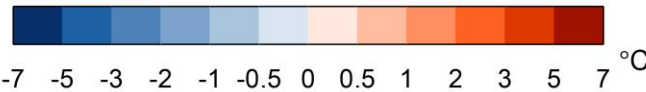
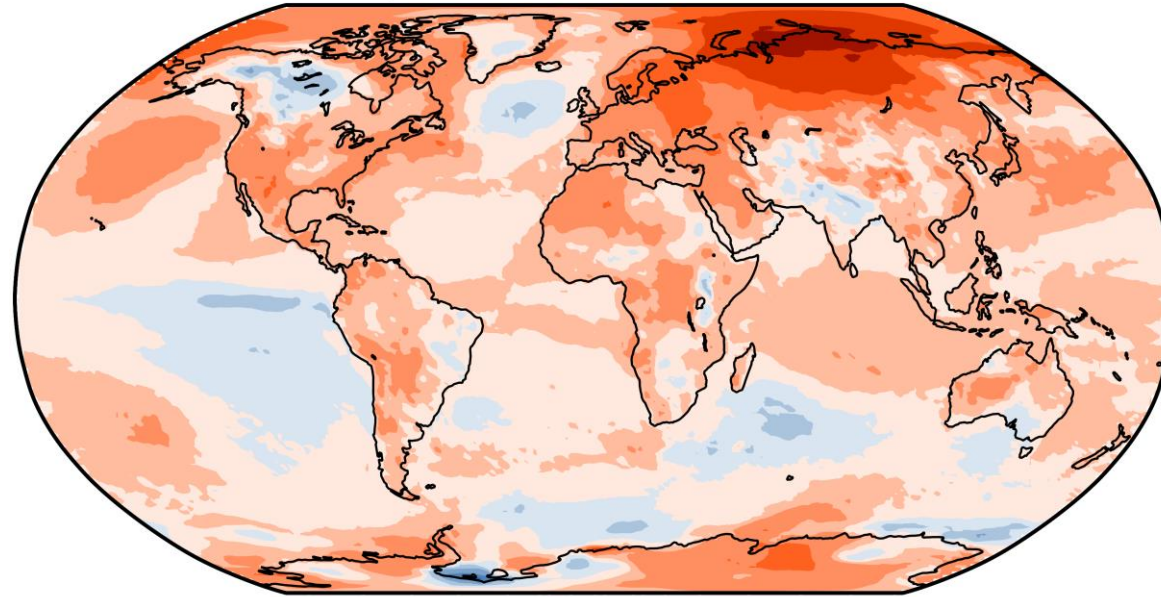


Temperature difference 2020 and 1981-2010



Data source: ERA5

7.5 THE GREENHOUSE EFFECT AND INCREASES IN GREENHOUSE GASES

College Board Topic 9.3

Related Reading: Chapter 18

Learning Objectives and Essential Knowledge

ENDURING UNDERSTANDING

STB-4

Local and regional human activities can have impacts at the global level.

LEARNING OBJECTIVE

STB-4.C

Identify the greenhouse gases.

STB-4.D

Identify the sources and potency of the greenhouse gases.

ESSENTIAL KNOWLEDGE

STB-4.C.1

The principal greenhouse gases are carbon dioxide, methane, water vapor, nitrous oxide, and chlorofluorocarbons (CFCs).

STB-4.C.2

While water vapor is a greenhouse gas, it doesn't contribute significantly to global climate change because it has a short residence time in the atmosphere.

STB-4.C.3

The greenhouse effect results in the surface temperature necessary for life on Earth to exist.

STB-4.D.1

Carbon dioxide, which has a global warming potential (GWP) of 1, is used as a reference point for the comparison of different greenhouse gases and their impacts on global climate change. Chlorofluorocarbons (CFCs) have the highest GWP, followed by nitrous oxide, then methane.

SUGGESTED SKILL



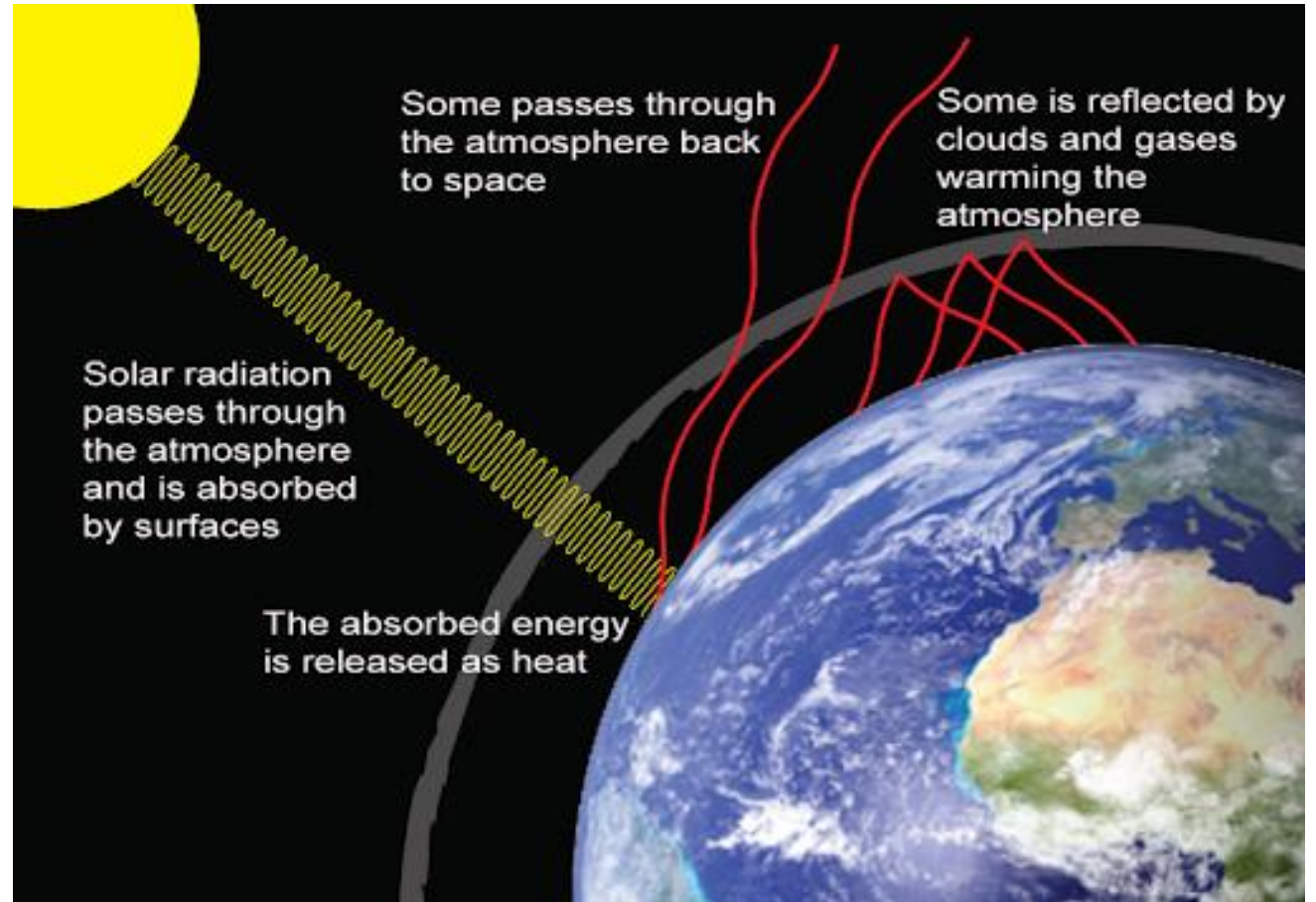
Concept Explanation

1.B

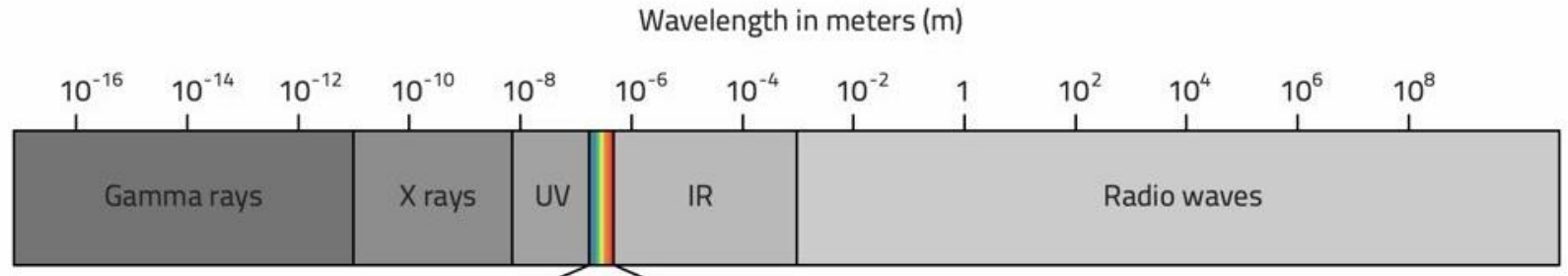
Explain environmental concepts and processes.

The Greenhouse Effect

- The *greenhouse effect* occurs naturally when gases in the atmosphere absorb outgoing heat (IR radiation) from the surface of Earth and reradiate this heat back towards Earth's surface.
- Without the greenhouse effect the planet could not sustain life as we know it.
 - Without it, surface temperatures on Earth would be 33°C colder on average.
 - Temperature differences between night and day would be far greater than they are now.



The Greenhouse Effect

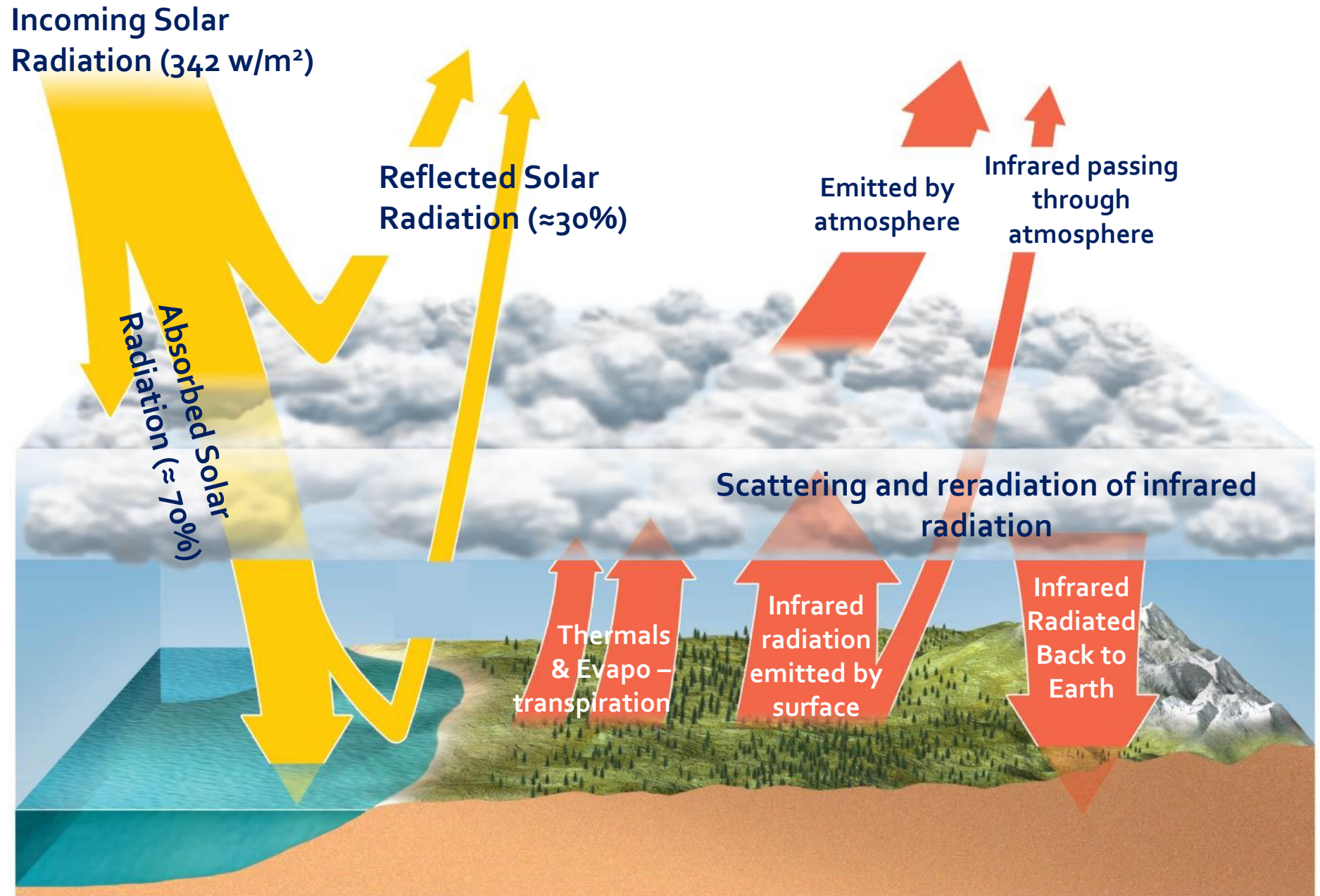


- Earth and its lower atmosphere receive 342 watts/m^2 of solar radiation, primarily in a range of wavelengths that include ***ultraviolet (UV), visible light, and Infrared (IR) radiation.***
 - $\approx 30\%$ of this energy is reflected by earth and its atmosphere back into space.
 - $\approx 70\%$ of this energy is absorbed by earth and its atmosphere.

Of the 70% of energy absorbed:

- Shorter wavelengths, such as UV and visible light, are mostly transmitted through the atmosphere, while longer wavelengths of IR tends to be absorbed by gases in the atmosphere.
- UV and visible light reaching the planets surface that is not reflected, is absorbed and reradiated as IR.
- Much of the outgoing IR is absorbed by gases in the atmosphere and reradiated back towards Earth causing additional warming of the planet (***the greenhouse effect***)

- Preindustrial Earth (1750) absorbed and emitted 342 watts/m² of energy.
- This balance helped keep temperatures relatively constant on preindustrial Earth



GHG's absorb IR, but transmit UV and visible light

- Naturally occurring greenhouse gases (GHG's) in the atmosphere include:
 - Water vapor (H_2O) from evaporation and transpiration
 - Carbon Dioxide (CO_2) from respiration, decomposition, fires, volcanoes
 - Methane (CH_4) from anaerobic decomposition
 - Nitrous Oxide (N_2O) a byproduct of denitrification ($\text{NO}_3 \rightarrow \text{N}_2$) carried out by soil bacteria.
 - Ozone (O_3) from photochemical reactions that split O_2 in the stratosphere
- Stratospheric ozone's beneficial UV absorbing property outweighs its impacts as a greenhouse gas. Naturally occurring stratospheric ozone levels are declining.
 - Tropospheric ozone levels have increased, but the residence time is so short that anthropogenic increases in ozone have little overall contribution to enhancing the green
- While water vapor is technically a GHG, human activity has little effect on its concentration in the atmosphere since it has such a short residence time.
 - As the concentration vapor begins to rise, water condenses and falls as precipitation, lowering the atmospheric concentration of water vapor once again.
- Human activities are increasing the concentrations of many of these naturally occurring GHG's and adding an additional, man-made class of GHG's to the atmosphere, halocarbons (CFC's, HCFC's, HFC's).

The enhanced greenhouse effect

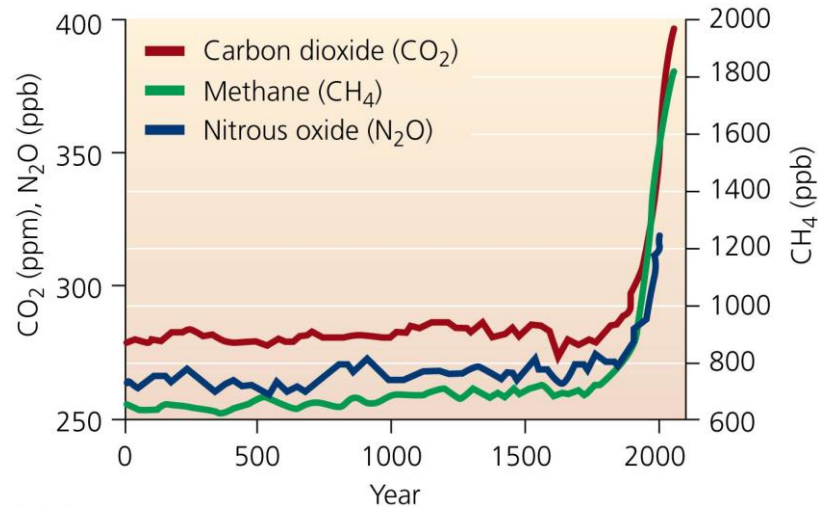


TABLE 18.1 Global Warming Potentials of Four Greenhouse Gases

GREENHOUSE GAS	RELATIVE HEAT-TRAPPING ABILITY (IN CO ₂ EQUIVALENTS)
Carbon dioxide	1
Methane	25
Nitrous oxide	298
Hydrochlorofluorocarbon HFC-23	14,800

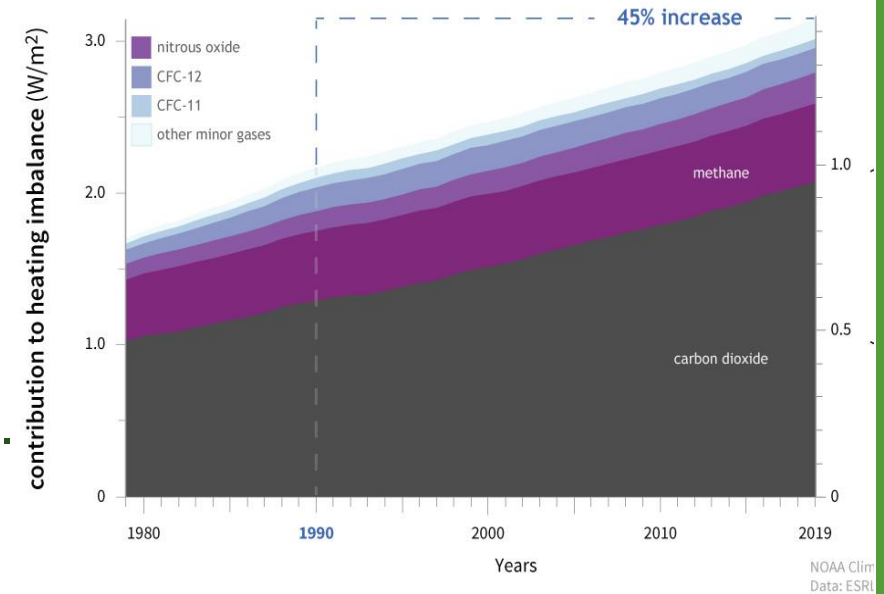
Data are for a 100-year time horizon, from IPCC, 2007. Fourth assessment report. Climate change 2007: The physical science basis.

- Increases in the concentration of GHG's in the atmosphere increases the amount of infrared radiation (IR) absorbed and reradiated back to earth by the atmosphere.
 - Increases the amount of energy retained at the surface of earth and the troposphere
 - Earth now retains an additional ≈ 1.6 watts/m² that it does not reradiate into space, resulting in an increase in the average global temperature.
 - Human induced change in the greenhouse effect is sometimes called the *Enhanced Greenhouse Effect*
- **Some GHG's have a larger impact on global temperatures than others.**
 - Global Warming potential (GWP) is a measure of how much a given molecule contributes to warming over a 100 year period relative to a molecule of CO₂.
 - GWP depends on infrared absorption and residence time in the atmosphere.
 - Man-made halocarbons have low concentrations but a very high GWP.
 - CO₂ has the lowest GWP but has the greatest warming effect since it is so abundant.

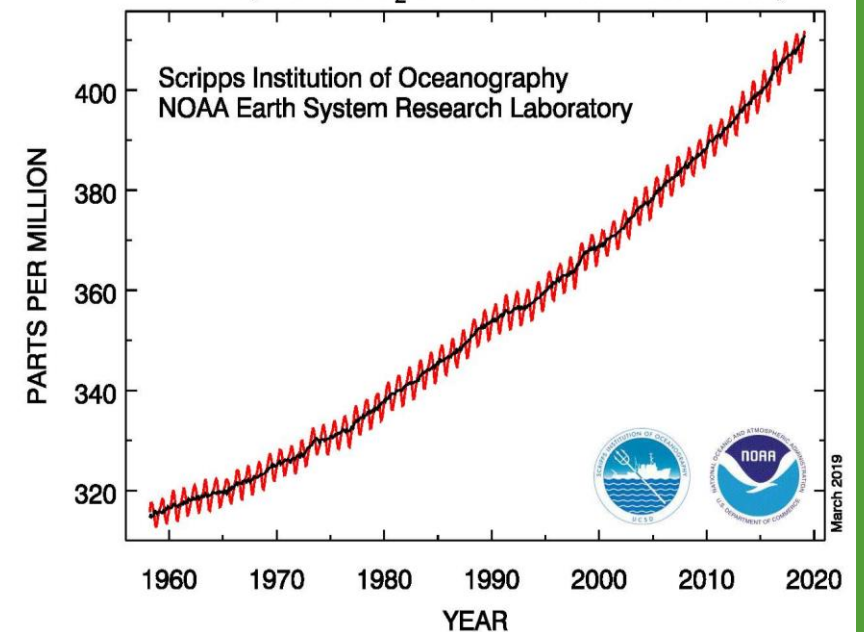
Anthropogenic causes of CO₂ increase

- **Carbon dioxide is the major contributor to the enhanced Greenhouse effect.**
 - CO₂ is responsible for 64% of manmade global warming.
 - The preindustrial level (1750) of CO₂ in the atmosphere was 278 ppm, it is currently 417 ppm (2021).
 - This is the highest CO₂ concentration in the last 800,000 years.
- **Combustion of fossil fuels is primarily to blame (electricity, driving, industry) for increasing CO₂**
 - $\text{Hydrocarbons} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$
 - Carbon released is fossil carbon that would have stayed out of the atmosphere indefinitely.
- **Deforestation, especially tropical deforestation, is another major contributor to the rise in atmospheric CO₂.**
 - Photosynthesis removes CO₂ from the atmosphere.
 - With less forested areas, CO₂ is removed more slowly from the atmosphere, resulting in a rise in atmospheric CO₂.
 - Tropical forests have the highest NPP (grams C/m²/yr) of all terrestrial ecosystems and remove more CO₂ per unit of area than any other biome.

COMBINED HEATING INFLUENCE OF GREENHOUSE GASES



Atmospheric CO₂ at Mauna Loa Observatory



Anthropogenic causes of CH₄ increase

- **Methane (CH₄) is the second leading contributor to the enhanced greenhouse effect.**
 - Increases in Methane are responsible for 17% of man-made global warming.
 - Methane levels have risen from 722 ppb in pre-industrial times (1750) to 1866 ppb (2019)
 - This is the highest concentration of atmospheric methane in the last 800,000 years.
- **Sources of Anthropogenic Methane**
 - Feedlot agriculture (37% of anthropogenic CH₄ emissions): increases in anaerobic decomposition caused by construction of manure lagoons and CH₄ releases from cattle burping as part of their digestion of cellulose.
 - Rice Agriculture (18%): Waterlogged soils and swamp-like environments required for rice production increases anaerobic decomposition by soil organisms.
 - Landfills (18%): Large amounts of organic material and oxygen depleted environments leads to anaerobic decomposition.
 - Oil and natural gas supply chain (15%): normal operations, leaks, and venting of equipment results in releases of methane.



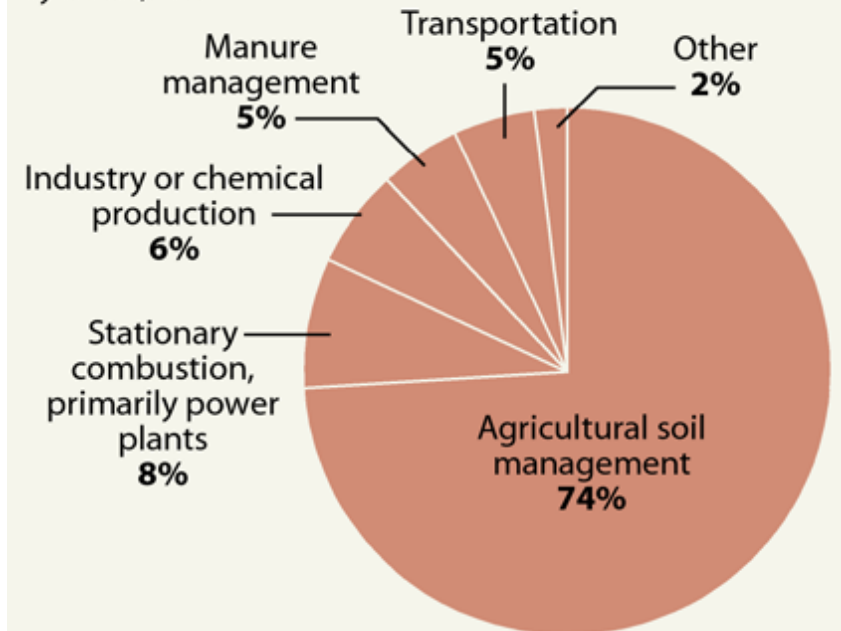
Anthropogenic causes of N₂O increase

- Nitrous Oxide (N₂O) is the third leading cause of the enhanced greenhouse effect.
 - N₂O is responsible for 6% of man-made global warming.
 - N₂O levels in the atmosphere have risen from 280 ppb in preindustrial times (1750) to 328 ppb (2015)
 - This is the highest level in the last 800,000 years.
- Agriculture is the major anthropogenic source of N₂O.
 - Increases in Nitrogen fertilizers → increases in soil nitrogen → increases in denitrification. Denitrification produces N₂O as a byproduct.
 - Anaerobic decomposition of nitrogenous compounds in feedlot manure lagoons produces N₂O
- Other anthropogenic sources of N₂O include power plants, industrial chemical production, waste incineration, and treatment of wastewater.



U.S. NITROUS OXIDE EMISSIONS

By source, 2017



Anthropogenic causes of Halocarbon Increases

Gas	Pre-1750 tropospheric concentration ¹	Recent tropospheric concentration ^{2,3}	GWP ⁴ (100-yr time horizon)	Atmospheric lifetime ⁵ (years)	Increased radiative forcing ⁶ (W/m ²)
Concentrations in parts per trillion (ppt)					
CFC-11 (CCl ₃ F)	zero	232 ³	4,660	45	0.060
CFC-12 (CCl ₂ F ₂)	zero	516 ³	10,200	100	0.166
CFC-113(CCl ₂ CClF ₂)	zero	72 ³	5,820	85	0.022
HCFC-22(CHClF ₂)	zero	233 ³	1,760	11.9	0.049
HCFC-141b(CH ₃ CCl ₂ F)	zero	24 ³	782	9.2	0.0039
HCFC-142b(CH ₃ CClF ₂)	zero	22 ³	1,980	17.2	0.0041
Halon 1211 (CBrClF ₂)	zero	3.6 ³	1,750	16	0.0010
Halon 1301 (CBrClF ₃)	zero	3.3 ³	6,290	65	0.0010
HFC-134a(CH ₂ FCF ₃)	zero	84 ³	1,300	13.4	0.0134
Carbon tetrachloride (CCl ₄)	zero	82 ³	1,730	26	0.0140
Sulfur hexafluoride (SF ₆)	zero	8.6 ^{3,11}	23,500	3200	0.0049

- Halocarbons (ex: CFC's, HCFC's, HFC's) are the fourth leading cause of the enhanced greenhouse effect.
 - Halocarbons are responsible for about 4% of man-made global warming.
 - Halocarbon concentrations have increased from zero a few decades ago to only a few ppt, but most have a very high GWP.
 - Concentrations of halocarbons are beginning to stabilize as they are replaced with safer alternatives.
 - Montreal Protocol has helped remove CFC's and replace them with alternatives that have less Ozone Depleting Potential, but many of these replacements have equal or greater GWP.
 - Halocarbons industrial chemicals produced mainly as refrigerants, fire suppressants, and aerosol propellants.

Video Resources

- Global Climate Change
 - <https://www.youtube.com/watch?v=QLteLZNXmyI>