Science of Climate Change

EE 376

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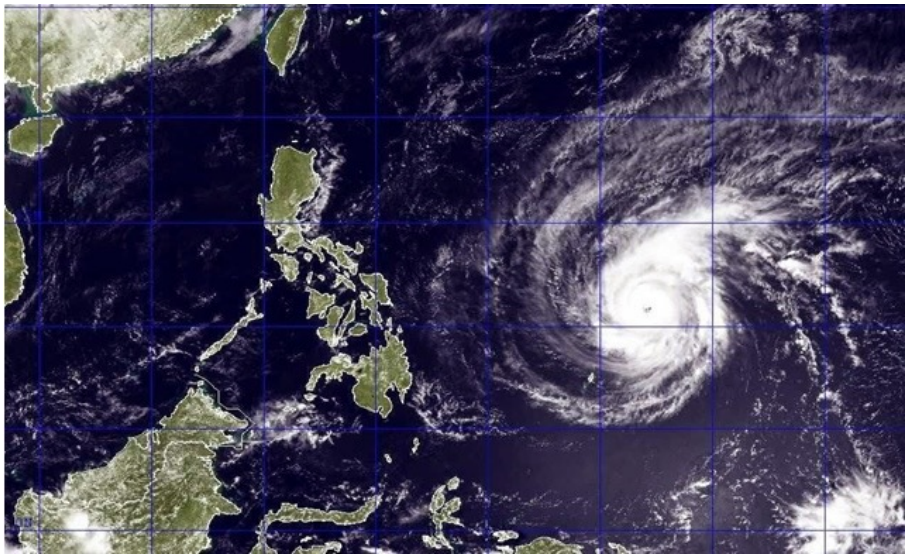
Outline

- Definition and notes on Climate Change (CC)
- Scientific evidence for CC
- Relationship between Greenhouse Gases (GHGs) and global temperature
  - The Earth-Atmosphere Energy Balance
  - Anthropogenic emission of GHGs
- Greenhouse gases
  - Important GHGs
  - Carbon dioxide and Carbon cycle

What is Climate Change?

https://www.youtube.com/watch?v=IJoAcD0oUww

Impacts of climate change



Introduction

- Climate Change is the most severe environmental crisis of the century that has impacts on
  - Human and all living things on earth
- Climate Change is the caused by economic activities that increase levels of greenhouse gases (GHGs) in the atmosphere beyond the average concentration
  - Greenhouse effect traps heat radiating from earth toward space --> Global Warming
- Econ. --> GHGS -->Greenhouse Effect --> Global Warming
- References: https://climate.nasa.gov/causes/

I. Definition of Climate Change (CC)

- The Intergovernmental Panel on Climate Change (IPCC) defines CC as

"A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that **persists for an extended period**, typically decades or longer."

- Climate change may be due to **natural** internal processes or **external forcing**, or to persistent **anthropogenic changes** in the composition of the atmosphere or in land use. [https://archive.ipcc.ch/pdf/special-reports/srex/SREX-Annex_Glossary.pdf]

I. Definition of Climate Change (CC)

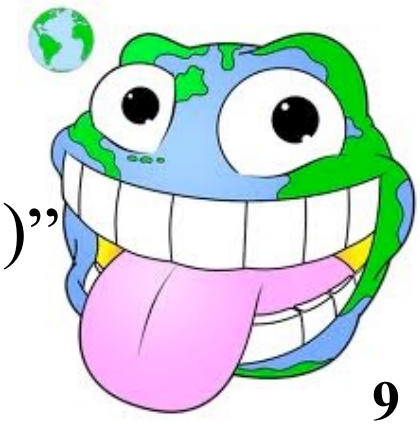
- The United Nations Framework Convention on Climate Change (UNFCCC)
- "a change of climate which is attributed **directly or indirectly to human activity** that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

Remarks on Climate Change

- CC is changes in *long-term* averages of daily weather
- Weather [ฝนฟ้าอากาศ] is what you see outside on any day (what you get).
- Climate [ภูมิอากาศ] is the average of that weather (what you expect)
- It can be measured by scientific method.
- Mostly emphasize on anthropogenic activities since economic activities cause the accumulation of GHGs over the usual global trend.

Remarks on Climate Change

- When scientists conclude that the earth is warming, it means the increase in average temperature of all earth surfaces over the long-term (centuries or more)
- Although its layman's term is " Global warming," CC does not mean that all seasons will be warmer
- CC may result in a form of seasonal variability: extreme heat or cold, for longer duration, or at unusual periods
- "Wierdo Earth (ภาวะโลกเพี้ยน ภาวะโลกรวน)"



II.Scientific evidence for CC by IPPC

- IPCC (2007) Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report (AR4) of the IPPC concludes that

  "Warming of the climate system is unequivocal. This can be found in evidence of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising sea levels."

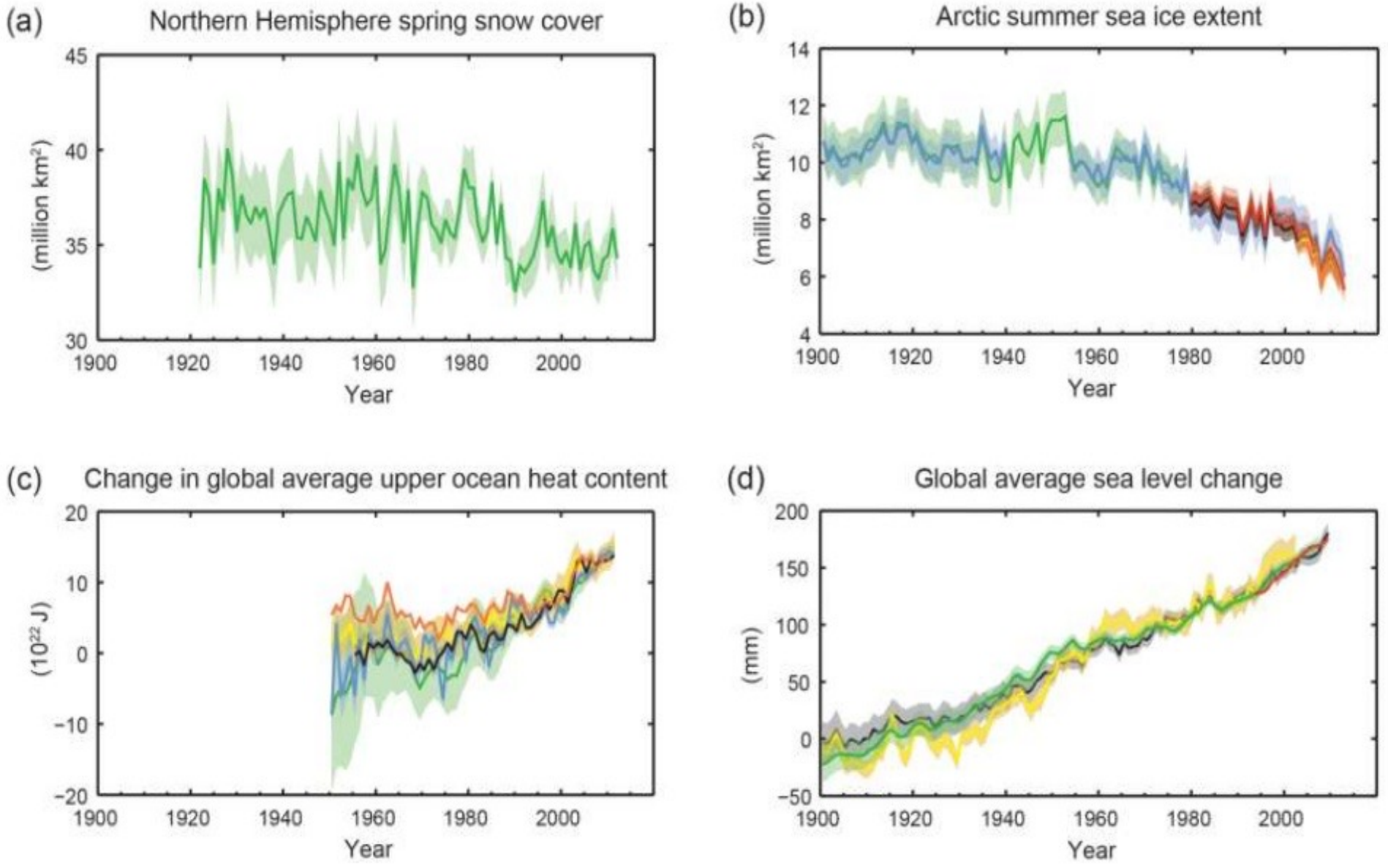
  https://www.ipcc.ch/report/ar4/syr/

II. Scientific evidence for CC by IPPC

- IPPC (2021) Sixth Assessment Report (AR6) Working Group 1: The Physical Science Basis, Summary for policy maker
- "It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred."

Figure SPM.3

Multiple observed indicators of a changing global climate



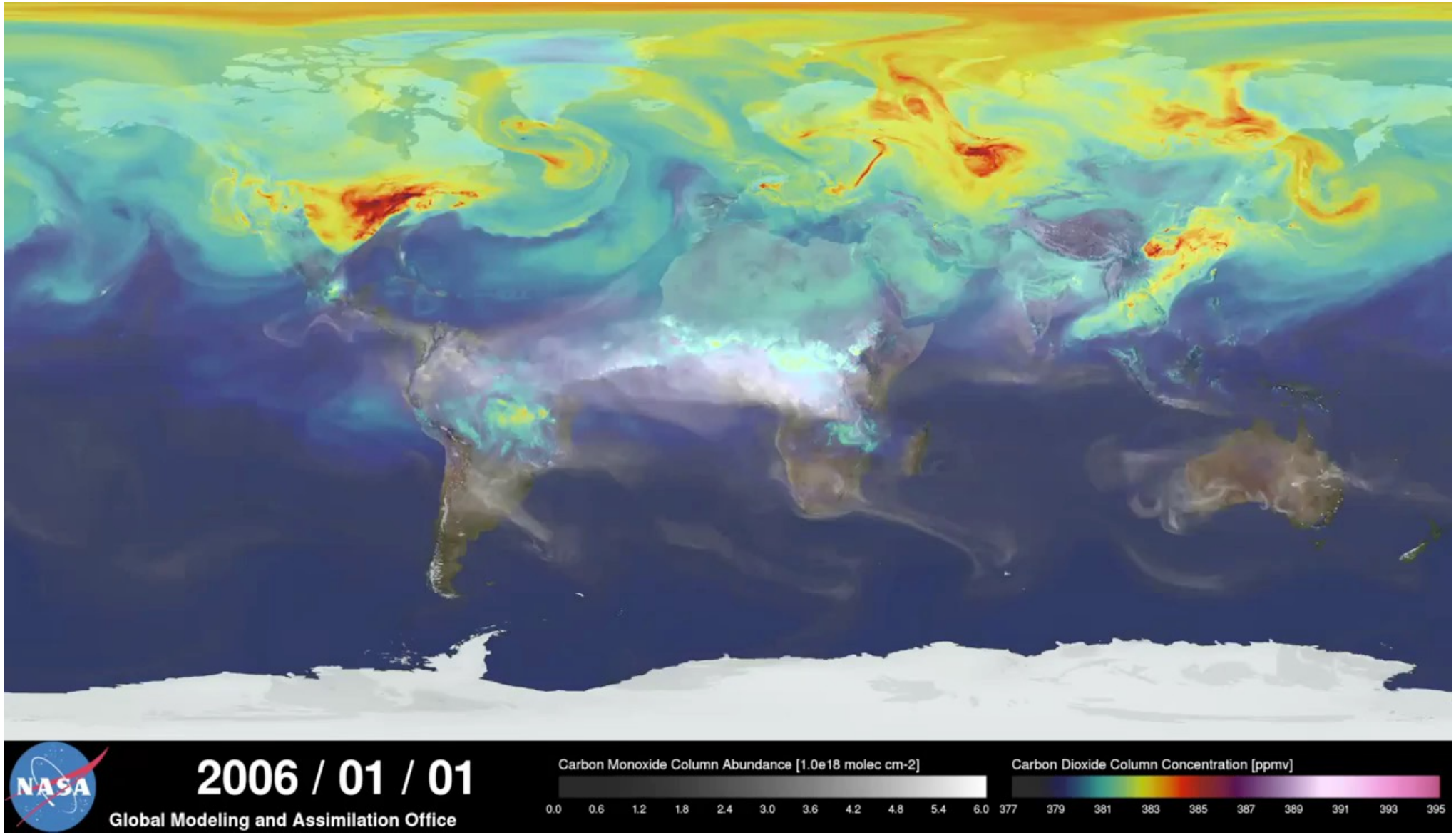
II. Scientific evidences for CC by IPPC (AR6)

- Global surface temperature was 1.09 [0.95 to 1.20] ^{o}C higher in 2011–2020 than 1850–1900
- with larger increases over land (1.59 [1.34 to 1.83] ^{o}C) than over the ocean (0.88 [0.68 to 1.01] ^{o}C)
- Global mean sea level increased by 0.20 [0.15 to 0.25] m between 1901 and 2018. Then rise by 1.3 [0.6 to 2.1] mm/yr between 1901 and 1971, increasing to 1.9 [0.8 to 2.9] mm/yr between 1971 and 2006, and further increasing to 3.7 [3.2 to 4.2] mm/yr between 2006 and 2018 (high confidence).
- Arctic ice sheets have decreased at a rate of 2.7 % [2.1-3.3%] per century

II. Scientific evidences for CC by IPPC (AR6)

- Human influence is very likely the main driver of the global retreat of glaciers since the 1990s and the decrease in Arctic sea ice area between 1979–1988 and 2010–2019 (decreases of about 40% in September and about 10% in March).
- Human influence very likely contributed to the decrease in Northern Hemisphere spring snow cover since 1950. It is very likely that human influence has contributed to the observed surface melting of the Greenland Ice Sheet over the past two decades

Changes of CO_2 concentration over a year

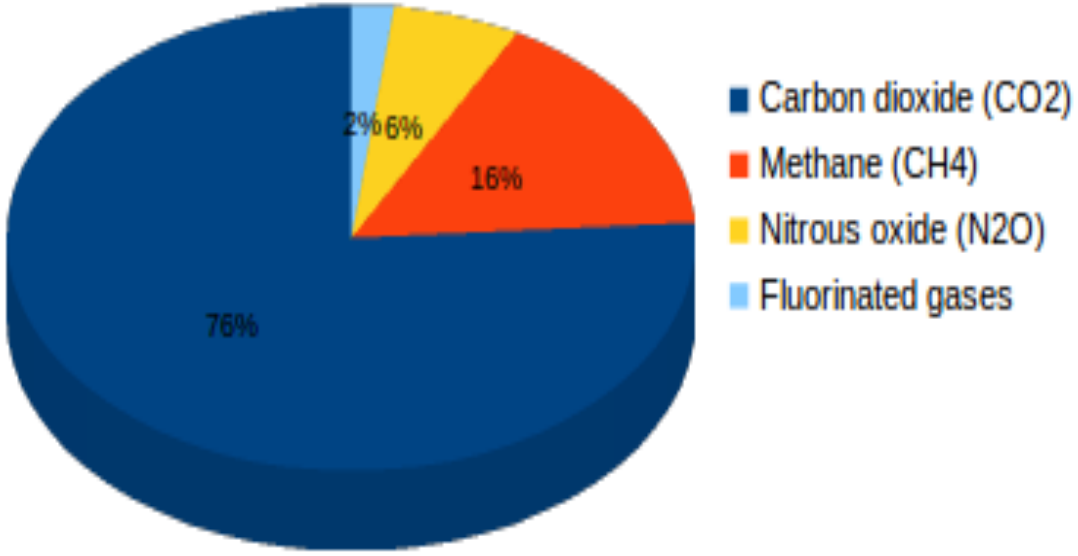


III.Greenhouse Gases (GHGs) and global temperature

- Normally the Earth can maintain its balance of average temperature by receiving shortwave radiation from the sun
  - About 30% is reflected back to space by atmosphere molecules
  - The remaining energy is absorbed and change to thermal radiation (heat) in the form of longwave radiation, infrared
  - A part of the infrared is radiated back to space. The remaining part is reflected and accumulated in the atmosphere
- The amount of energy being accumulated depends on what kind of gases are in the atmosphere

III.Greenhouse Gases (GHGs) and global temperature

- GHGs acts like a blanket for the Earth keeping it warm
- If there is no greenhouse effect, the average temperature of the Earth will be -23°C instead of 17°C at present
- Important GHGs:
  - Carbon dioxide (CO_2)
  - Methane (CH_4)
  - Nitrus oxide (N_20)
  - Fluorinated gases
  - Ozone (O_3)



Source: Forcing greenhouse gases - Global emissions (2012), International Energy Agency.

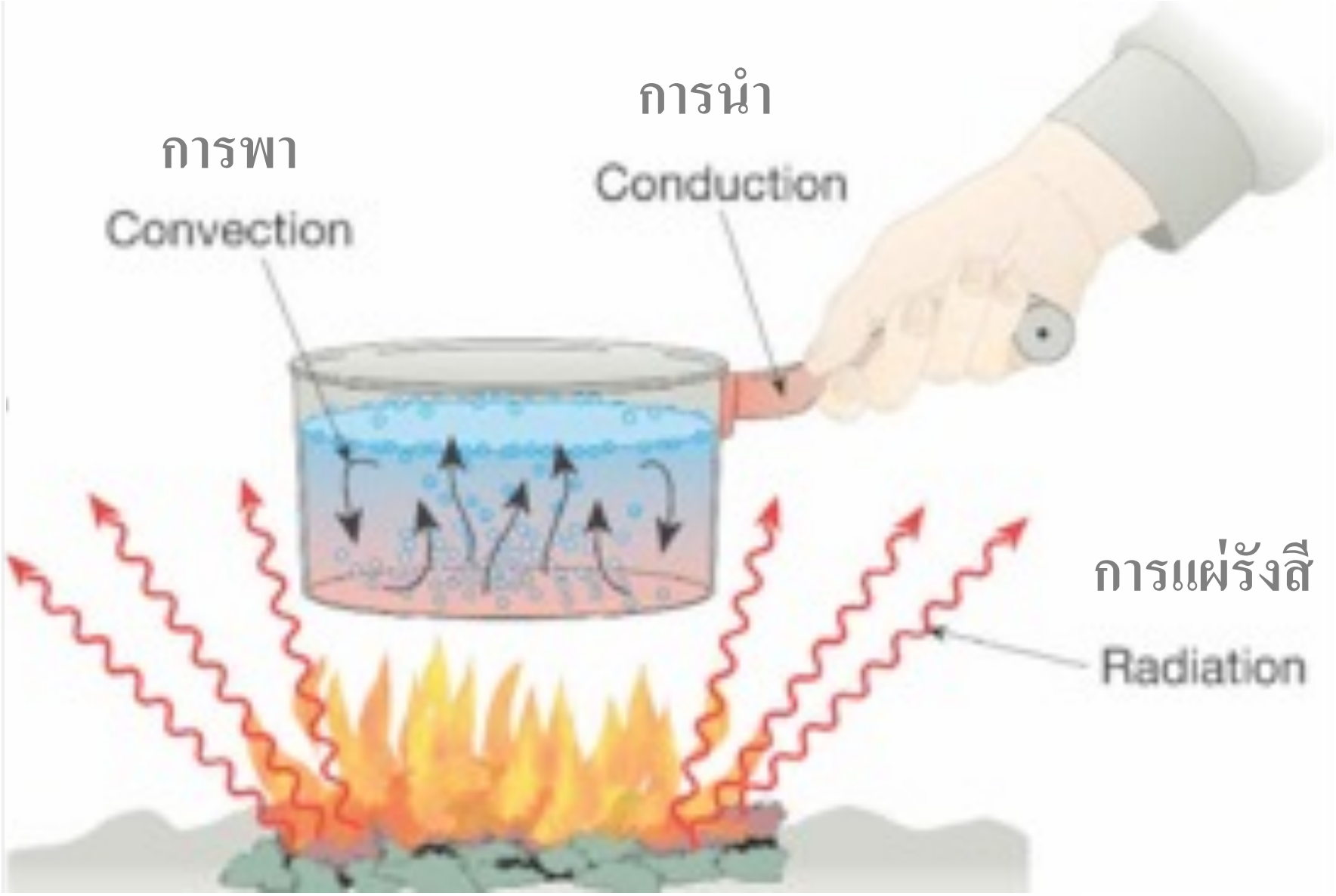
The composition of the atmosphere in 2007

Gas	Mixing ratio or mole fraction[a] expressed as fraction* or parts per million (ppm)
Nitrogen (N_2)	0.78*
Oxygen (O_2)	0.21*
Water vapour (H_2O)	Variable (0–0.02*)
Carbon dioxide (CO_2)	380
Methane (CH_4)	1.8
Nitrous oxide (N_2O)	0.3
Chlorofluorocarbons	0.001
Ozone (O_3)	Variable (0–1000)

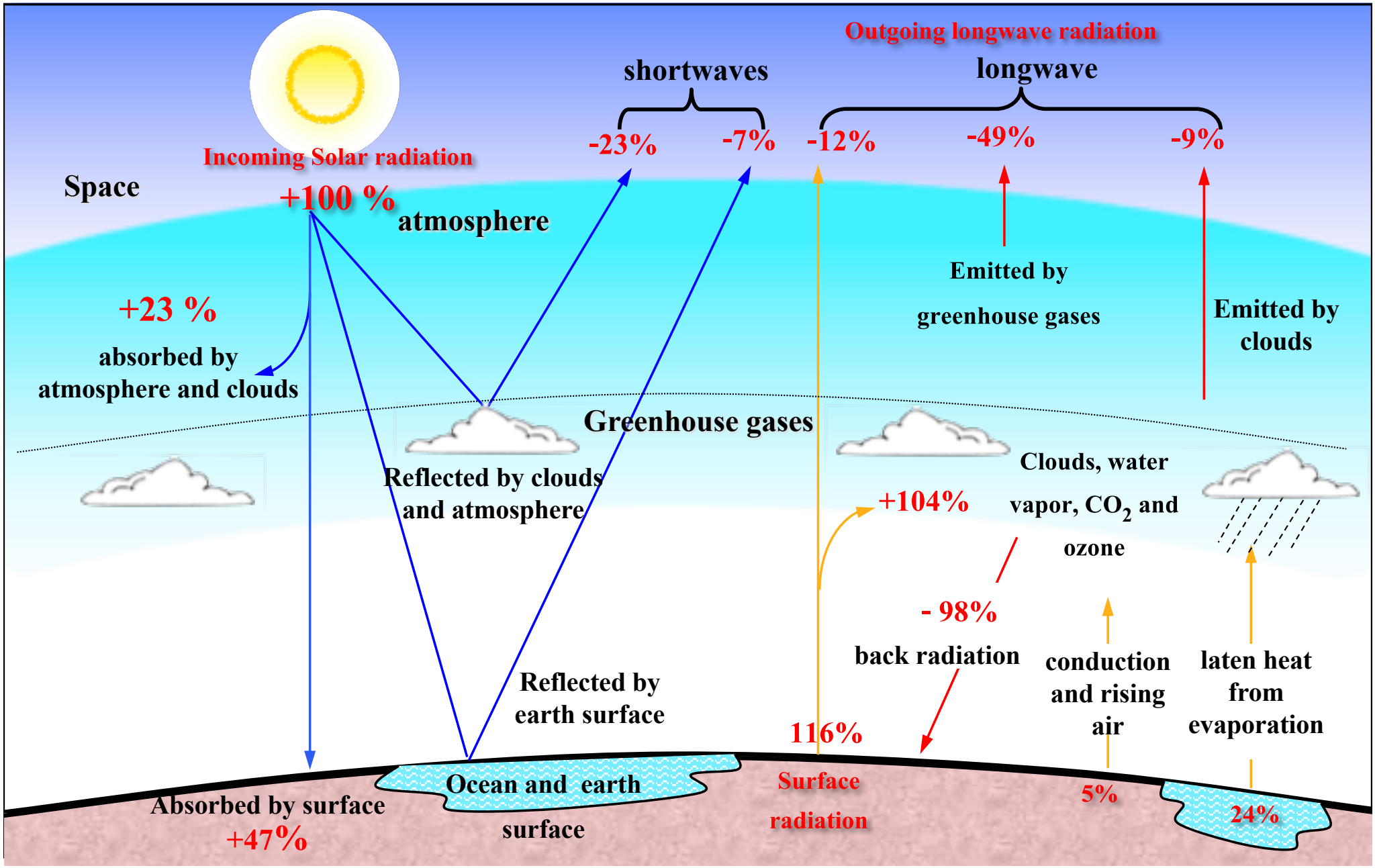
[a] For definition see Glossary.

Houghton, J(2009), Table 2.1, p.20.

Heat transfer methods

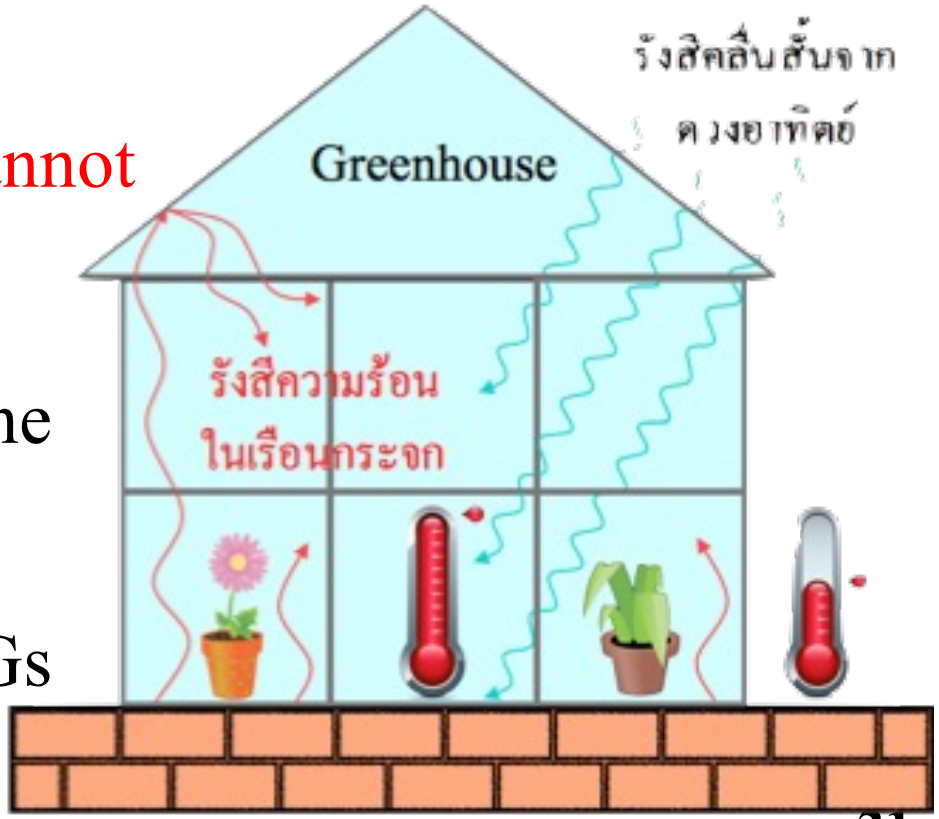


The Earth-Atmosphere Energy Balance



Greenhouse Effects and Global Warming

- Shortwave radiation from the sun can pass through the atmosphere or greenhouse
- It is being absorbed by surface and converted to Longwave radiation (infrared) which cannot radiate back
- GHGs can reflect infrared, the Earth is warmer because the higher concentration of GHGs

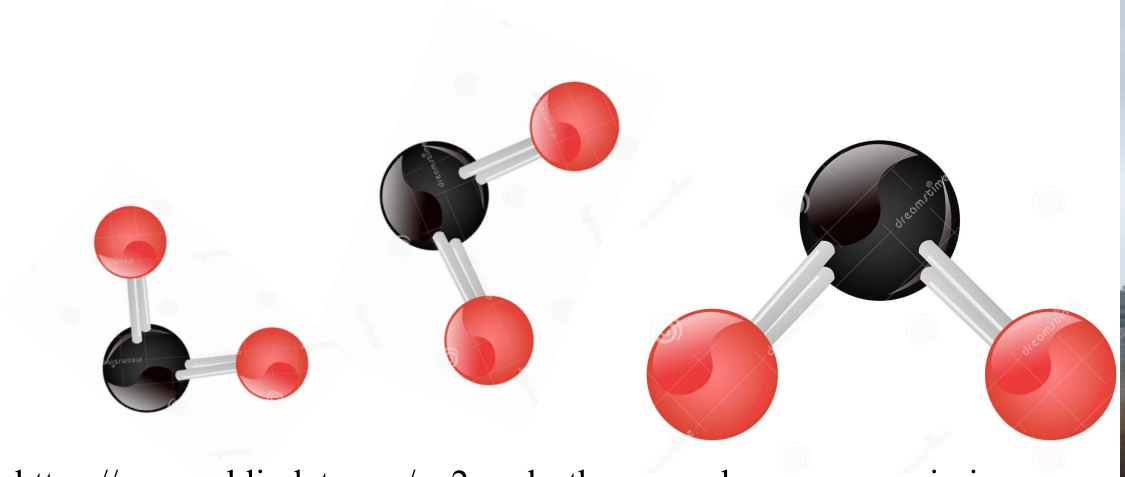


Anthropogenic emission of GHGs

- CC is derived from human activities that release CO_2:
  - Combustion of fossil fuels
    - Coal, oil, natural gas
  - Slash-and-burn agriculture

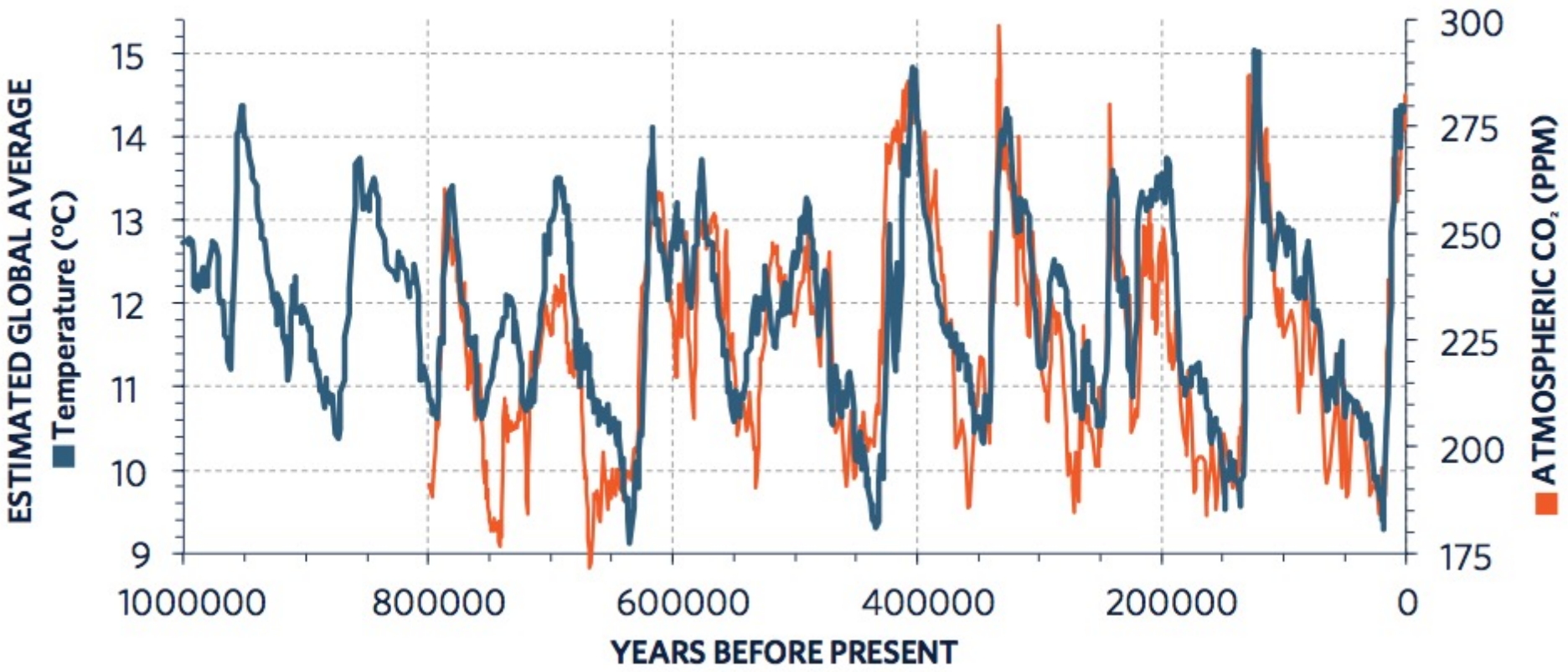
Anthropogenic emission of GHGs

- Mostly occurred after the industrial revolution in the late 18 century (1750)
- Global emissions increased from 2 billion tons of carbon dioxide in 1900 to over 36 billion tons 115 years later.
- Most CO_2 can last in the atmosphere more than 100 years



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

Carbon dioxide and global warming

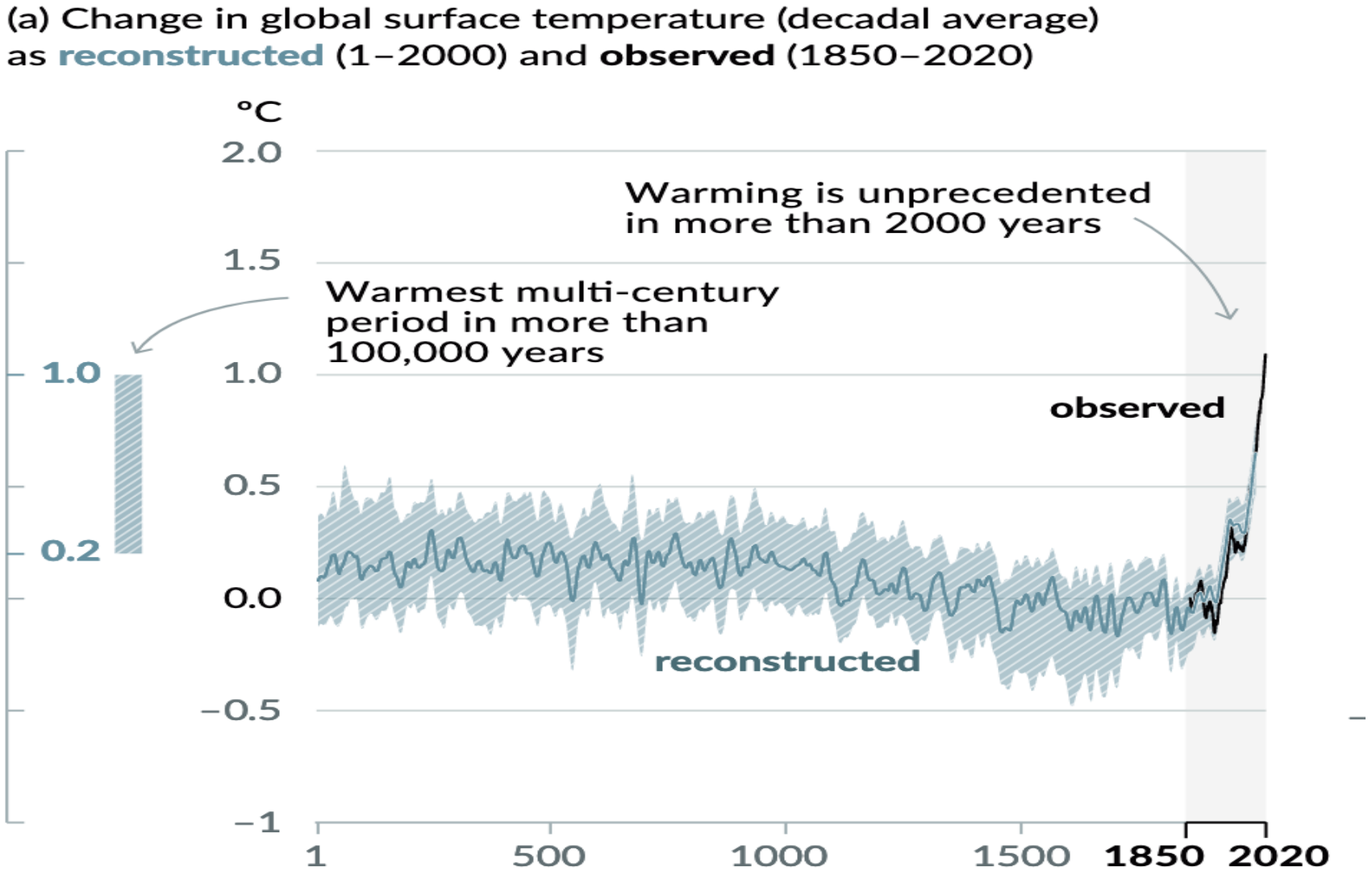


Frozen in Time: Climate Clues Hidden in Ice

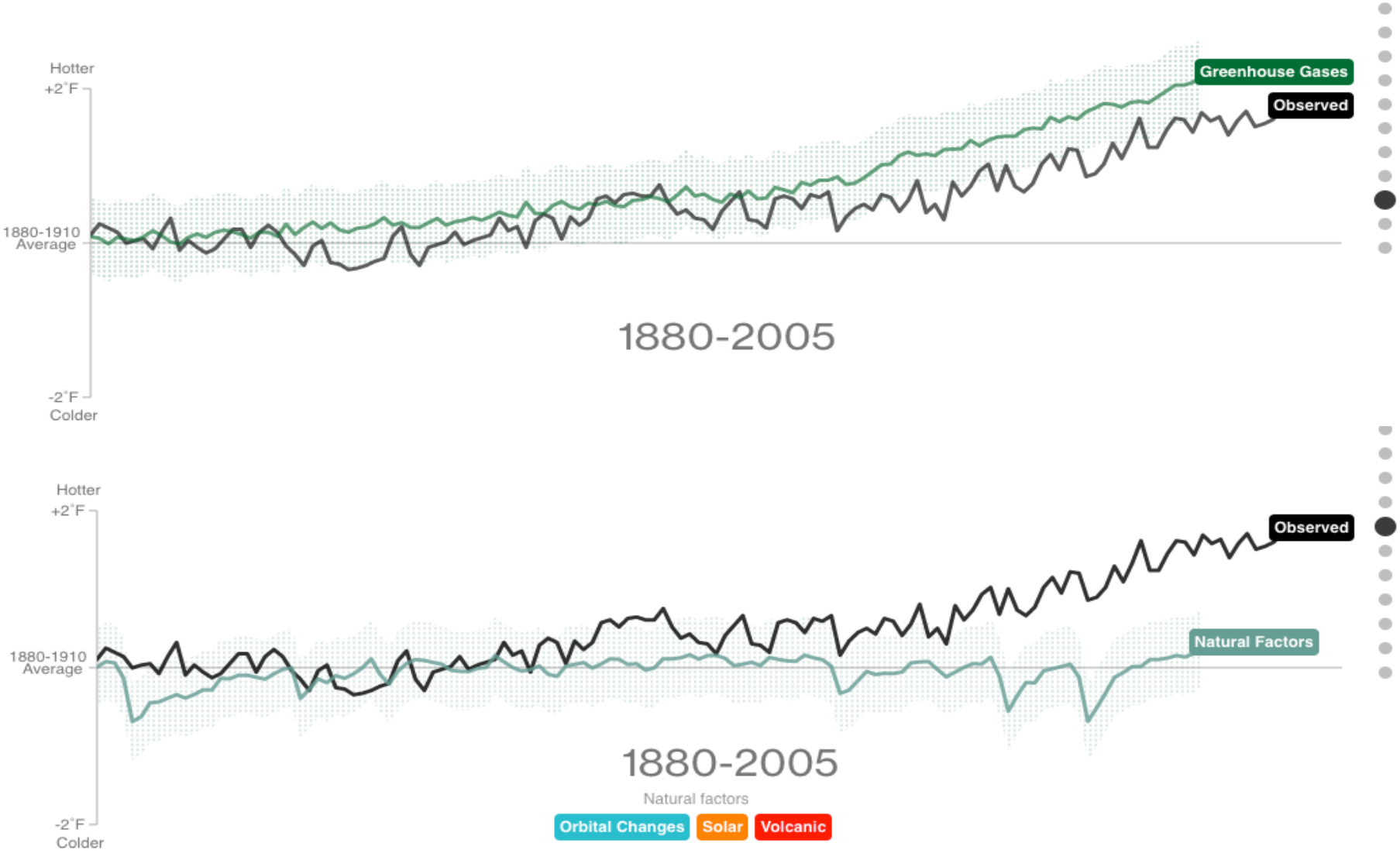
Source: Smithsonian National Museum of Natural History, 2018

https://www.youtube.com/watch?v=_8dzKWfAcwM&t=1s

Changes in global surface temperature relative to 1850–1900 [Figure SPM.1, AR 6]



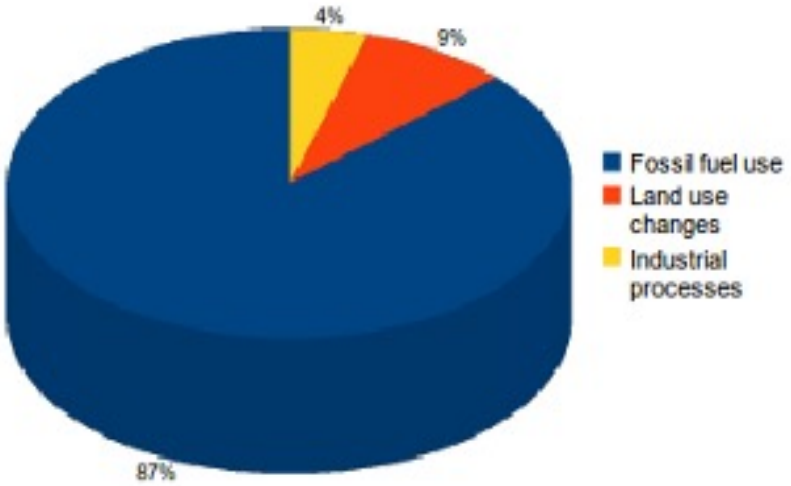
What really warming the world?



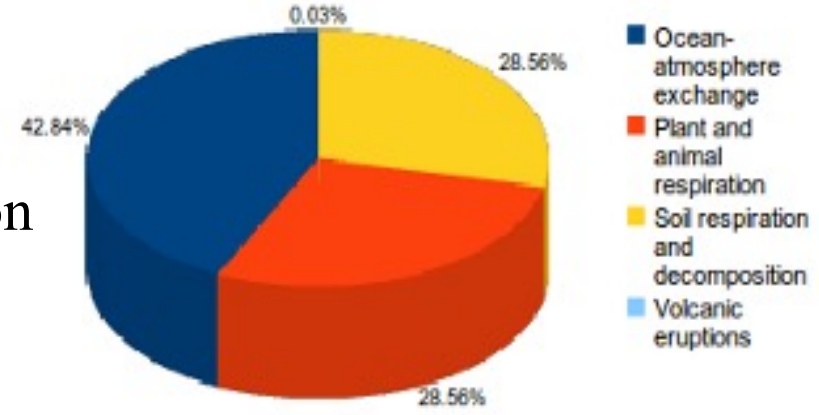
https://www.bloomberg.com/graphics/2015-whats-warming-the-world/?fbclid=IwAR3eKRyBiLY0ksDIHnjG5E0KaUqPmNfyToz_4cwunisjNB3ehT2xyEmfMc0

IV. Important Greenhouse Gases

- Carbon dioxide (CO_2):
  - Human sources: 87%
    - Fossil fuel combustion
    - Land use changes: forest fires
    - Industrial processes
  - Natural sources
    - Ocean-atmosphere exchange
    - Plant and animal respiration
    - Soil respiration and decomposition
    - Volcanic eruptions



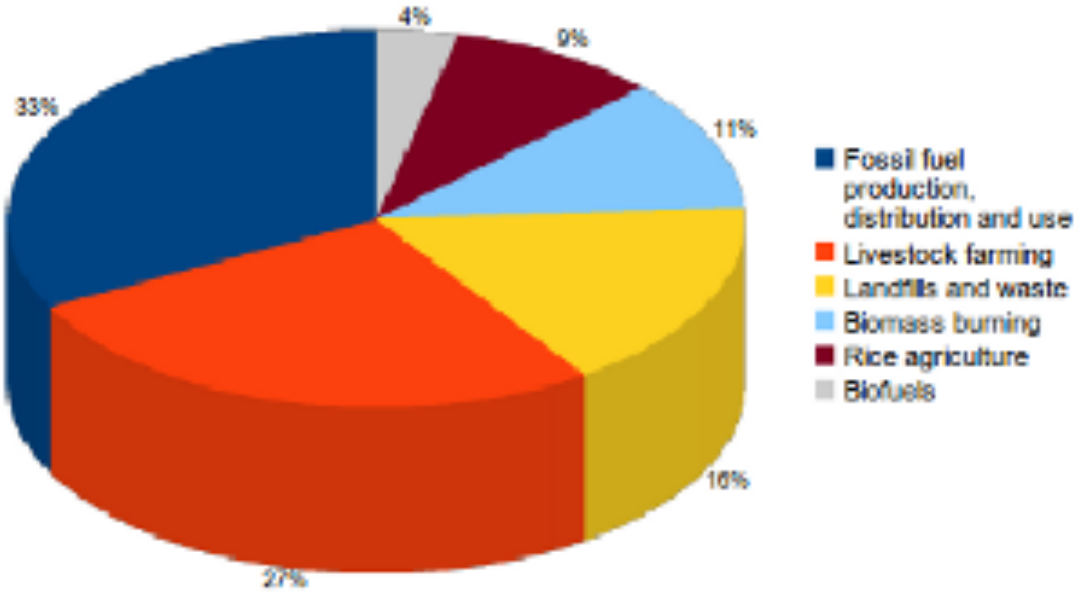
Le Quéré, C. et al. (2013). The global carbon budget 1959-2011.

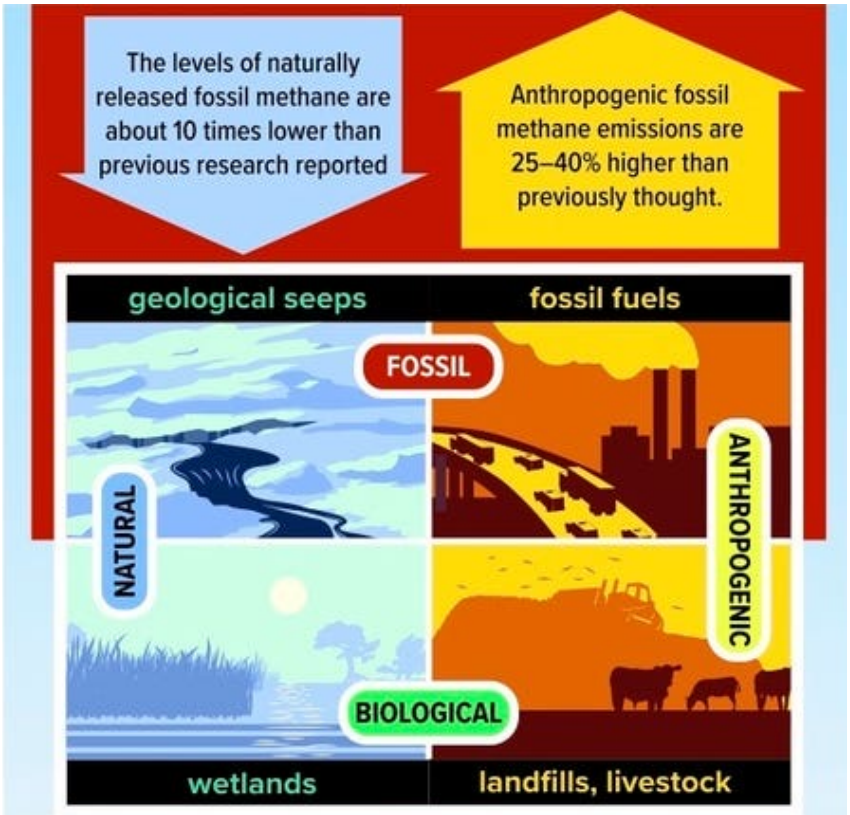


IPCC Fourth Assessment Report: Climate Change 2007

IV. Important Greenhouse Gases (cont.)

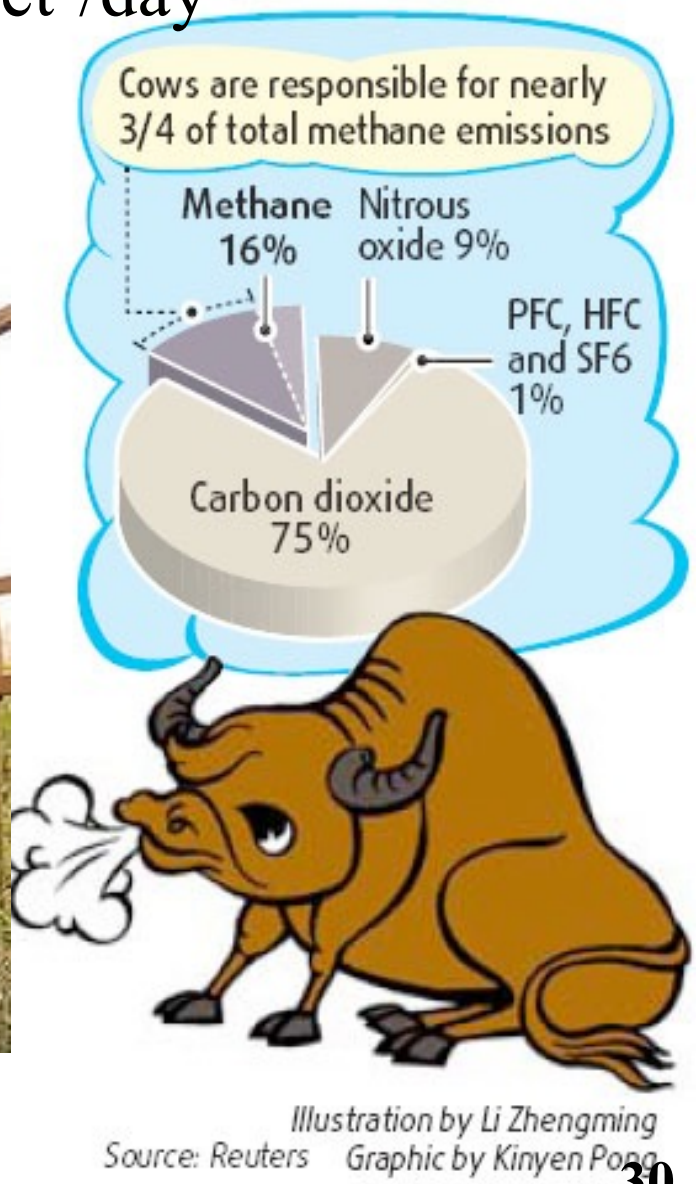
- Methane (CH_4): generated from fossil fuel production (33%), livestock farming (27%), landfills and waste (16%), biomass burning (11%), rice (9%), biofuels (4%)
- Methane can trap heat 28 times more powerful than CO_2





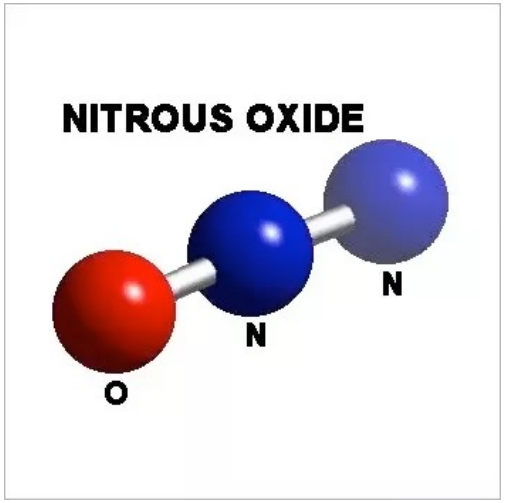
Methane from livestock farming

A cow generates methane up to 25-35 feet^3/day



IV. Important Greenhouse Gases (cont.)

- Nitrous oxide: N_2O: 67% of human sources come from agriculture (fertilized soils and livestock manure 42%, and runoff and leaching of fertilizers 25%)
- Nitrous Oxide (N_2O) has a GWP 265–298 times that of CO_2 for a 100-year timescale.
- Nitrous oxide has also been implicated in thinning the ozone layer



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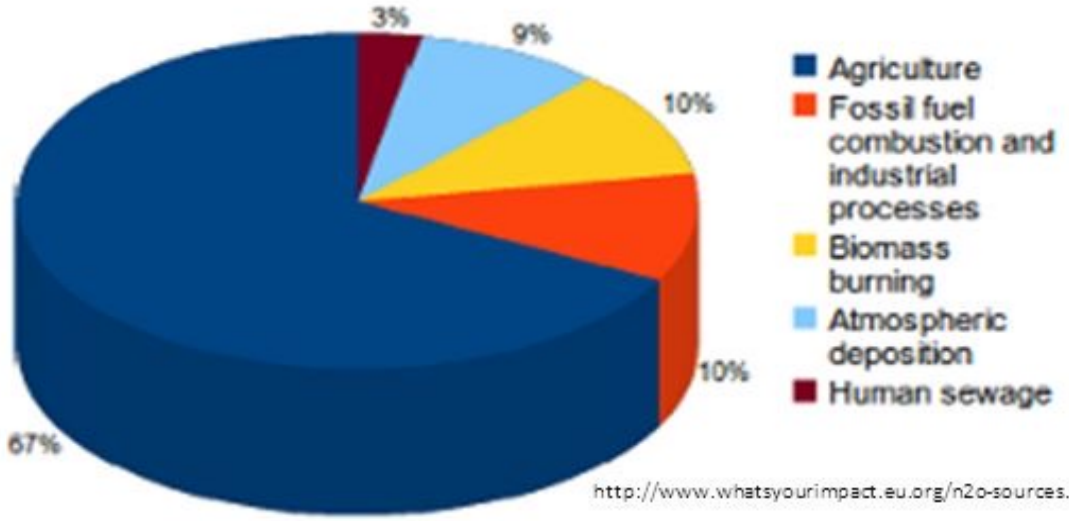
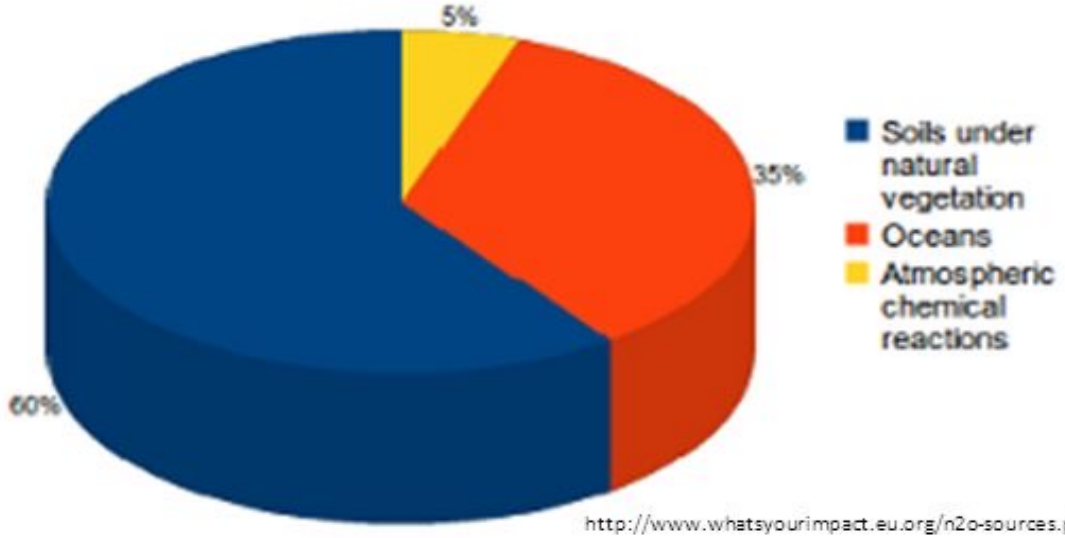
Human sources of nitrous oxide

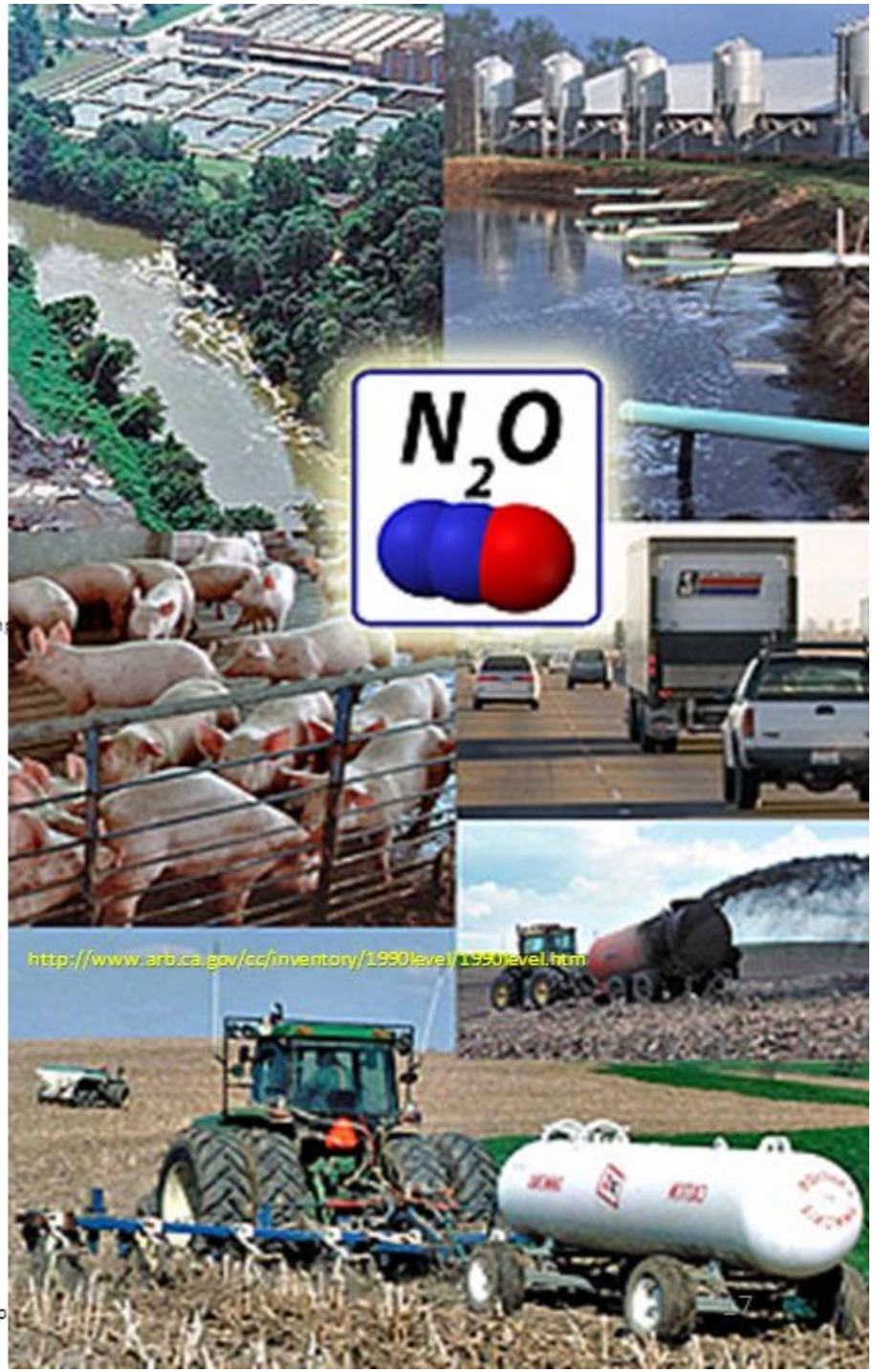


http://www.whatsyourimpact.eu.org/n2o-sources.php

Natural sources of nitrous oxide



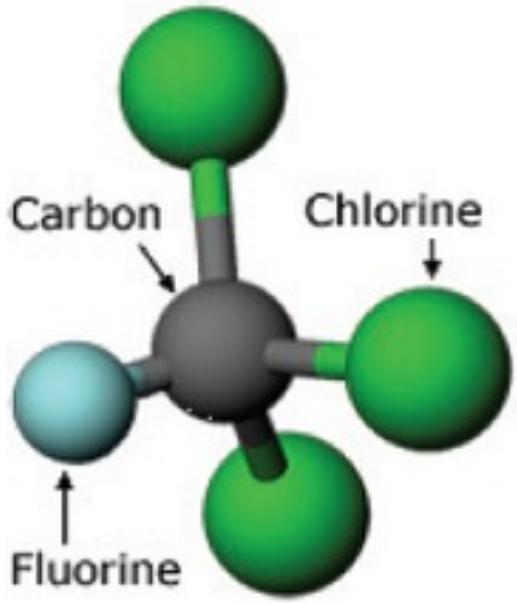
http://www.whatsyourimpact.eu.org/n2o-sources.php

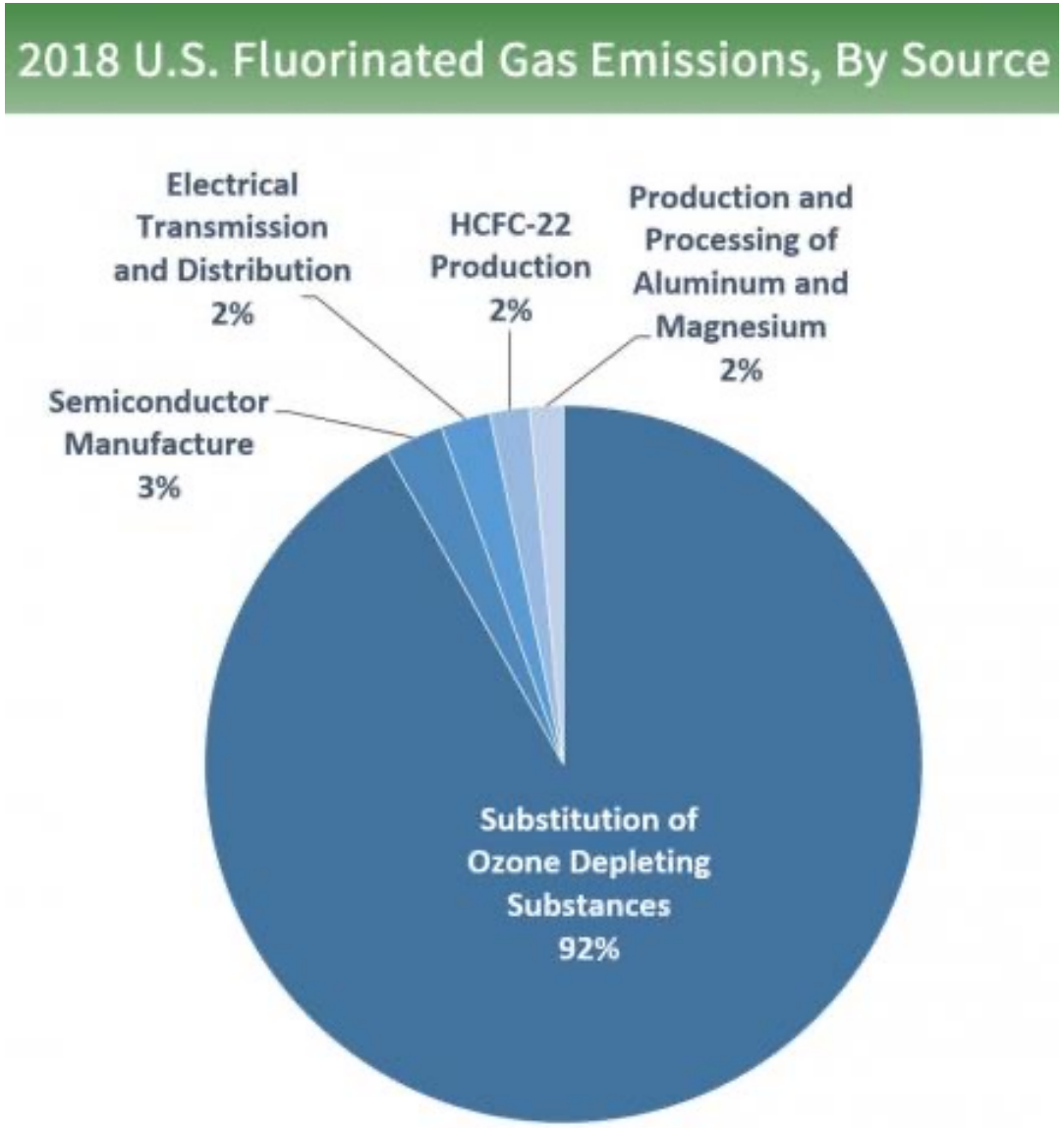


IPCC Fourth Assessment Report: Climate Change 2007

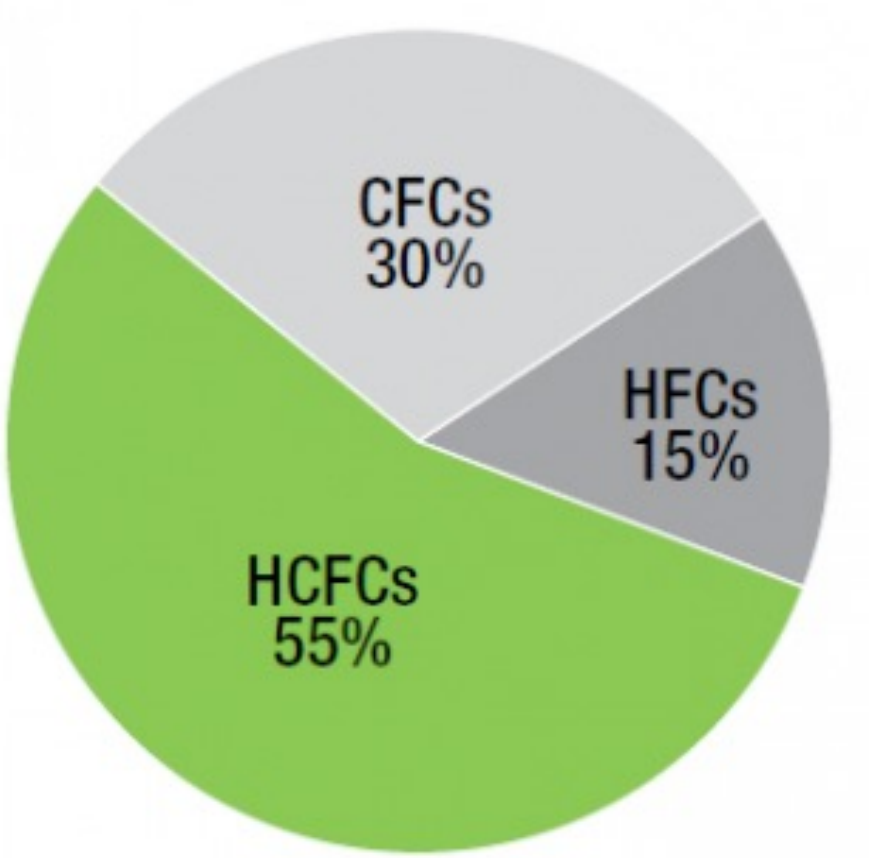
IV. Important Greenhouse Gases (cont.)

- **Fluorinated Gases:** have no natural sources and only come from human-related activities.
- They are emitted through their use as substitutes for ozone-depleting substances (e.g., as refrigerants) and through a variety of industrial processes such as aluminum and semiconductor manufacturing.





Share of refrigerants



https://www.epa.gov/ghgemissions/overview-greenhouse-gases#f-gases

http://www.foodandland.org/the-growing-climate-threat-from-halocarbon-refrigerants-cfcs-hcfcs-and-hfcs/

Important GHGs

- Water vapor
- Ozone (O_3): human sources of ozone are pharmaceutical production, synthetic lubricant
  - Ozone that occurs at the Earth surface is a pollutant that cause smog and global warming
  - Natural occurred ozone molecules are formed through the action of ultraviolet (UV) radiation from the Sun on molecules of oxygen. They absorb UV radiation that would otherwise be harmful to life at the Earth's surface.

Important GHGs

- CFCs, one of the fluorinated gases used as refrigerant, is the main cause of ozone hole over Antarctica which leads to the campaign to phase out CFCs
- Other fluorinated gases:
  - Sulfur hexafluoride (SF_6): used as insulator in electrical industry
  - Hexafluoroethane (C_2F_6): used as a versatile etchant in semiconductor manufacturing

Direct radiative effects

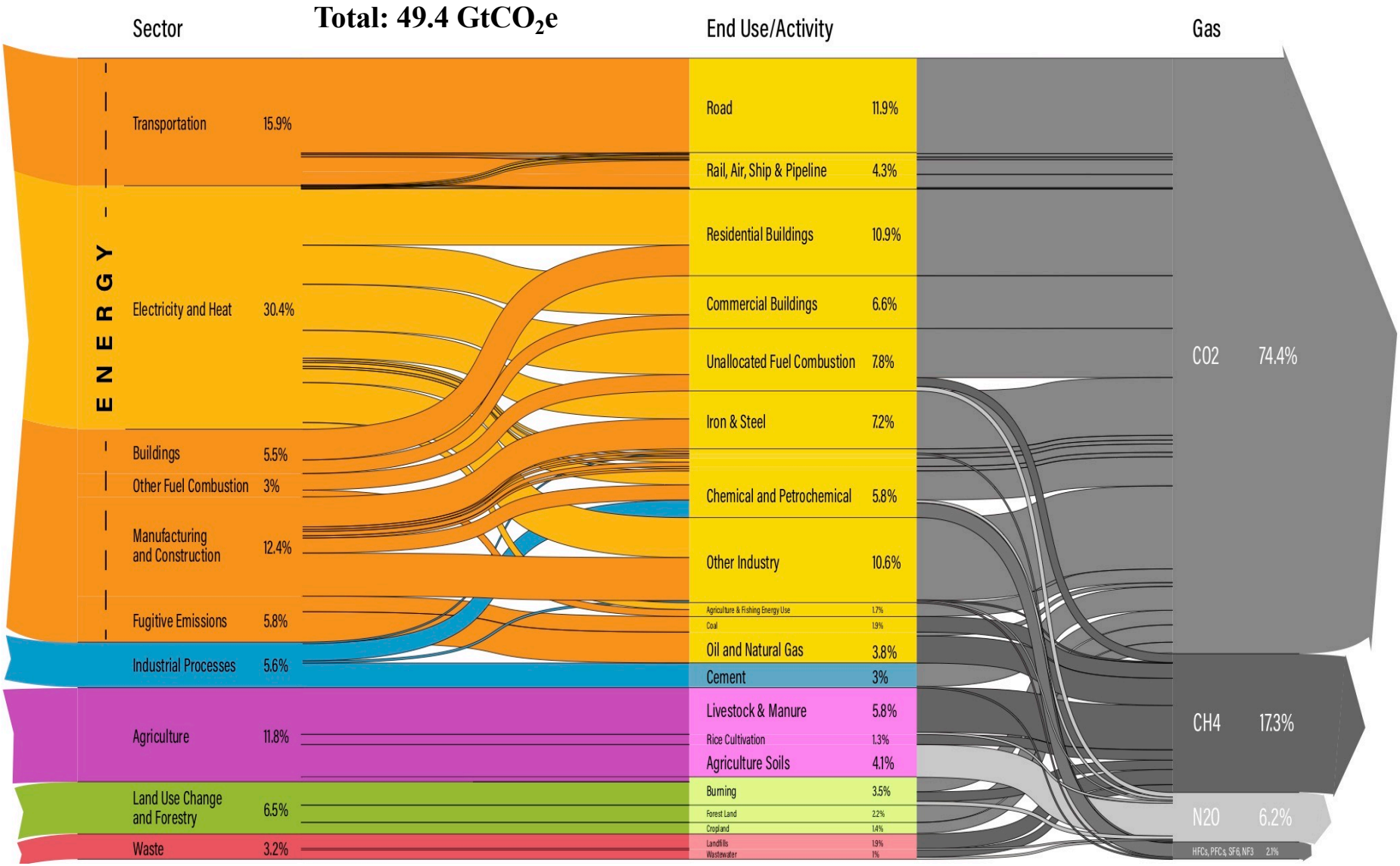
- Radiative forcing: The change in average net radiation at the top of the troposphere (the lower atmosphere) which occurs because of a change in the concentration of a greenhouse gas
  - Water vapor is a GHG which generate the highest direct radiative effect (36 – 72%), CO_2 (9–26%), Methane (4 – 9%), Ozone (3 – 7%)
- Global Warming Potential (GWP) is the ratio of the enhanced greenhouse effect of any gas compared with that of CO_2 which has a GWP = 1

Global Warming Potential (GWP)

GWP values and lifetimes	Lifetime in years	Global Warming Potential (GWP)		
		20 years	100 years	500 years
Cabon dioxide CO_2	100	1	1	1
Methane (CH_4)	12	72	25	8
Nitrous oxide (N_2O)	114	289	298	153
CFC-12 (CCl_2F_2)	100	11,000	10,900	5,200
HCFC-22 ($CHClF_2$)	12	5,160	1,810	549
HFC-134a (hydrofluorocarbon)	14	3,830	1,430	435
CFC-11 (chlorofluorocarbon)	45	6,730	4,750	1,620
Carbon tetrafluoride (CF_4)	50,000	5,210	7,390	11,200
HFC-23 (hydrofluorocarbon)	270	12,000	14,800	12,200
Sulfur hexafluoride (SF_6)	3,200	16,300	22,800	32,600

Source: Wikipedia

World Greenhous Gas Emissions in 2016

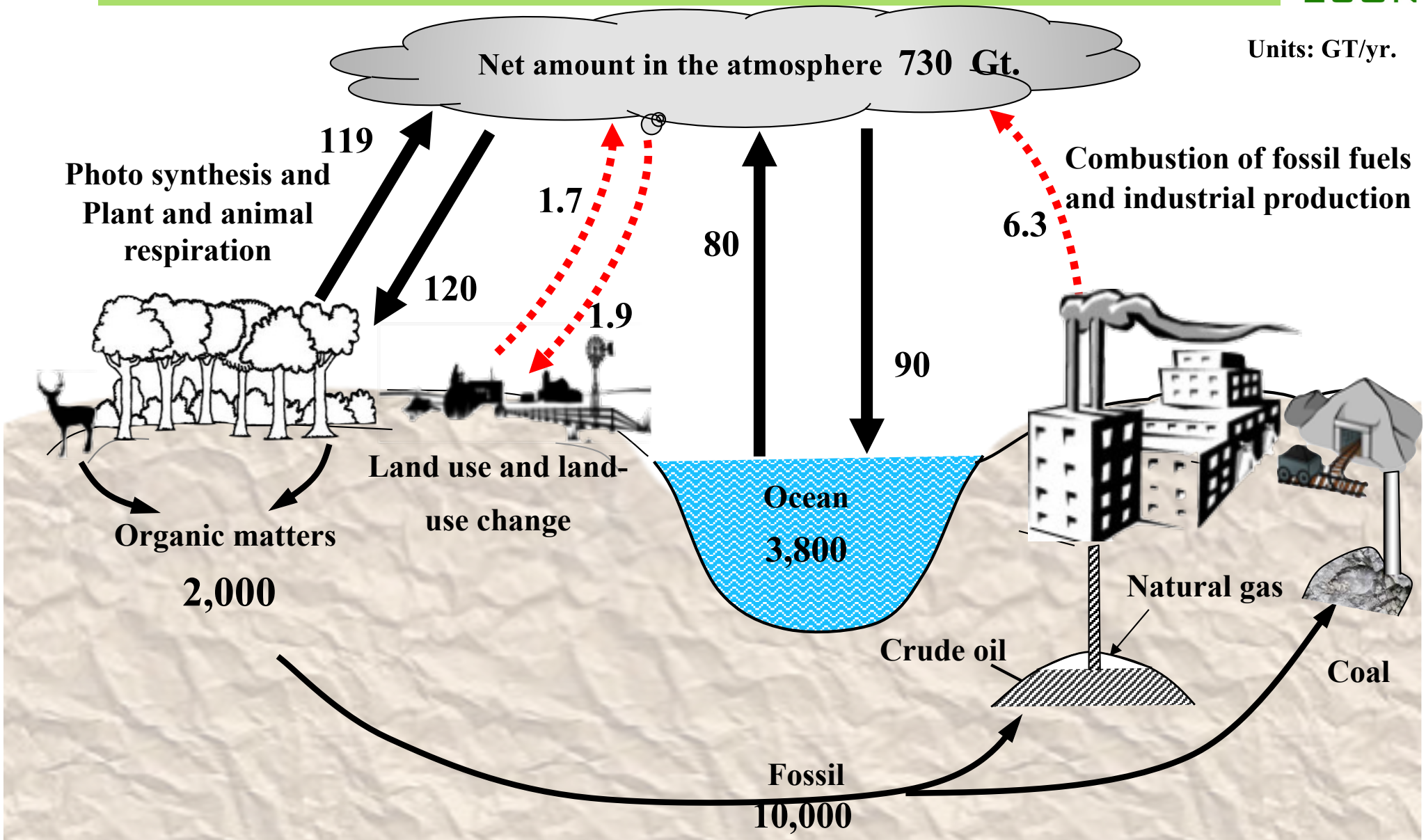


Source: Greehouse gas emission on Climate Wath, World Resources Institute. Available at: https://wriorg.s3.amazonaws.com/s3fs-public/world-greenhouse-gas-emissions-sankey-chart-2019_2.jpg

World greenhouse gas emission in 2016

- CO_2 is the most important anthropogenic GHGs (74.4%) follows by methane (17.3%) and Nitrous oxide (6.2%)
- Share by sectors
  - Electricity and heat (30.4%) Transportation (15.9%)
  - Manufacturing and construction (12.4%) Agriculture (11.8%)
- Share by End use/Activity
  - Residential and commercial building (17.5%), Road (11.9%)
  - Iron & steel (7.2%) Chemical and petrochemical (5.8%)
  - Livestock & manure (5.8%)

CO_2 and carbon cycle

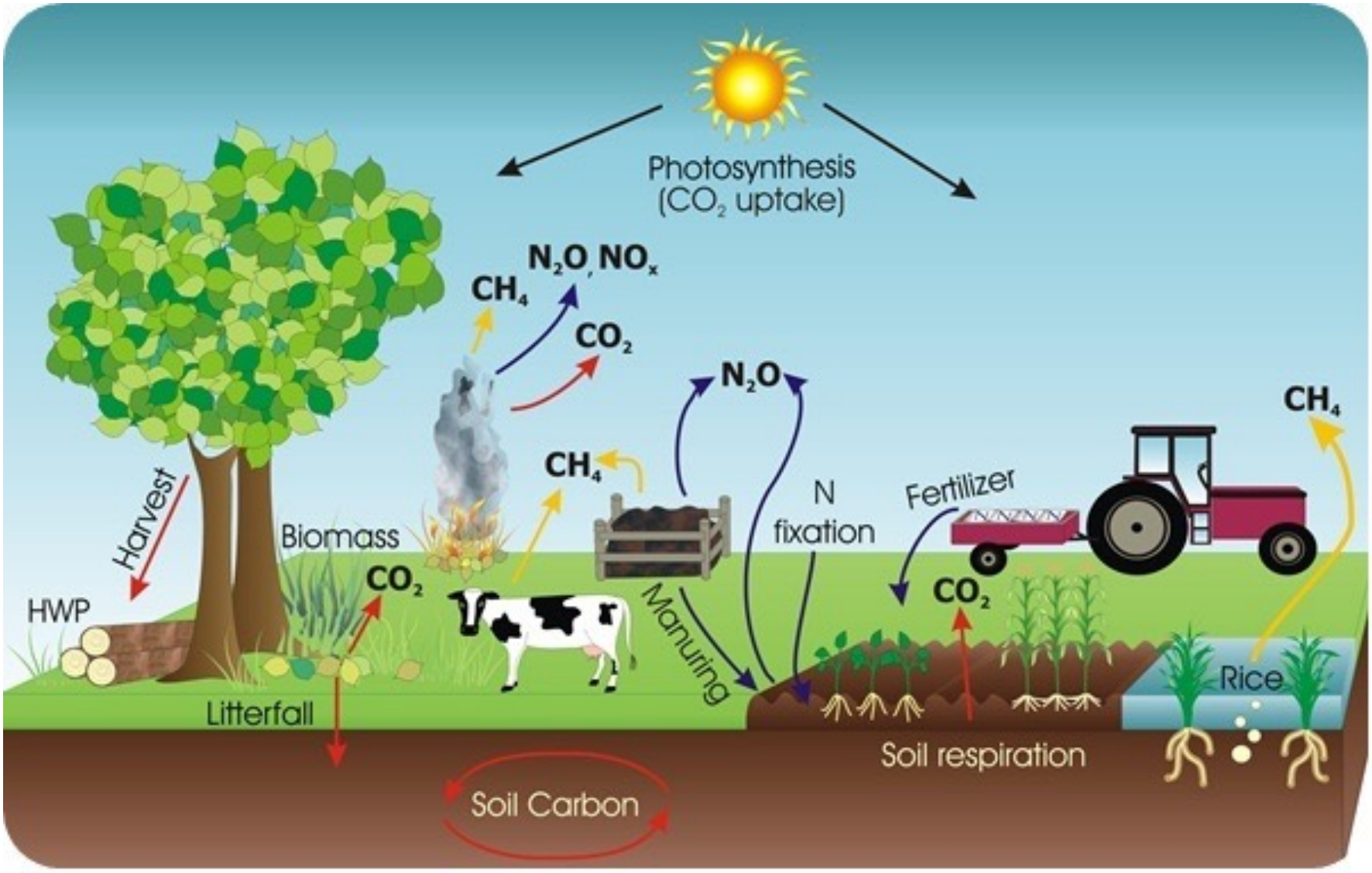


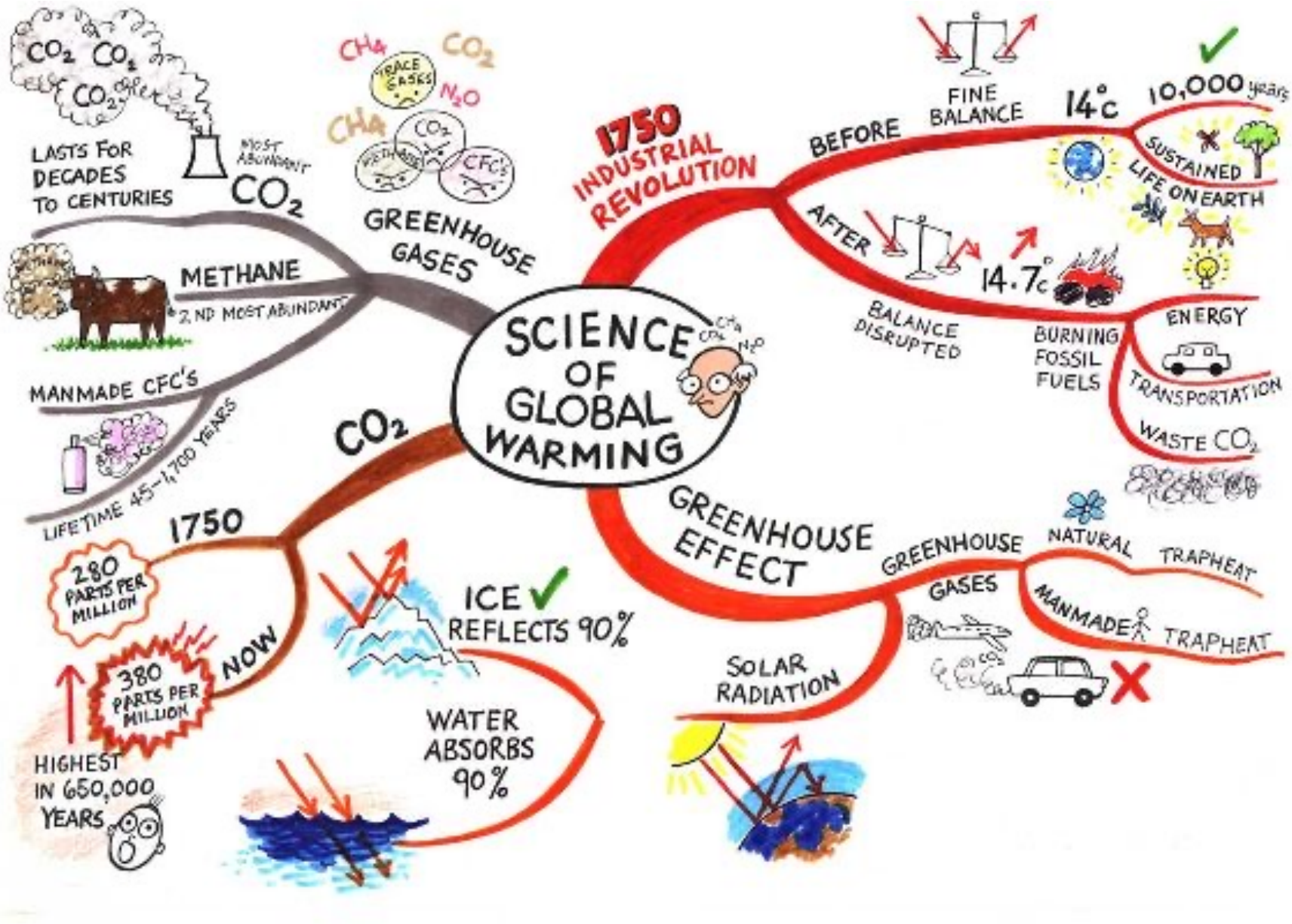
carbon cycle

- Natural cycle
  - Increases CO_2
    - Respiration
    - Diffusion from ocean
    - Organic decomposition
- Man made
  - Increases CO_2
    - Fossil burning
    - Land use and land use change

- **Natural cycle**
  - Decreases CO_2
    - Photosynthesis
    - Diffusion to ocean
    - Fossilization
- Man made
  - Decreases CO_2
    - Carbon capture and storage
    - Afforestation and reforestation

Agriculture and GHGs





https://www.mindmapart.com/category/mind-mappers/sharon-genovese-mind-maps/

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