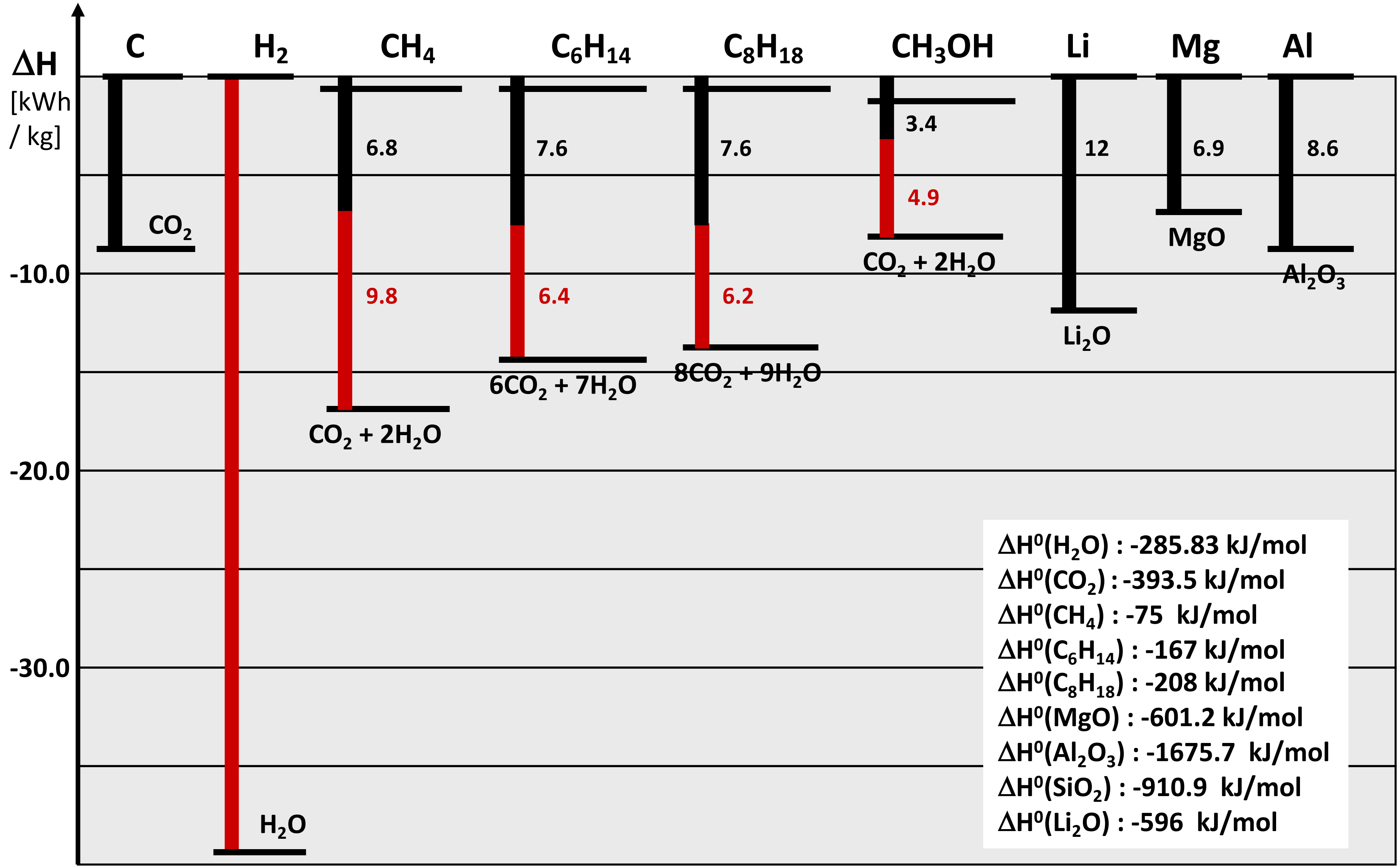
$\Delta G_R = \Delta H_R - T \cdot \Delta S_R = -5116.5\ kJ - T \cdot 483.8\ J/mol \cdot K\ (H_2O)_{gas}$

$\Delta G_R < 0$ for all temperatures $\rightarrow$ spontaneous reaction!

3.6.4. Combustion enthalpy of hydrocarbons

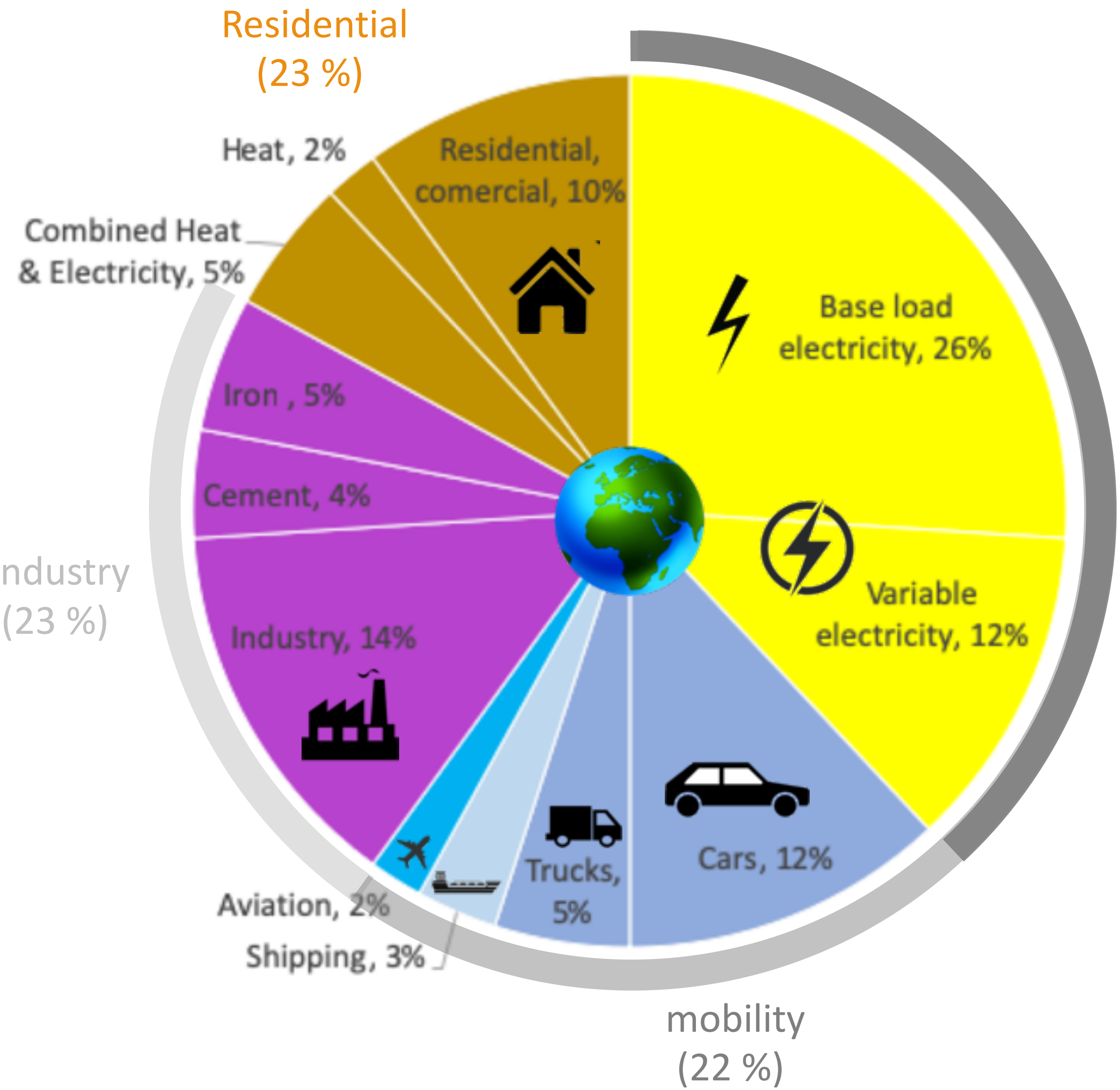


3.6.5. Gravimetric energy density of combustibles



3.7. CO_2 Emmitters

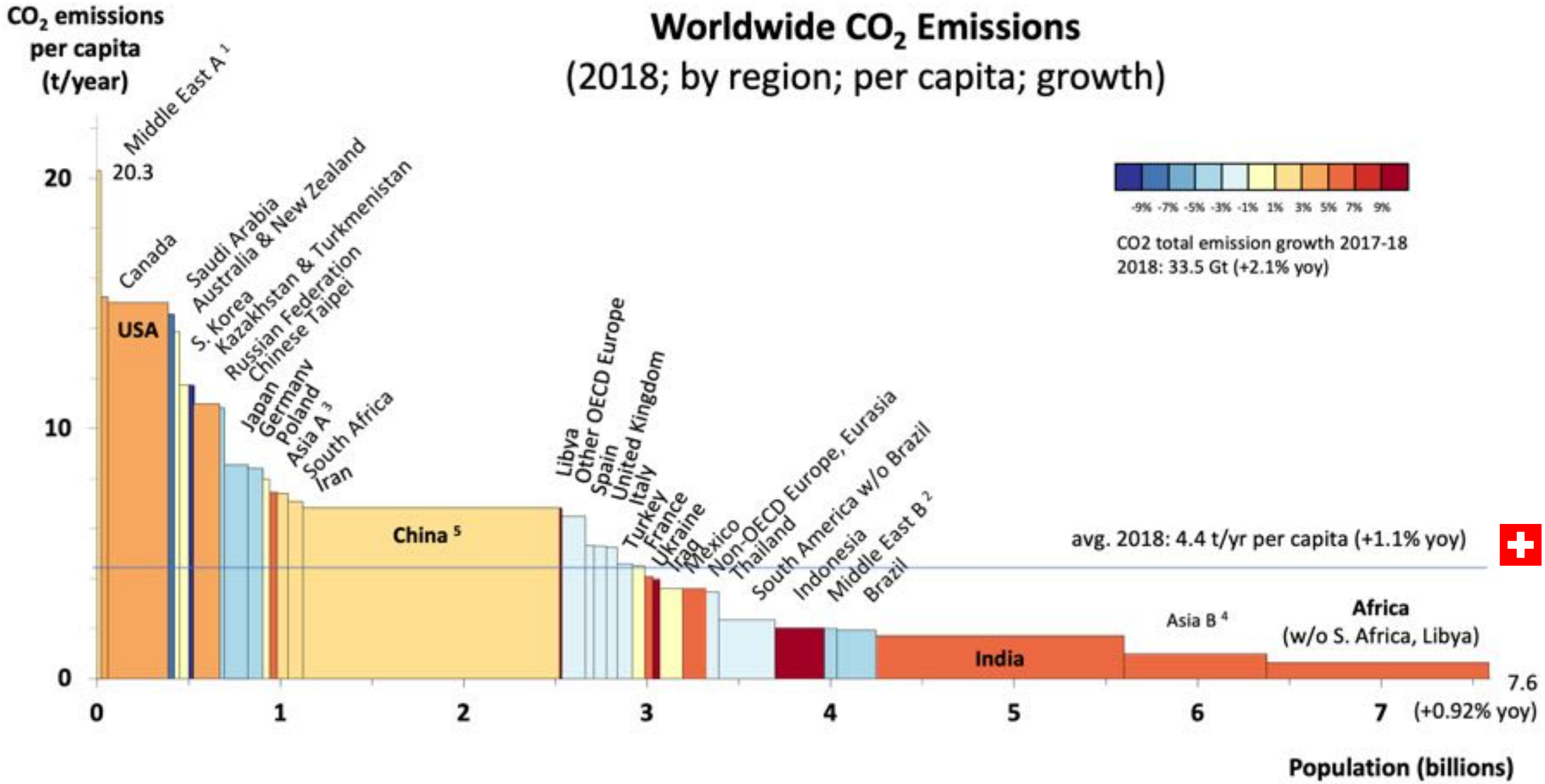
3.7.1. CO_2 Emitters by sector



100% = 33.9Gt (2014)

Ref.: Davis, S. J. et al. « Net-zero emissions energy systems », *Science* 360 (2018), pp. 1–9.

3.7.2. Global CO_2 emission per capita by countries



Notes:

Energy-related CO2 emissions only; no other greenhouse gases or natural sources; aviation and marine bunkers not shown as territory, but included in average and totals.

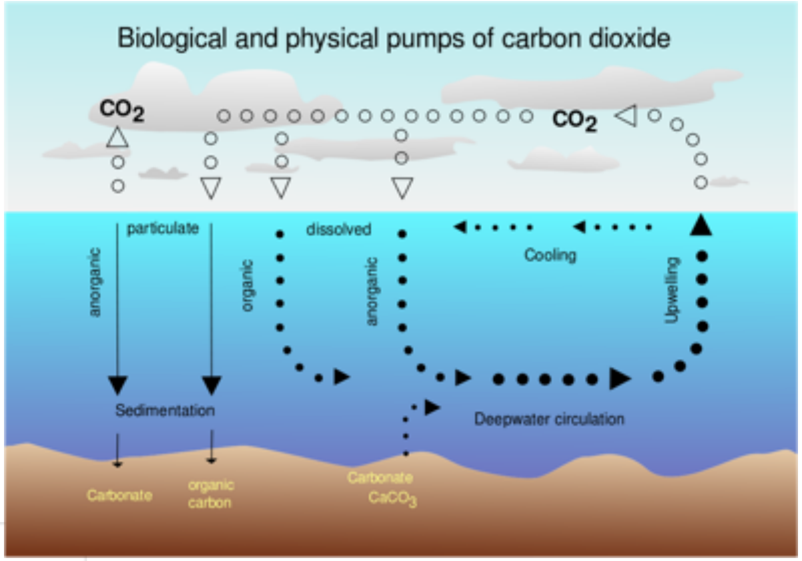
[1] Middle East A: Bahrain, Oman, Kuwait, Qatar, United Arab Emirates
[2] Middle East B: Israel, Jordan, Lebanon, Syrian Arab Republic, Yemen
[3] Asia A: Brunei Darussalam, Malaysia, Mongolia, Singapore
[4] Asia B: Asia without Asia A, China, India, Thailand, Chinese Taipei, Indonesia, S. Korea, Japan
[5] China: People's Rep. of China, Hong Kong

Attribution:

Version:
25-Oct-2020 by Thomas Schulz, AQAL Capital GmbH (https://aqalcapital.com)

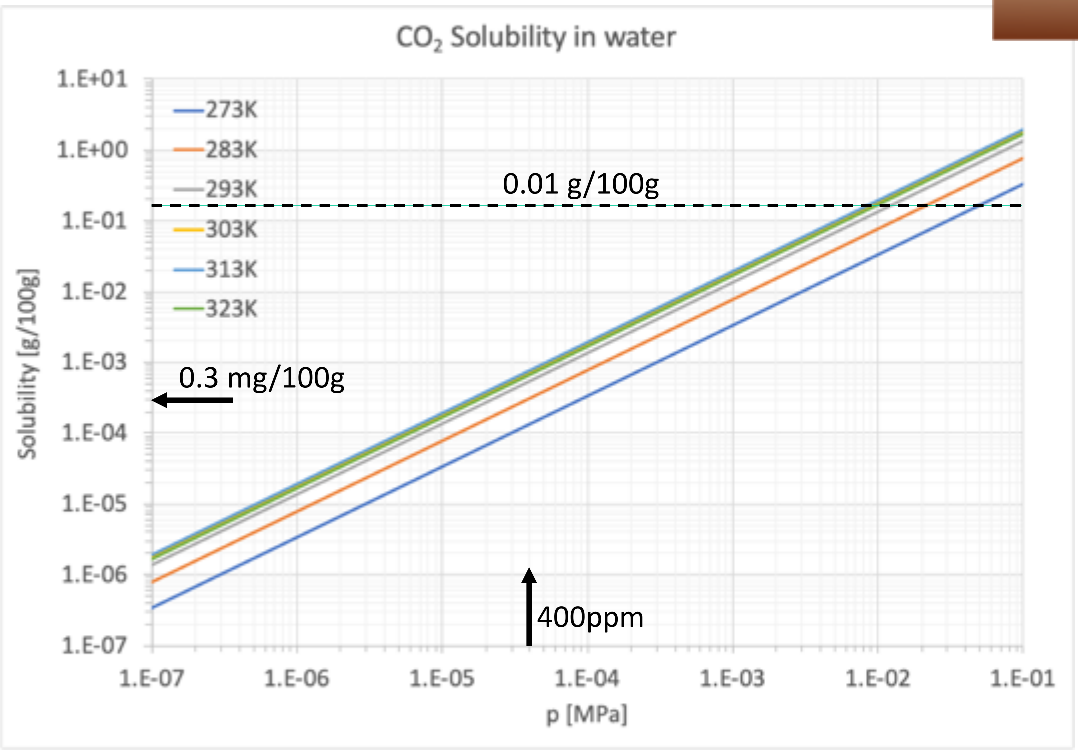
3.7.3. CO_2 IN WATER

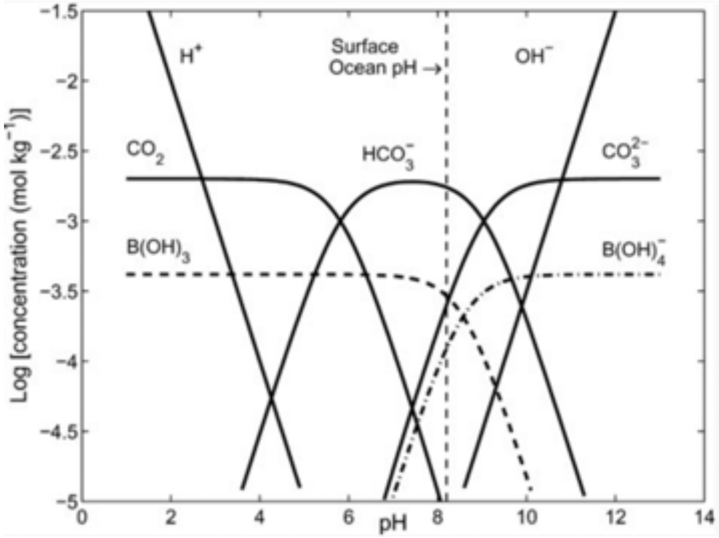
The average concentration of inorganic carbon in the ocean is ~2.3 mmol·kg^{-1} (0.01g/100g) and its residence time is ~200'000 years.



X [mol CO_2/mol H_2O] = $p(CO_2)/H$

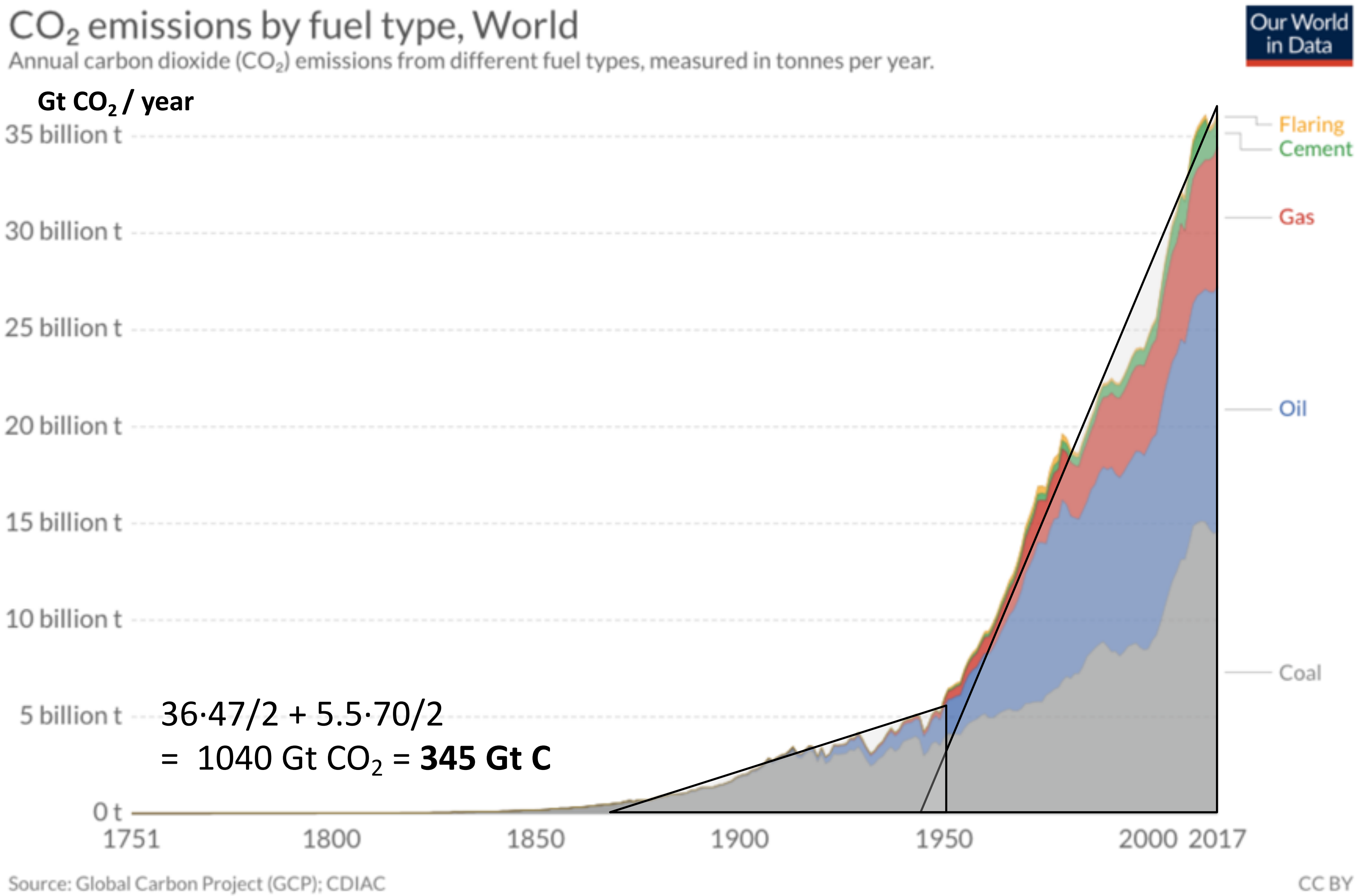
$\ln(H/\mathrm{MPa}) = -6.8346 + 1.2817\cdot10^4/T - 3.7668\cdot10^6/T^2 + 2.997\cdot10^8/T^3$





Ref.: J.J. Carroll, J. D. Slupsky, and A. E. Mather, "The Solubility of CO_2 in Water at low Pressure", J. Phys. Chem. Ref. Data 20:6 (1991), pp. 1201-1209

3.7.4. Global CO_2 - Emission



Ref.: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

3.7.5. Atmosphere

Mass of the atmosphere?

$F = m \cdot g = p \cdot A = 1.013 \cdot 10^5 Pa \cdot 4 \cdot \pi \cdot (6371 km)^2$

$m = 5.26$ M Gt

70 km

QUESTION & SOLUTION

What is the mass and the number of molecules in the atmosphere.

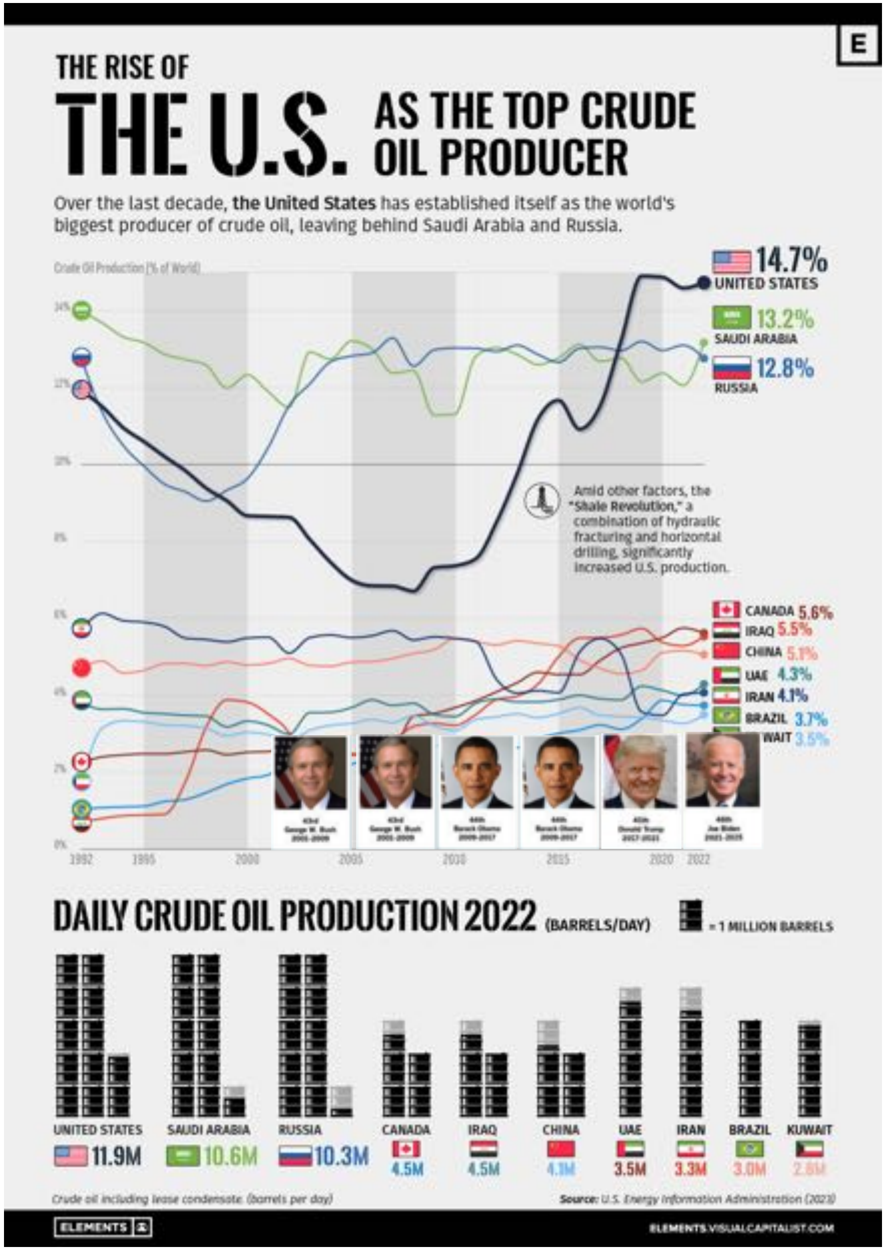
$p = F/A = m \cdot g/A = m \cdot g/(4 \cdot \pi \cdot r^2)$ with $g = 9.81$ m/s2; $r = 6.37 \cdot 10^6$ m; $p = 1.013 \cdot 10^5$ Pa

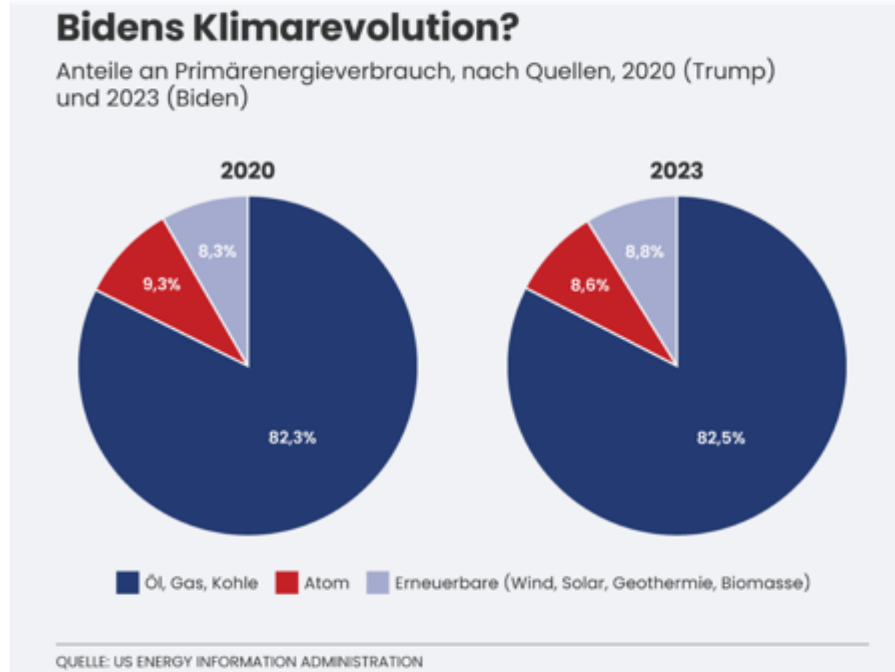
$\underline{m} = 4 \cdot \pi \cdot r^2 \cdot p/g = 5.265 \cdot 10^{18}$ kg = $\underline{5.26 \text{ MGt}}$

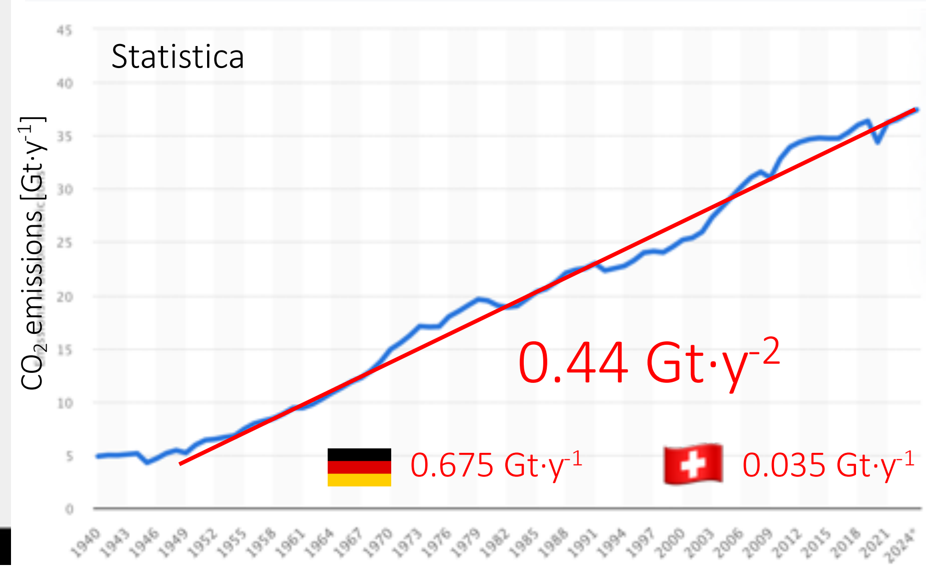
Gas: 80% N_2, 20% O_2 leads to $M = 0.8 \cdot 28$g/mol + $0.2 \cdot 32$g/mol = 28.8 g/mol

$\underline{n} = m/M = \underline{1.83 \cdot 10^{20} \text{ mol}}$

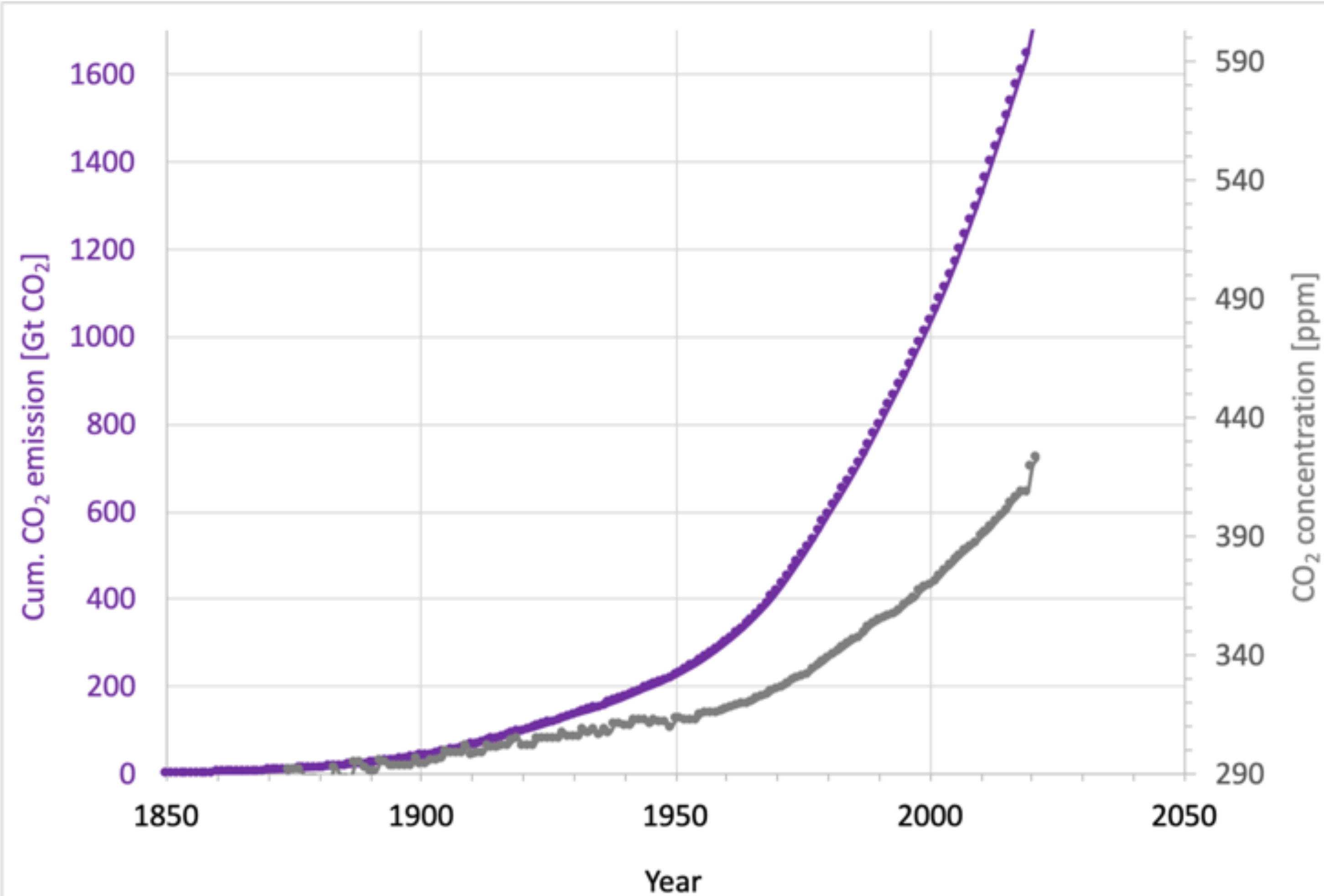
3.7.6. CO_2 Emissions and fossil fuel







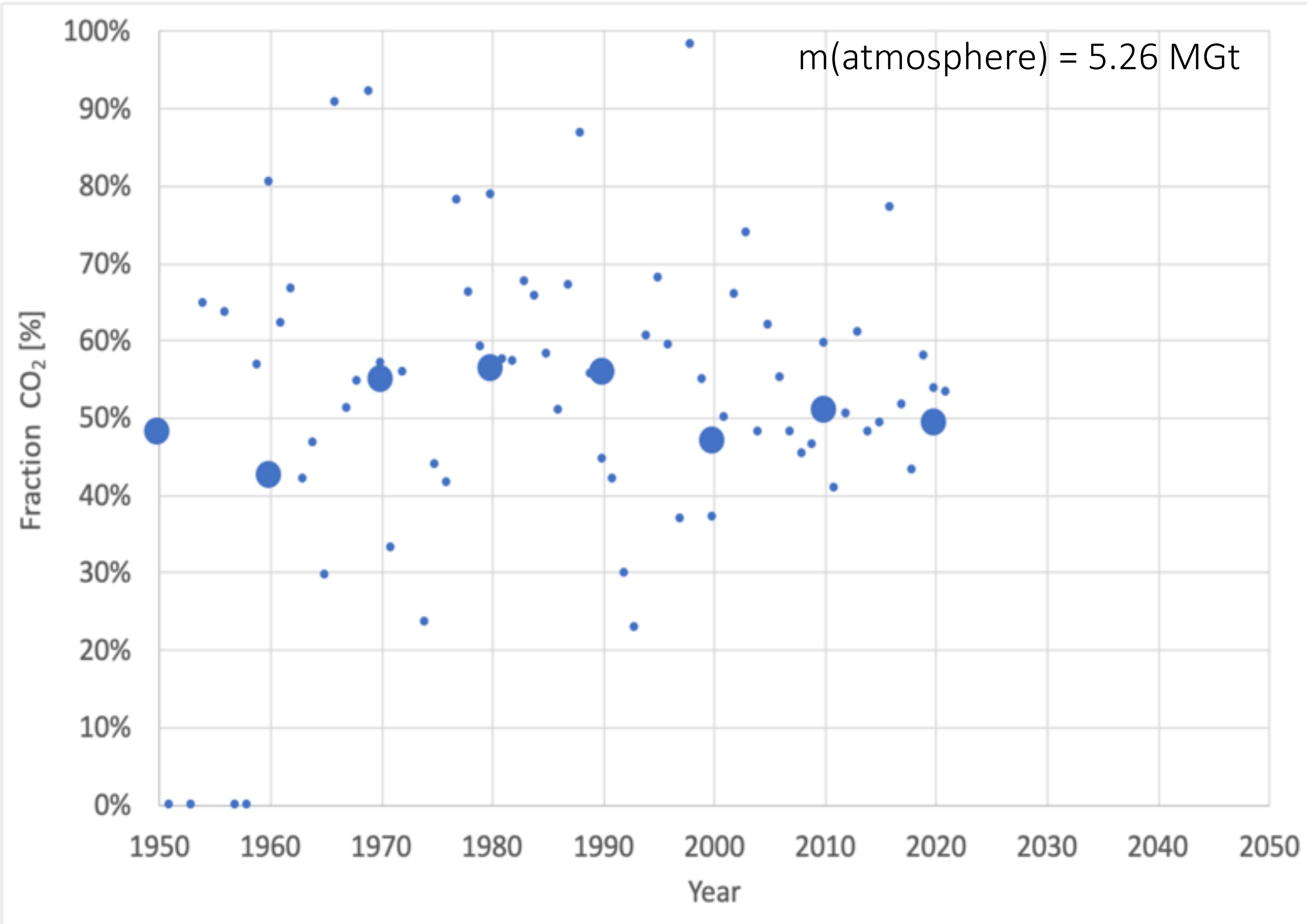
3.7.7. Anthropogenic CO_2 emissions and atmospheric concentration



Cumulated anthropogenic CO_2 emissions and concentration of CO_2 in the atmosphere vs. time. The difference is assumed to be due to natural sinks. The mass of the atmosphere is 5.26 MGt.

Ref.: https://ourworldindata.org/co2-emissions

3.7.8. CO_2 remaining in the atmosphere

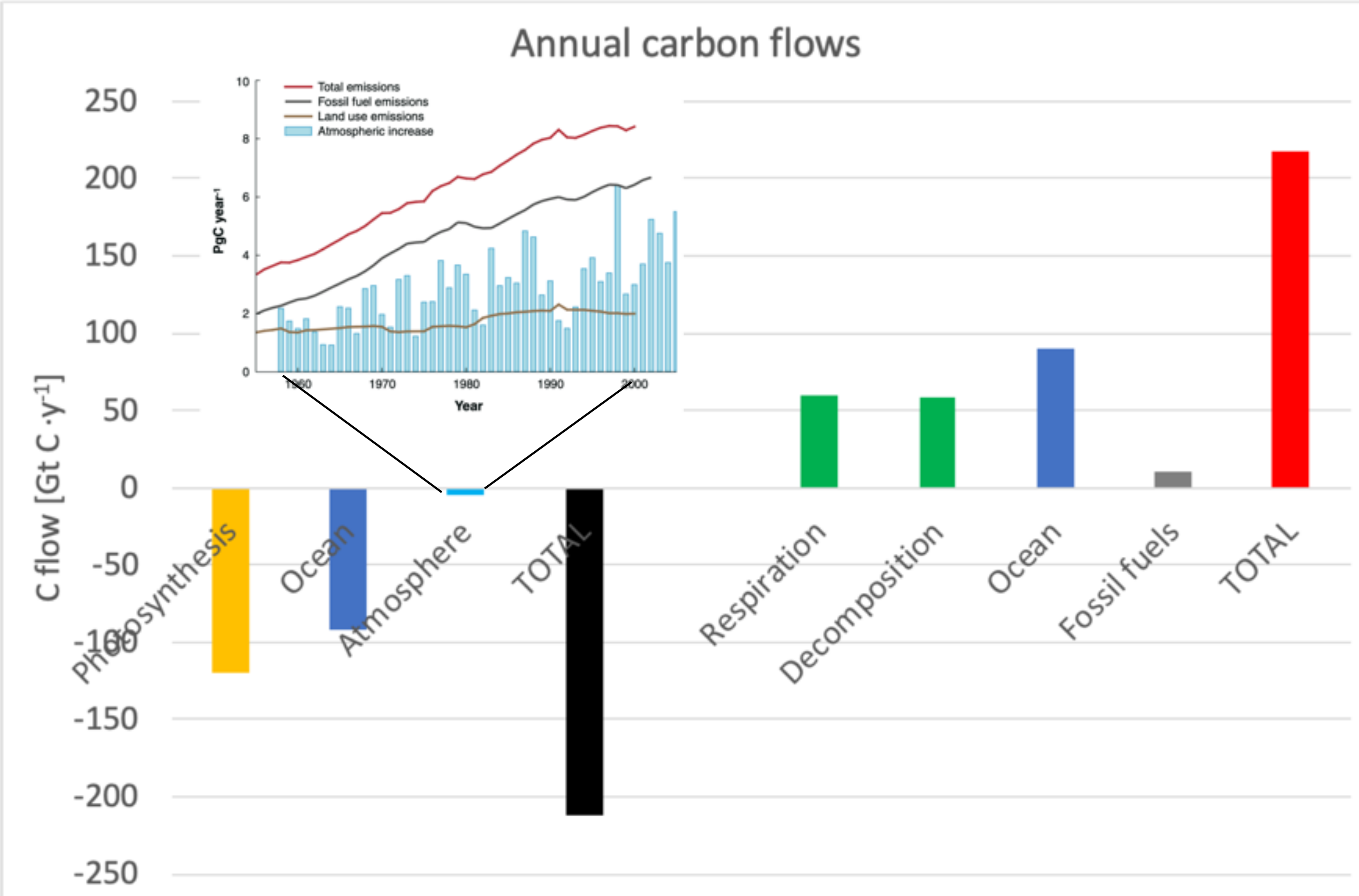


Fraction of CO_2 in the atmosphere vs. year. In average 50% of emitted CO_2 remains in the atmosphere.

Ref.: https://ourworldindata.org/co2-emissions

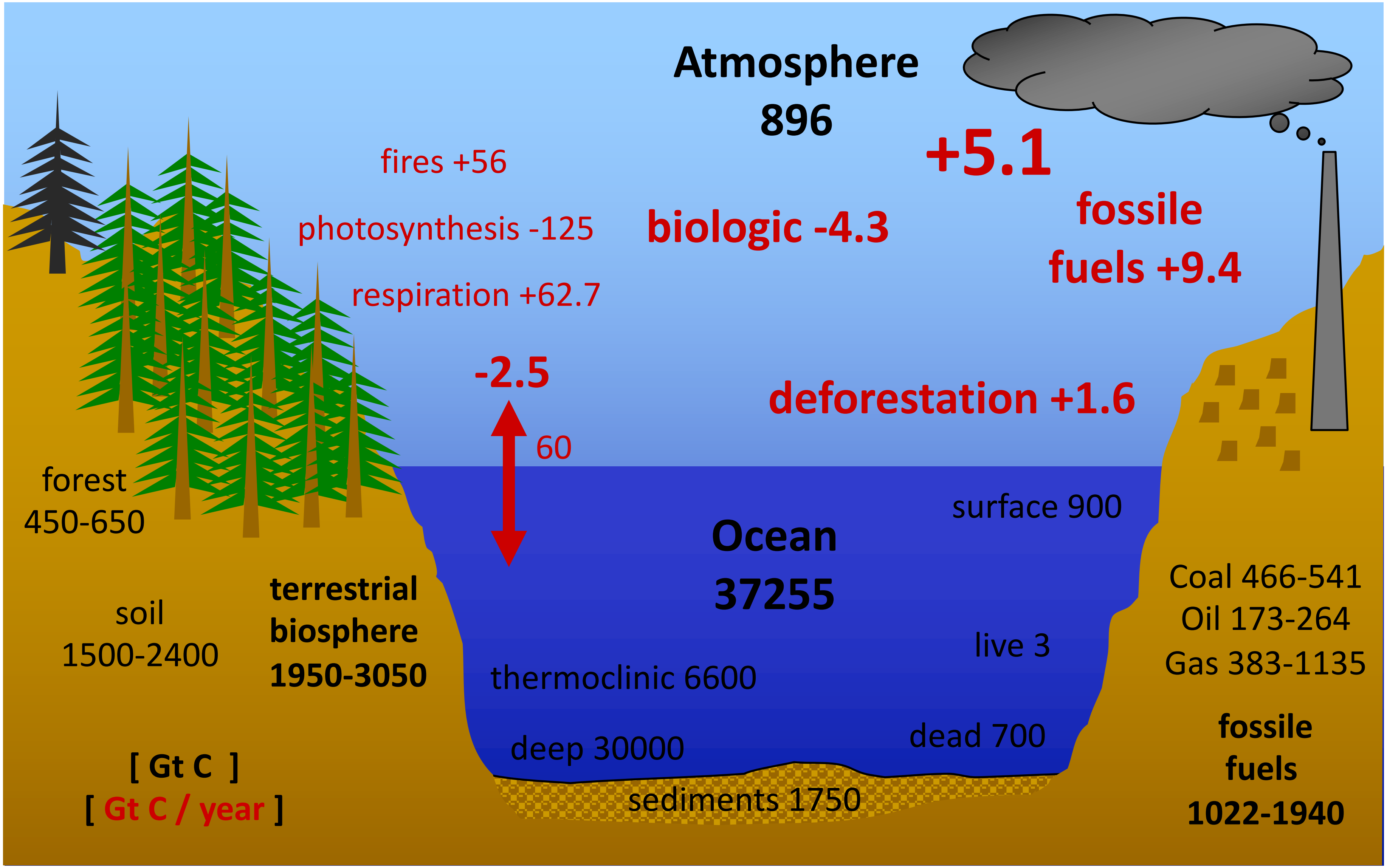
3.7.9. CO_2 Emission and Absorption

2020



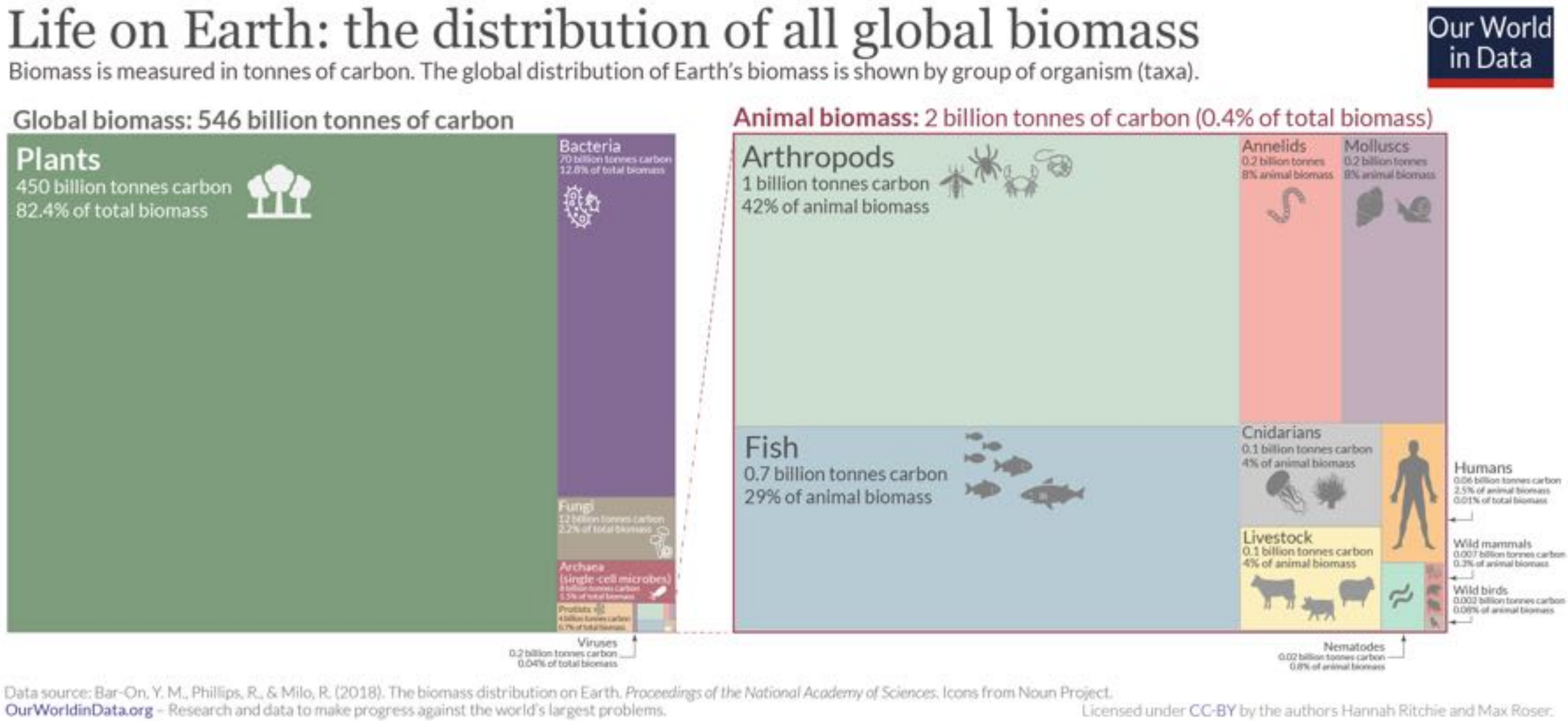
Ref.: R.A. Houghton, "Balancing the Global Carbon Budget", Annu. Rev. Earth Planet. Sci. 2007. 35:313–47

3.7.10. Global carbon balance sheet 2020



Kandasamy S and Nagender Nath B (2016) "Perspectives on the Terrestrial Organic Matter Transport and Burial along the Land-Deep Sea Continuum: Caveats in Our Understanding of Biogeochemical Processes and Future Needs.", Front. Mar. Sci. 3:259. doi: 10.3389/fmars.2016.00259

3.7.11. Biomass distribution



Live biomass has been removing 4.9 to 5.5 GtC y^{-1} from the atmosphere, offsetting 4.6 ± 0.1 GtC y^{-1} of gross emissions from disturbances (+1%).
Different regions show varying rates of biomass change:
China has gained biomass at a rate of 0.11 GtC y^{-1}. Brazil and Indonesia have gained 0.05 and 0.03 GtC y^{-1}, respectively. European Union has shown an insignificant increase due to increasing forest disturbance.
Boreal forests are accumulating carbon at a rate of 0.10 MgC ha^{-1} y^{-1}.

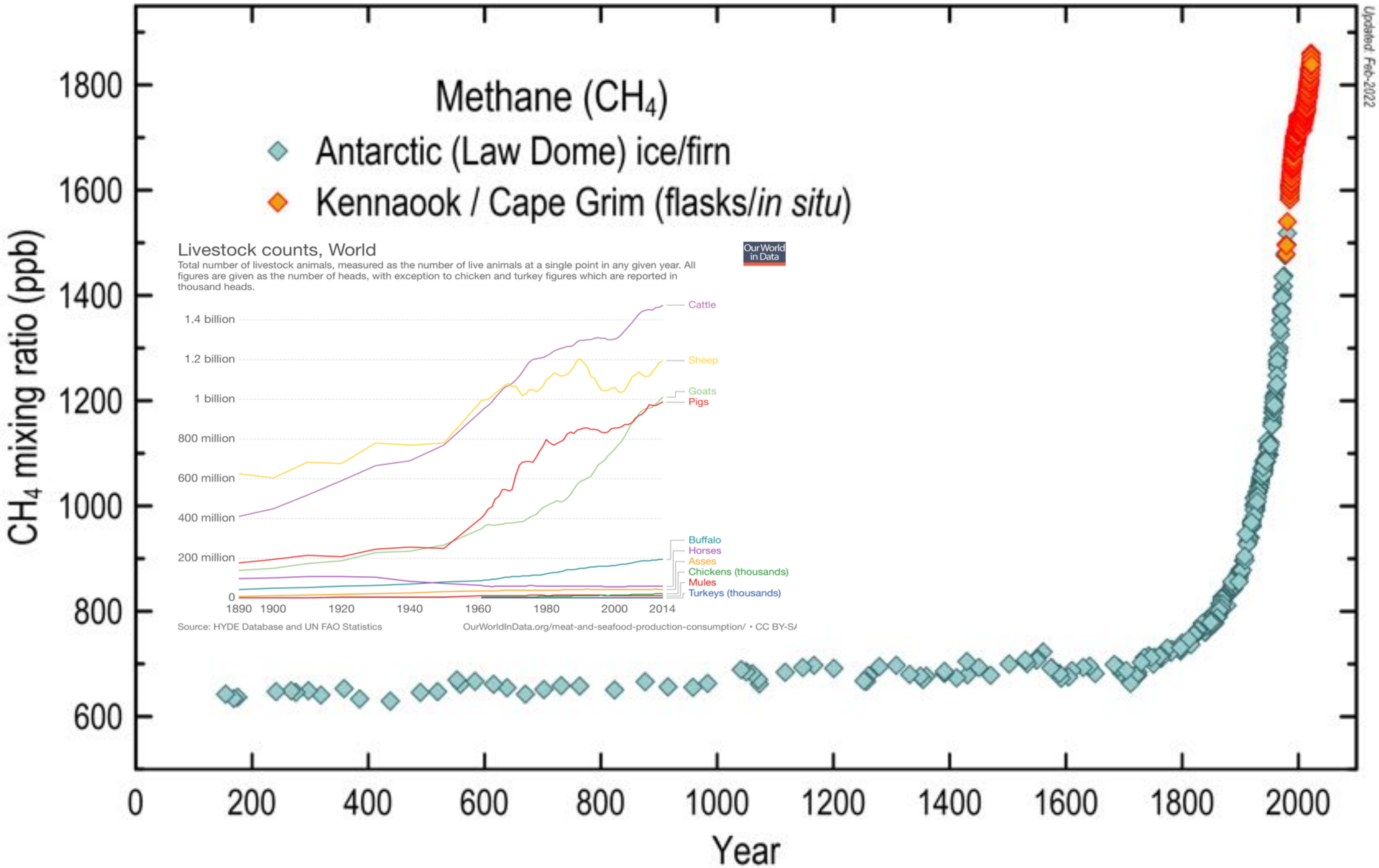
Ref.: Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. Proceedings of the National Academy of Sciences. Icons from Noun Project.

3.7.12. Net primary productivity of biomass

Nearly 20 years of satellite observations of net primary productivity reveal the seasonal and yearly cycles of Earth's vegetation. More subtle vegetation patterns include a decrease in productivity at high latitudes of the Northern Hemisphere following the eruption of Mt. Pinatubo in 1991, and global-scale decreases in productivity during El Niño events. Biomass net productivity has increased 6% in the last 18 years. 86% of the world's biomass is located in the global South.

Ref.: https://earthobservatory.nasa.gov/features/GlobalGarden

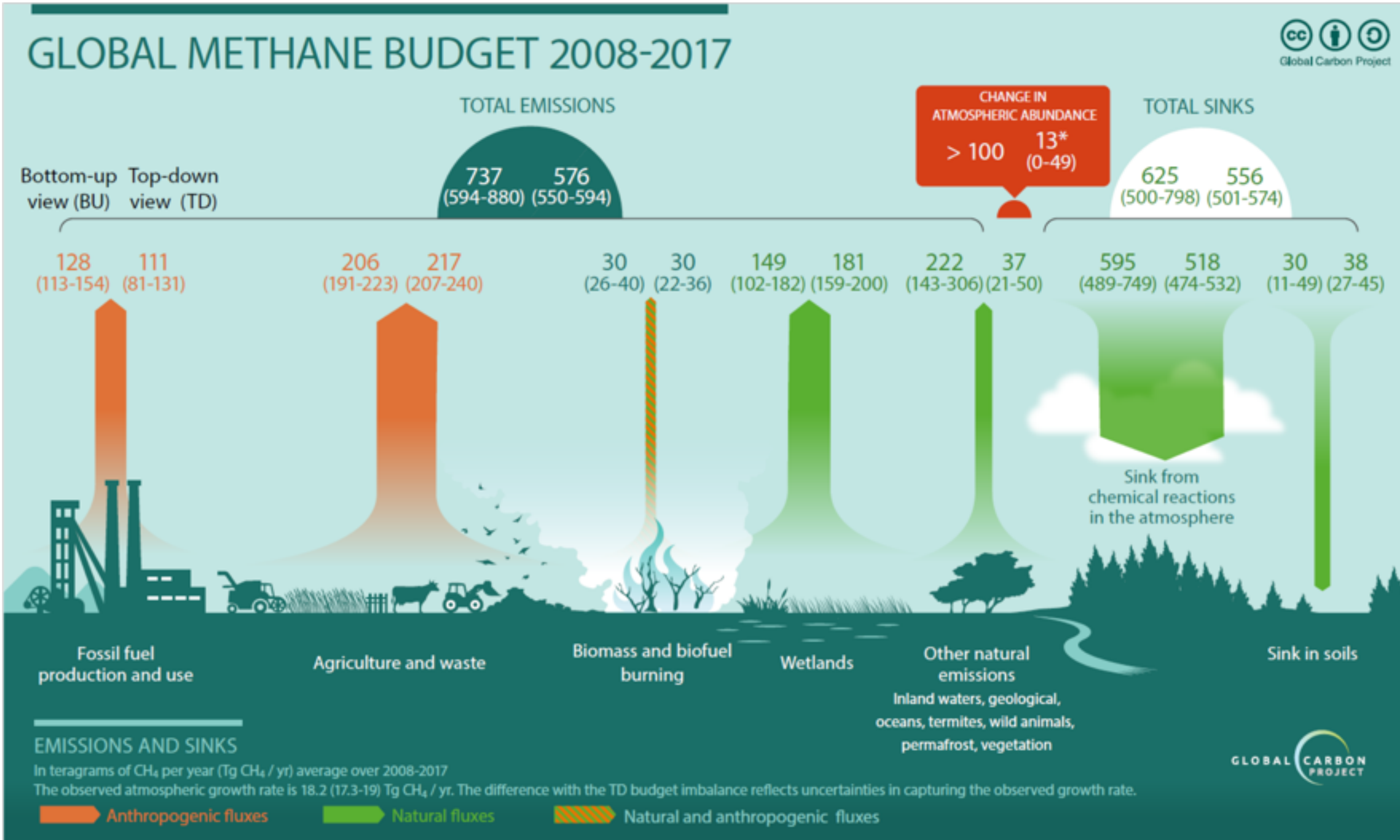
3.7.13. Atmospheric CH_4 concentration



Atmospheric methane concentrations (in ppb) over the last 2000 years, based on measurements of air trapped in Antarctic ice and firn, shown in blue-grey diamonds, and the modern Cape Grim in situ record, shown in orange.

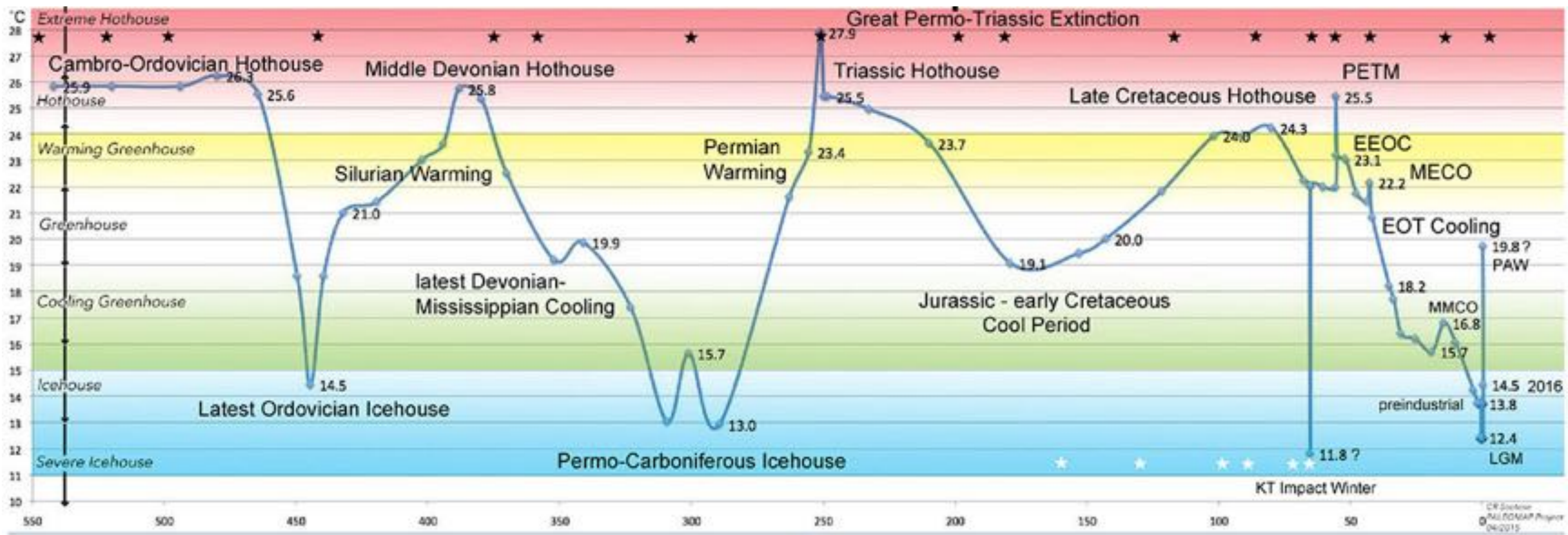
Ref.: https://www.csiro.au/en/research/environmental-impacts/emissions/global-greenhouse-gas-budgets/global-methane-budget

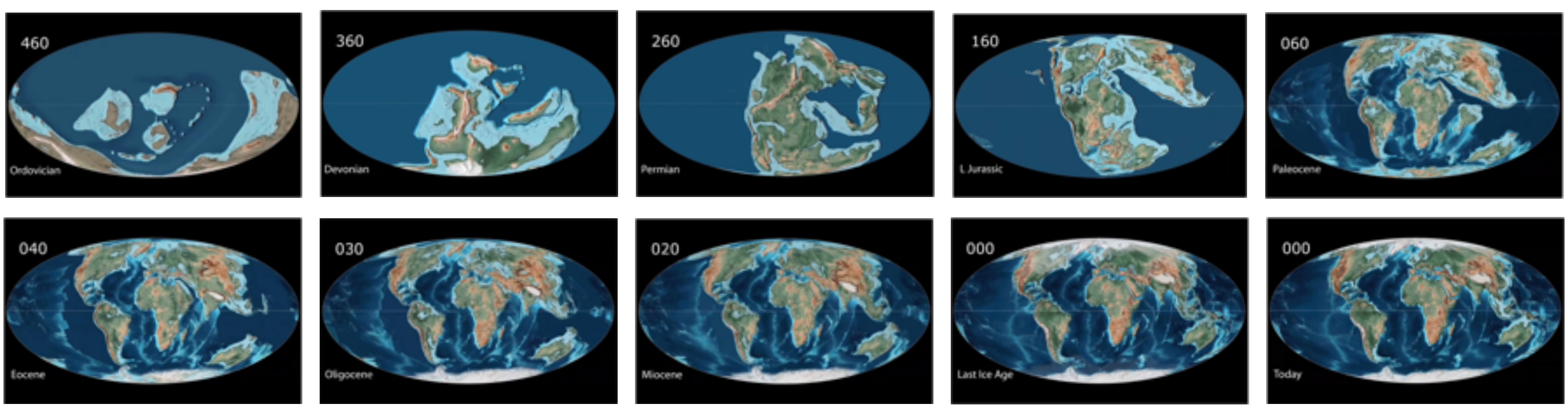
3.7.14. CH_4 Global Budget



Ref.: https://www.globalcarbonproject.org/methanebudget/

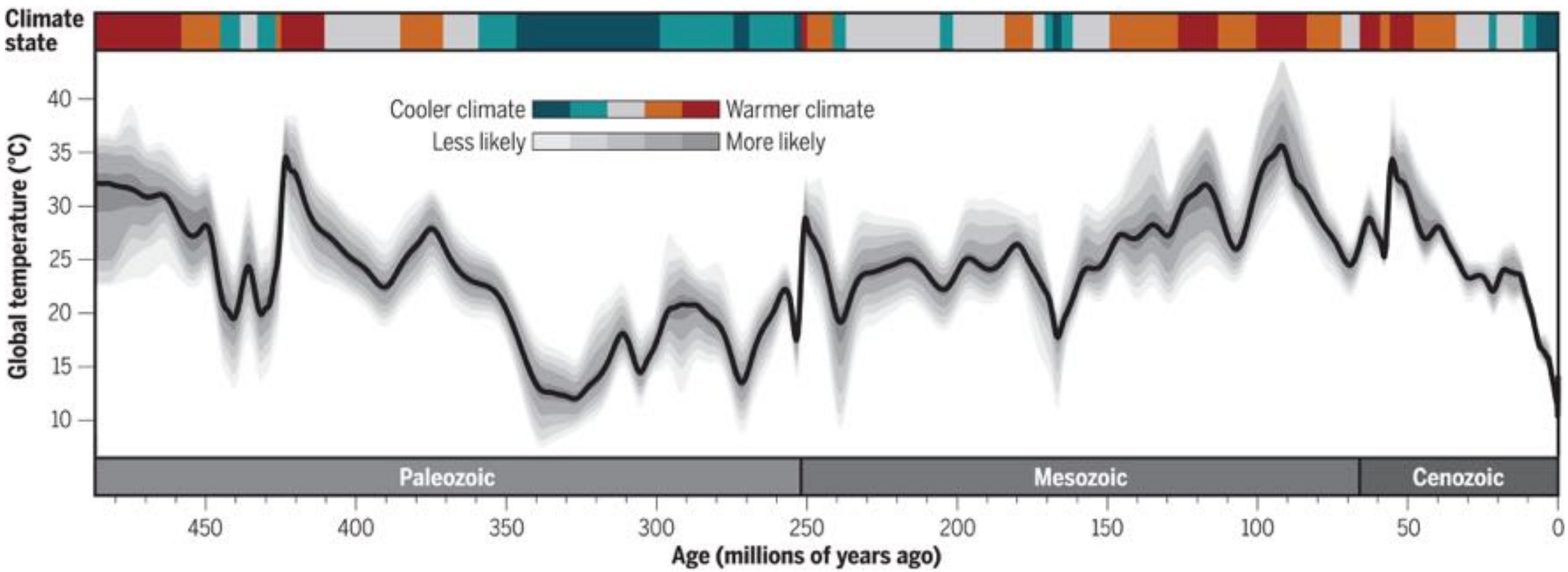
3.8. Global temperature





Ref.: Christopher Scotese, 2016. "Plate Tectonics, Paleogeography, and Ice Ages, (Modern World - 540Ma)", YouTube Animation https://youtu.be/g_iEWvtKcuQ.

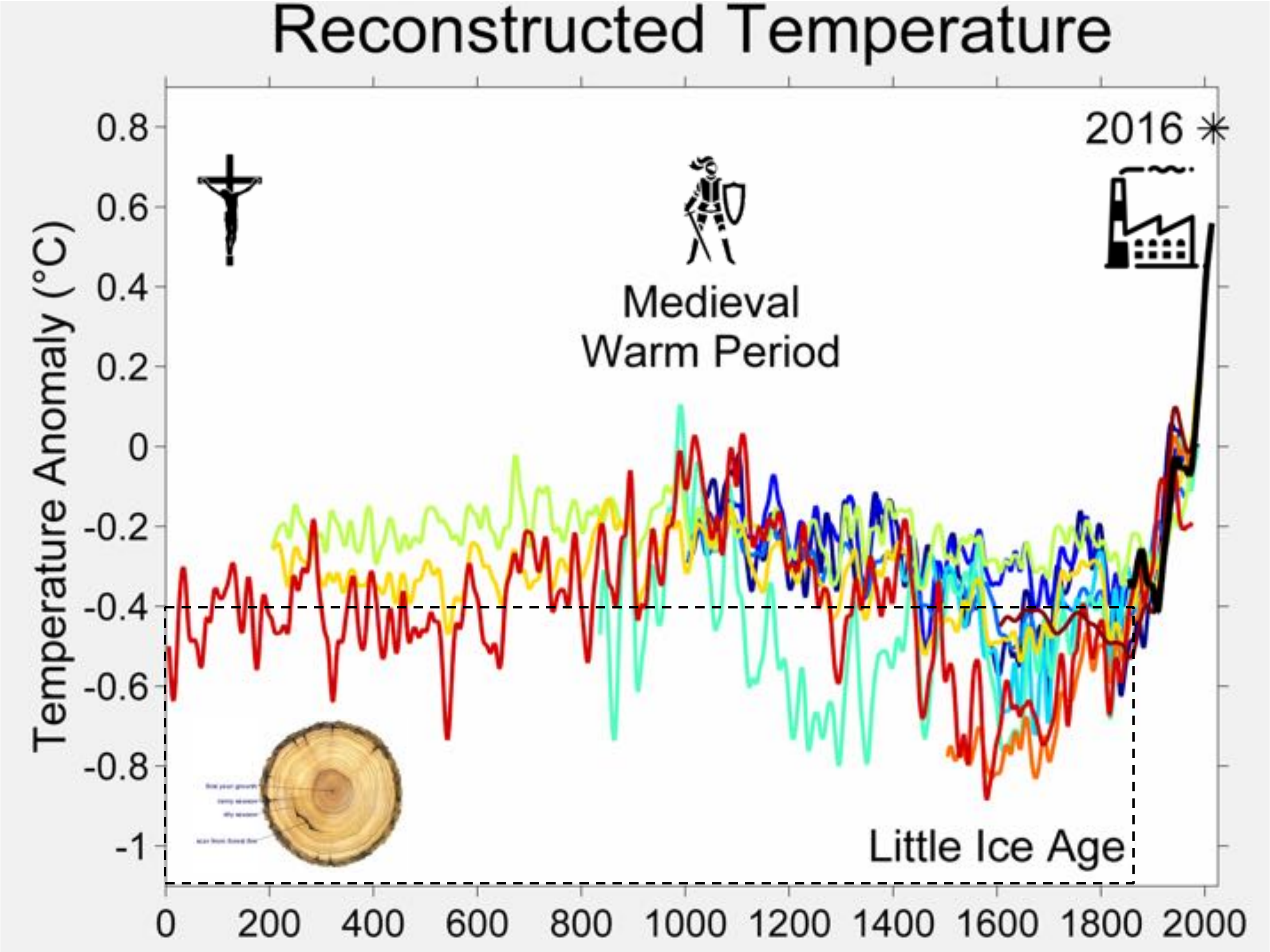
3.8.1. Temperature on earth over the last 500 Million years



PhanDA global mean surface temperature across the last 485 million years.
The gray shading corresponds to different confidence levels, and the black line shows the average solution. The colored bands along the top reflect the climate state, with cooler colors indicating icehouse (coolhouse and coldhouse) climates, warmer colors indicating greenhouse (warmhouse and hothouse) climates, and the gray representing a transitional state.

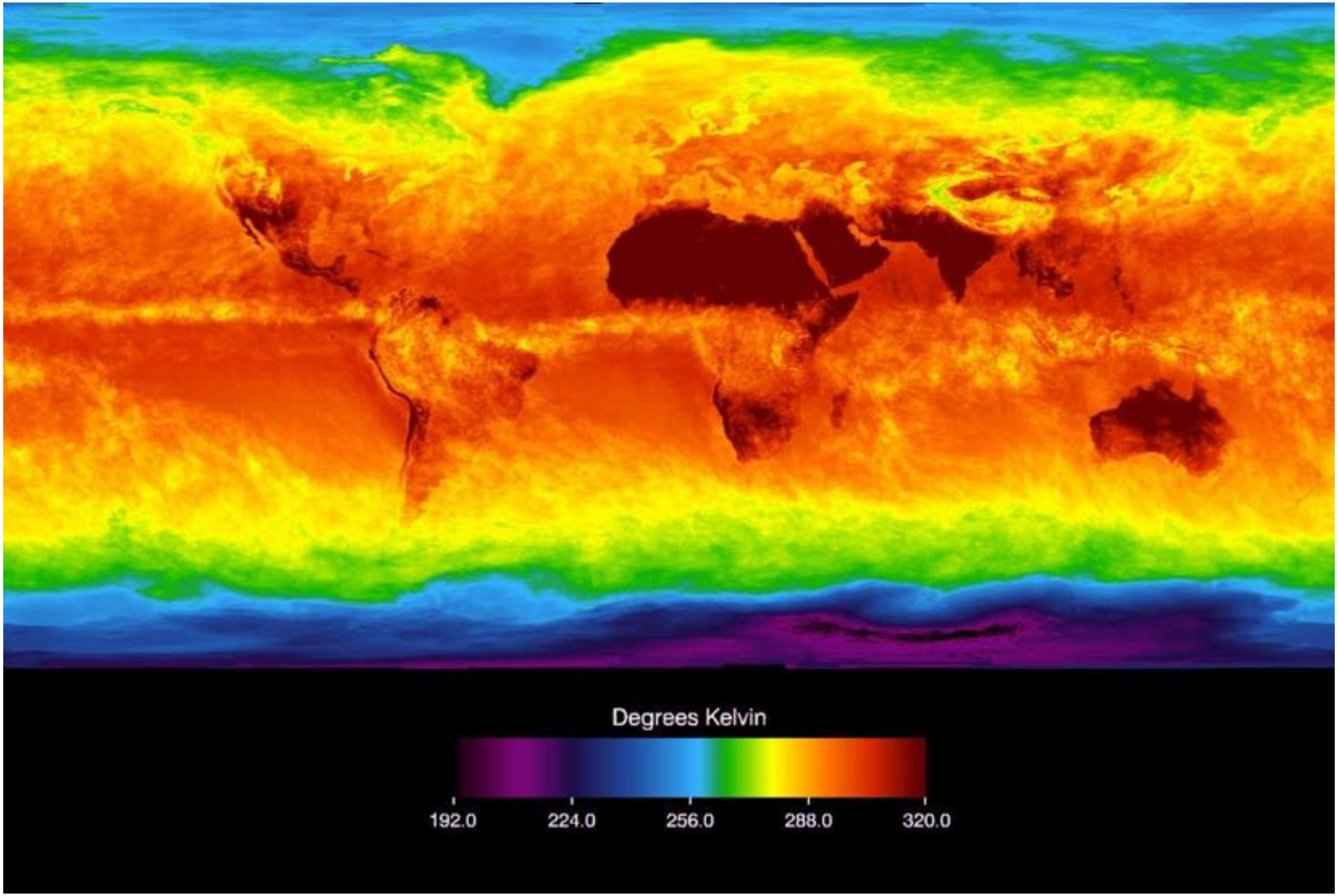
Ref.: EMILY J. JUDD, JESSICA E. TIERNEY, DANIEL J. LUNT, ISABEL P. MONTAÑEZ, BRIAN T. HUBER, SCOTT L. WING, AND PAUL J. VALDES , "A 485-million-year history of Earth's surface temperature", SCIENCE 385 (2024), Issue 6715
DOI: 10.1126/science.adk3705

3.8.2. Surface temperature from tree rings



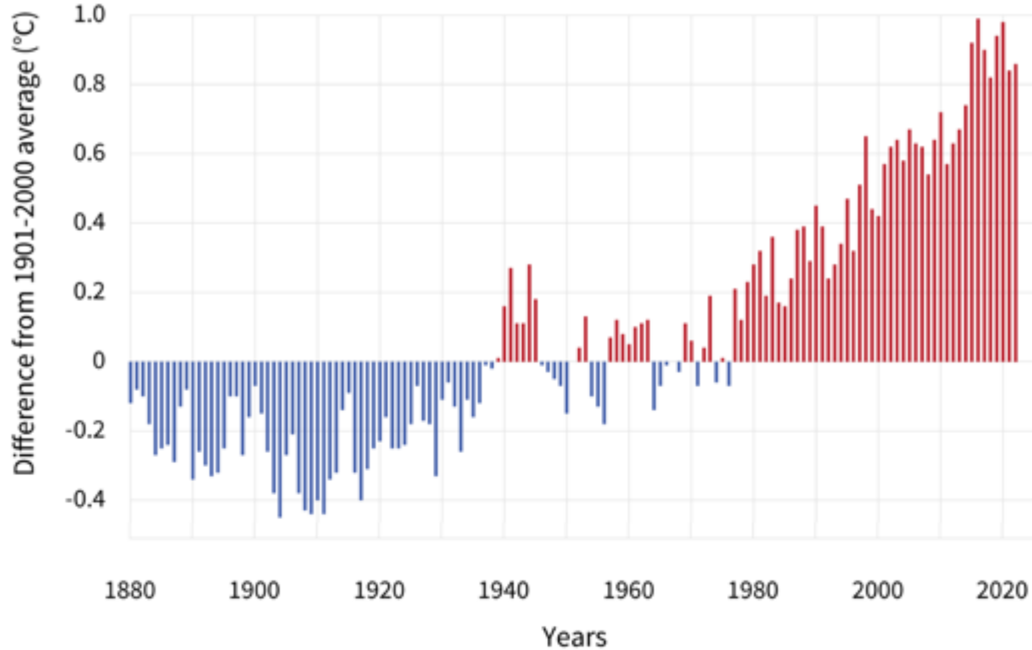
Ref.: Edward R. Cooka, Jan Esper, Rosanne D. D'Arrigo, "Extra-tropical Northern Hemisphere land temperature variability over the past 1000 years", Quaternary Science Reviews 23 (2004), pp. 2063 – 2074.
https://upload.wikimedia.org/wikipedia/commons/c/c1/2000_Year_Temperature_Comparison.png

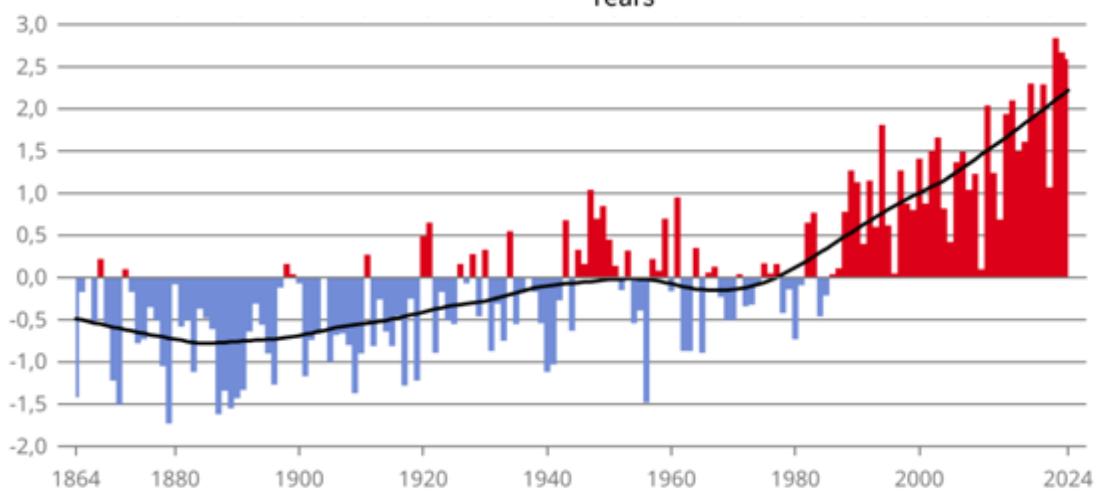
3.8.3. Satellite based surface temperature



Ref.: The Atmospheric Infrared Sounder (AIRS) instrument aboard NASA's Aqua satellite senses temperature using infrared wavelengths. This image shows temperature of the Earth's surface or clouds covering it for the month of April 2003. The scale ranges from -81°C in black/blue to 47°C in red. (Image: © AIRS Science Team, NASA/JPL)

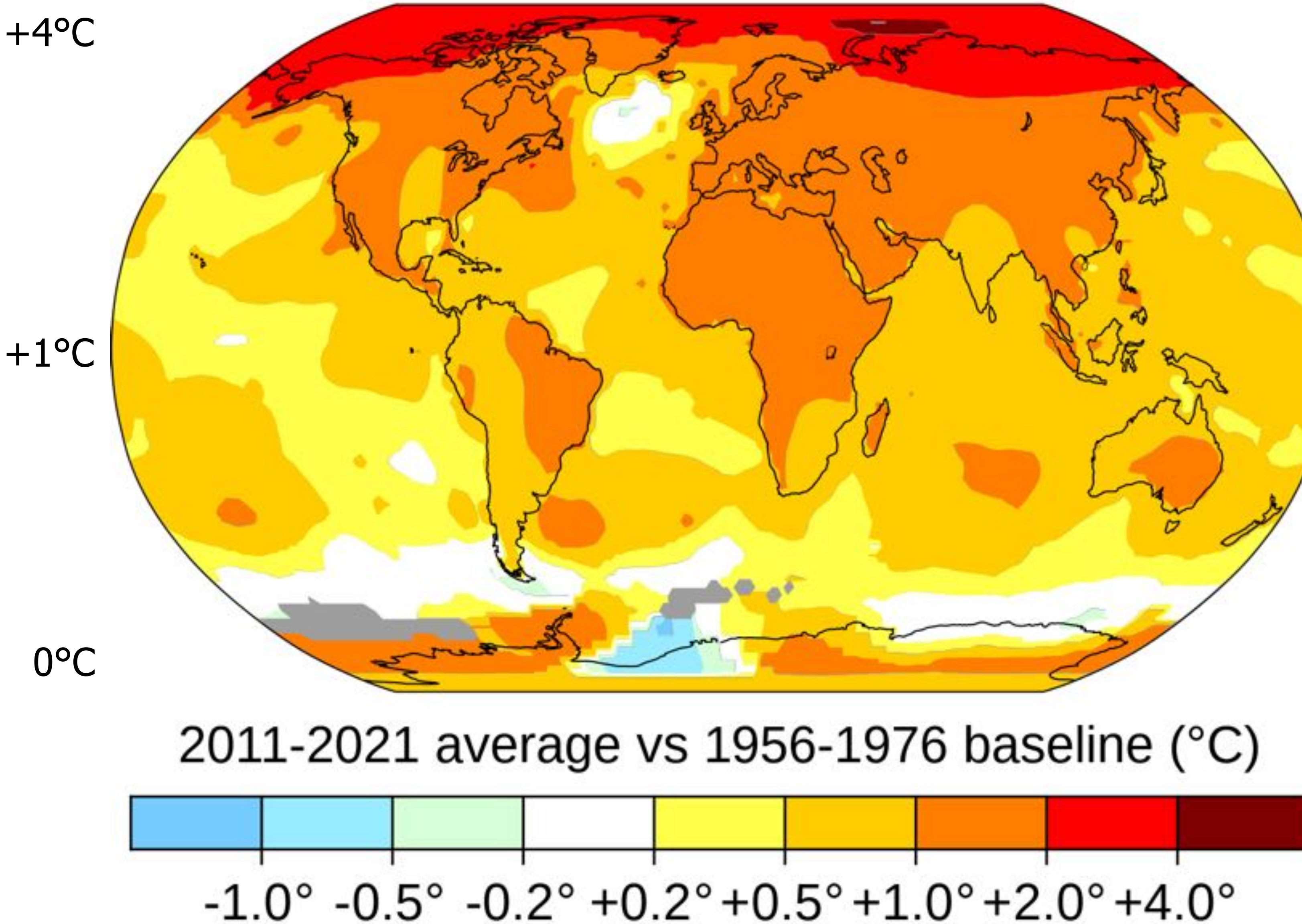
3.8.4. Global average annual temperature development





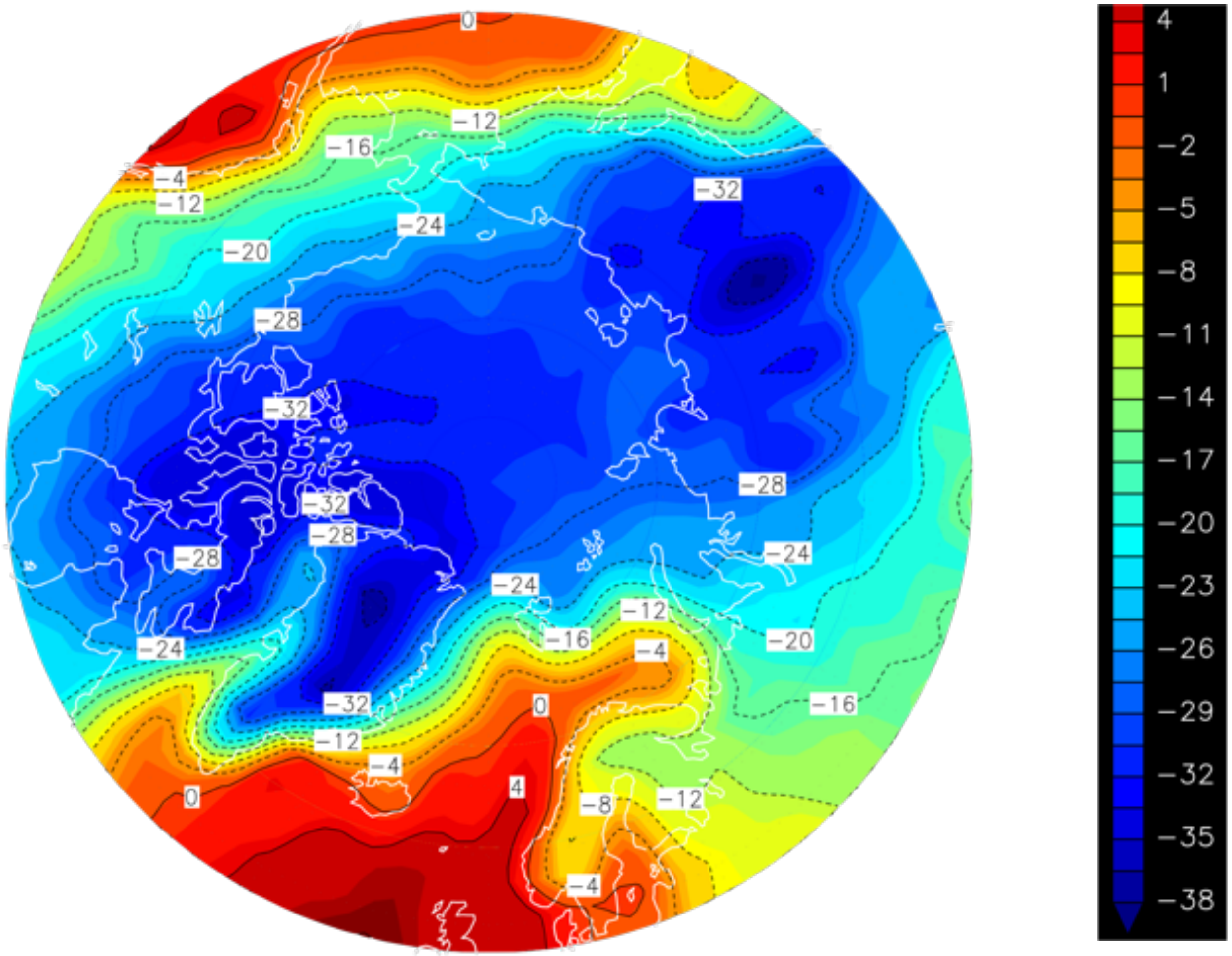
Ref.: Holland, G., Gilfillan, S. (2013). Application of Noble Gases to the Viability of CO2 Storage. In: Burnard, P. (eds) The Noble Gases as Geochemical Tracers. Advances in Isotope Geochemistry. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-28836-4_8.
https://www.meteoschweiz.admin.ch

3.8.5. Local warming during the last 50 years



NASA's Scientific Visualization Studio, Key and Title by uploader (Eric Fisk) - https://data.giss.nasa.gov/gistemp/maps/index_v4.html

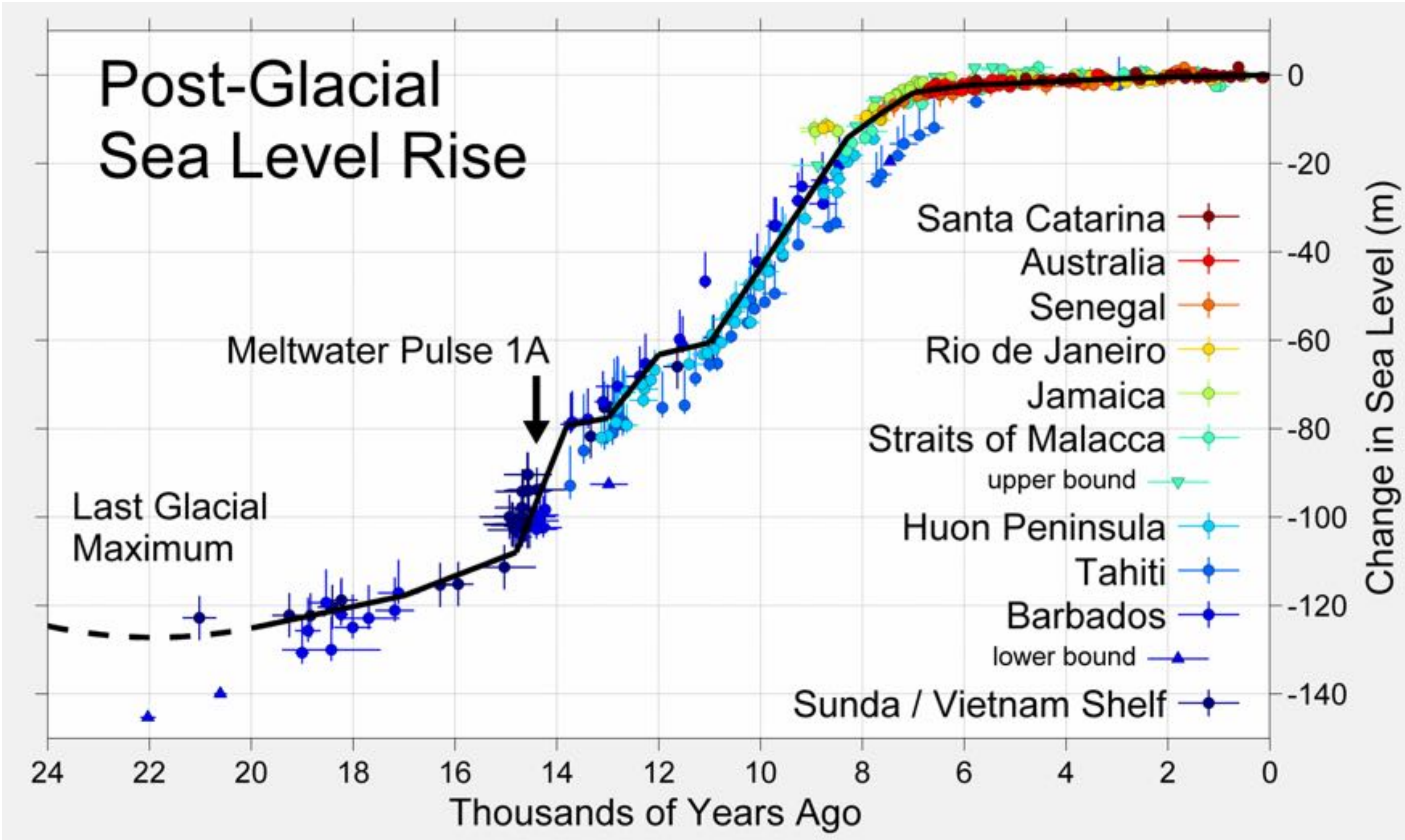
3.8.6. 1968 to 1996 January mean surface air temperature [°C]



This map shows the mean surface air temperature (2 meters above the surface) over the Arctic in January, from NCEP/NCAR Reanalysis data from 1968 to 1996.

Ref.: United States National Oceanic and Atmospheric Administration (NOAA) and User:StephenHudson - Produced at http://www.cdc.noaa.gov/cgi-bin/DataMenus.pl?dataset=NCEP Modified by User: Stephen Hudson to improve readability.

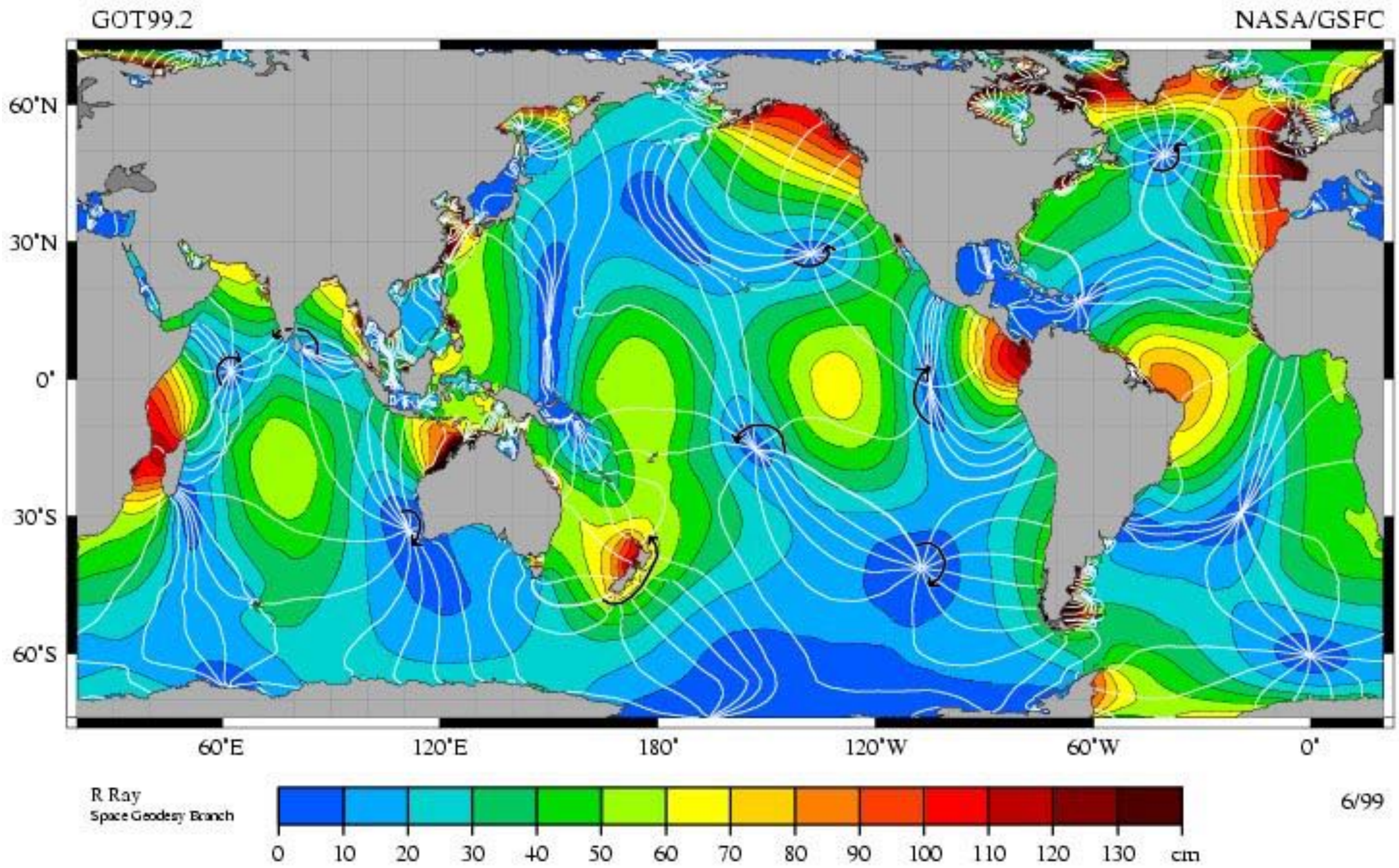
3.9. Sea level rise



Ref.: Fleming, Kevin, Paul Johnston, Dan Zwartz, Yusuke Yokoyama, Kurt Lambeck, and John Chappell (1998). "Refining the eustatic sea-level curve since the Last Glacial Maximum using far- and intermediate-field sites". Earth and Planetary Science Letters 163 (1-4): 327-342. doi:10.1016/S0012-821X(98)00198-8
https://en.m.wikipedia.org/wiki/File:Post-Glacial_Sea_Level.png

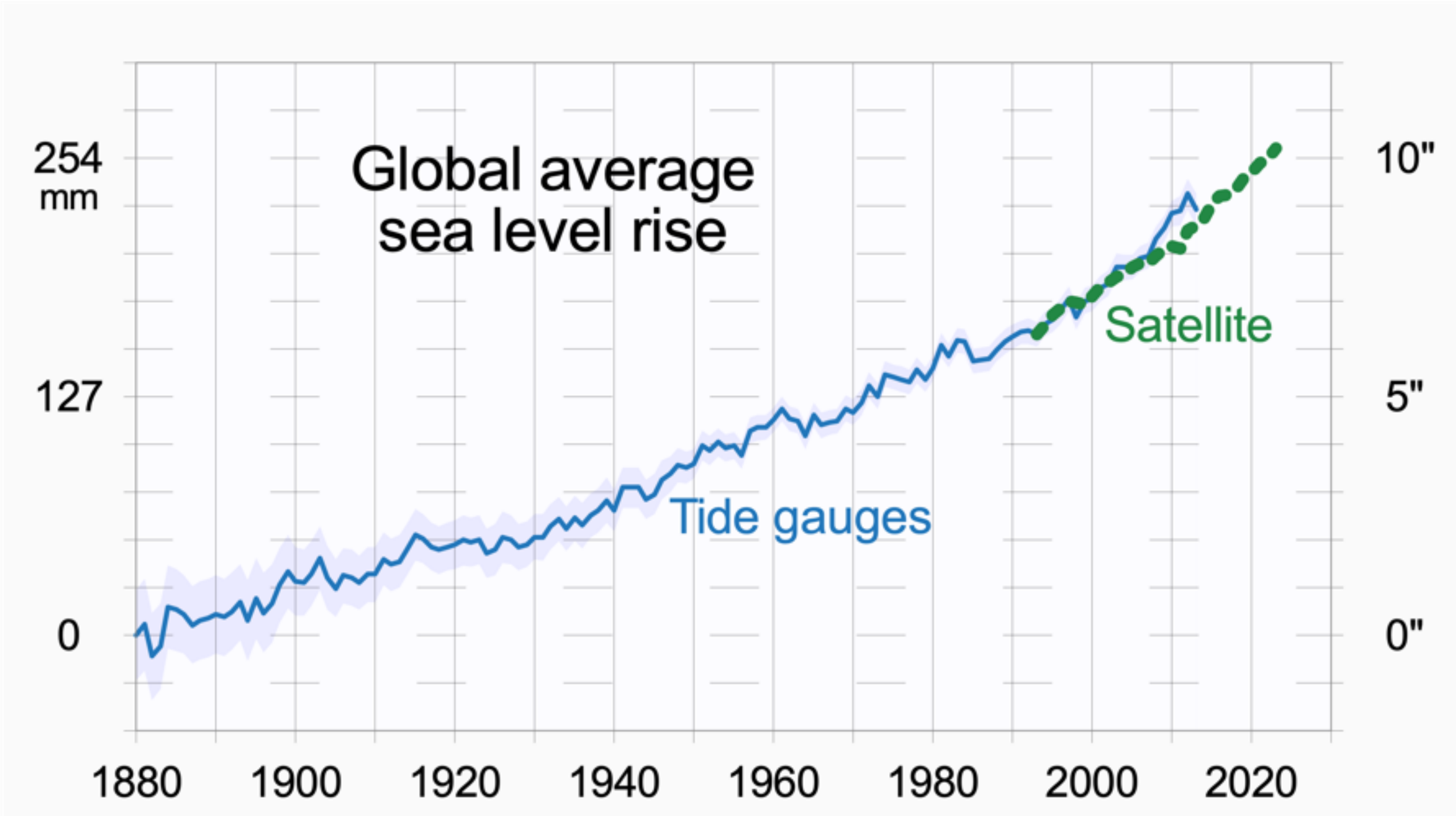
3.9.1. Tidal range

Tidal range is up to 10 m at the coast



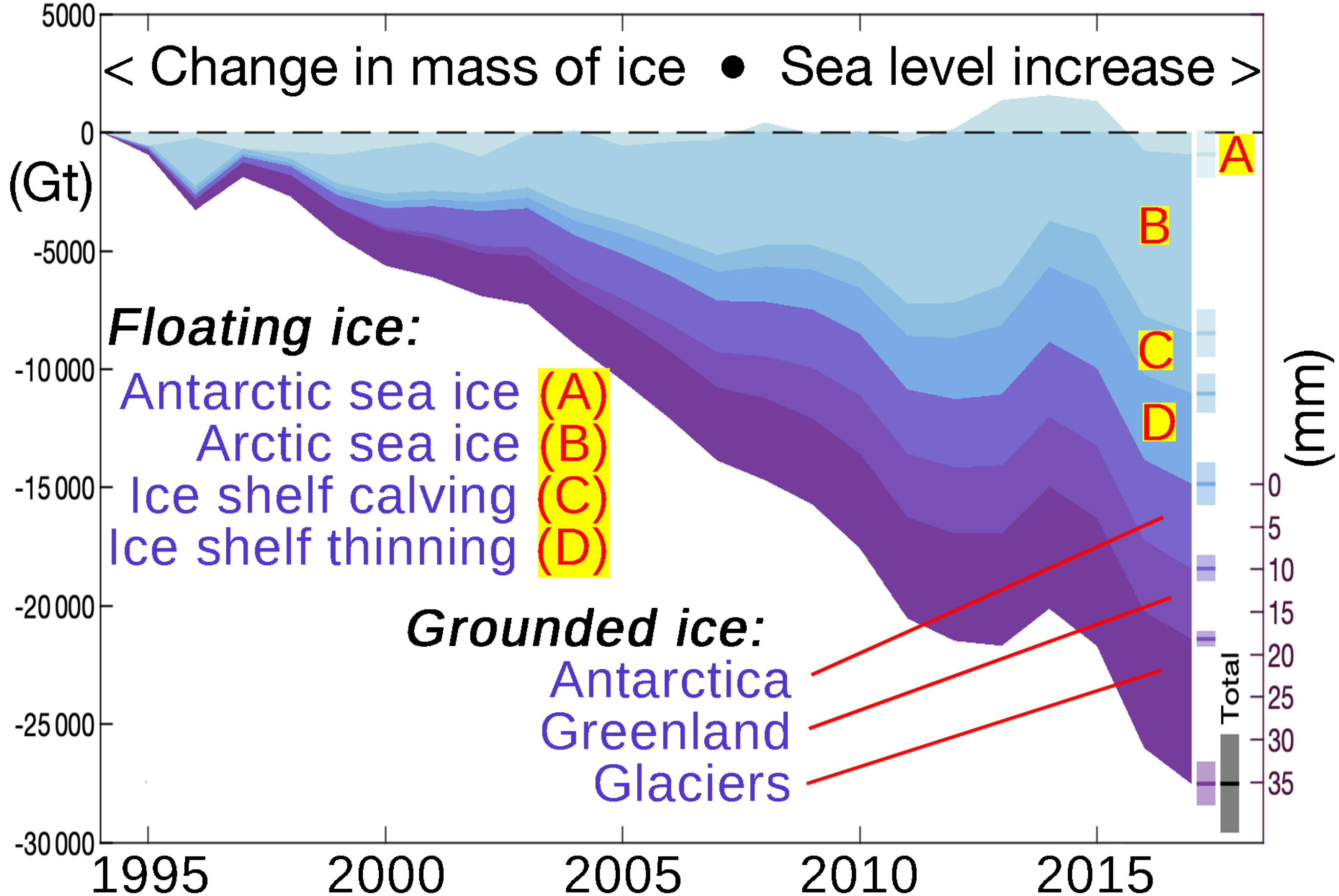
Ref.: https://en.wikipedia.org/wiki/Tidal_range

3.9.2. Recent global average sea level rise



Ref.: "Climate Change Indicators: Sea Level / Figure 1. Absolute Sea Level Change". EPA.gov. U.S. Environmental Protection Agency (EPA). July 2022. Archived from the original on 4 September 2023. Data sources: CSIRO, 2017. NOAA, 2022.

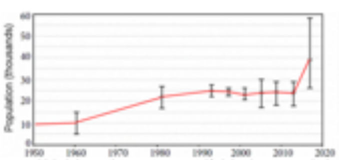
3.9.3. Ice melting and sea level rise

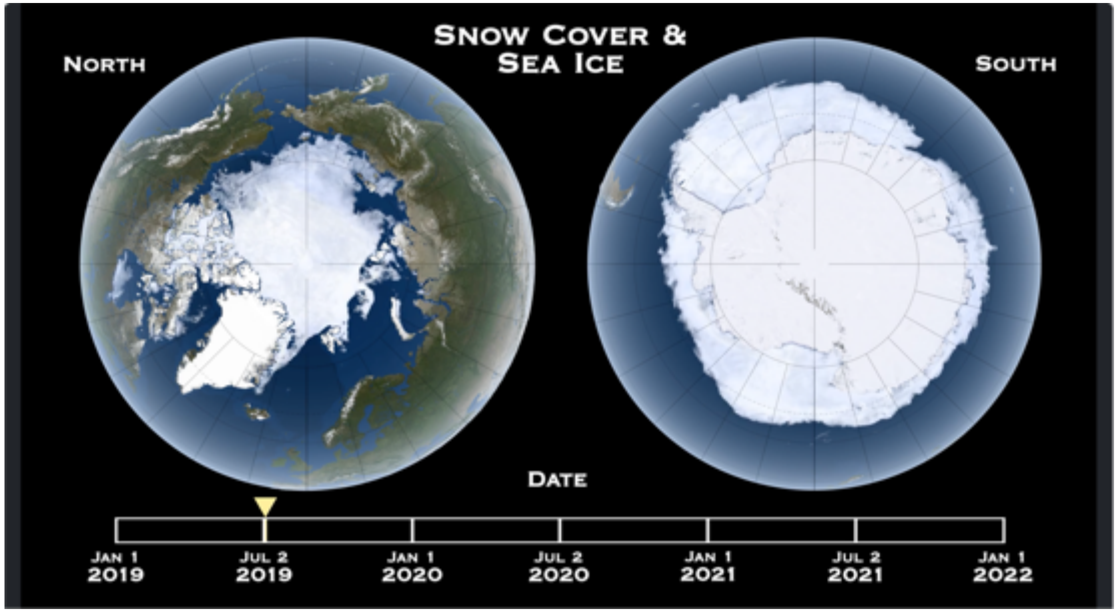


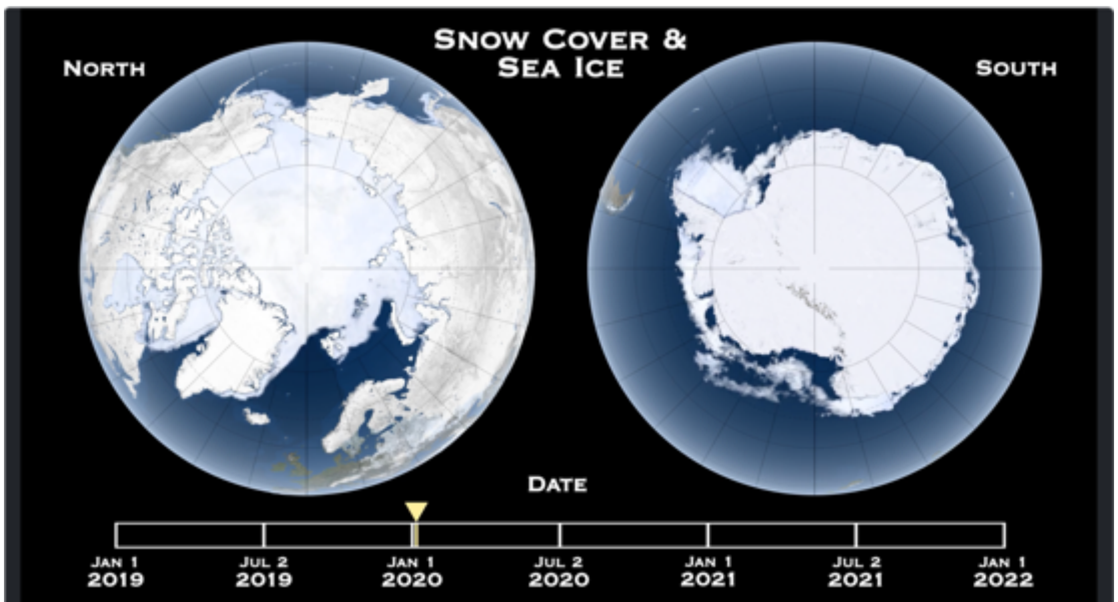
Earth lost $28 \cdot 10^{12}$ t of ice between 1994 and 2017, with melting grounded ice (ice sheets and glaciers) raising the global sea level by 34.6 ± 3.1 mm. The rate of ice loss has risen by 57% since the 1990s − from 0.8 to $1.2 \cdot 10^{12}$ t per year.

Ref.: Slater, Thomas; Lawrence, Isobel R.; Otosaka, Inès N.; Shepherd, Andrew; et al. (25 January 2021). "Review article: Earth's ice imbalance". The Cryosphere. 15 (1): 233–246. Bibcode:2021TCry...15..233S. doi:10.5194/tc-15-233-2021. ISSN 1994-0416. Abstract; Fig. 4.

3.9.4. Global snow cover and sea ice cycle at both poles

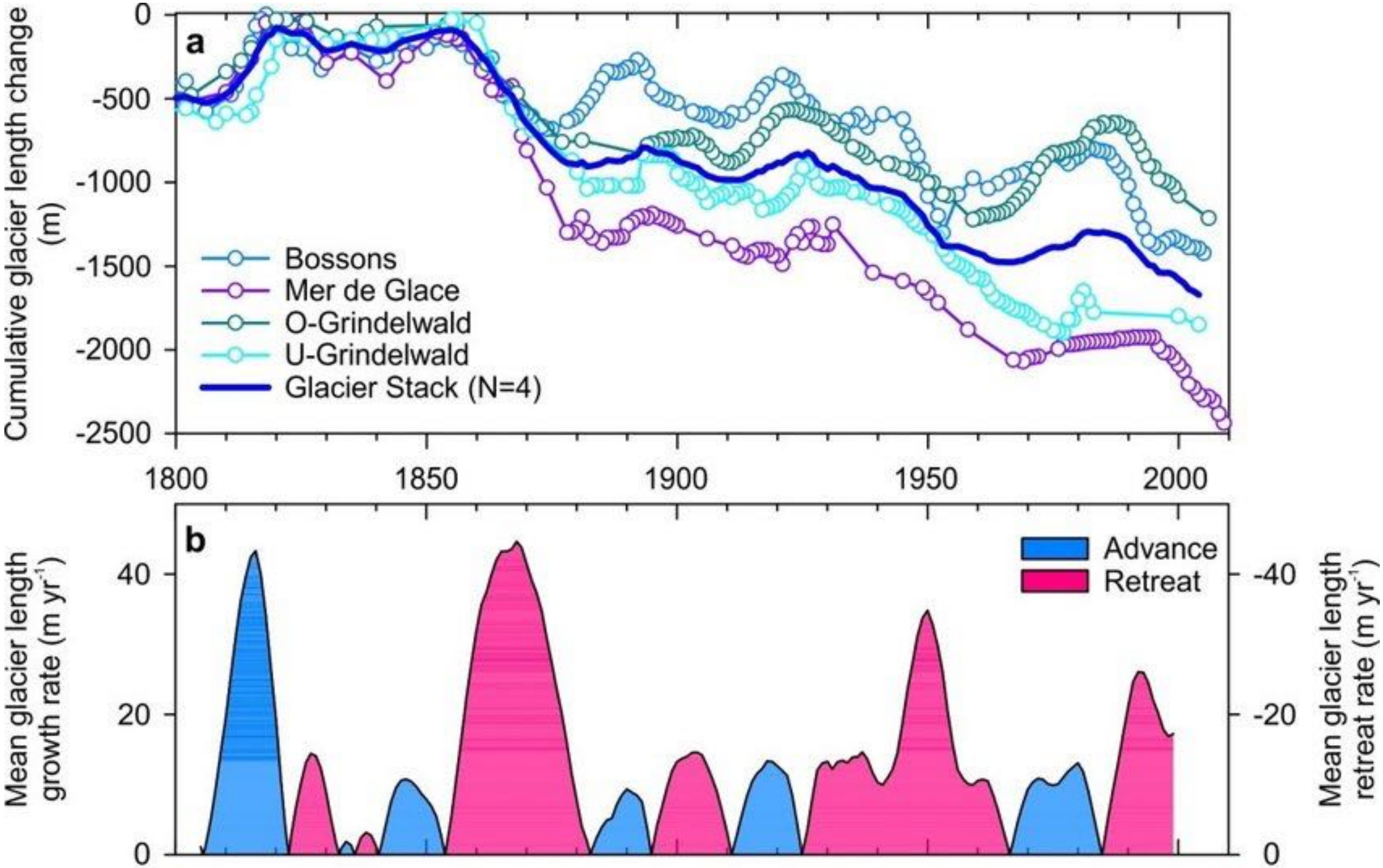






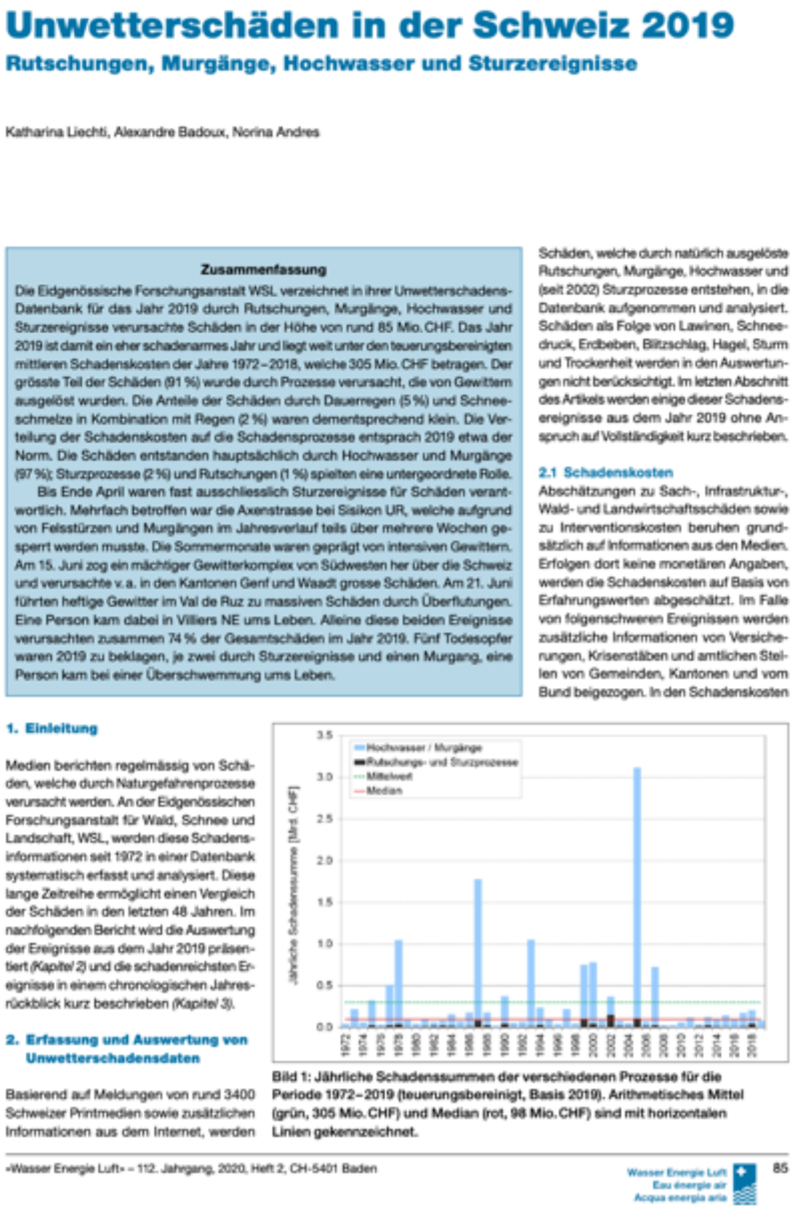
Ref.: https://svs.gsfc.nasa.gov/4995/; https://climateataglance.com/climate-at-a-glance-polar-bears-and-climate/

3.9.5. Glaciers growth and retraction



Ref.: Engel, M., 2018. Paleoclimate Relevance to Global Warming. Reference Module in Earth Systems and Environmental Sciences. Elsevier, doi: 10.1016/B978-0-12-409548-9.11264-3.
Michael Sigl, Nerilie J. Abram, Jacopo Gabrieli, Theo M. Jenk, Dimitri Osmont, Margit Schwikowski, “No role for industrial black carbon in forcing 19th century glacier retreat in the Alps“, journal The Cryosphere (2018).

3.10. Environmental damages in Switzerland



Unwetterschäden in der Schweiz 2019

Rutschungen, Murgänge, Hochwasser und Sturzereignisse

Katharina Liechti, Alexandre Badoux, Norina Andres

Zusammenfassung

Die Eidgenössische Forschungsanstalt WSL verzeichnet in ihrer Unwetterschadens-Datenbank für das Jahr 2019 durch Rutschungen, Murgänge, Hochwasser und Sturzereignisse verursachte Schäden in der Höhe von rund 85 Mio. CHF. Das Jahr 2019 ist damit ein eher schadenarmes Jahr und liegt weit unter den teuerungsbereinigten mittleren Schadenskosten der Jahre 1972–2018, welche 305 Mio. CHF betragen. Der grösste Teil der Schäden (91 %) wurde durch Prozesse verursacht, die von Gewittern ausgelöst wurden. Die Anteile der Schäden durch Dauerregen (5 %) und Schneeschmelze in Kombination mit Regen (2 %) waren dementsprechend klein. Die Verteilung der Schadenskosten auf die Schadensprozesse entsprach 2019 etwa der Norm. Die Schäden entstanden hauptsächlich durch Hochwasser und Murgänge (97 %); Sturzprozesse (2 %) und Rutschungen (1 %) spielten eine untergeordnete Rolle.
Bis Ende April waren fast ausschliesslich Sturzereignisse für Schäden verantwortlich. Mehrfach betroffen war die Axenstrasse bei Sisikon UR, welche aufgrund von Felsstürzen und Murgängen im Jahresverlauf teils über mehrere Wochen gesperrt werden musste. Die Sommermonate waren geprägt von intensiven Gewittern. Am 15. Juni zog ein mächtiger Gewitterkomplex von Südwesten her über die Schweiz und verursachte v. a. in den Kantonen Genf und Waadt grosse Schäden. Am 21. Juni führten heftige Gewitter im Val de Ruz zu massiven Schäden durch Überflutungen. Eine Person kam dabei in Villiers NE ums Leben. Alleine diese beiden Ereignisse verursachten zusammen 74 % der Gesamtschäden im Jahr 2019. Fünf Todesopfer waren 2019 zu beklagen, je zwei durch Sturzereignisse und einen Murgang, eine Person kam bei einer Überschwemmung ums Leben.

Schäden, welche durch natürlich ausgelöste Rutschungen, Murgänge, Hochwasser und (seit 2002) Sturzprozesse entstehen, in die Datenbank aufgenommen und analysiert. Schäden als Folge von Lawinen, Schneedruck, Erdbeben, Blitzschlag, Hagel, Sturm und Trockenheit werden in den Auswertungen nicht berücksichtigt. Im letzten Abschnitt des Artikels werden einige dieser Schadensereignisse aus dem Jahr 2019 ohne Anspruch auf Vollständigkeit kurz beschrieben.

2.1 Schadenskosten

Abschätzungen zu Sach-, Infrastruktur-, Wald- und Landwirtschaftsschäden sowie zu Interventionskosten beruhen grundsätzlich auf Informationen aus den Medien. Erfolgen dort keine monetären Angaben, werden die Schadenskosten auf Basis von Erfahrungswerten abgeschätzt. Im Falle von folgenschweren Ereignissen werden zusätzliche Informationen von Versicherungen, Krisenstäben und amtlichen Stellen von Gemeinden, Kantonen und vom Bund beigezogen. In den Schadenskosten

1. Einleitung

Medien berichten regelmässig von Schäden, welche durch Naturgefahrenprozesse verursacht werden. An der Eidgenössischen Forschungsanstalt für Wald, Schnee und Landschaft, WSL, werden diese Schadensinformationen seit 1972 in einer Datenbank systematisch erfasst und analysiert. Diese lange Zeitreihe ermöglicht einen Vergleich der Schäden in den letzten 48 Jahren. Im nachfolgenden Bericht wird die Auswertung der Ereignisse aus dem Jahr 2019 präsentiert (Kapitel 2) und die schadenreichsten Ereignisse in einem chronologischen Jahresrückblick kurz beschrieben (Kapitel 3).

2. Erfassung und Auswertung von Unwetterschadensdaten

Basierend auf Meldungen von rund 3400 Schweizer Printmedien sowie zusätzlichen Informationen aus dem Internet, werden

Bild 1: Jährliche Schadenssummen der verschiedenen Prozesse für die Periode 1972–2019 (teuerungsbereinigt, Basis 2019). Arithmetisches Mittel (grün, 305 Mio. CHF) und Median (rot, 98 Mio. CHF) sind mit horizontalen Linien gekennzeichnet.

«Wasser Energie Luft» – 112. Jahrgang, 2020, Heft 2, CH-5401 Baden — 85

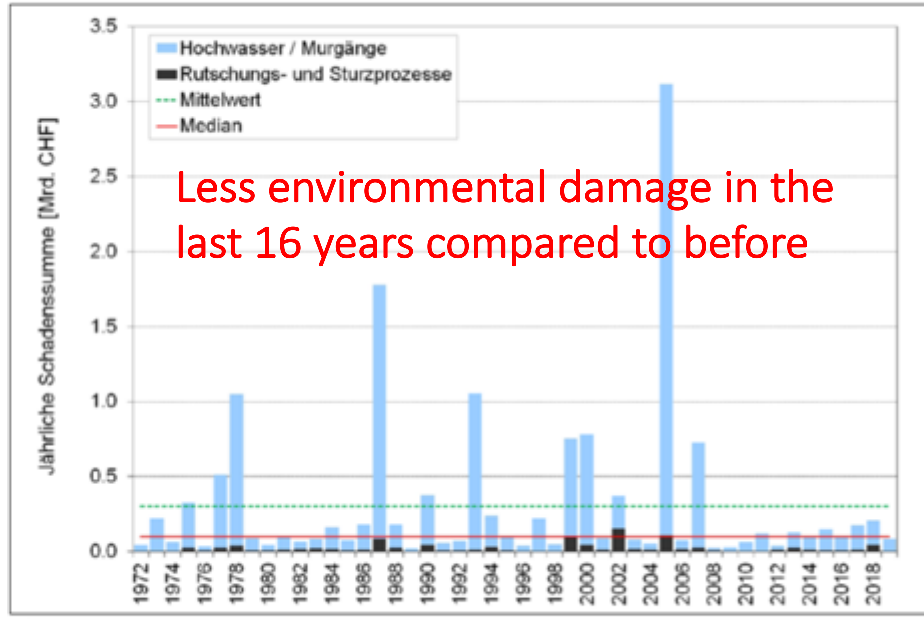
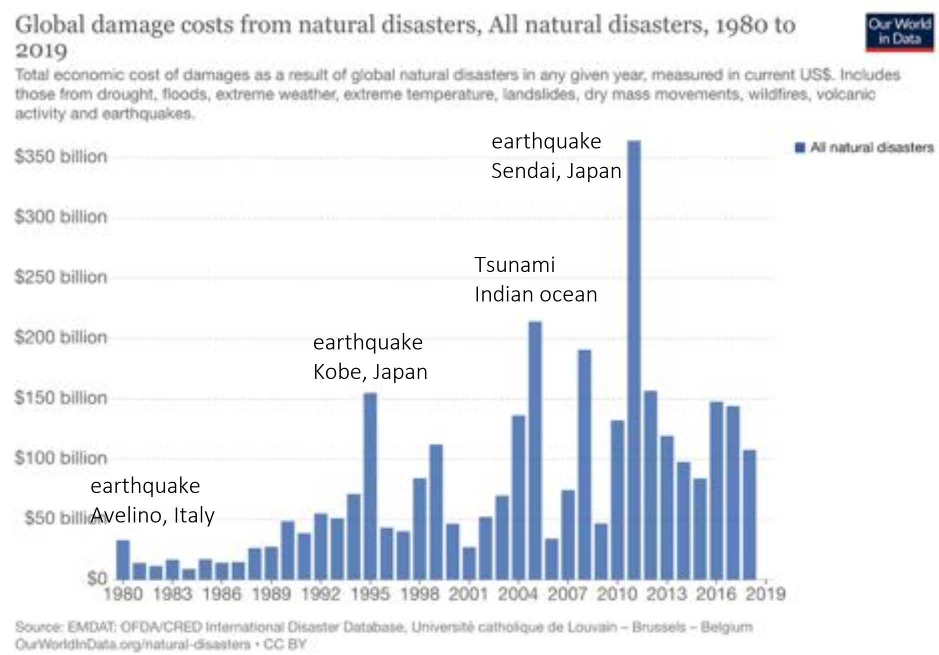
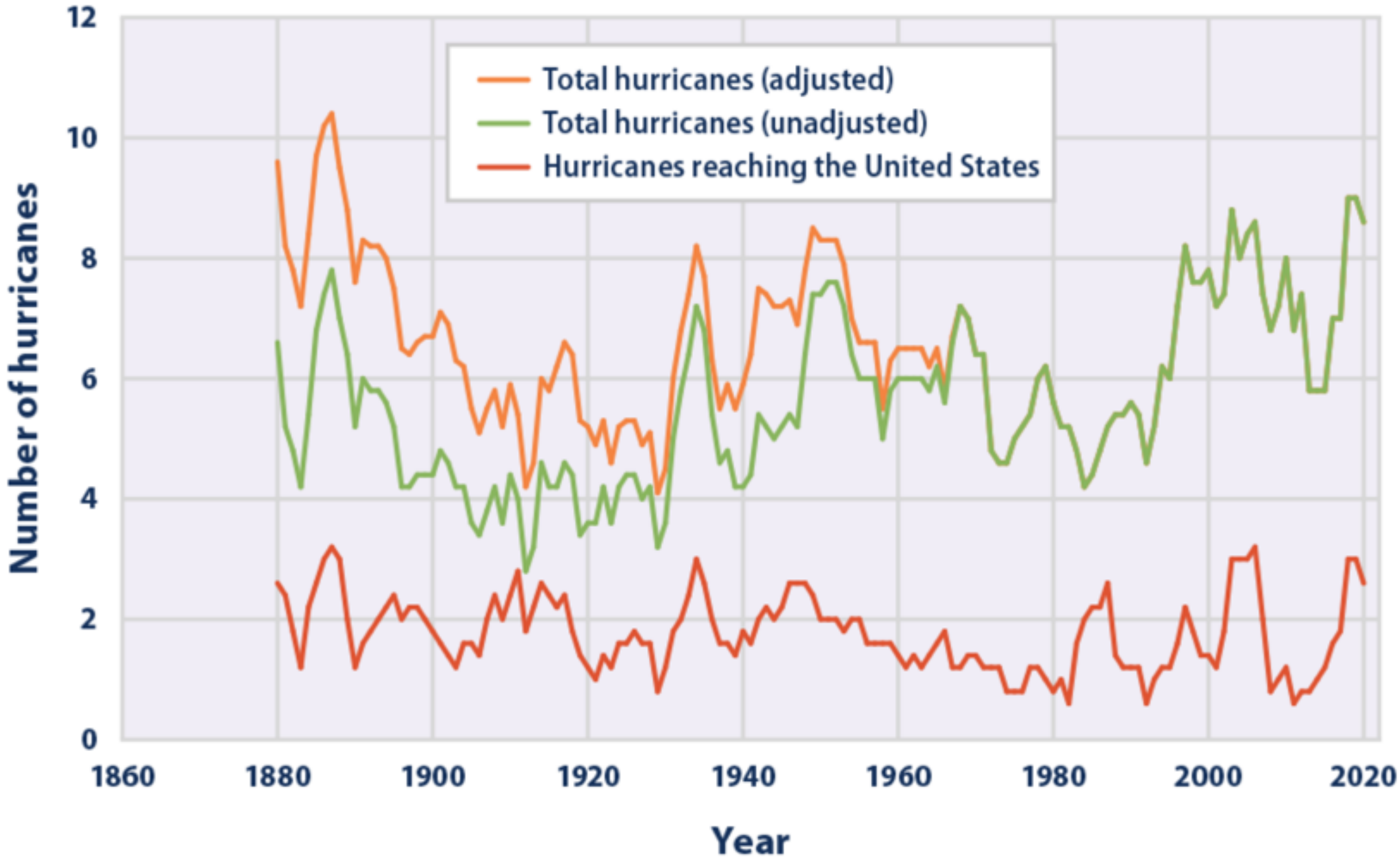


Bild 1: Jährliche Schadenssummen der verschiedenen Prozesse für die Periode 1972-2019 (teuerungsbereinigt, Basis 2019).



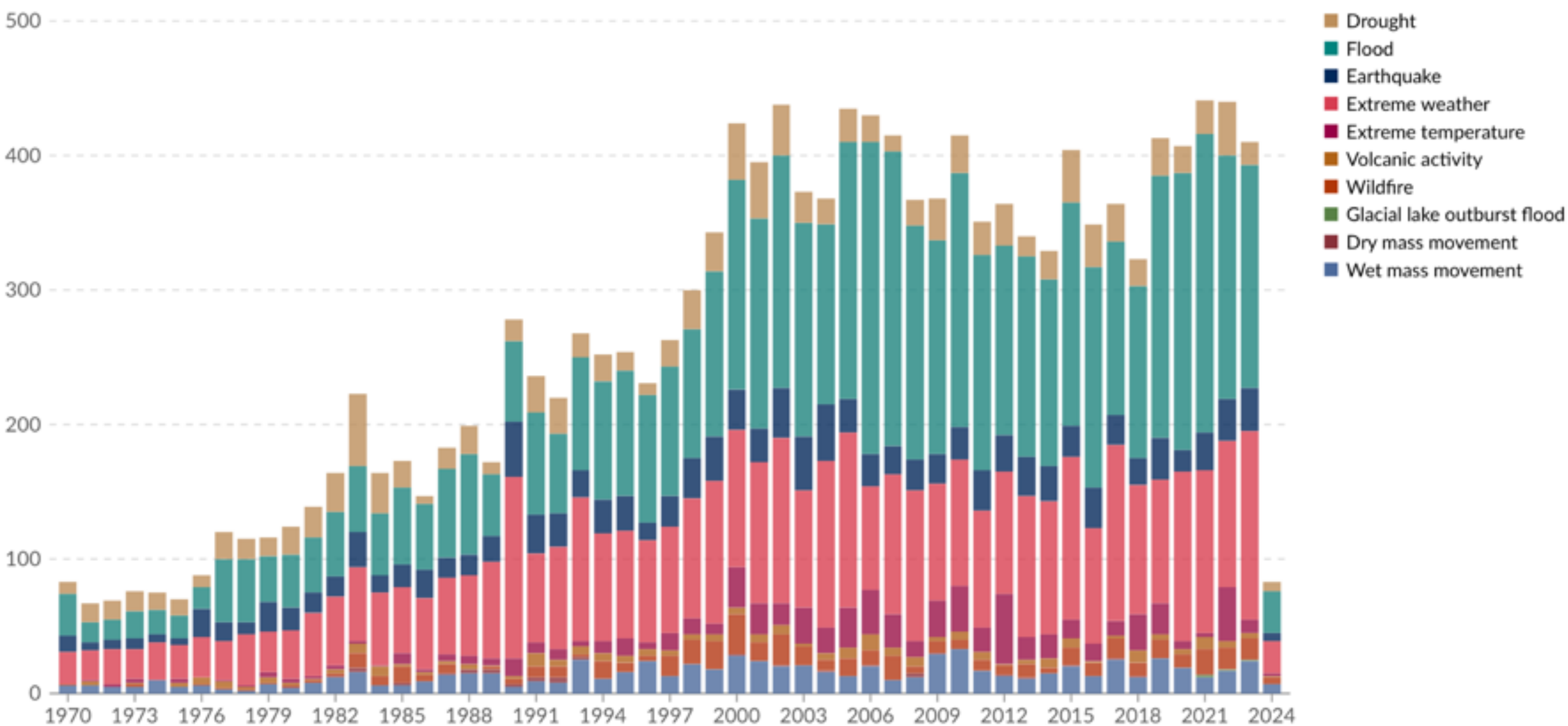
3.10.1. Hurricanes



Ref.: NOAA (National Oceanic and Atmospheric Administration). (2023). North Atlantic hurricane basin (1851–2022): Comparison of original and revised HURDAT. www.aoml.noaa.gov/hrd/hurdat/comparison_table.html
Vecchi, G. A., & Knutson, T. R. (2011). Estimating annual numbers of Atlantic hurricanes missing from the HURDAT database (1878–1965) using ship track density. Journal of Climate, 24(6), 1736–1746. https://doi.org/10.1175/2010JCLI3810.1

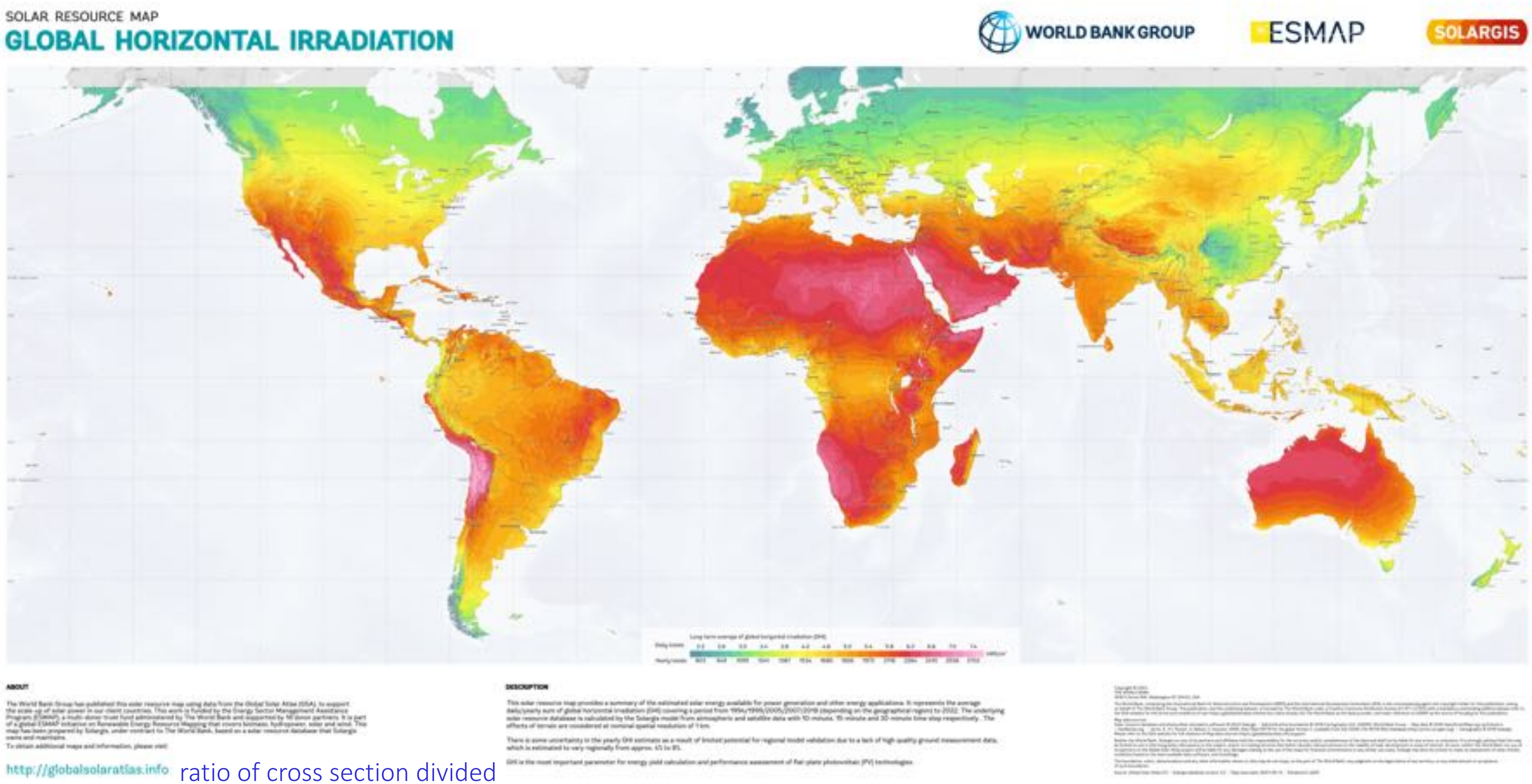
3.10.2. Global reported natural disasters by type, 1970 to 2024

The global reported natural disaster events in any given year. Note that this largely reflects increases in data reporting, and should not be used to assess the total number of events.



Ref.: Data source: EM-DAT, CRED / UCLouvain (2024) - Learn more about this data
Note: Data includes disasters recorded up to April 2024.
OurWorldinData.org/natural-disasters | CC BY

3.11. Global annual solar irradiation intensity

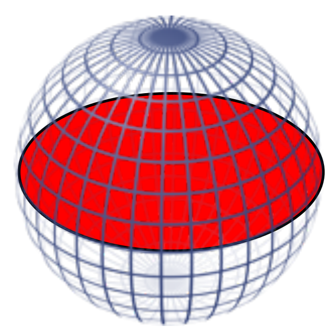


ratio of cross section divided by the surface area of a sphere

solar constant

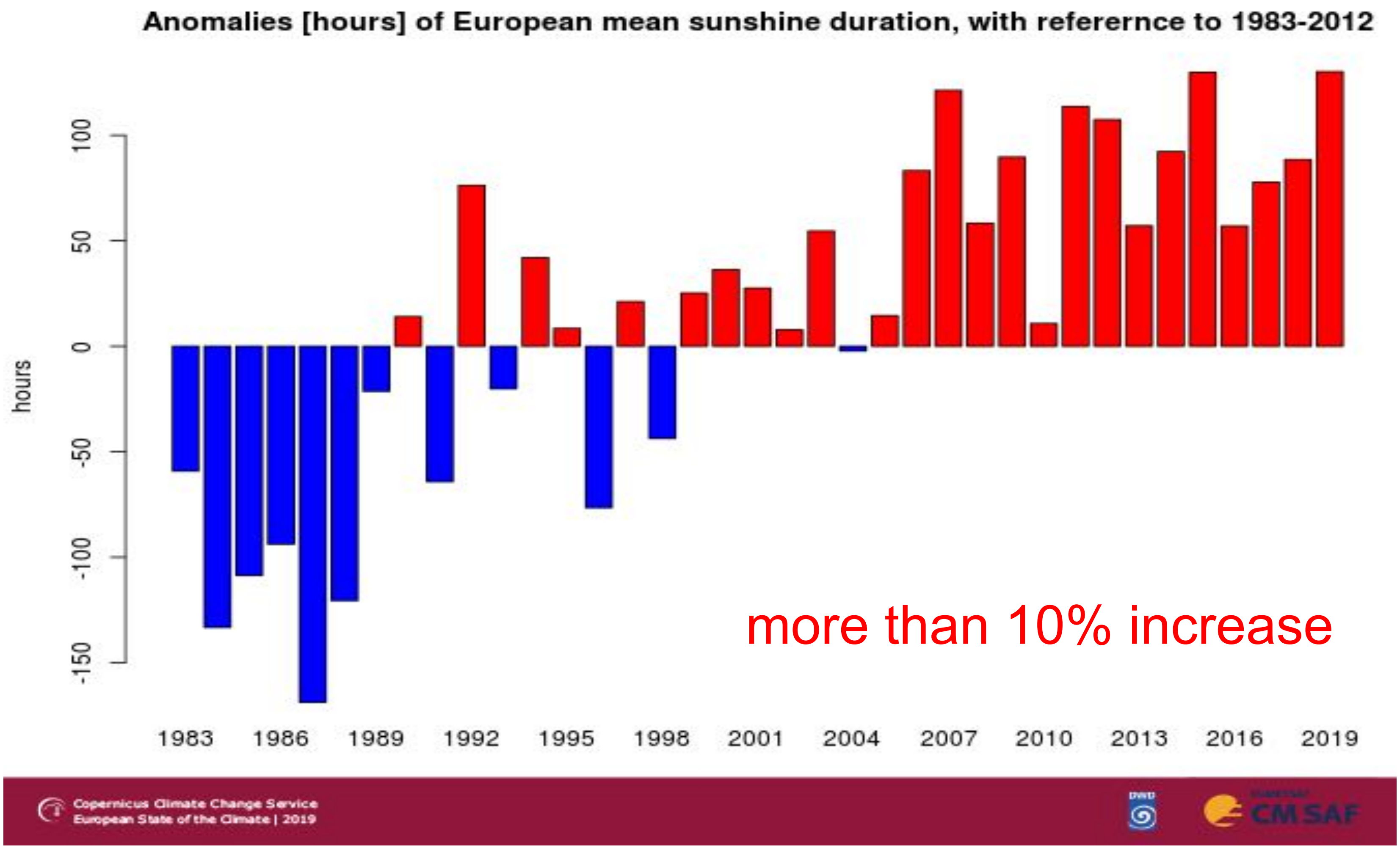
30% reflection

$$I = S/4 \cdot 0.7 \cdot 24h/d \cdot 365d = 1366\ W \cdot m^{-2}/4 \cdot 0.7 \cdot 24h/d \cdot 365d$$
$$= 2094\ kWh \cdot m^{-2}$$



Source: https://solargis.com/maps-and-gis-data/download/world

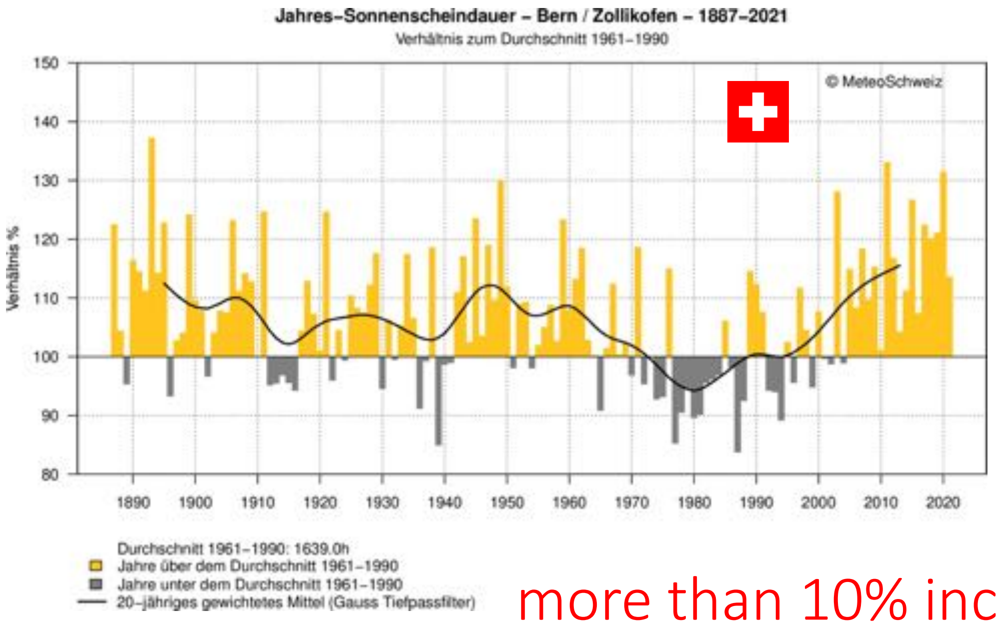
3.11.1. Sun shine hours in Europe

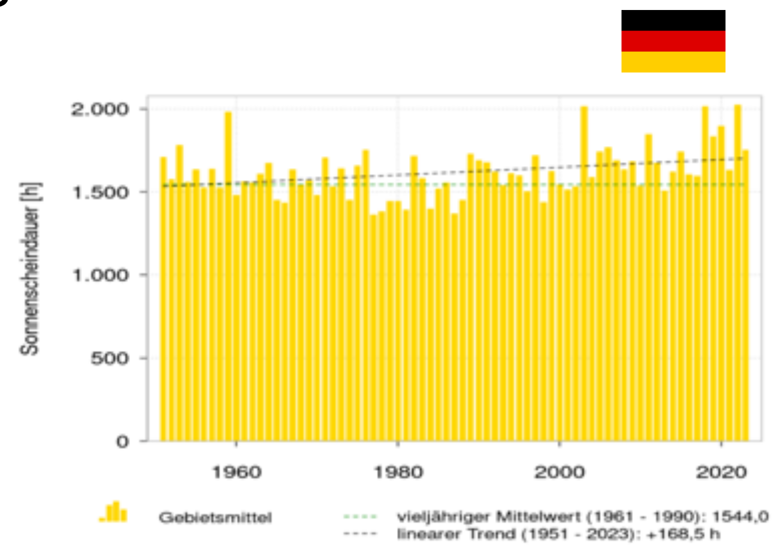


Annual average anomalies of sunshine duration (in hours) over Europe for 1983-2019 compared to the 1983-2012 reference period. For Europe, the geographical area is used as in the figure below. Data source: EUMETSAT CM SAF sunshine duration climate data record. Credit: Copernicus Climate Change Service (C3S)/EUMETSAT CM SAF/DWD.

Ref.: https://www.sciencenews.org/article/heat-record-june-july-water-climate
https://climate.copernicus.eu/ESOTC/2019/sunshine-duration-and-clouds

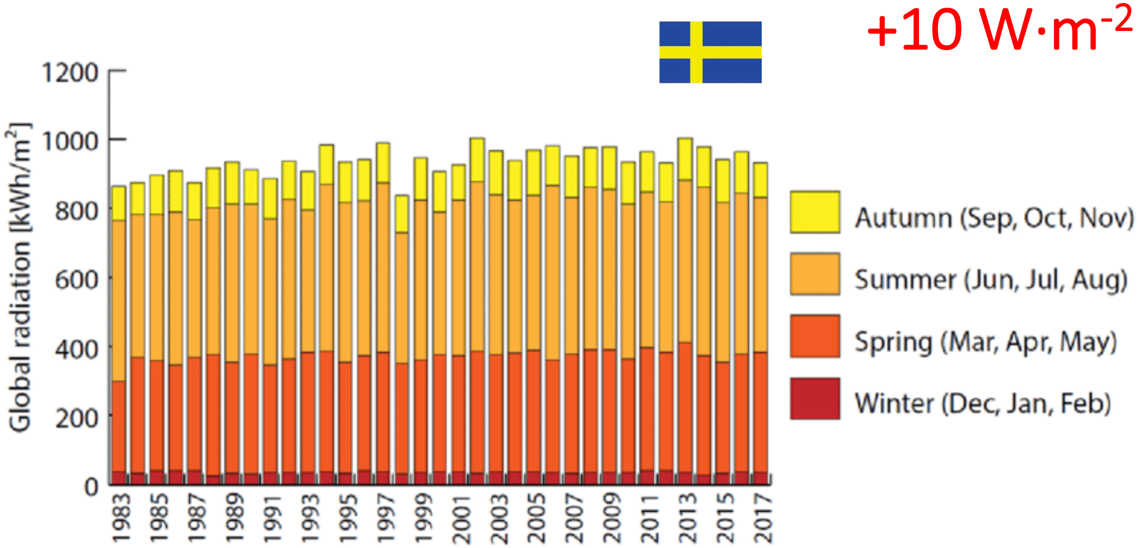
3.11.2. Sun shine hours in different regions





more than 10% increase

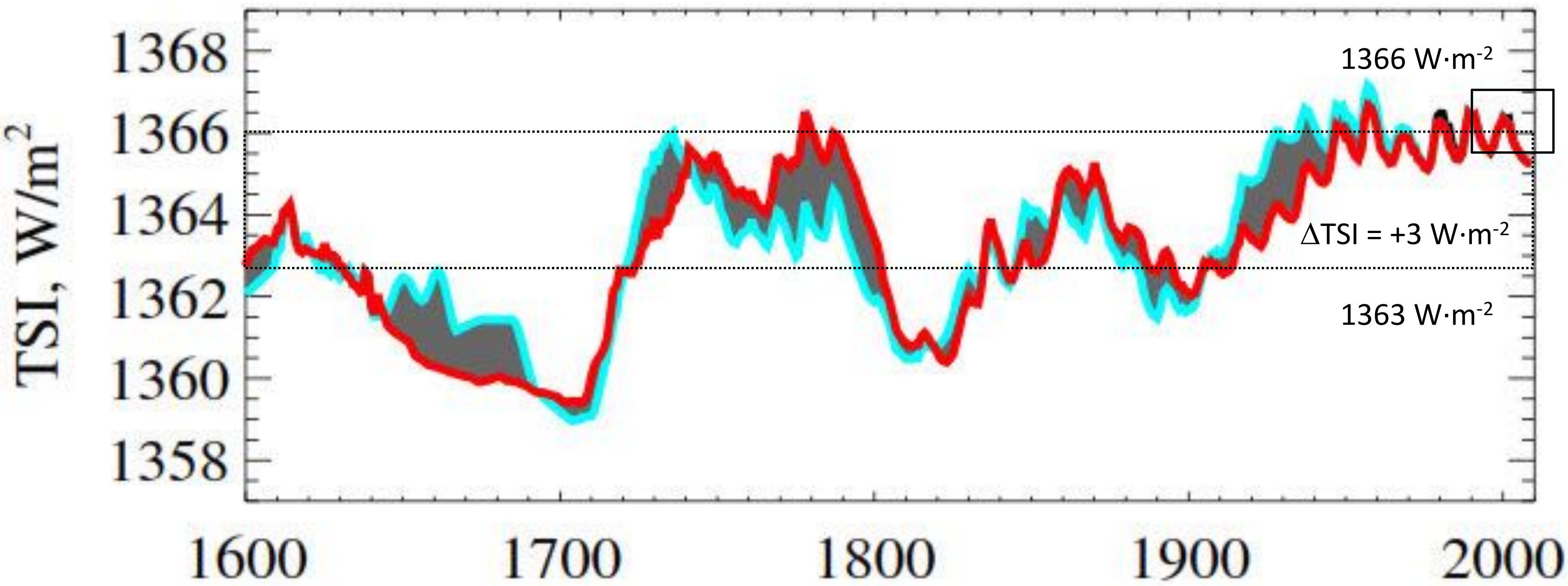
+10 W·m^{-2}

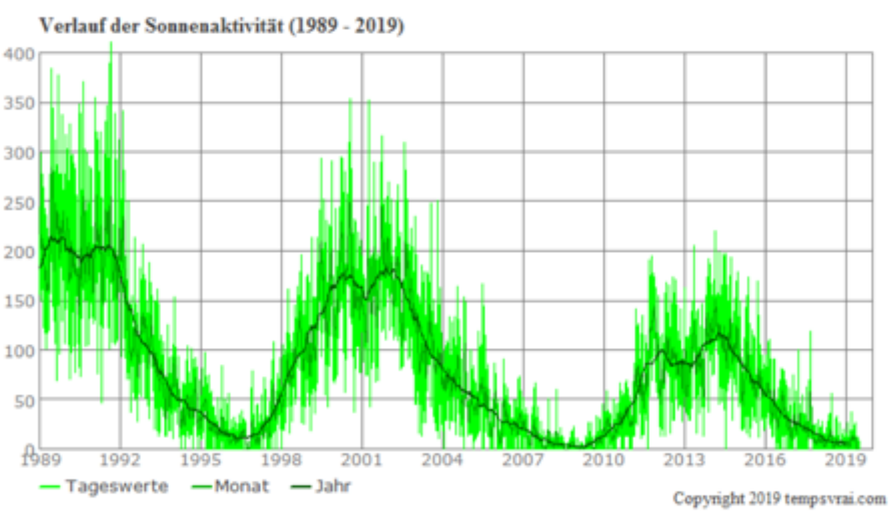


Source:
https://www.klimareporter.de/deutschland/deutschland-ueber-der-zwei-grad-grenze
Wild et al., 2005) (see the longest available SSR series of Stockholm, Sweden
Johan Lindahl, Cristina Stoltz, "National Survey Report of PV Power Applications in Sweden 2017", Report (), https://www.researchgate.net/publication/328197766; IEA PVPS Task1: Strategic PV Analysis & Outreach
MeteoSchweiz

400 years

3.11.3. Total solar irradiation (TSI)





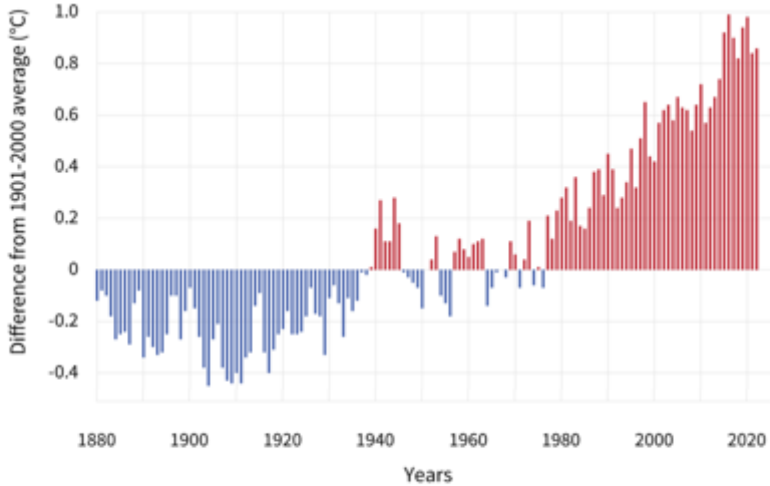
Ref.: A new approach to long-term reconstruction of the solar irradiance leads to large historical solar forcing (http://arxiv.org/PS_cache/arxiv/pdf/1102/1102.4763v1.pdf)

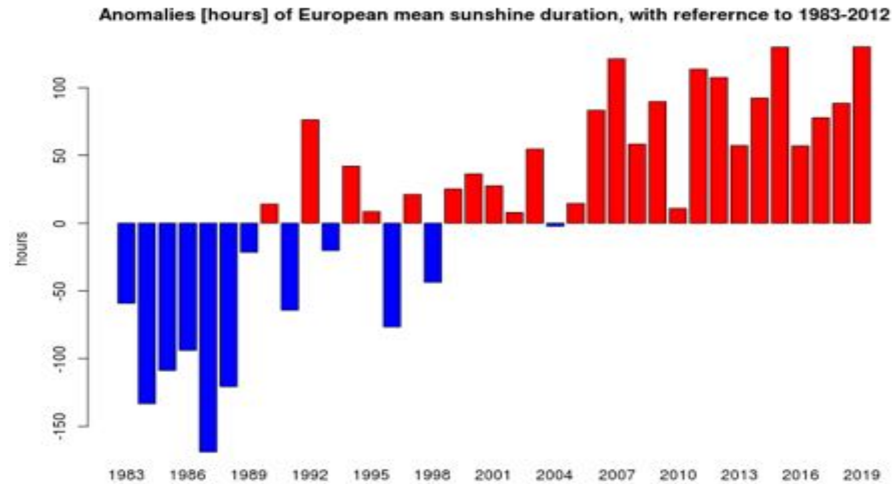
3.12. INTERPRETATION: Beginning of the climate crisis

Ref.: 10.08.**1986**, 13.00 Uhr • aus DER SPIEGEL 33/1986

Ref.: 04.11.**2022**, 13.00 Uhr • aus DER SPIEGEL 45/2022

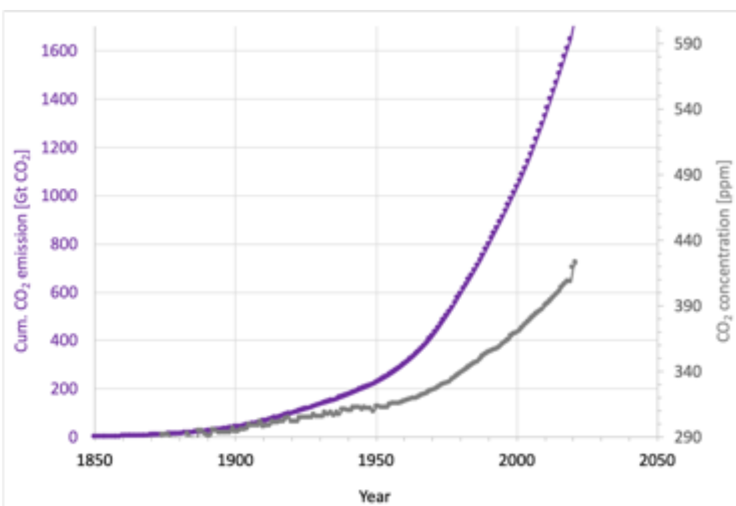
3.12.1. Observations 1/2

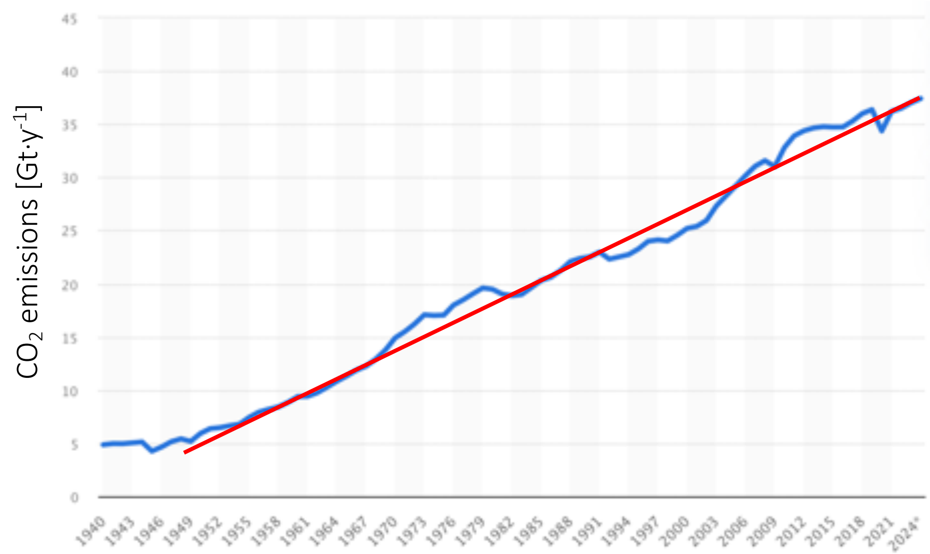




The global temperature increased since 1975 linearly ≈0.8°C in 50 years

The sun shine hours increased ≈10% in the last 40 years

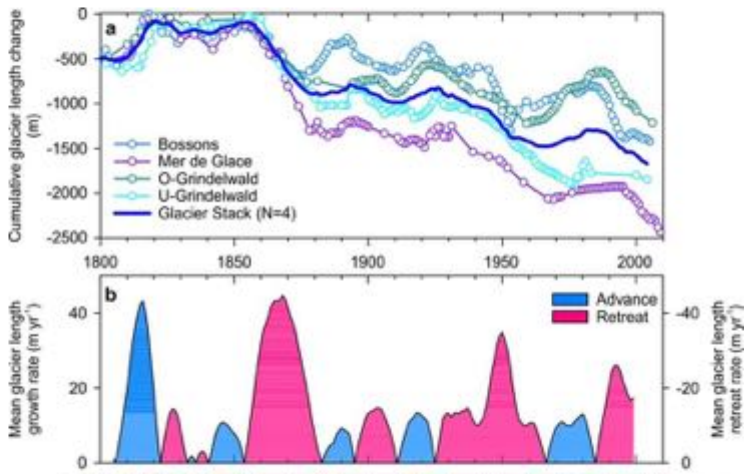


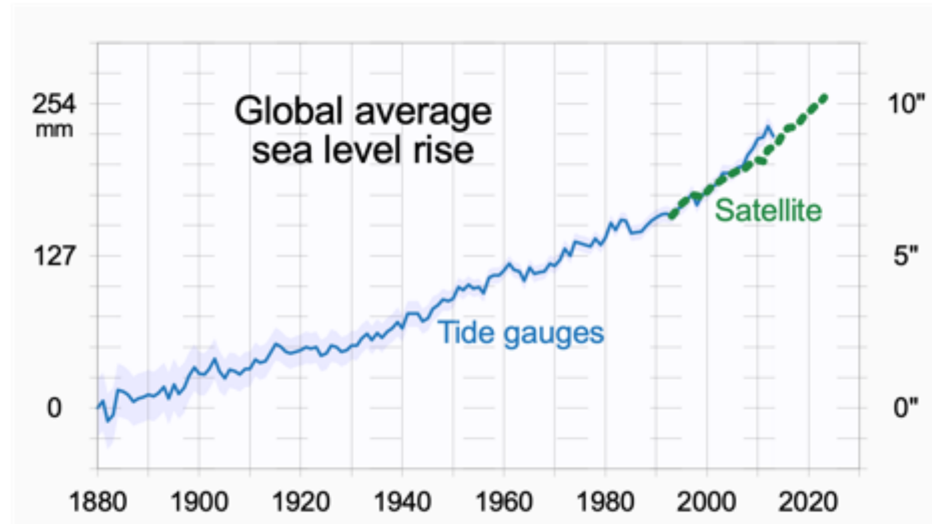


CO_2 concentration increasing proportional to the cumulated CO_2 emissions.

The CO_2 emissions from fossil fuels increase since 75 years by 0.44 $Gt{\cdot}y^{-2}$

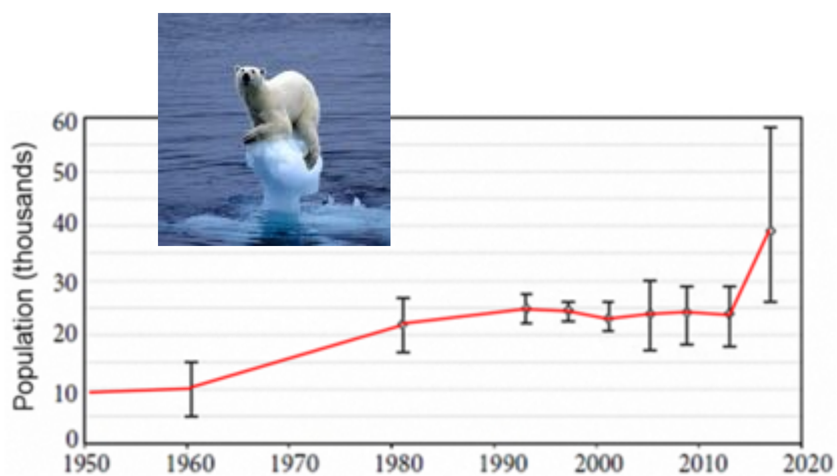
3.12.2. Observations 2/2

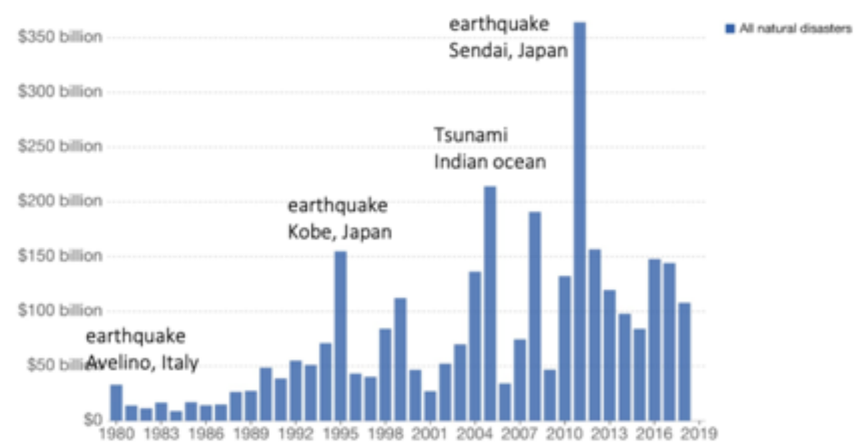




≈2/3 of the glacier retraction was observed before 1975

The sea level increased since 1975 ≈12 cm in 50 years continuing the trend from before





Polar bear population is growing

Less natural disasters in the last 20 years

3.12.3. CO_2 and climate change

"On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground"

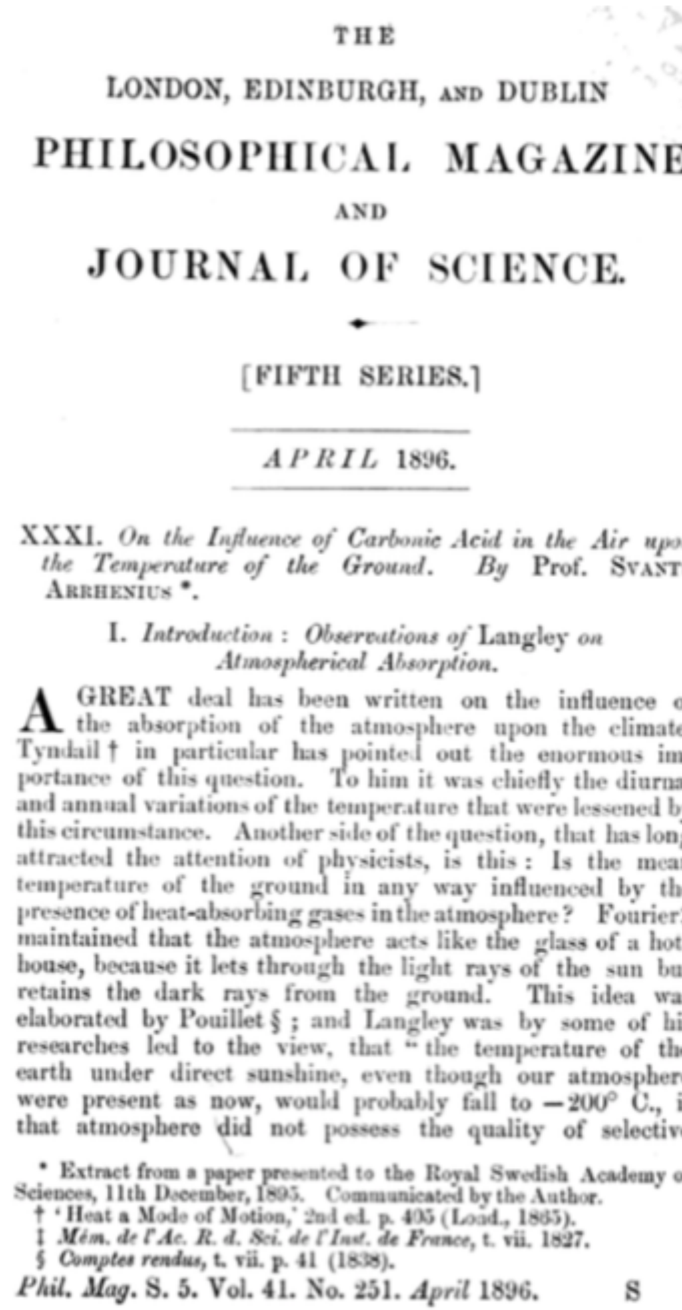
Philosophical Magazine 41, (1896), pp. 237-276

+5°C ± 2°C

Svante Arrhenius (1859-1927)

Arrhenius's paper is the first to quantify the contribution of carbon dioxide to the greenhouse effect (Sections I-IV) and to speculate about whether variations in the atmospheric concentration of carbon dioxide have contributed to long-term variations in climate (Section V). Throughout this paper, Arrhenius refers to carbon dioxide as "carbonic acid" in accordance with the convention at the time he was writing.

Contrary to some misunderstandings, Arrhenius does not explicitly suggest in this paper that the burning of fossil fuels will cause global warming, though it is clear that he is aware that fossil fuels are a potentially significant source of carbon dioxide (page 270), and he does explicitly suggest this outcome in later work.



THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* *By* Prof. SVANTE ARRHENIUS *.

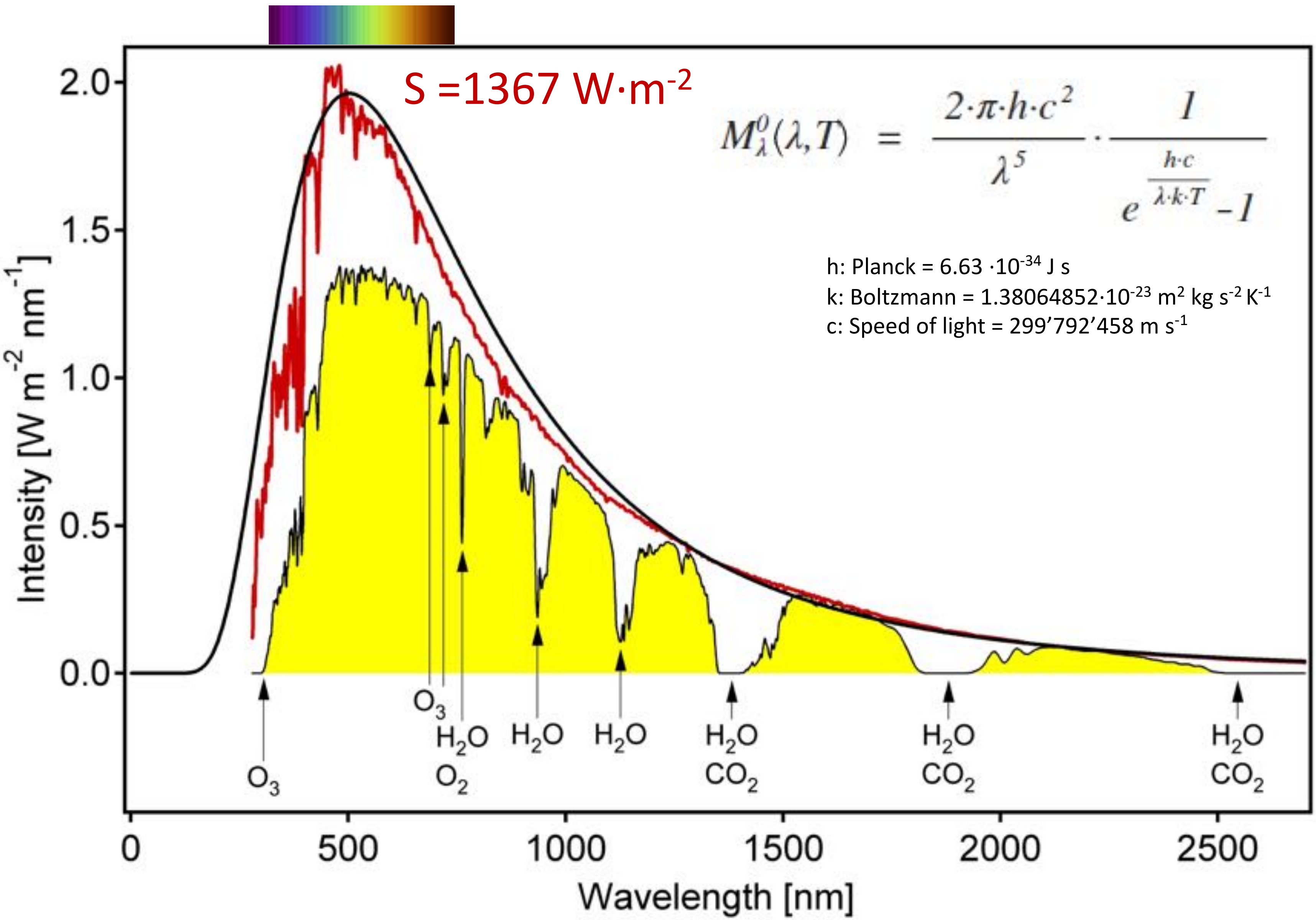
I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier ‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.
† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond., 1865).
‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
§ *Comptes rendus*, t. vii. p. 41 (1838).

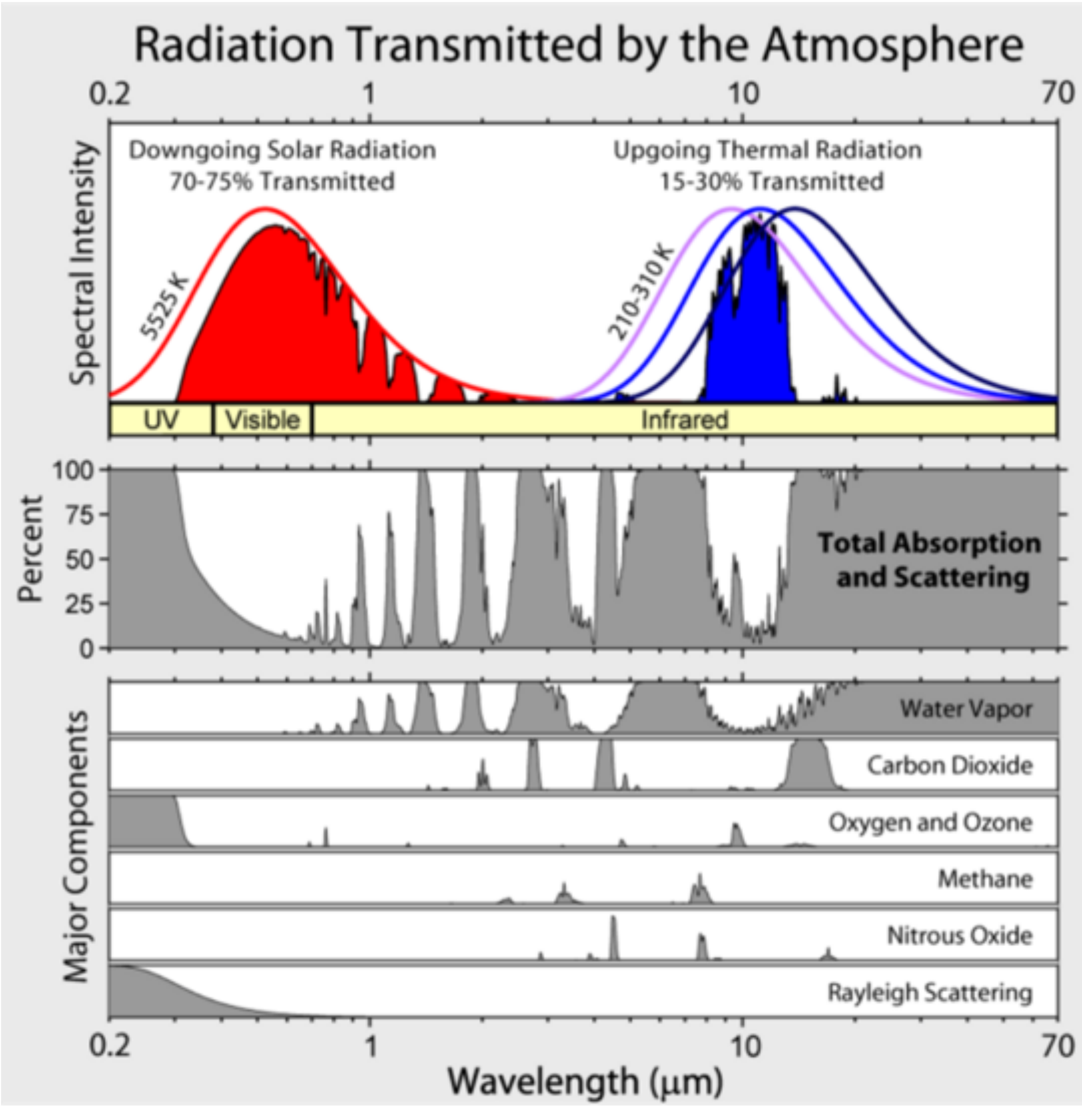
Phil. Mag. S. 5. Vol. 41. No. 251. *April* 1896. S

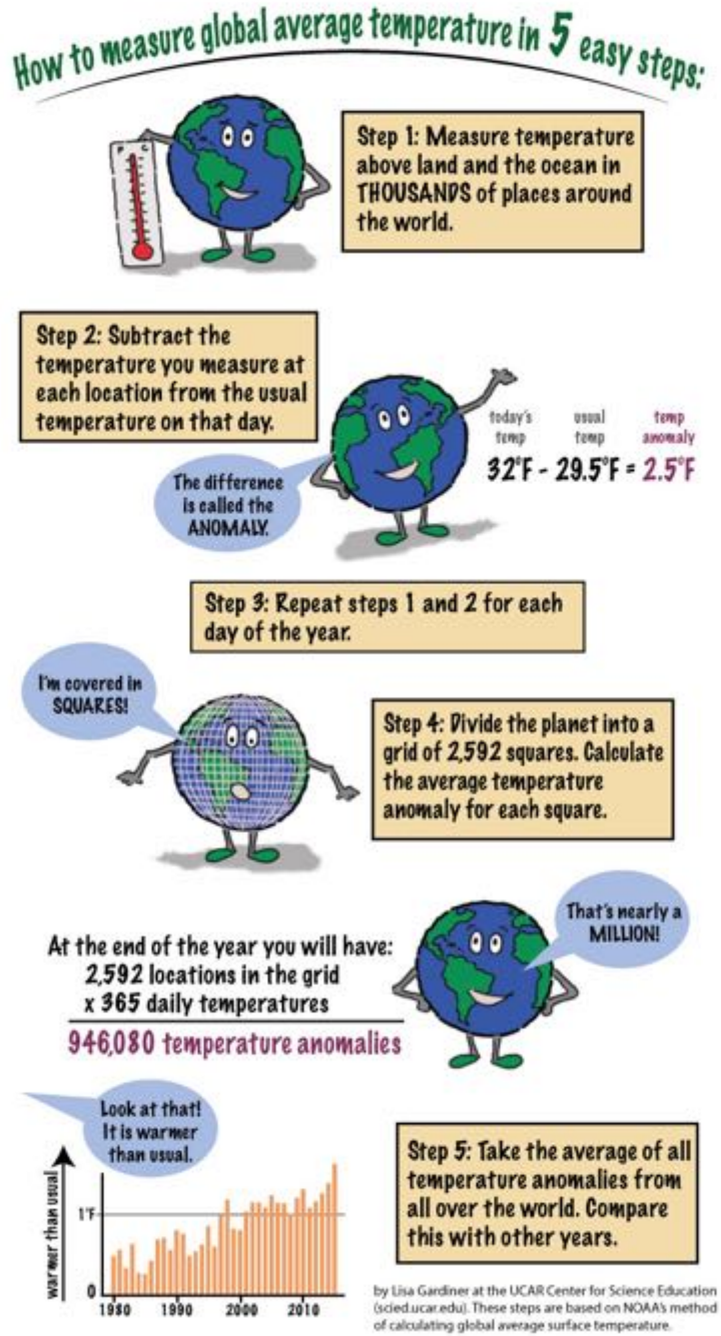
3.12.4. Solar irradiation and absorption bands



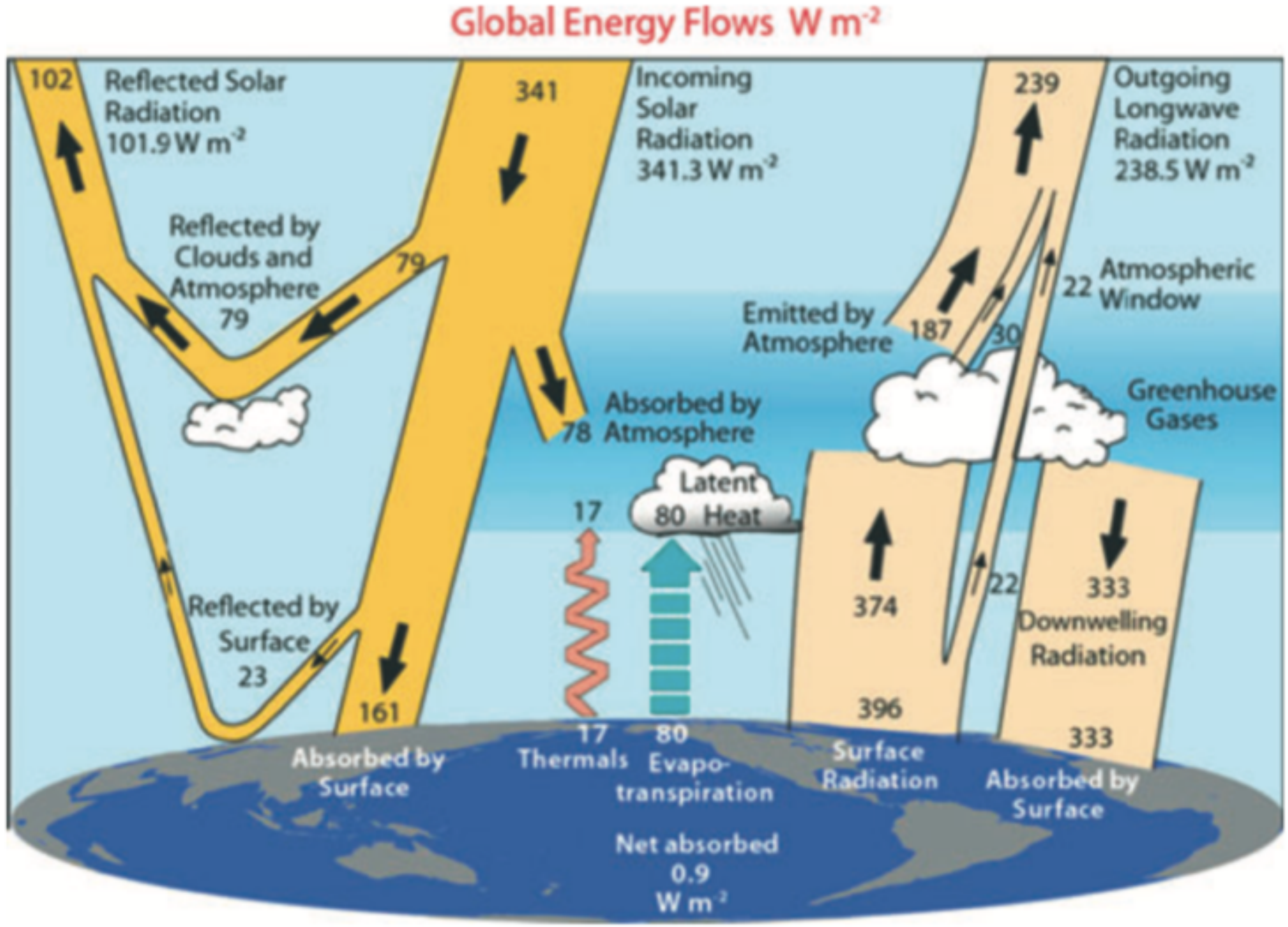
https://compass.astm.org/download/G173.37383.pdf

3.12.5. Radiation transmission





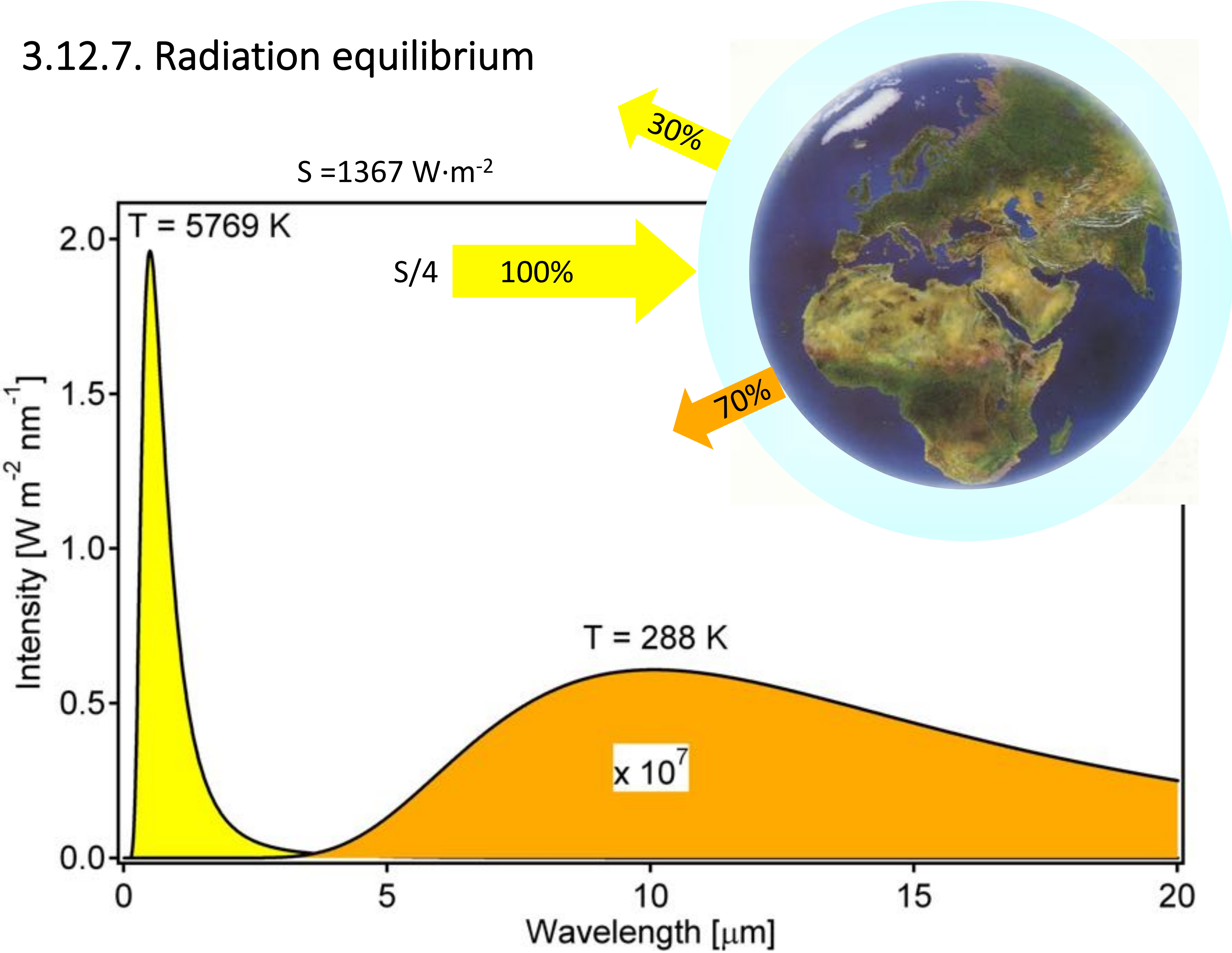
3.12.6. Radiation absorption and reflection



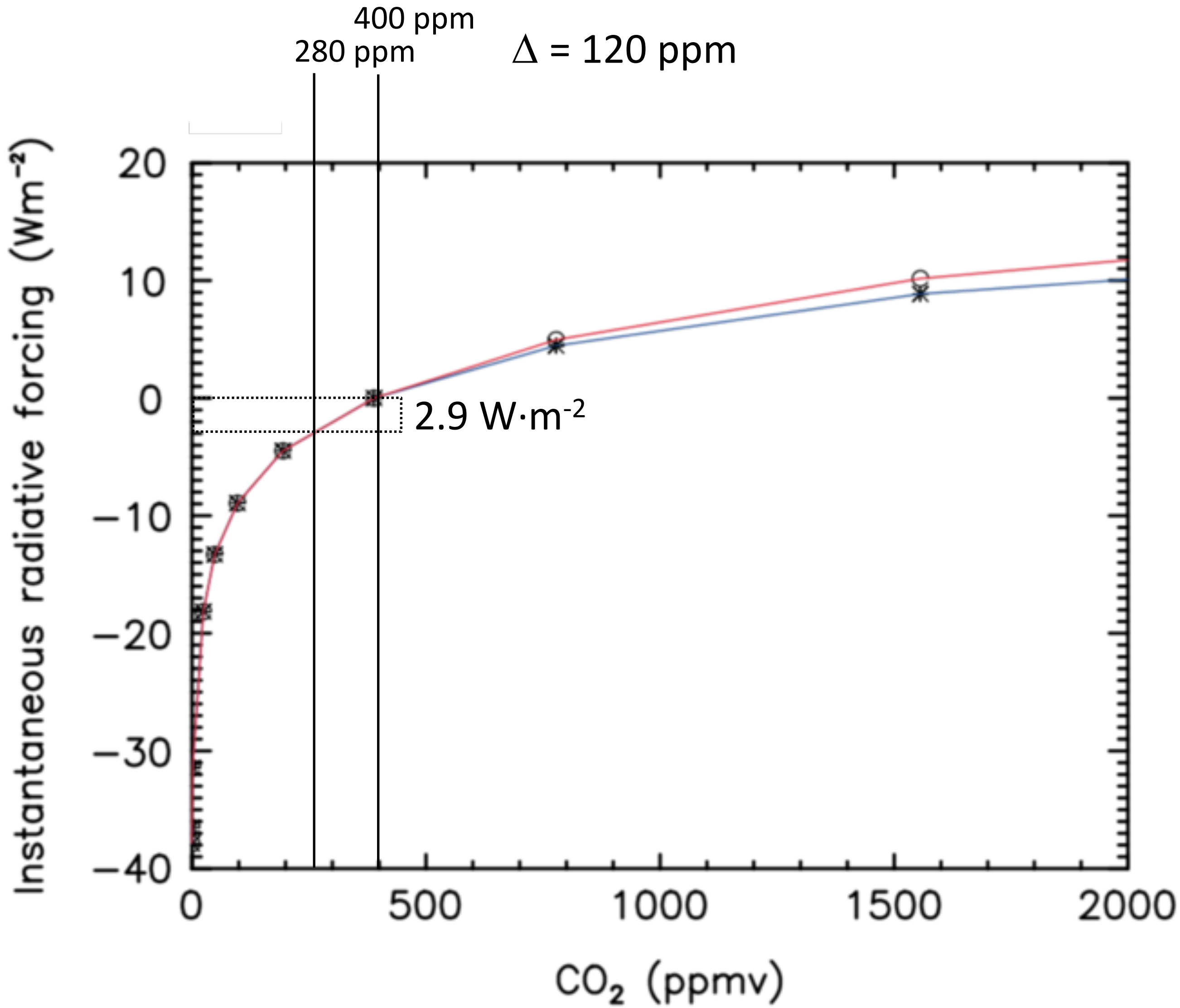
The global annual mean energy budget of Earth's climate system

Ref.: Trenberth KE, Fasullo JT, "Tracking earth's energy: from El Nino to global warming". Surv. Geophys. 33 (2012), pp 413 - 426. doi:10.1007/s10712-011-9150-2 and Trenberth, K.E., Fasullo, J.T., Kiehl, J., 2009, Earth's global energy budget, Bulletin of the American Meteorological Society, 90, 311-324, doi.org/10.1175/200BAMS2634.1.

3.12.7. Radiation equilibrium



3.12.8. Radiative forcing

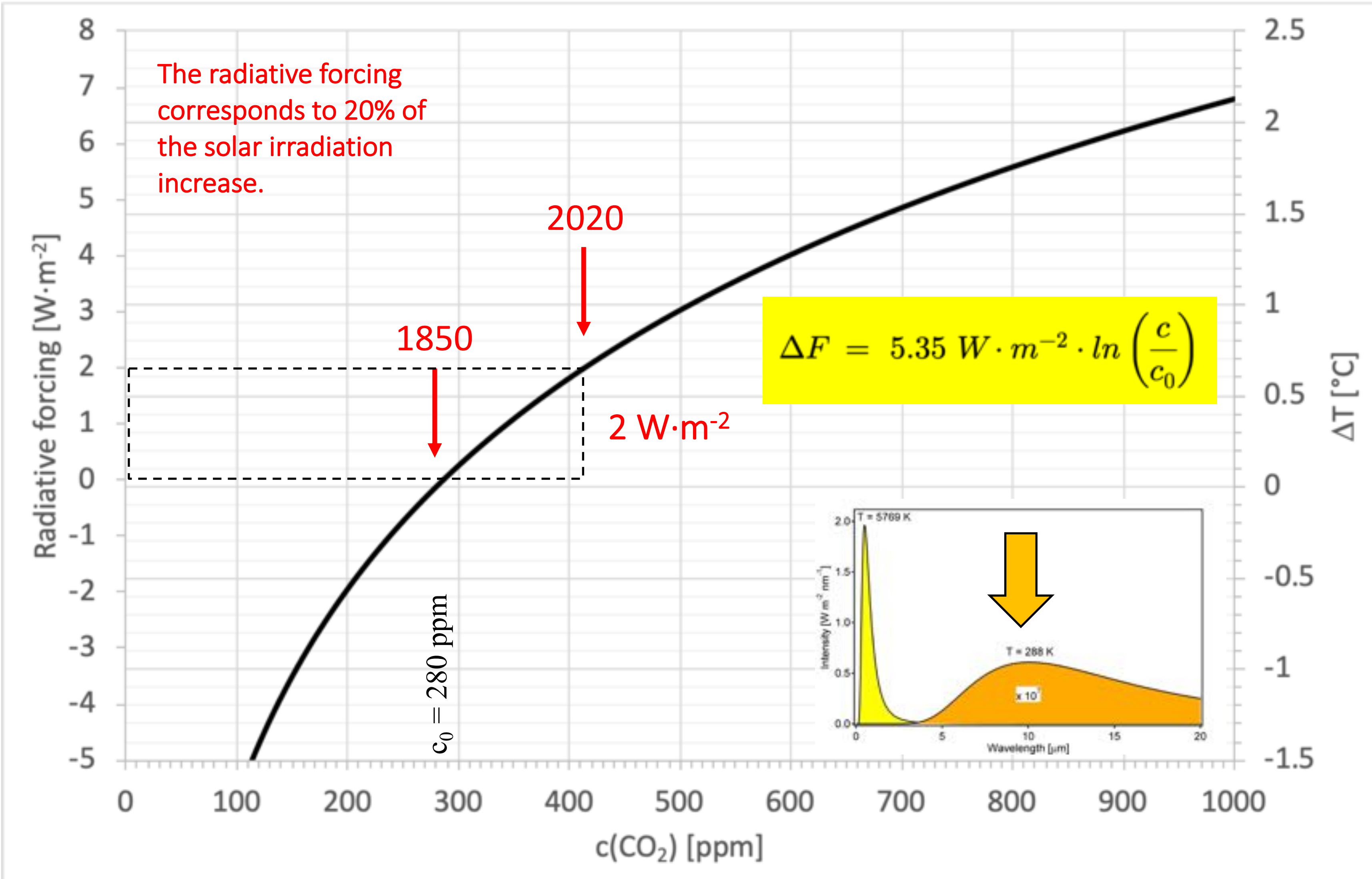


Ref.: Trenberth KE, Fasullo JT, "Tracking earth's energy: from El Nino to global warming". *Surv. Geophys.* **33** (2012), pp 413 - 426. doi:10.1007/s10712-011-9150-2

Instantaneous Radiative Forcing of CO_2 (relative to the present-day concentration) as a function of volume mixing ratio. The red curve is for the whole infrared region, 0–3000cm^{-1}. The blue curve covers only the spectral region 550–800cm^{-1} (i.e. the 15µm band).

3.12.9. Radiative forcing and temperature

$$\Delta T = 0.31 \frac{^{\circ}C}{W \cdot m^{-2}} \cdot \Delta F$$

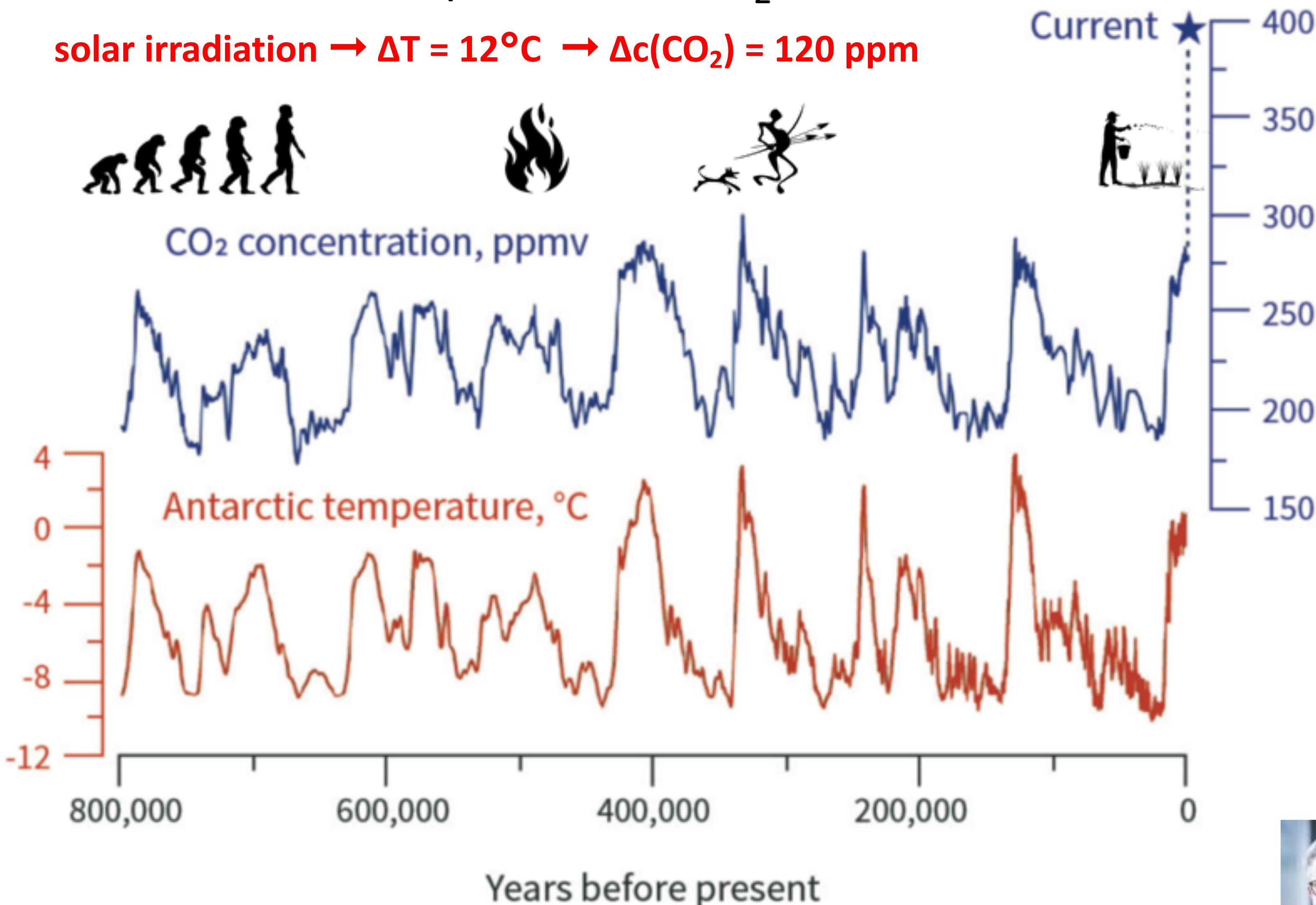


Ref.: http://www.globalwarmingequation.info/global%20warming%20eqn.pdf and Myhre, G., Highwood, E.J., Shine, K.P., and Stordal, F. “New estimates of radiative forcing due to well mixed greenhouse gases.” Geophys. Res. Lett. 25 (1998): 2715- 2718.

800'000 years

3.12.10. Historical temperature & CO_2 concentration

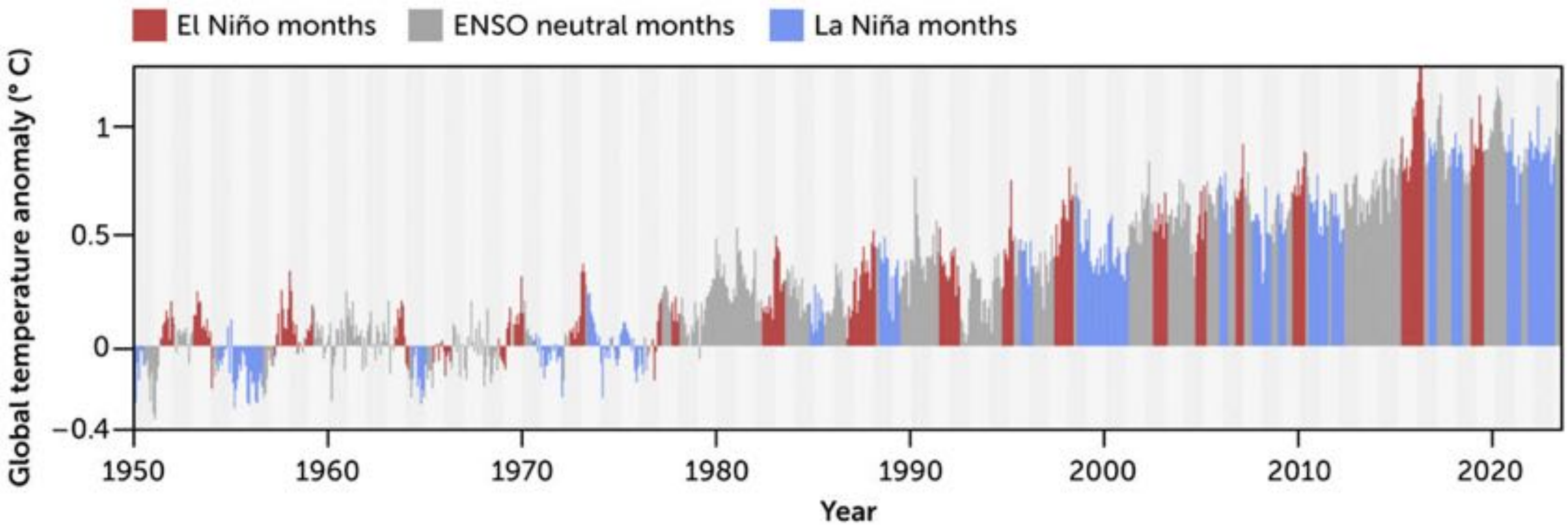
solar irradiation → ΔT = 12°C → Δc(CO_2) = 120 ppm



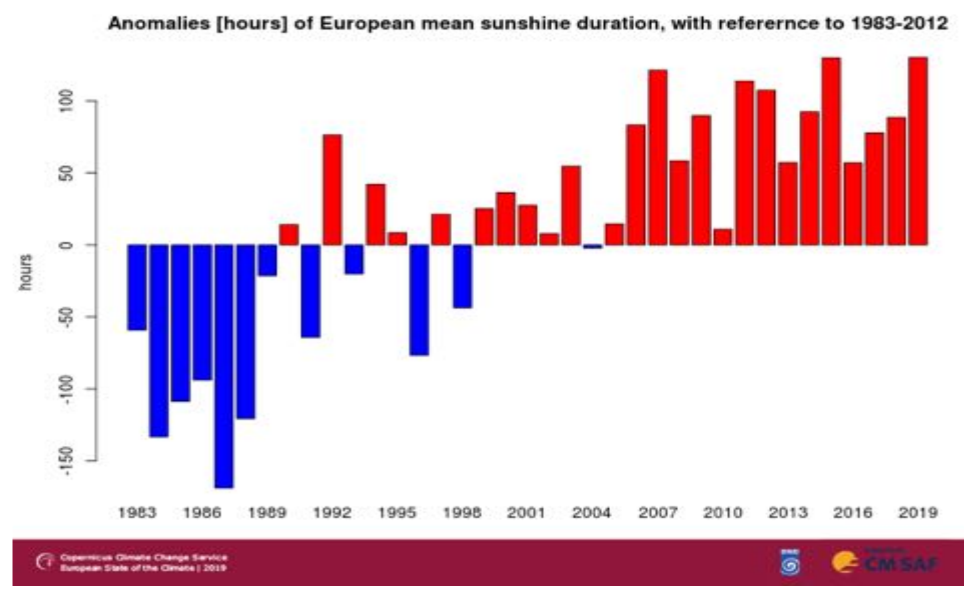
Thomas F. Stocker

Ref.: J. Jouzel et al., "Orbital and Millennial Antarctic Climate Variability over the Past 800,000 Years", Science 317:5839 (2007), pp. 793-796; Dieter Lüthi et al., "High-resolution carbon dioxide concentration record 650,000–800,000 years before present", Nature 453,(2008), pp. 379 – 382

3.13. Global temperature Anomaly



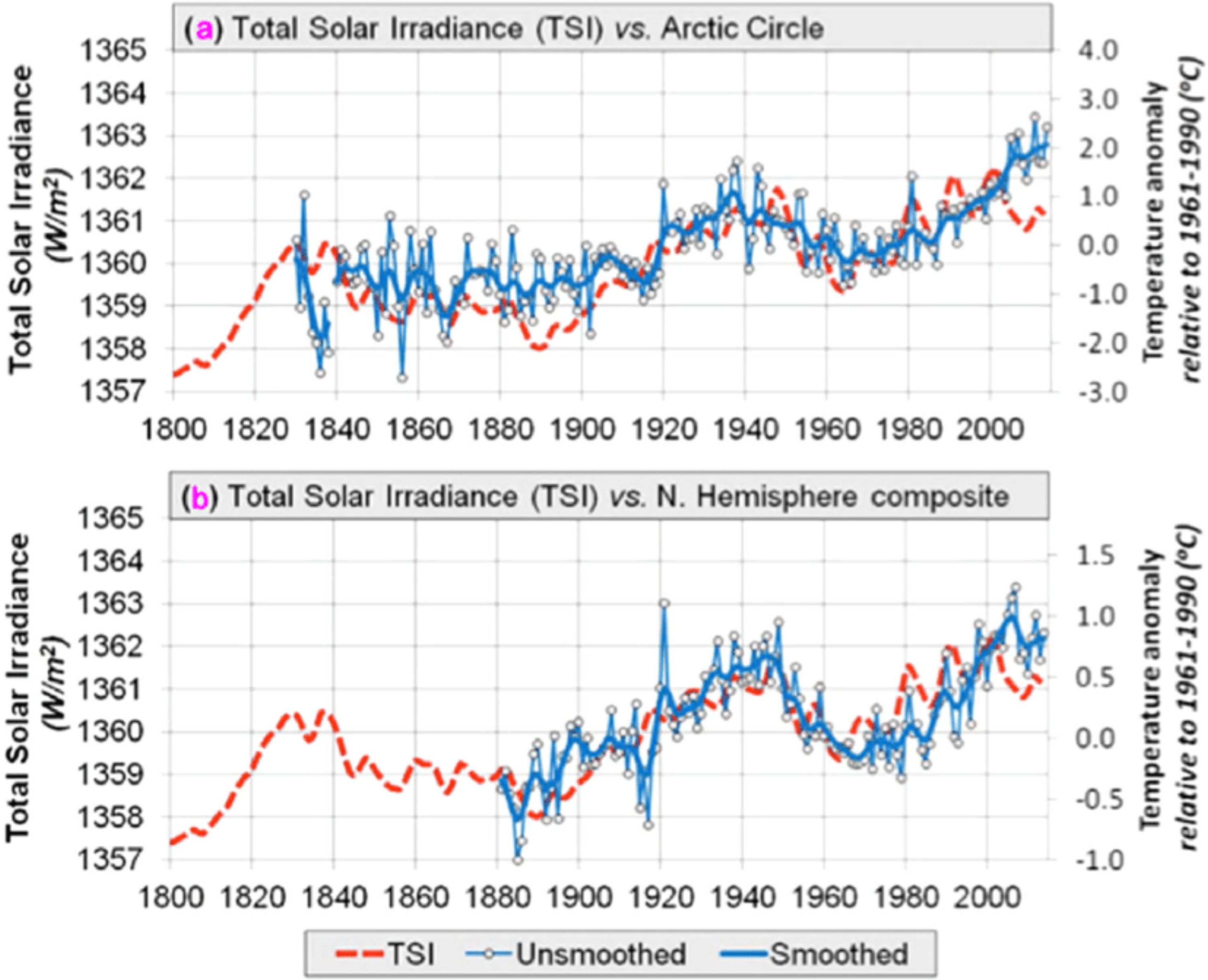
Annual average anomalies of sunshine duration (in hours) over Europe for 1983-2019 compared to the 1983-2012 reference period. For Europe, the geographical area is used as in the figure below. Data source: EUMETSAT CM SAF sunshine duration climate data record. Credit: Copernicus Climate Change Service (C3S)/EUMETSAT CM SAF/DWD.



sun shine hours correlate with temperature

Ref.: https://www.sciencenews.org/article/heat-record-june-july-water-climate
https://climate.copernicus.eu/ESOTC/2019/sunshine-duration-and-clouds

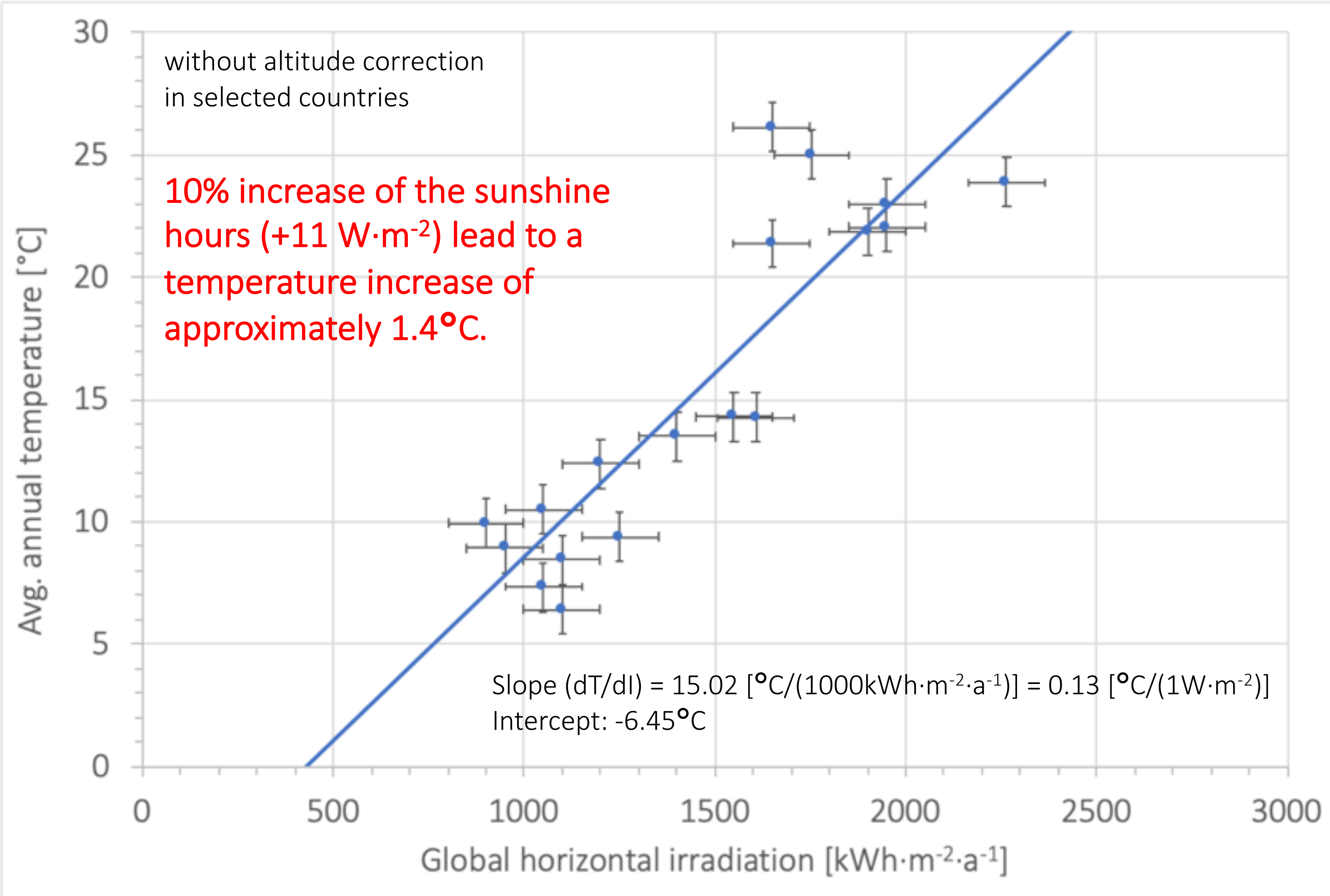
3.13.1. Total solar irradiance on northern hemisphere



1850 – 2020
+2 W·m^{-2} , +2°C

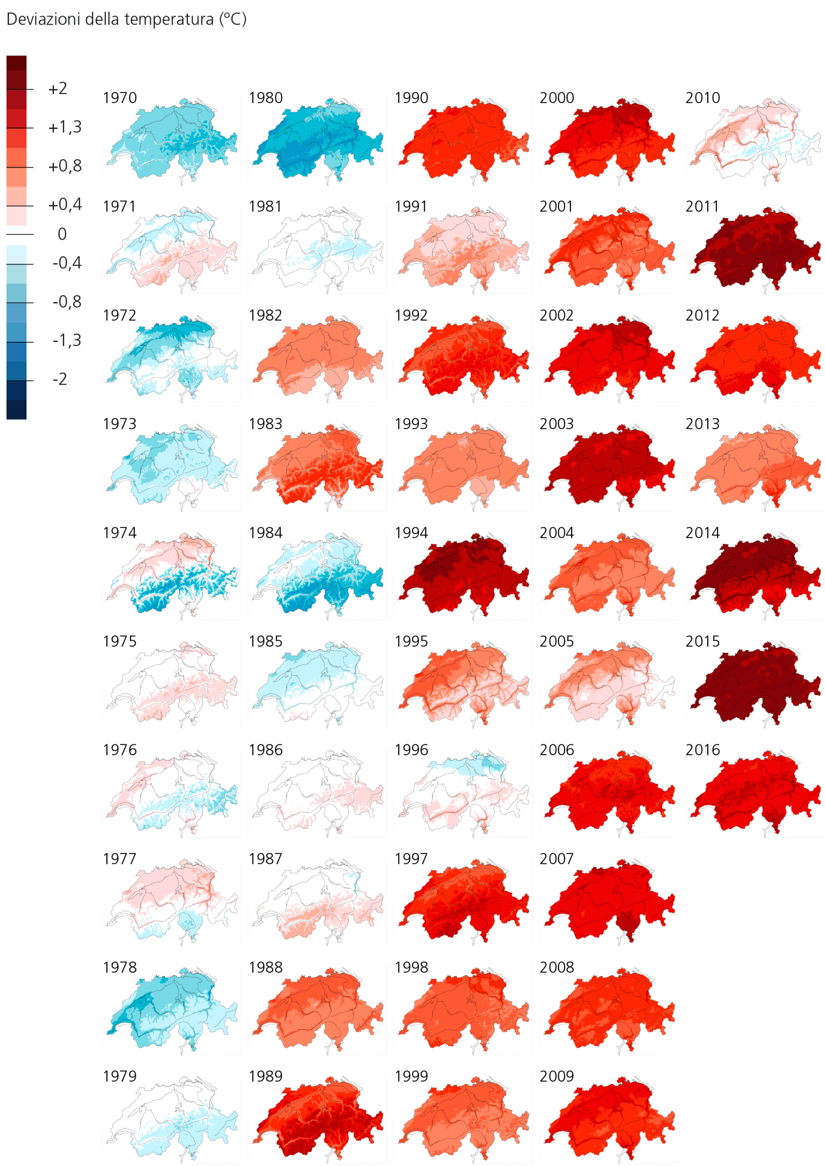
1850 – 2020
+2 W·m^{-2} , +1.2°C

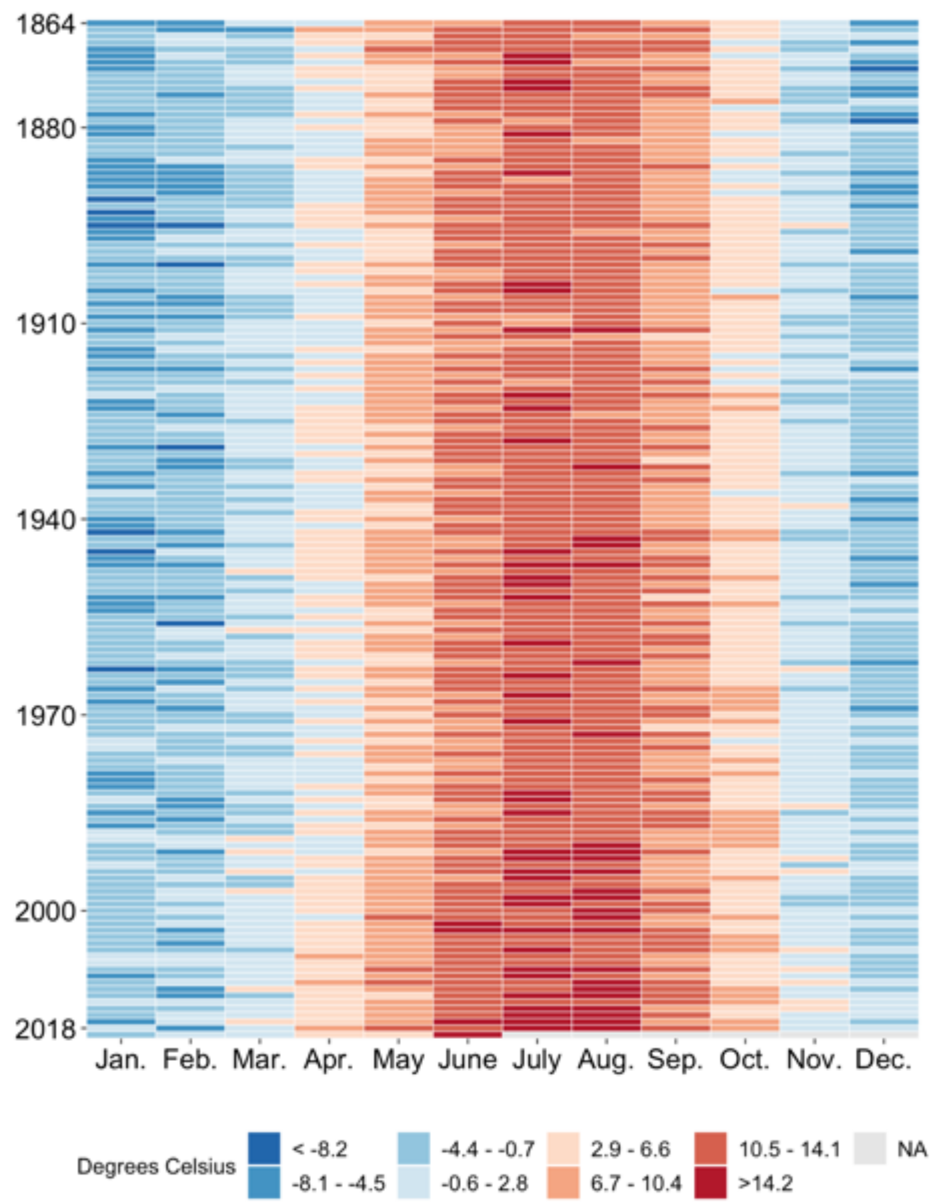
3.13.2. Average annual temperature vs. horizontal irradiation



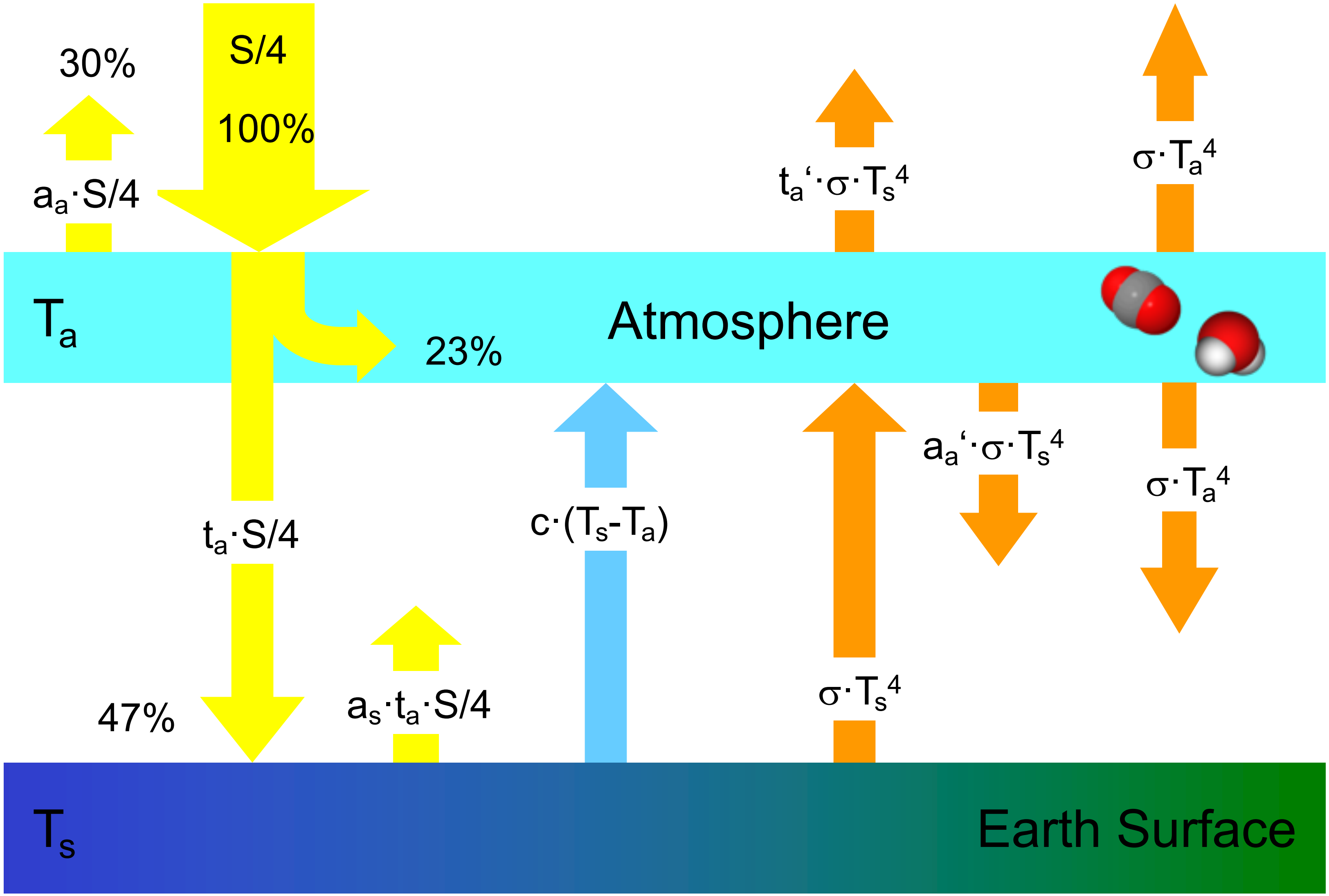
Source: https://solargis.com/maps-and-gis-data/download/world

3.13.3. Temperature in Switzerland





3.14. Greenhouse gas model



3.14.1. Detailed greenhouse gas model

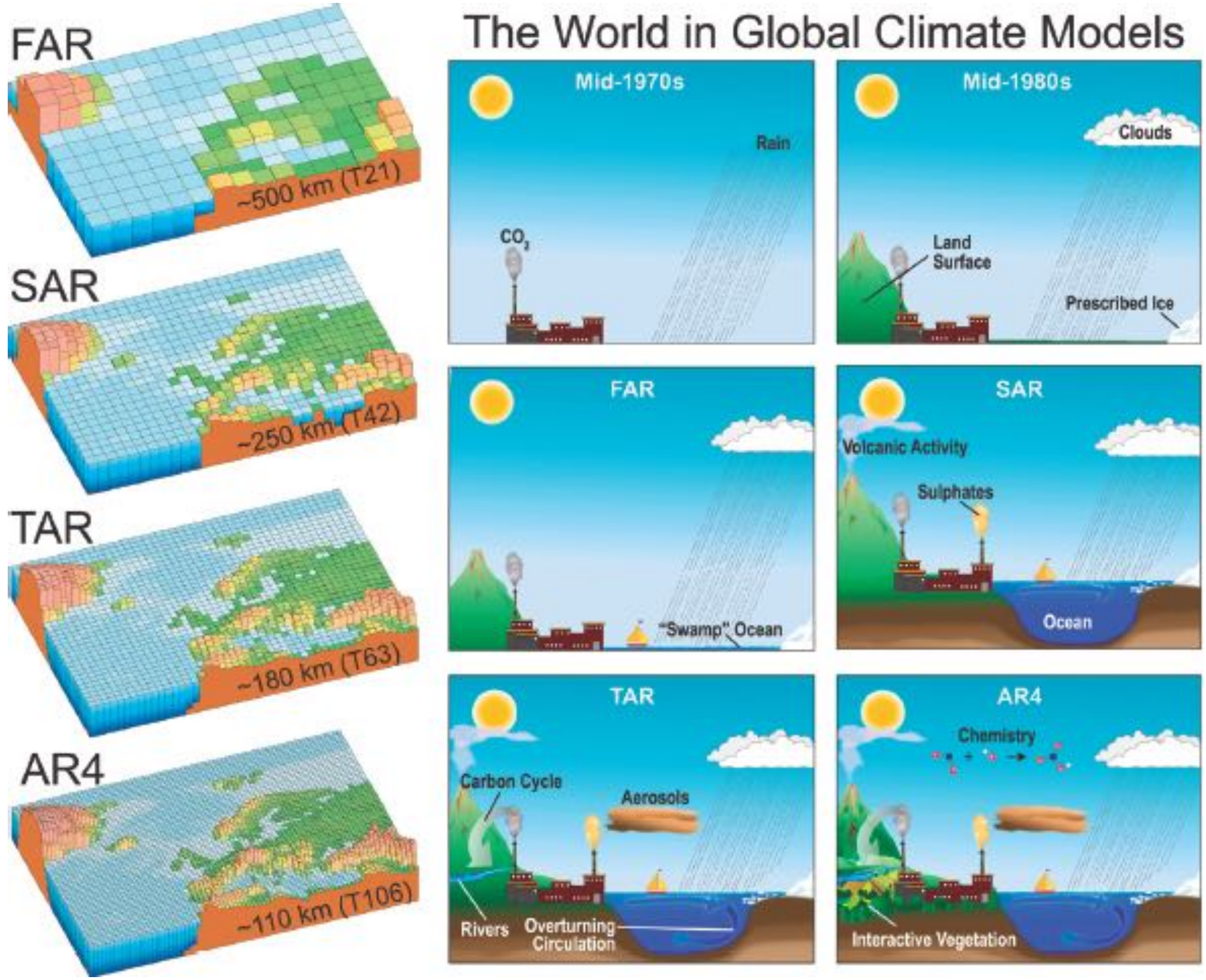


Illustration of increasing complexity and diversity of elements incorporated into common models used in the Intergovernmental Panel on Climate Change (IPCC) process over the decades. Evolution of the resolution (left side) and physical complexity (right side) of climate models used to inform IPCC reports from the mid-1970s to the most recent IPCC report (IPCC, 2007a,b,c). The illustrations (left) are representative of the most detailed horizontal resolution used for short-term climate simulations. SOURCES: Figure 1.2 and 1.4 from IPCC (2007c). FAR, First Assessment Report, 1990; SAR, Second Assessment Report, 1995; TAR, Third Assessment Report, 2001; AR4, Fourth Assessment Report, 2007.
Berend Smit et al., "Introduction to Carbon Capture and sequestration", The Berkley Lectures on Energy – Vol. 1, (2014), Imperial College Press.

3.14.2. Temperature on earth without atmosphere

Stefan-Boltzmann with an Albedo of 0.3 (30% of the incoming Intensity is reflected

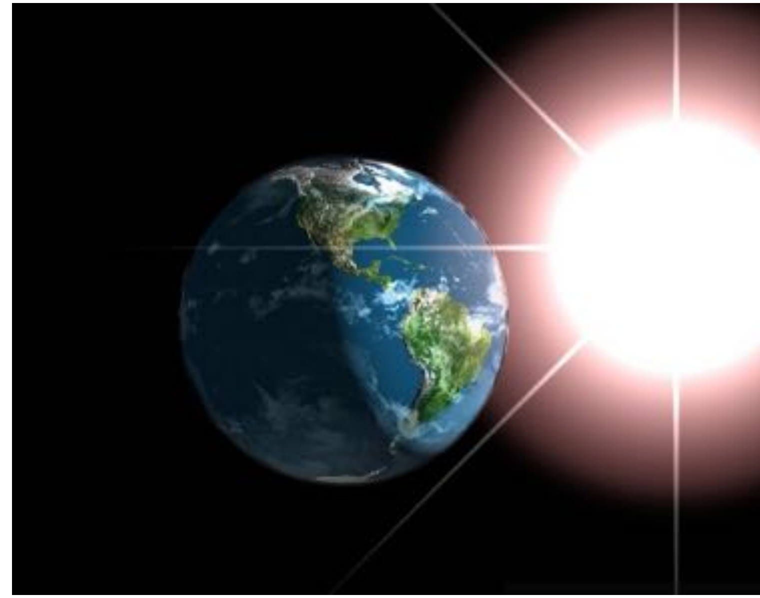
$$P = A \cdot \sigma \cdot T^4$$

$$(1 - 0.3) \cdot \frac{P}{4 \cdot A} = \sigma \cdot T^4$$

$$T = \sqrt[4]{\frac{0.7 \cdot P}{4 \cdot \sigma \cdot A}}$$

$$T = \sqrt[4]{\frac{0.7 \cdot 1369\, W \cdot m^{-2}}{4 \cdot 5.67 \cdot 10^{-8}\ W \cdot m^{-2} \cdot K^{-4}}} = 254.9 K = -18°C$$

Temperature on earth without an atmosphere.



Solar constant: S = 1369 W/m^2 irradiates $\boldsymbol{\pi} \cdot R^2$ and is distributed on $4 \cdot \boldsymbol{\pi} \cdot R^2$

3.14.3. Radiative forcing of greenhouse gases

The total global warming of all of the greenhouse gases (GHG) of 324 W m^{-2} causes a temperature increase of 33°C from -18 °C (255K), the earth's temperature with no GHG, to the current average temperature of +15°C (288K)
Therefore, the temperature increase by radiative forcing is
$33°C/324\ W \cdot m^{-2} = 0.10\ °C/W \cdot m^{-2}$

Table 1. This table shows the individual and total RF of all GHG except water vapor in 2005. Because the total is only 3.4% of the total RF of 324 W m^{-2}, water vapor accounts for the remainder of approximately 96%.

	1750	˘ RF	2005	% of 324
Carbon dioxide	7.01	1.66	8.67	2.7
Methane	0.57	0.48	1.05	0.3
Nitrous oxide	0.58	0.16	0.74	0.2
Halocarbons	0.0	0.34*	0.34	0.1
Ozone	-	0.30*	0.30	0.1
Total			11.10	3.4

Ref.: UNEP (2005) Global surface temperature. United Nations Environment Programme, Vital Climate Graphics, Trend in global average surface temperature. Available at: http://www.grida.no/publications/vg/climate/page/3070.aspx.
Lightfoot, H. D., & Mamer, O. A. (2014). "Calculation of Atmospheric Radiative Forcing (Warming Effect) of Carbon Dioxide at Any Concentration." Energy & Environment, 25(8), 1439-1454.

3.14.4. CO_2 Concentration and temperature

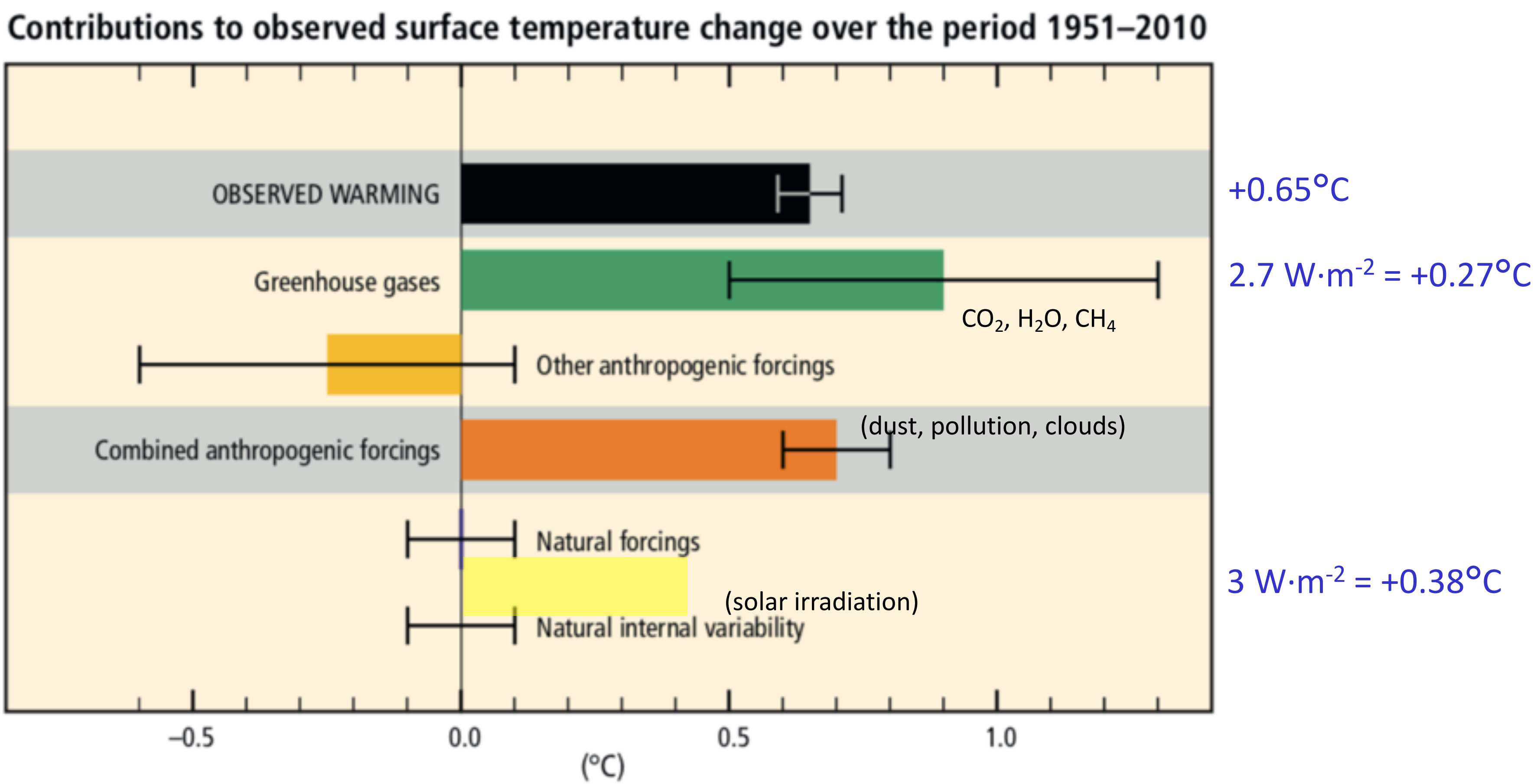

Thomas F. Stocker

before 1850		*2015*	
780'000 ppm	N_2		
210'000 ppm	O_2		
3900 ppm	H_2O	+210 ppm	+0.5°C
280 ppm	CO_2	+120 ppm	+0.3°C
<1 ppm	CH_4	+1 ppm	
4181 ppm	GHG	+331 ppm	
$\Delta T = +33°C$		$\Delta T = +33.8°C$	

Ref.: Thomas F. Stocker, Uni Bern

3900 ppm H_2O lead to +31°C, then 4110 ppm H_2O lead to +31.5°C.
280 ppm CO_2 lead to +2°C, then 400 ppm CO_2 lead to +2.3°C.

3.14.5. Relative temperature change



temperature vs. radiation: 0.13°C /(W·m^{-2})

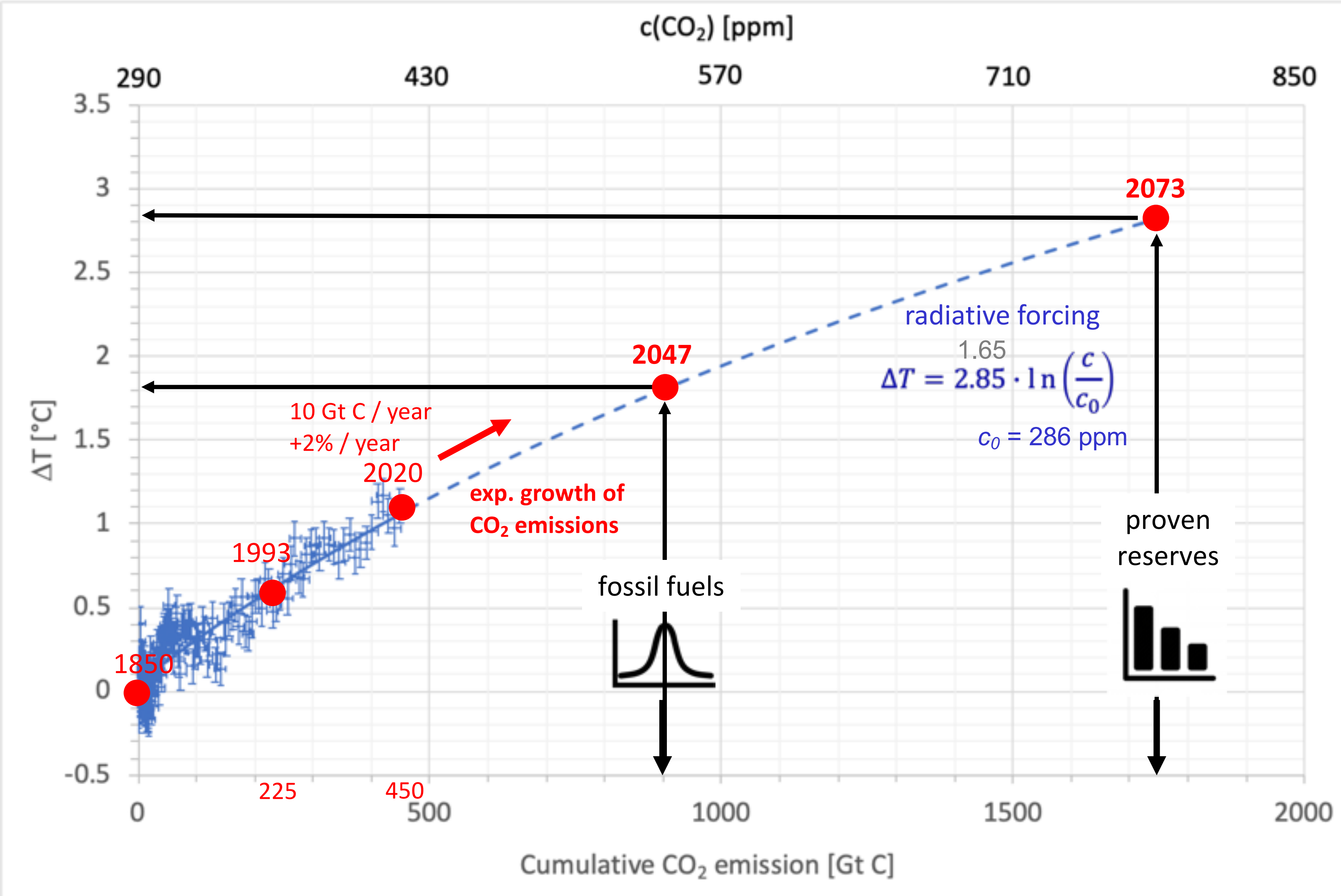
Radiative forcing: 120 ppm CO_2 → +2.0 W·m^{-2} (+0.27°C/W·m^{-2})

TSI: +3 W·m^{-2} change since 1850 (+0.38°C/W·m^{-2})

Solar irradiation → +10 W·m^{-2} (+1.3°C/W·m^{-2})

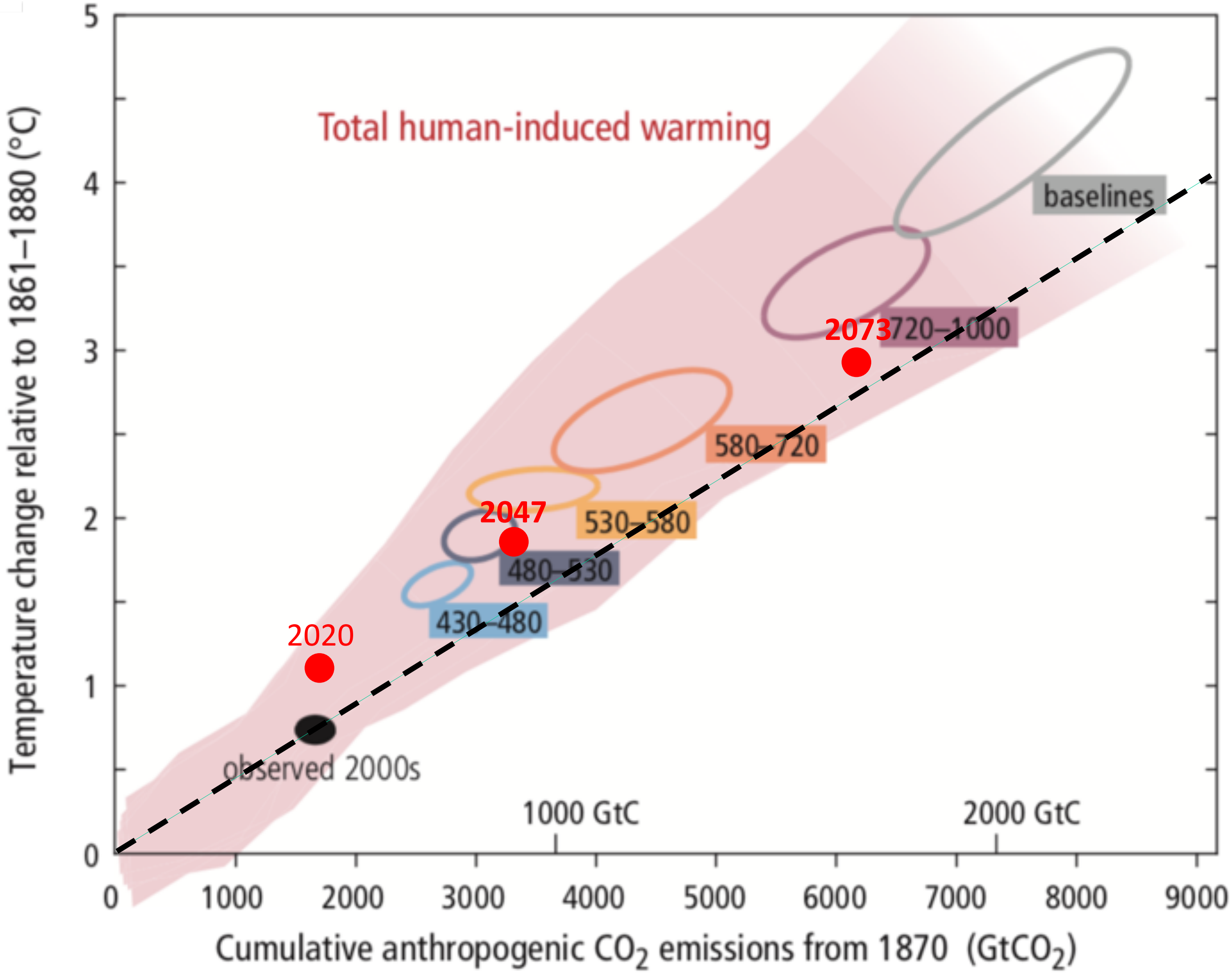
Ref.: Climate Change 2014 Synthesis Report, Summary for Policymakers Chapter, https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf

3.14.6. Calculated warming vs. cumulative CO_2 emission



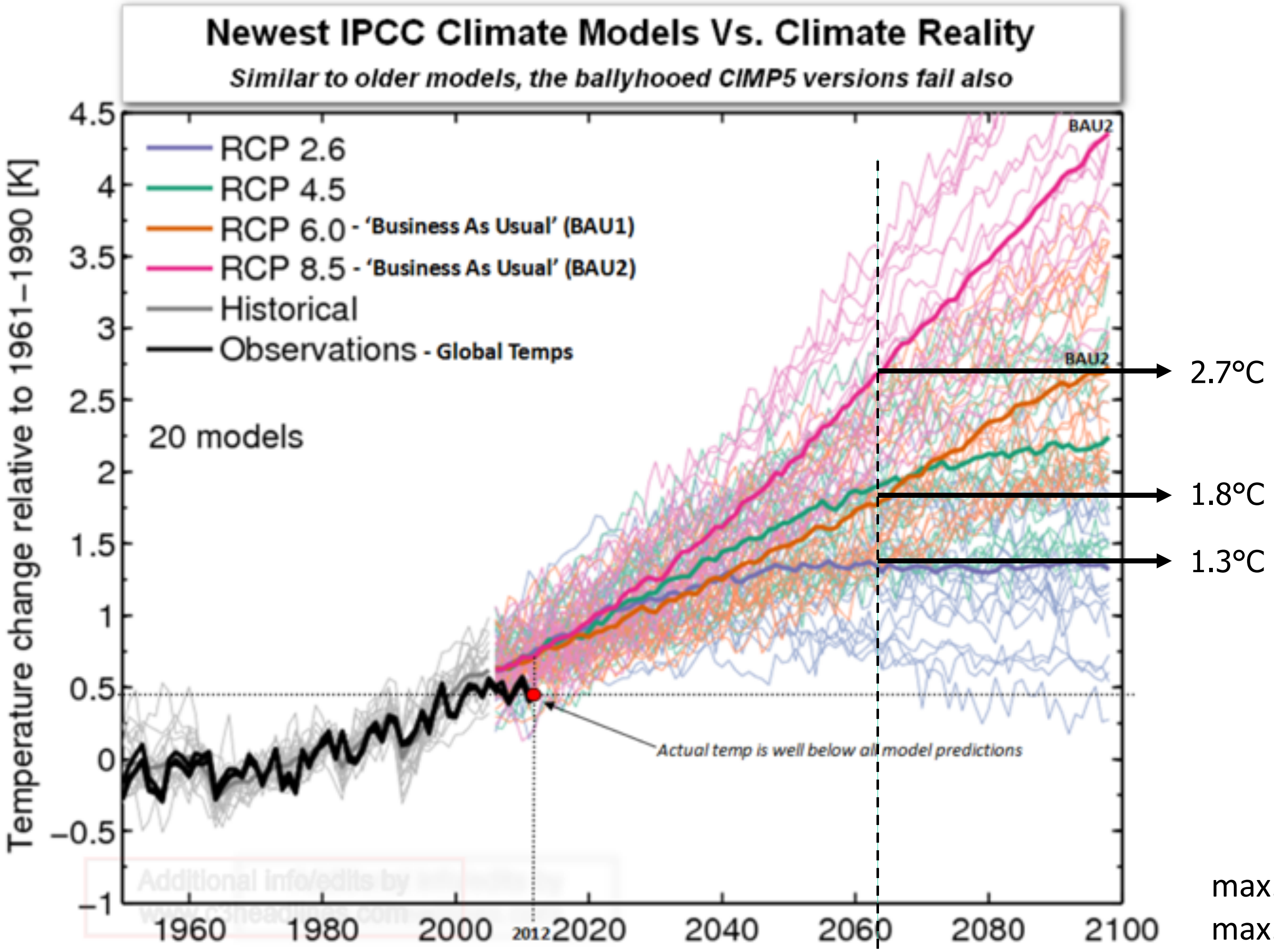
Ref.: http://www.globalwarmingequation.info/global%20warming%20eqn.pdf and Ollila, A. (2014), "The potency of carbon dioxide (CO2) as a greenhouse gas", Development in Earth Science, Vol. 2, pp. 20-30, available at: www.seipub.org/des/paperInfo.aspx?ID=17162

3.14.7. Warming vs. cumulative CO_2 emission



Ref.: Climate Change 2014 Synthesis Report, Summary for Policymakers Chapter,
https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf

3.14.8. Global surface temperature models



max. 1750 Gt C cum. emission
max. 900 ppm

RCP-Szenarien für den 5. IPCC-Sachstandsbericht				
Bezeichnung	RCP8.5	RCP6.0	RCP4.5	RCP2.6
Treibhausgaskonzentration im Jahre 2100	1370 ppm CO_2-äq	850 ppm CO_2-äq	650 ppm CO_2-äq	400 ppm CO_2-äq
Strahlungsantrieb 1850-2100	8,5 W/m^2	6,0 W/m^2	4,5 W/m^2	2,6 W/m^2
Einstufung	sehr hoch	hoch	mittel	sehr niedrig

RCP-Szenarien für den 5. IPCC-Sachstandsbericht

Ref.: https://www.c3headlines.com/climate-models/

3.15. Challenging the scientific basis

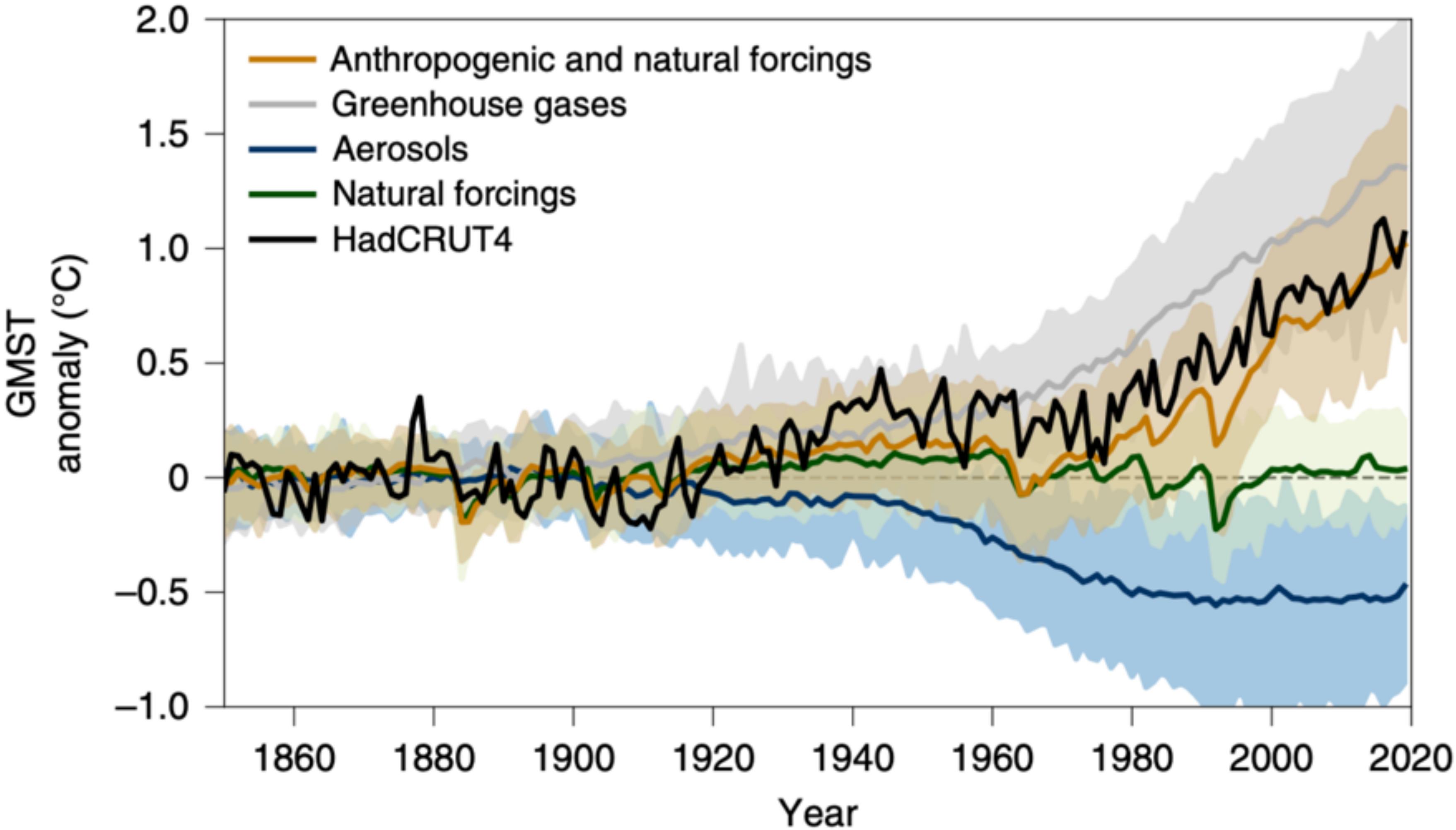
Purpose – The purpose of this paper is to analyze the scientific basis of the Paris climate agreement. Design/methodology/approach – The analyses are based on the IPCC's own reports, the observed temperatures versus the IPCC model-calculated temperatures and the warming effects of greenhouse gases based on the critical studies of climate sensitivity (CS).

Findings – The future emission and temperature trends are calculated according to a baseline scenario by the IPCC, which is the worst-case scenario RCP8.5. The selection of RCP8.5 can be criticized because the present CO_2 growth rate 2.2 ppmy^{-1} should be 2.8 times greater, meaning a CO_2 increase from 402 to 936 ppm. The emission target scenario of COP21 is 40 Gt CO_2 equivalent, and the results of this study confirm that the temperature increase stays below 2°C by 2100 per the IPCC calculations. The IPCC-calculated temperature for 2016 is 1.27°C, 49% higher than the observed average of 0.85°C in 2000.

Originality/value – Two explanations have been identified for this significant difference in the IPCC's calculations: The model is too sensitive for CO_2 increase, and the positive water feedback does not exist. The CS of 0.6°C found in some critical research studies means that the temperature increase would stay below the 2°C target, even though the emissions would follow the baseline scenario. This is highly unlikely because the estimated conventional oil and gas reserves would be exhausted around the 2060s if the present consumption rate continues.

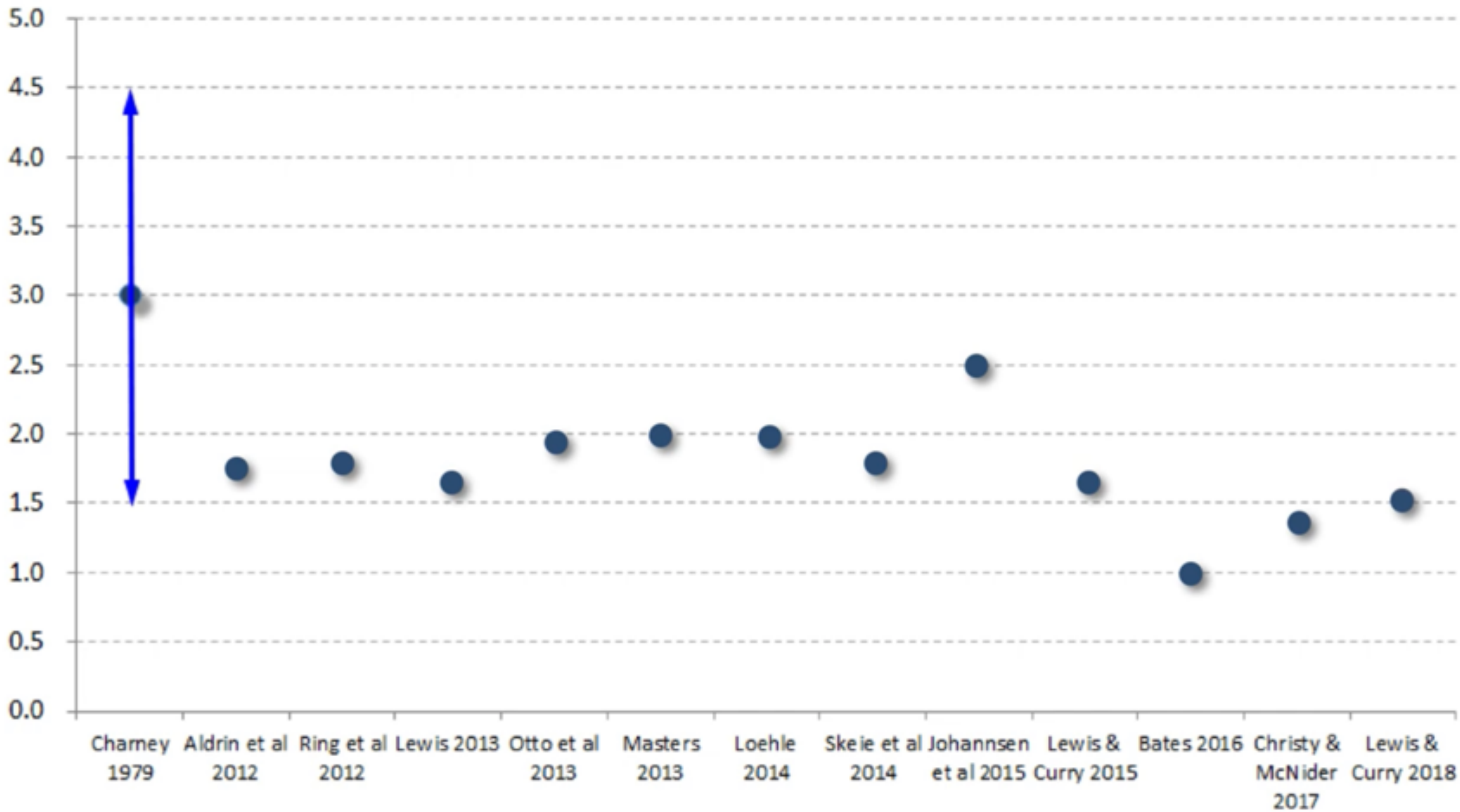
Ref.: Antero OLLILA, "Challenging the scientific basis of the Paris climate agreement", Int. J. of Climate change strategies and Management 11:1 (2019), pp. 18-34

3.15.1. Global mean surface temperature



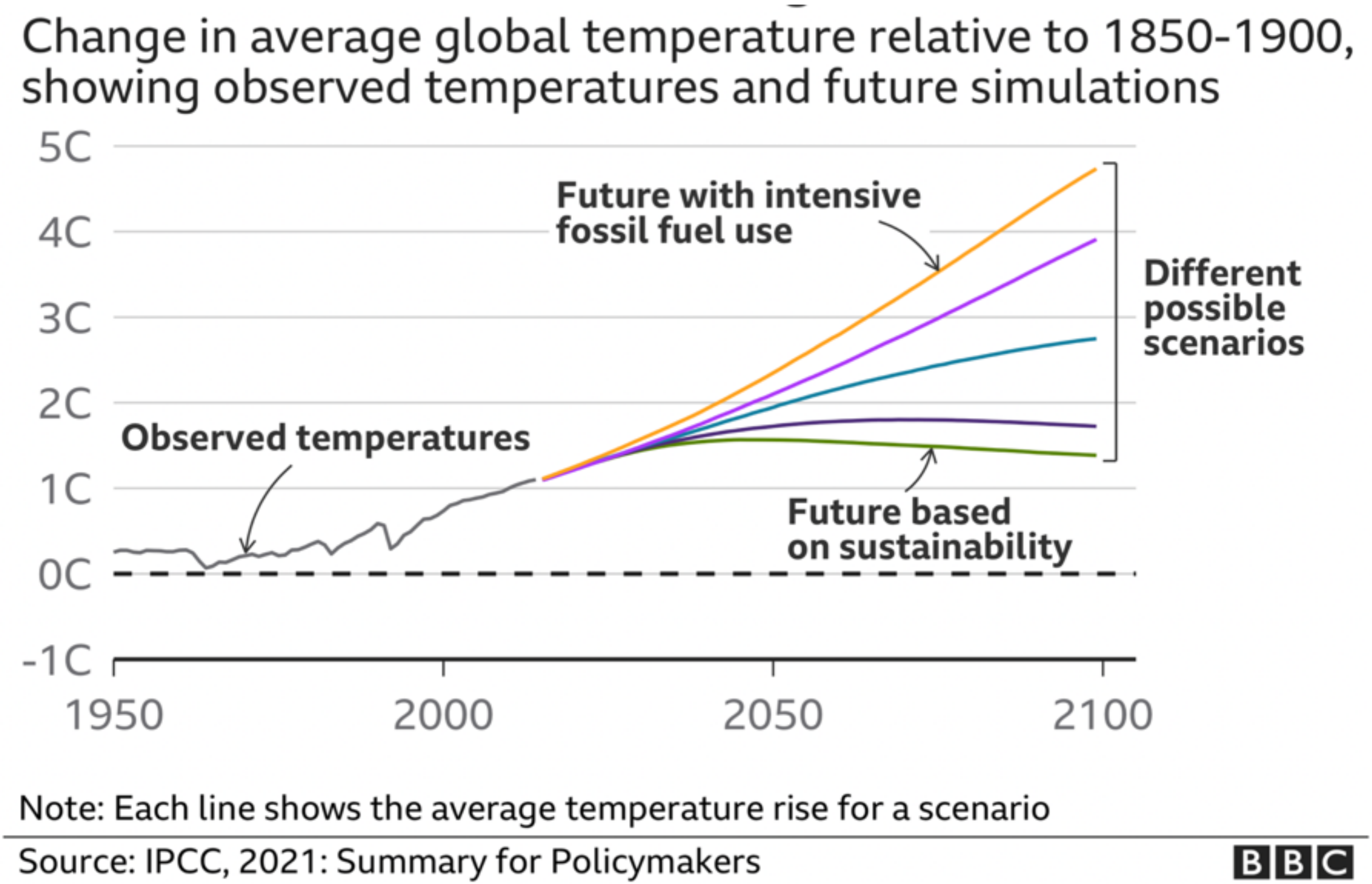
Ref.: Gillett, N.P., Kirchmeier-Young, M., Ribes, A. et al. "Constraining human contributions to observed warming since the pre-industrial period." Nature Climate Change (2021). https://doi.org/10.1038/s41558-020-00965-9

3.15.2. Estimated global temperature increase

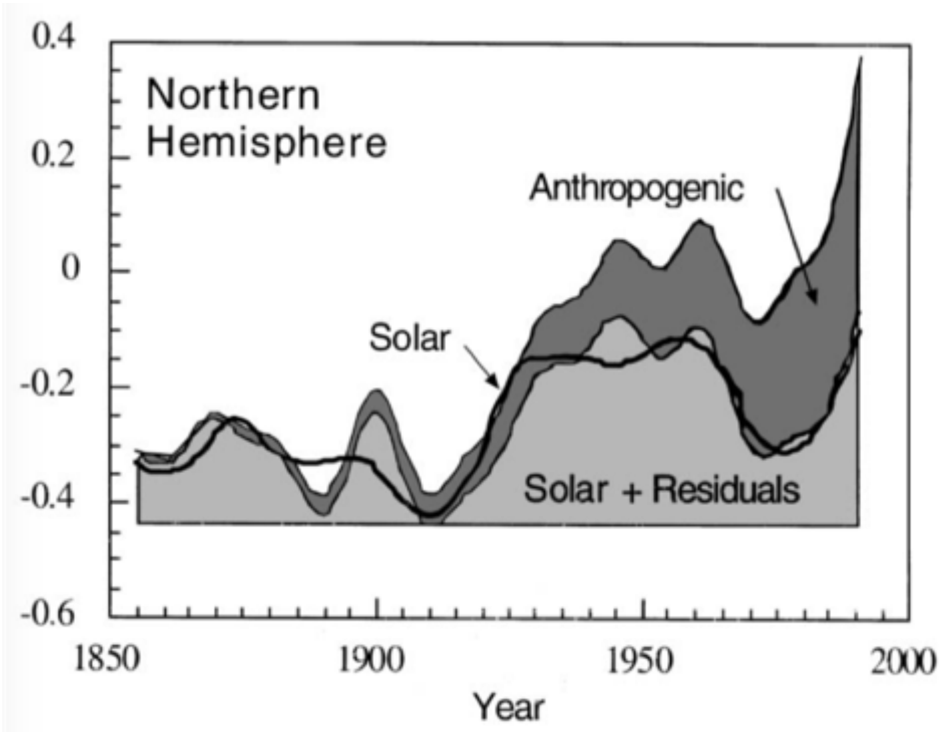


Nicholas Lewis, Judith Curry, "The impact of recent forcing and ocean heat uptake data on estimates of climate sensitivity", 2018 American Meteorological Society. For information regarding reuse of this content and general copyright information, consult the AMS Copyright Policy (www.ametsoc.org/PUBSReuseLicenses). DOI: 10.1175/JCLI-D-17-0667.1
John S. Perry, National Research Council, Executive Secretary Robert S. Chen, National Academy of Sciences, Resident Fellow, "Carbon Dioxide and Climate: A Scientific Assessment", NATIONAL ACADEMY OF SCIENCES Washington, D.C. 1979

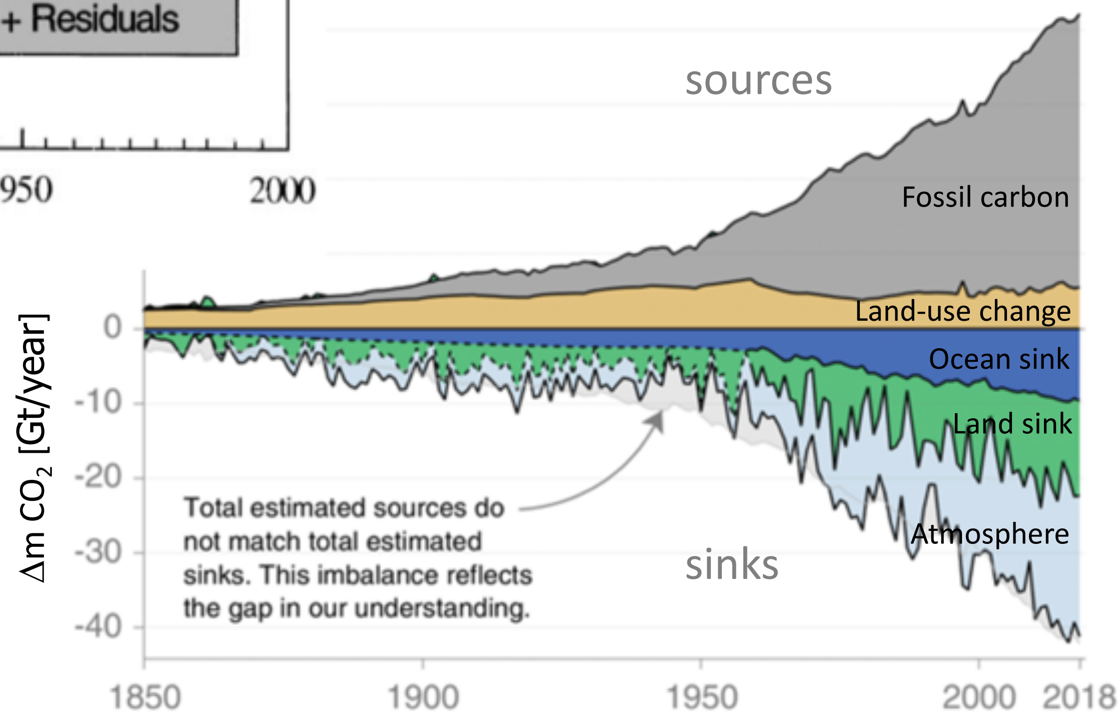
3.15.3. New estimated global surface temperature



3.15.4. Origin of temperature increase

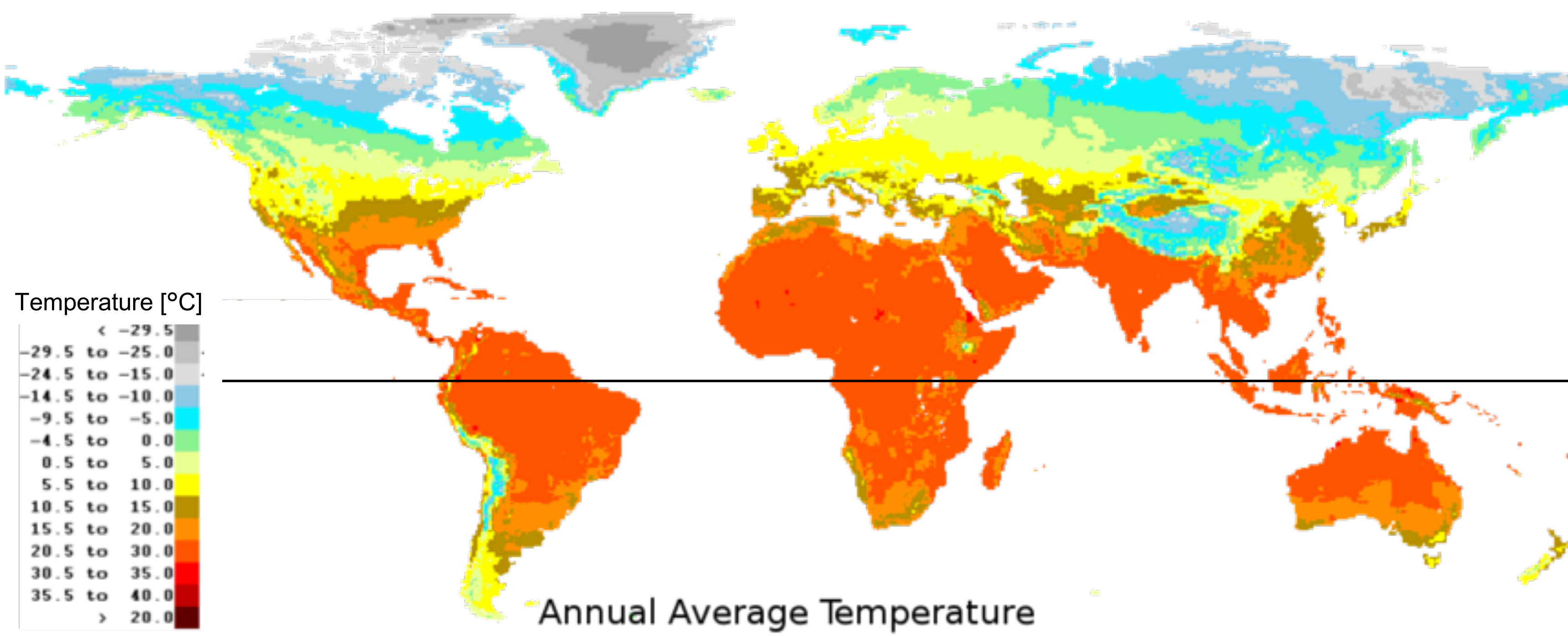


Ref.:J. Beer, W. Mende, R. Stellmacher, "The role of the sun in climate forcing", Quaternary Science Reviews 19 (2000), pp. 403-415

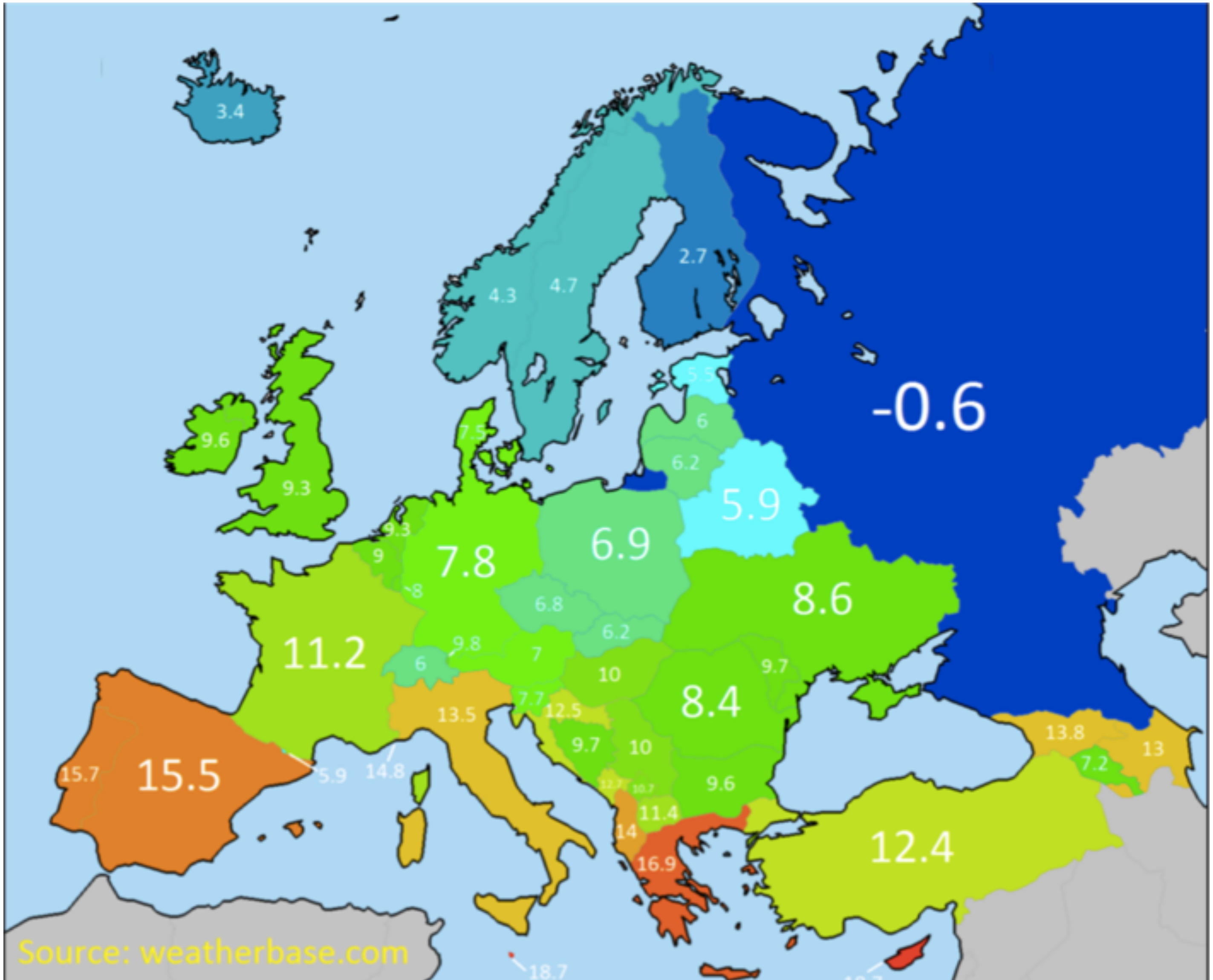


Ref.: Global Carbon Project, Data: CDIAC/GCP/NOAA-ESRL/UNFCC/BP/USGS

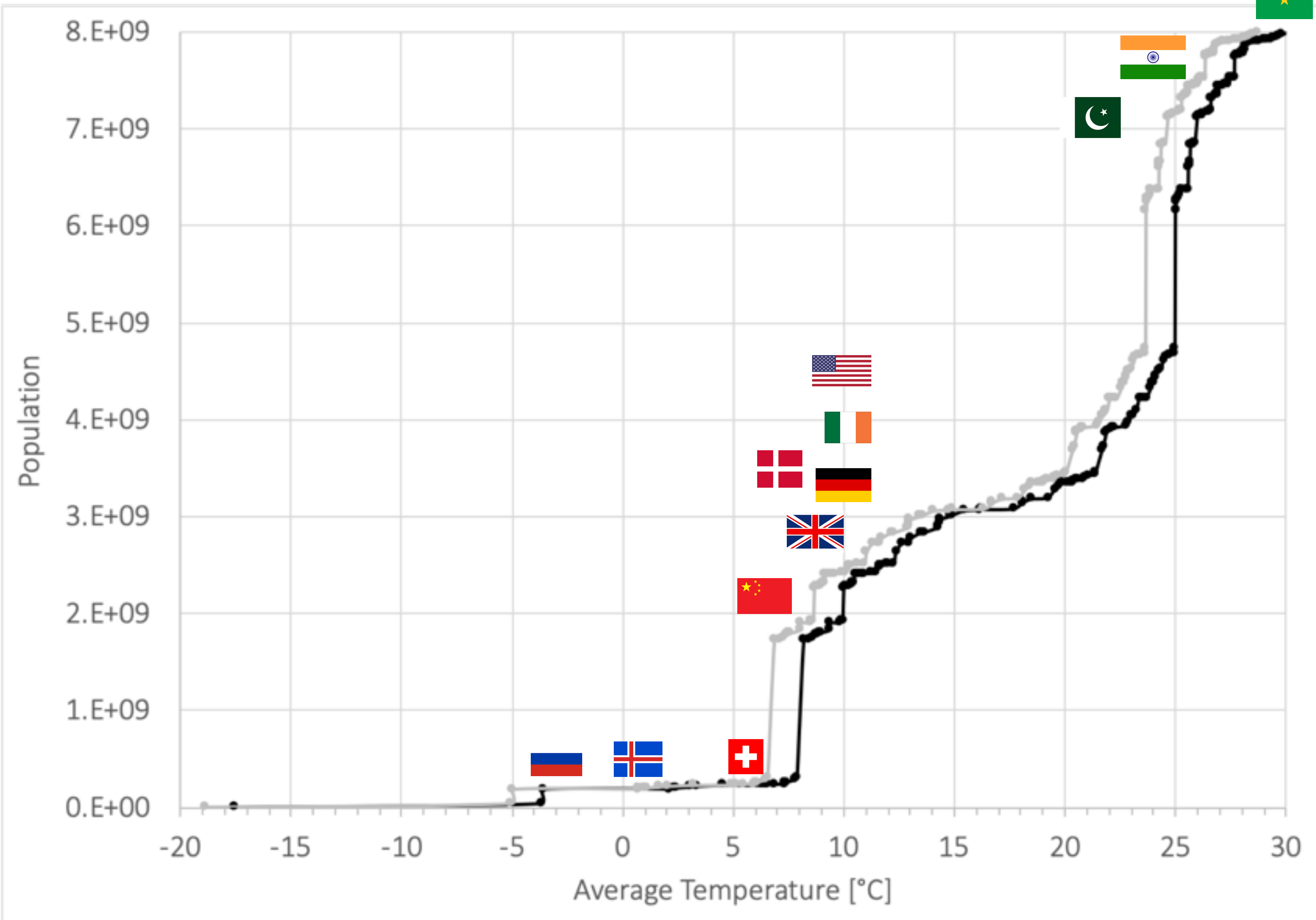
3.16. Global temperature distribution



3.16.1. Annual average temperatures in Europe [°C]



3.16.2. Population vs. average temperature (+1.5°C)



Ref.: ourworldindata.org

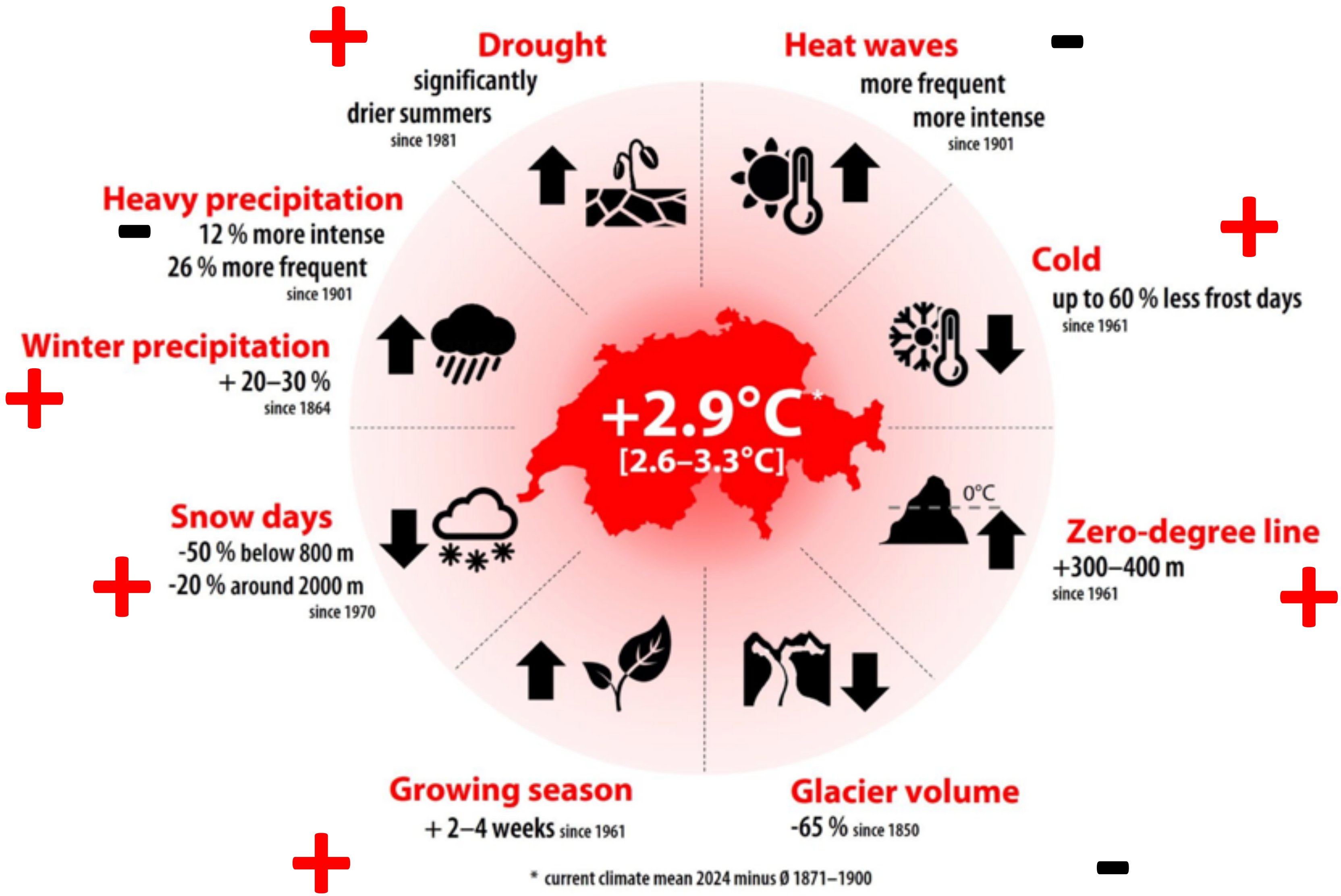
3.16.3. Weekly all-cause mortality for the European countries

A blue zone is a region in the world where people are claimed to have exceptionally long lives beyond the age of 80 due to a lifestyle combining physical activity, low stress, rich social interactions, a local whole-foods diet, and low disease incidence.

and comfortable warm climate

Ref.: https://www.euromomo.eu/bulletins/2024-14
https://www.news-medical.net/health/Unlocking-the-Secrets-of-Blue-Zones-A-Blueprint-for-Longevity-and-Health.aspx

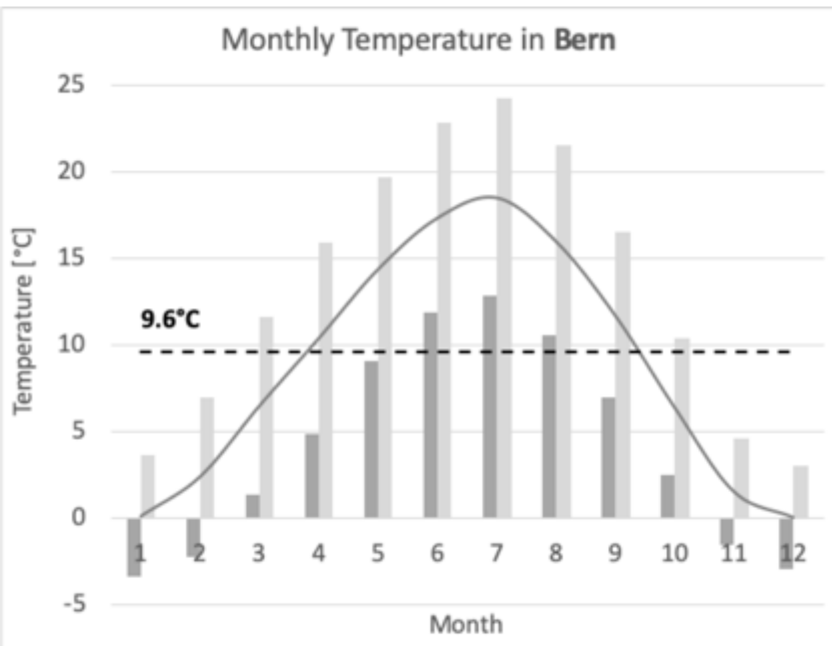
3.16.4. Consequences of climate change in Switzerland

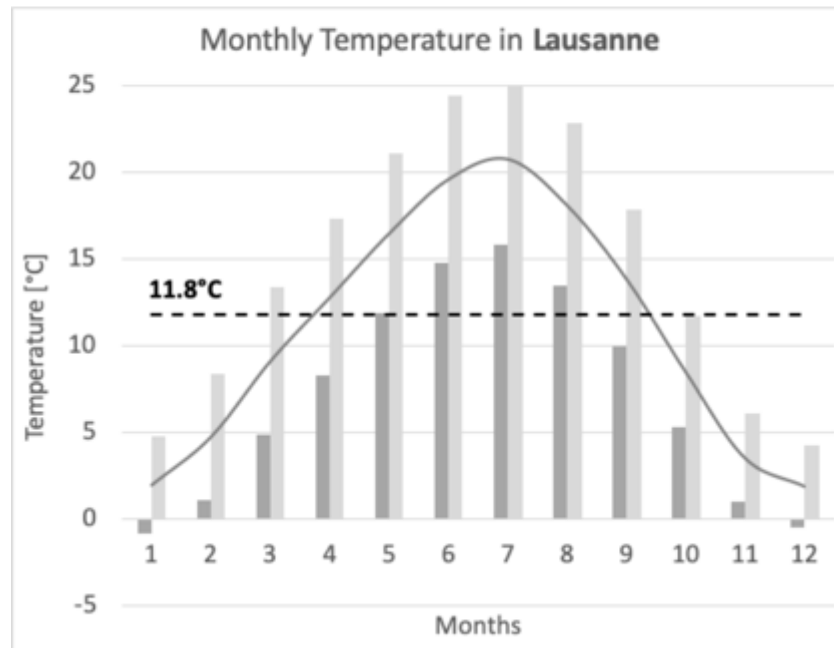


Ref.: https://www.meteoswiss.admin.ch/climate/climate-change.html

3.16.5. Annual average temperature

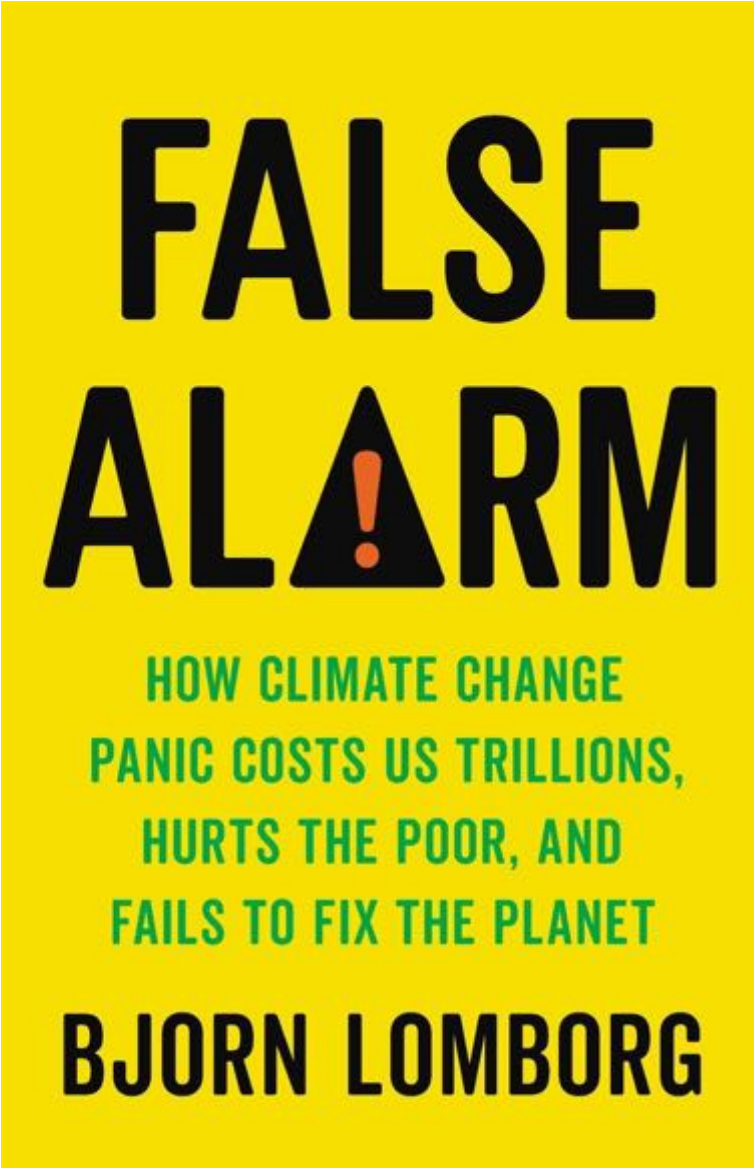
+2.2°C →





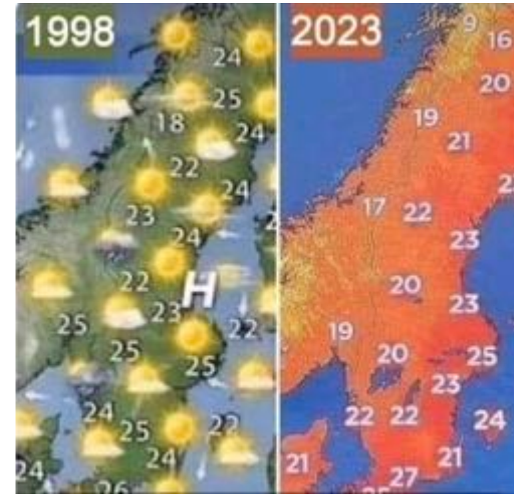
Ref.: https://www.weather-atlas.com/en/switzerland/zurich-climate & weatherbase.com

3.16.6. The skeptical environmentalist



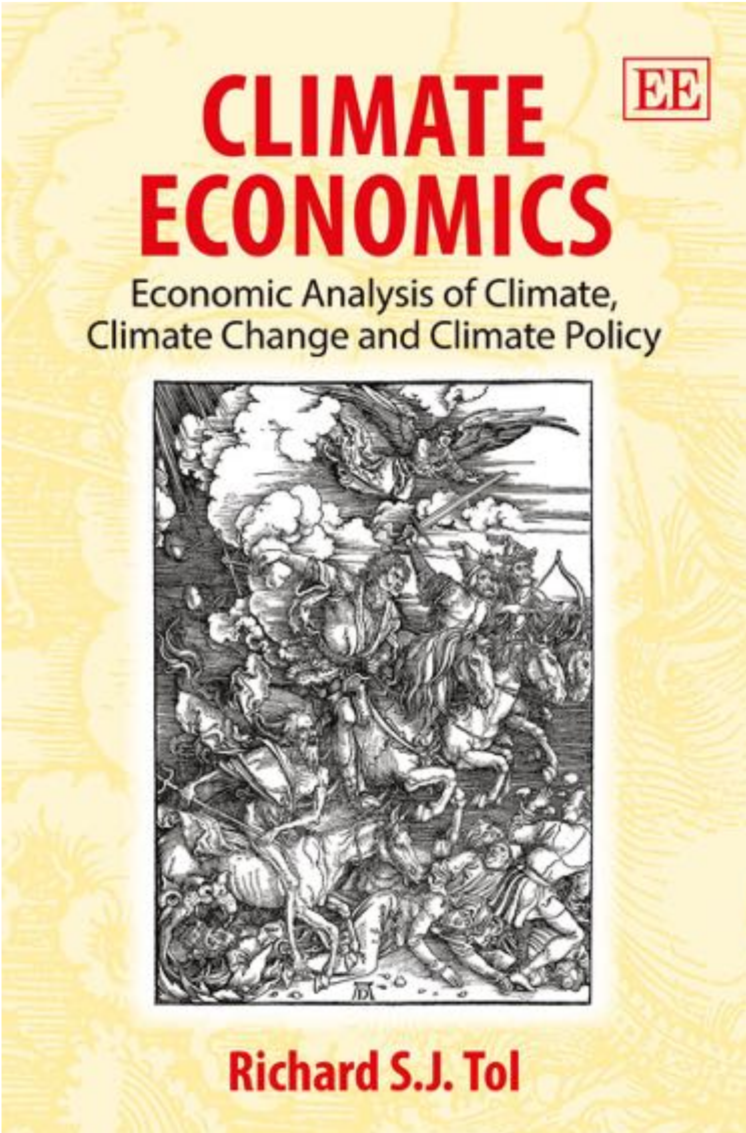
Ref.: https://de.wikipedia.org/wiki/Bjørn_Lomborg

Bjorn Lomborg



Bjorn Lomborg is the best-selling author of The Skeptical Environmentalist and Cool It. He is a visiting professor at Copenhagen Business School and at the Hoover Institution at Stanford. His work appears regularly in New York Times, Wall Street Journal, the Economist, the Atlantic, and Forbes. His monthly column appears in around 40 papers in 19 languages, with more than 30 million readers.
In 2011 and 2012, Lomborg was named Top 100 Global Thinker by Foreign Policy. In 2008 he was named "one of the 50 people who could save the planet" by the Guardian. He lives in Prague.

3.16.7. Climate Economics

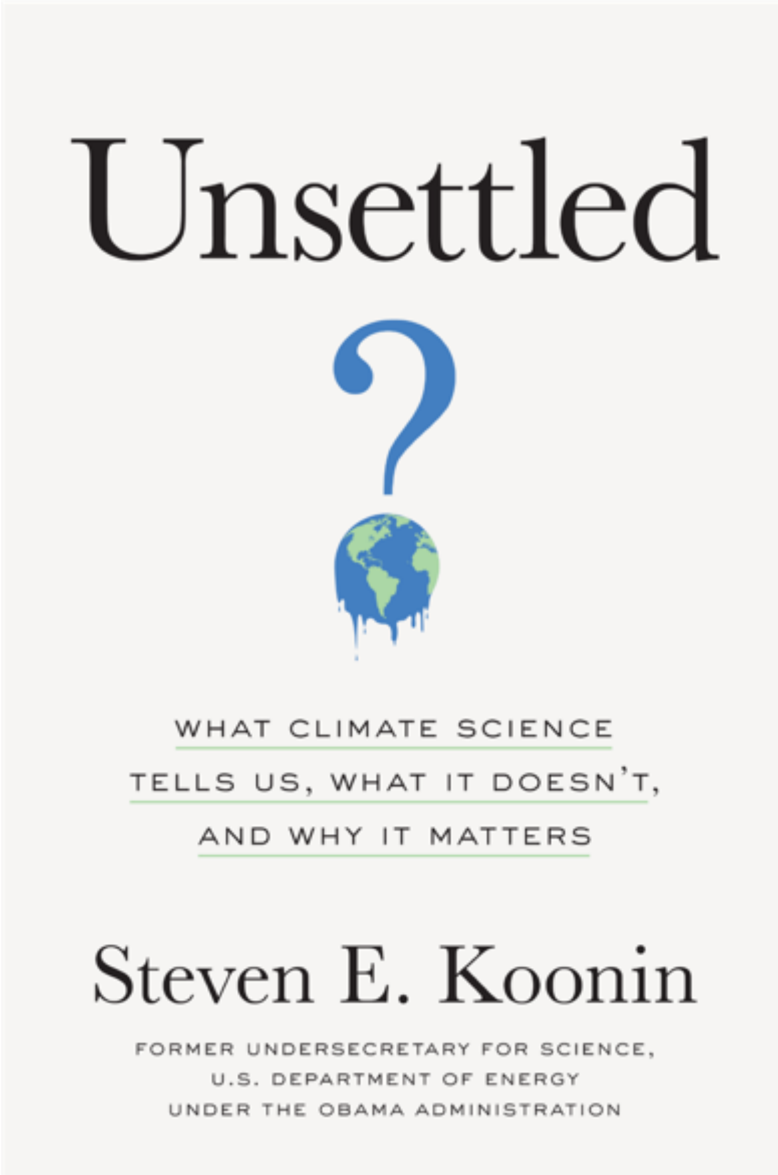


Richard S. J. TOL

Richard S. J. Tol is a Senior Research Officer at the Economic and Social Research Institute, Dublin; a Principal Researcher at the Institute for Environmental Studies, Vrije Universiteit, Amsterdam; and an Adjunct Professor at the Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh. The 70th-most prolific economist, Dr. Tol has 105 publications in learned journals and many other ones. An economist and statistician, he is interested in climate change, natural disasters, marine resources, tourism, land use, and water management. He is an editor of Energy Economics.

Ref.: https://www.world-economics-journal.com/Authors/Richard-S-J-Tol.aspx?AID=430

3.16.8. Unsettled



Steven Elliot KOONIN

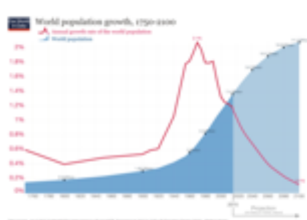
Steven Elliot Koonin (born 12 Dec. 1951 in Brooklyn) is an American theoretical physicist who works on nuclear physics. In an article for the Wall Street Journal entitled Climate Science Is Not Settled, Koonin wrote that current knowledge is far from sufficient for a good climate policy (We are very far from the knowledge needed to make good climate policy). He does not deny climate change as such or the human influence (Climate change is real and affected by human activity); however, he considers the human influence on the climate to be small (human influences [...] are physically small.

Ref.: https://www.world-economics-journal.com/Authors/Richard-S-J-Tol.aspx?AID=430

3.16.9. The KAYA Identity

The Kaya identity was developed by Japanese energy economist Yoichi Kaya. It is the subject of his book Environment, Energy, and Economy: strategies for sustainability co-authored with Keiichi Yokobori as the output of the Conference on Global Environment, Energy, and Economic Development (1993 : Tokyo, Japan). It is a mathematically more consistent variation of Paul R. Ehrlich & John Holdren's I=PAT formula that describes the factors of environmental impact.

$$Emi = Pop \cdot \frac{GDP}{Pop} \cdot \frac{Erg}{GDP} \cdot \frac{Emi}{Erg}$$



Pop: Population
GDP: Grand Domestic Product
Erg: Energy
Emi: Emissions

GDP/Pop: Wealth
Erg/GDP: Efficiency
Emi/Erg: spec. Emission

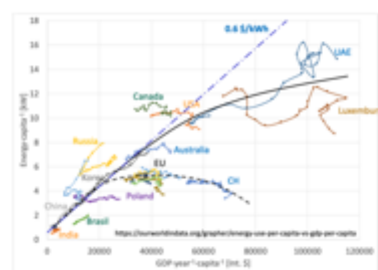
100 k$/capita

GDP/Pop [$/capita]

		Bevölkerung (in Mio.)	Wirtschaftsleistung pro Kopf (in Dollar)
1.	Monaco	0,036	159.400,0
2.	Liechtenstein	0,037	139.300,0
3.	Luxemburg	0,539	121.414,5
4.	Katar	2,150	102.100,0
5.	Norwegen	5,097	103.368,7
6.	Abu Dhabi	2,697	101.004,8
7.	Bermuda	0,064	86.511,8
8.	Schweiz	8,164	83.757,2
9.	Dänemark	5,640	62.399,4
10.	Kuwait	3,516	60.695,8

1.6 kWh/$

Erg/GDP [kWh/$]



Emi/Erg [g/kWh]

Carbon:	402
Oil:	269
Gas:	198
Nuclear:	0
Renewable:	0

Ref.: Kaya, Yoichi; Yokoburi, Keiichi (1997). *Environment, energy, and economy : strategies for sustainability*. Tokyo [u.a.]: United Nations Univ. Press. ISBN 9280809113

3.16.10. What are the biggest threats to humanity?

1. Nuclear war
2. Bioengineered pandemic
3. Superintelligence
4. Nanotechnology
5. Unknown unknowns

Climate change, no matter how scary, is unlikely to make the entire planet uninhabitable (but it could compound other threats if our defences to it break down). Meteors could certainly wipe us out, but we would have to be very unlucky. The average mammalian species survives for about a million years. Hence, the background natural extinction rate is roughly one in a million per year.

Ref.: The Conversation 29. May 2014

How likely are these catastrophes in 2019?

1.5% A severe pandemic such as flu

0.6% A nuclear war

0.6% Solar flare disrupting electricity grids

0.001% Supervolcanic eruption

Source: WHO, The Good Judgement Project, AER/Lloyd's of London, Royal Meteorological Society

Ref.: BBC News 15. February 2019

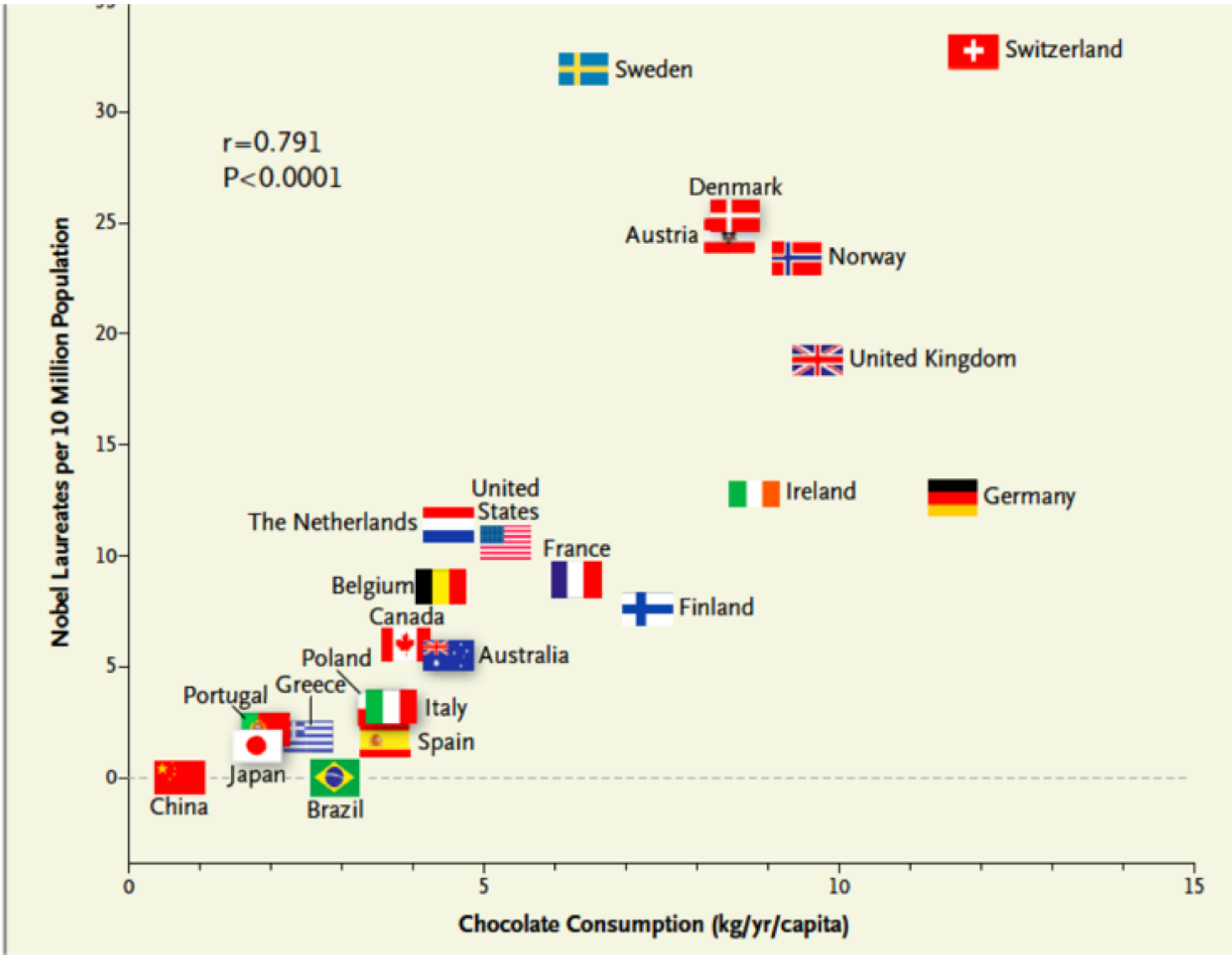
Top 5 Global Risks in Terms of Likelihood

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1st	Breakdown of critical information infrastructure	Asset price collapse	Asset price collapse	Asset price collapse	Storms and cyclones	Severe income disparity	Severe income disparity	Income disparity	Interstate conflict with regional consequences	Large-scale involuntary migration	Extreme weather events
2nd	Chronic disease in developed countries	Middle East instability	Slowing Chinese economy (<6%)	Slowing Chinese economy (<6%)	Flooding	Chronic fiscal imbalances	Chronic fiscal imbalances	Extreme weather events	Extreme weather events	Extreme weather events	Large-scale involuntary migration
3rd	Oil price shock	Failed and failing states	Chronic disease	Chronic disease	Corruption	Rising greenhouse gas emissions	Rising greenhouse gas emissions	Unemployment and underemployment	Failure of national governance	Failure of climate-change mitigation and adaptation	Major natural disasters
4th	China economic hard landing	Oil and gas price spike	Global governance gaps	Fiscal crises	Biodiversity loss	Cyber attacks	Water supply crises	Climate change	State collapse or crisis	Interstate conflict with regional consequences	Large-scale terrorist attacks
5th	Asset price collapse	Chronic disease, developed world	Retrenchment from globalization (emerging)	Global governance gaps	Climate change	Water supply crises	Mismanagement of population ageing	Cyber attacks	High structural unemployment or underemployment	Major natural catastrophes	Massive incident of data fraud/theft

Economic, Environmental, Geopolitical, Societal, Technological

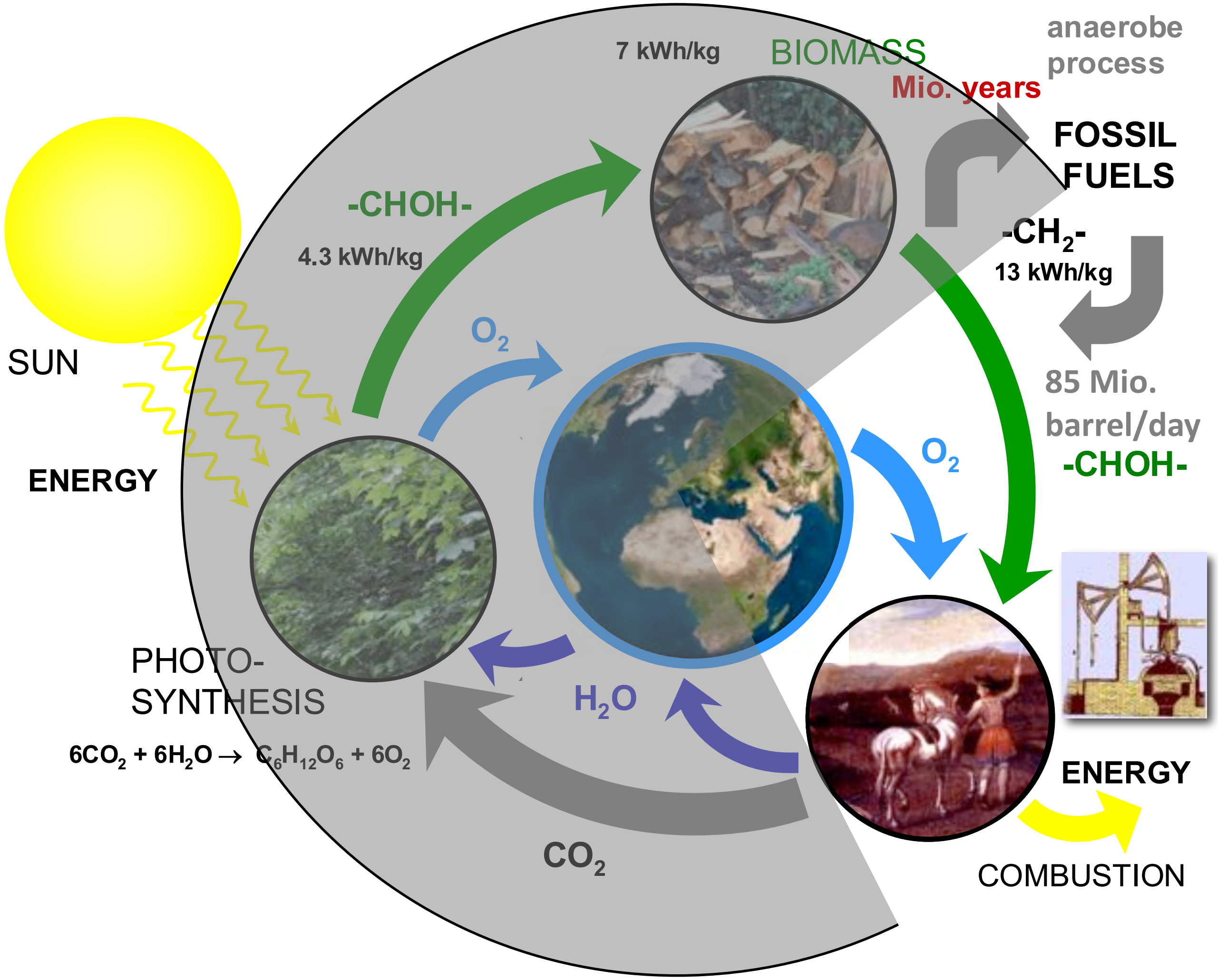
Ref.: World Economic Forum

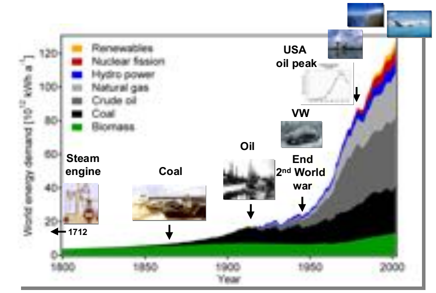
3.16.11. Correlation is not causality

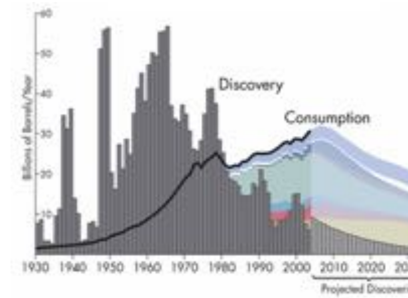


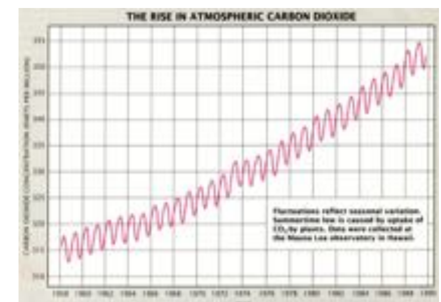
Ref.: Ashutosh Jogalekar, "Chocolate consumption and Nobel Prizes: A bizarre juxtaposition if there ever was one", SCIENTIFIC AMERICAN, November 20, 2012

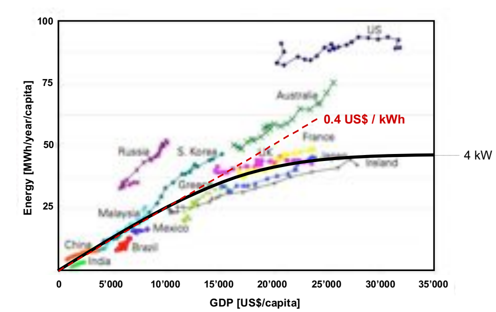
3.16.12. The natural energy cycle



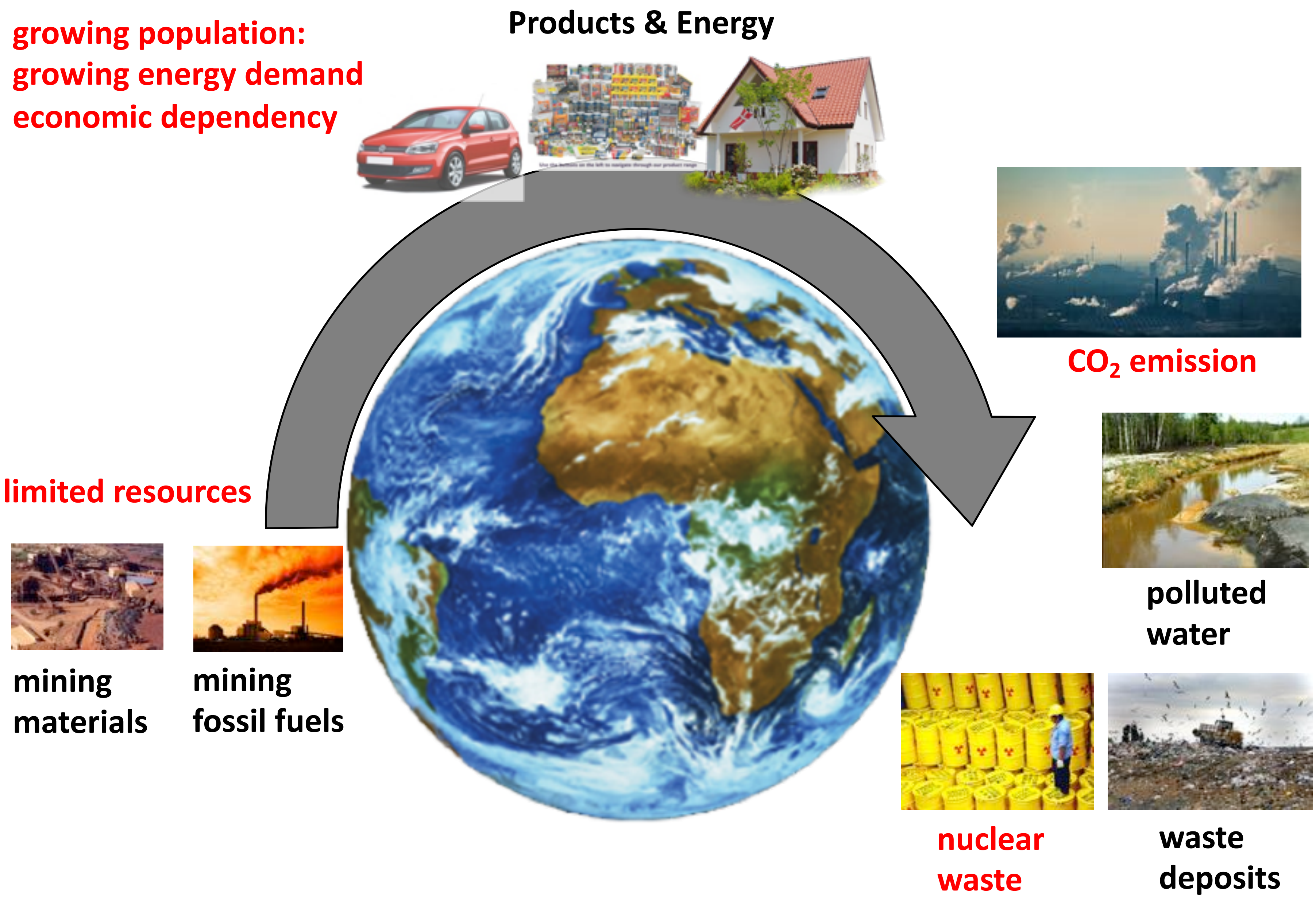








3.16.13. World heritage of 20th Century



EXERCISE

1) Calculate the oil price corresponding to the economic benefit of 1 kWh of energy.

2) Calculate how long (years) each resource lasts (based on current consumption)

3) Calculate the production of biomass in energy per surface area and time and estimate the economic value.

4) Construct an enthalpy diagram for the oxidation of methane ($CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$) and calculate the reaction enthalpy.

5) Estimate the temperature increase if all the fossil fuels are burned.