Solar and Terrestrial Radiation

June 9th, 2021

Energy

Ability to do work

Neither created nor destroyed

Different forms of energy

- Kinetic Energy
- Radiant Energy

Note: Temperature is measured using one of three scales:

- Fahrenheit – the is U.S. the only major country still using this scale
- Celsius
- Kelvin

Solar Energy

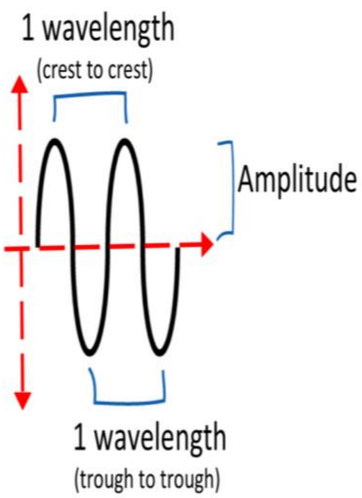
The Sun provides energy for Earth's atmosphere.

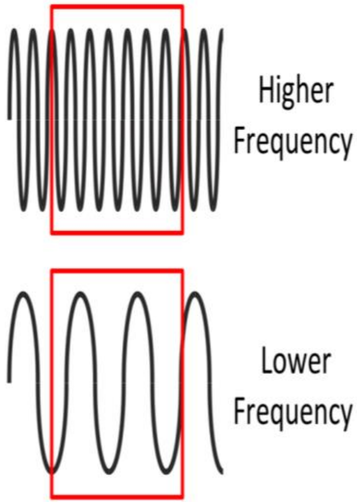
Solar energy consists of electromagnetic waves, which do not diminish in intensity despite traveling 150 million kilometers (93 million miles) to the Earth.

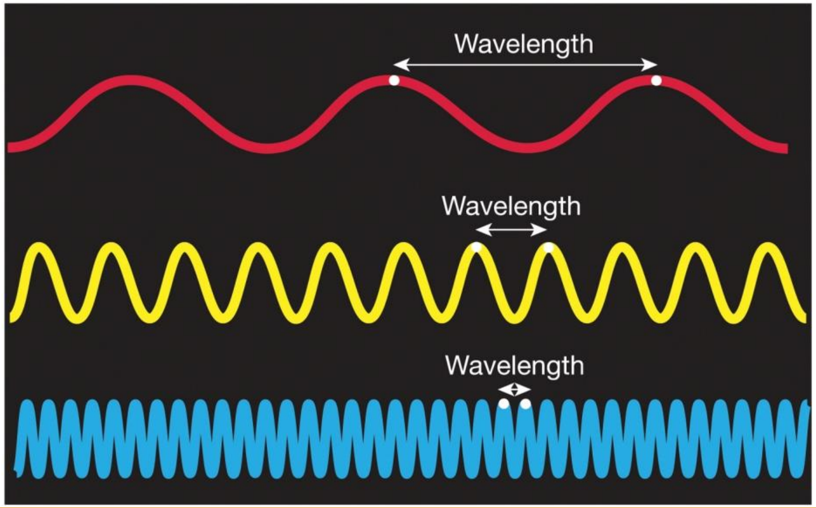
Energy travels at the speed of light (3×10^8 meters per second- or 186,282.03-miles s-1); takes 8 minutes to reach the Earth.

Incoming solar radiation - insolation

ENERGY: electromagnetic wave



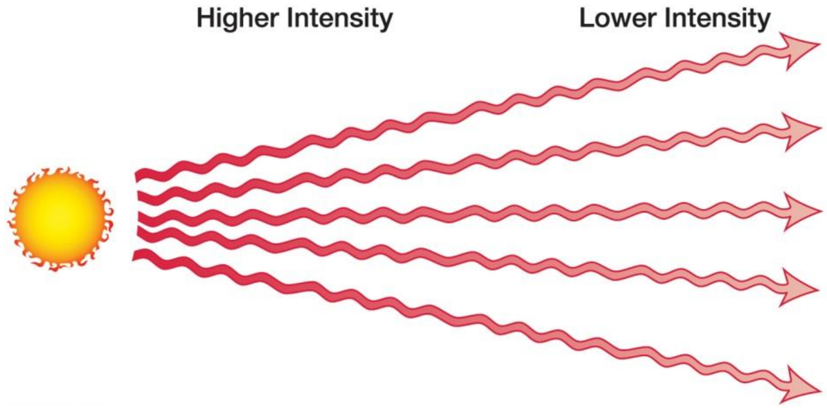


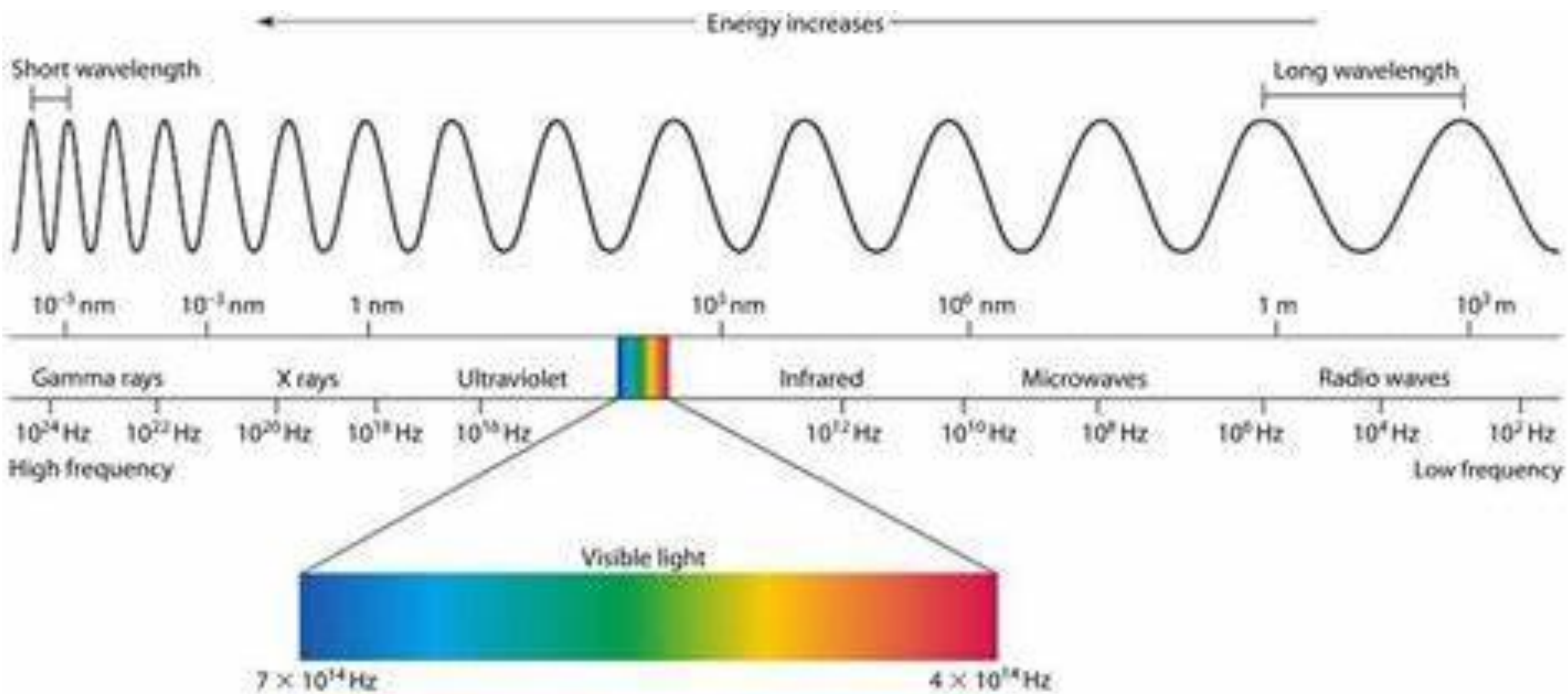


Regions of the Spectrum

The electromagnetic spectrum ranges from the shorter wavelengths to the longer wavelengths.

There are several regions (wavelength interval in the electromagnetic spectrum) which are useful for our ability to study our planet (remember remote sensing) as determined by the atmospheric window.





Energy increases
Short wavelength
Long wavelength
10^{-5} nm
10^{-3} nm
1 nm
10^{3} nm
10^{6} nm
1 m
10^{3} m
Gamma rays
X rays
Ultraviolet
Infrared
Microwaves
Radio waves
10^{24} Hz
10^{22} Hz
10^{20} Hz
10^{18} Hz
10^{16} Hz
10^{12} Hz
10^{10} Hz
10^{8} Hz
10^{6} Hz
10^{4} Hz
10^{2} Hz
High frequency
Low frequency
Visible light
7×10^{14} Hz
4×10^{14} Hz

https://24.media.tumblr.com/d047160f791cee149911c991ddb9ca49/tumblr_mf6r1mA5901rd0rbz01_500.gif

Electromagnetic Radiation

Three areas of the spectrum are important to the study of physical geography:

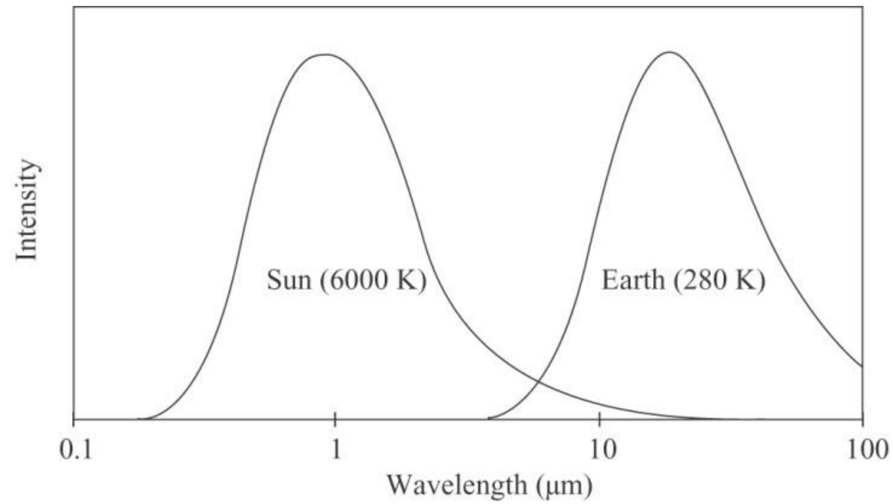
- Visible light—0.4 to 0.7 micrometers; makes up only 3 percent of all electromagnetic spectrum, but 41 % of solar energy.
- Ultraviolet Radiation—0.1 to 0.4 micrometers; too short to be seen by human eye; could cause considerable damage to living organisms if the shortest wavelengths were to reach the Earth's surface, but the atmosphere most of these filters out.
- Infrared Radiation —0.7 to 1000 micrometers; too long to be seen by human eyes; emitted by hot objects and sometimes called heat rays; Earth's radiation is entirely infrared (sometimes called thermal infrared), but only a small fraction of solar radiation.

The Solar-Terrestrial Radiation Divide

Solar Radiation —energy that gets to the Earth’s surface is almost completely in the form of visible light, ultraviolet, and shortwave infrared radiation (collectively referred to as shortwave radiation)

Radiation emitted by the Earth is entirely within the thermal infrared portion of the spectrum (AKA longwave radiation).

A wavelength of 4 micrometers is generally accepted as the boundary between short- and longwave radiation.



Two Laws

1. Hotter objects emit more radiation
   - Sun ~ 6000 degrees K
   - Earth ~ 300 degrees K
   - The Sun is 20 times hotter than Earth; emits 160,000 times more radiation

2. Hotter objects emit shorter wavelengths of energy
   - Sun emits short wavelength – peaks around 0.5 micrometers
   - Terrestrial emits longer wavelengths – peaks around 10 micrometers

Emitted energy

Stefan-Boltzmann law

- All matter above absolute zero (0 Kelvin or -273^{O} C) emits EM radiation
- Amount radiated is a function of surface temperature of the object

$$M = sT^4$$

  - M = total radiant emittance Watts (W) m-2 or the rate of energy emission from an object.
  - s = Stefan-Boltzmann constant (5.6697 x 10 -8 W m-2 K -4),
  - T = absolute temperate (K) of the emitting material in Kelvins
  - i.e., total energy emitted is proportional to T^4
- Hence, "Hotter objects emit more radiation" – Law 1

Emitted energy

Wein's displacement law

$$\lambda(max) = A/T$$

- λ(max) = wavelength of maximum spectral radiant exitance, μm or the dominant wavelength to leave an object)
- A = constant (2898 μm K)
- T = Temperature, Kelvins

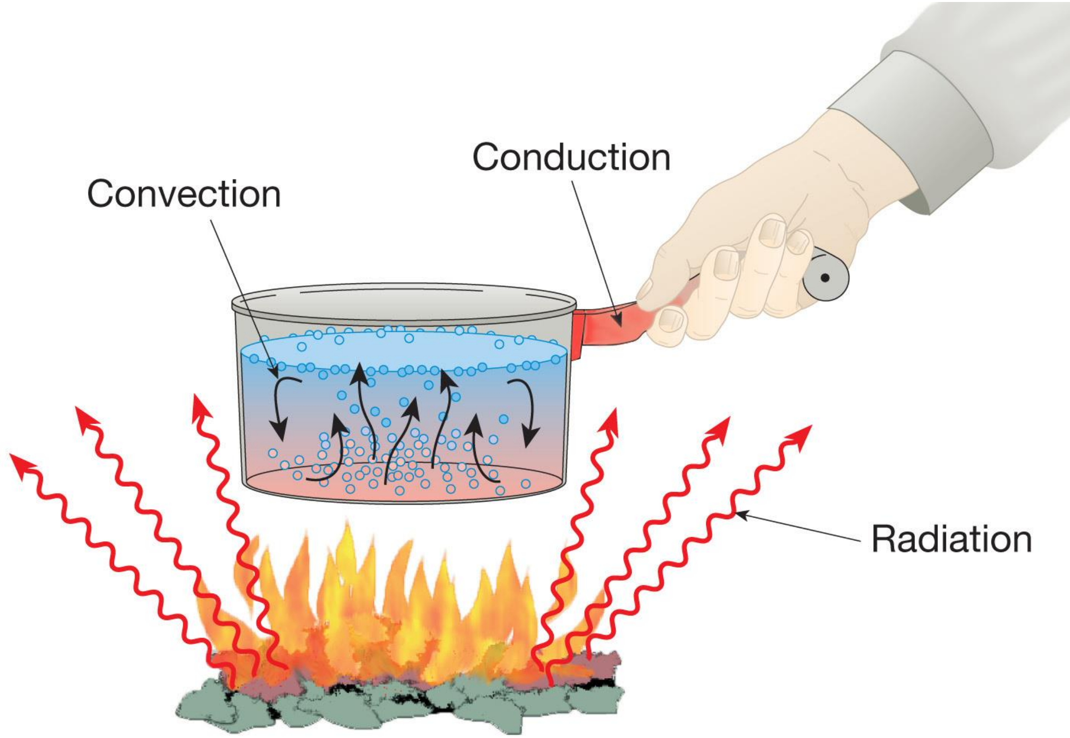
- Hence, "Hotter objects emit shorter wavelengths " – Law 2
- All objects with a temperature above absolute zero (0-degree Kelvin or -273 degrees Celsius) emits energy
- Shorter wavelengths have higher energy content

How does Energy get to us and move around the atmosphere?

Insolation Pathways:
Solar Radiation’s Arrival Into our Atmosphere

Heat energy moves from one place to another in three ways:

- Radiation
- Conduction
- Convection



https://www.simscale.com/docs/simwiki/heat-transfer-thermal-analysis/what-is-heat-transfer/

Radiation

Process by which electromagnetic energy is emitted from an object and transferred from one place to another without a medium (the presence of matter).

Temperature and nature of the surface of the object significantly affects radiation effectiveness.

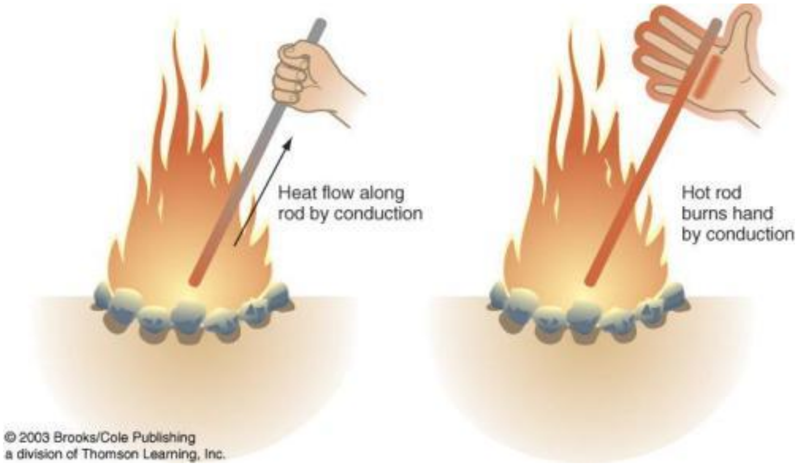
- Hot bodies are more potent than cool bodies (hotter object = more intense radiation at shorter wavelengths).
- Blackbody radiator—a theorethical body that emits the maximum amount of radiation possible, at every wavelength, for its temperature.
- Earth emits longer wavelengths of radiation (i.e., thermal infrared) energy.

Conduction

The movement of energy from one molecule to another without changes in the relative positions of the molecules.

It enables the transfer of heat between different parts of a stationary body, or from one object to a second object when the two are in contact.

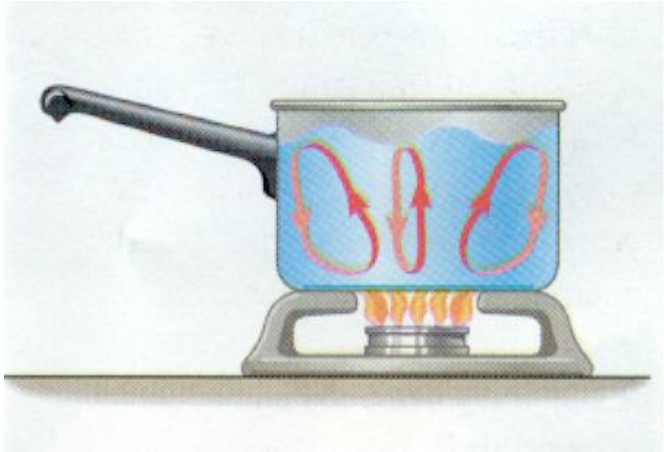
- Conduction requires molecular movement. Although the molecules do not move from their relative positions, they do become increasingly agitated as heat is added.
- The hot molecule collides against a cooler, calmer molecule, transferring kinetic energy to it through the back-and-forth vibratory action.
- In this manner heat is passed from one place to another.



Convection

The transfer of heat by a moving substance (opposite of conduction) such as air or water from one point to another by predominantly vertical circulation.

- Molecules move away from the heat source, from one place to another, rather than just vibrating from agitation (conduction).
- Convection Cell : very important in weather and climate studies
- Occurs in each hemisphere during its summer and throughout the year in the tropics.

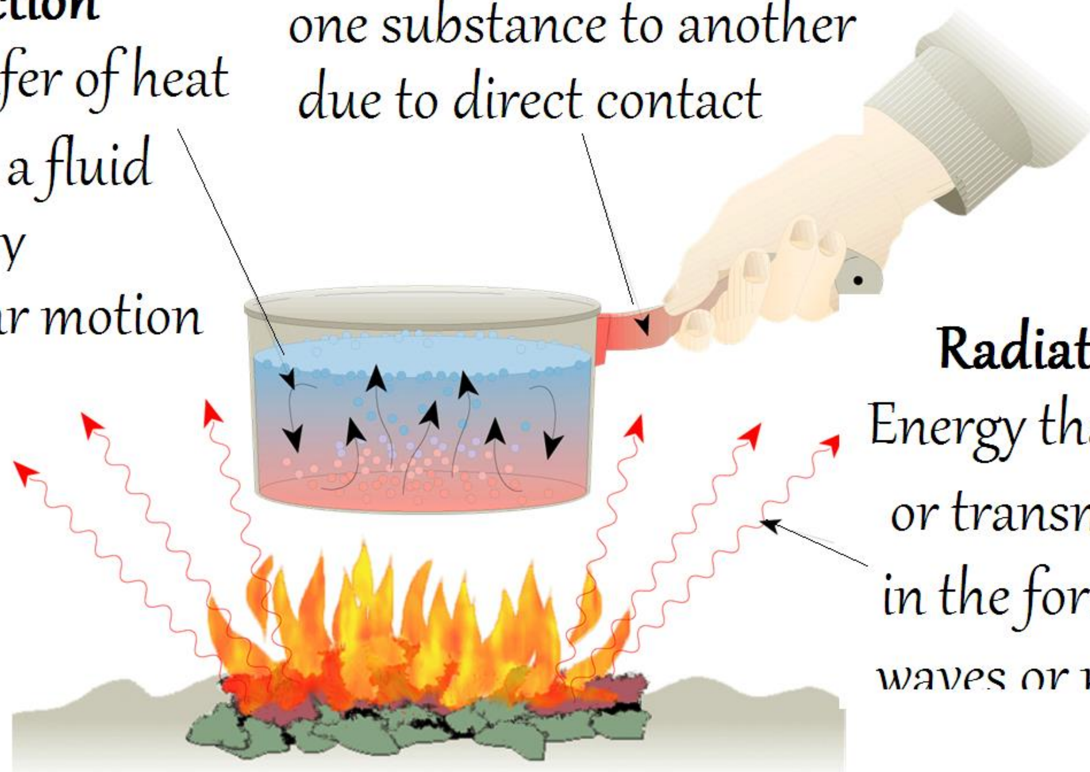


Conduction

The transfer of heat from one substance to another due to direct contact

Convection

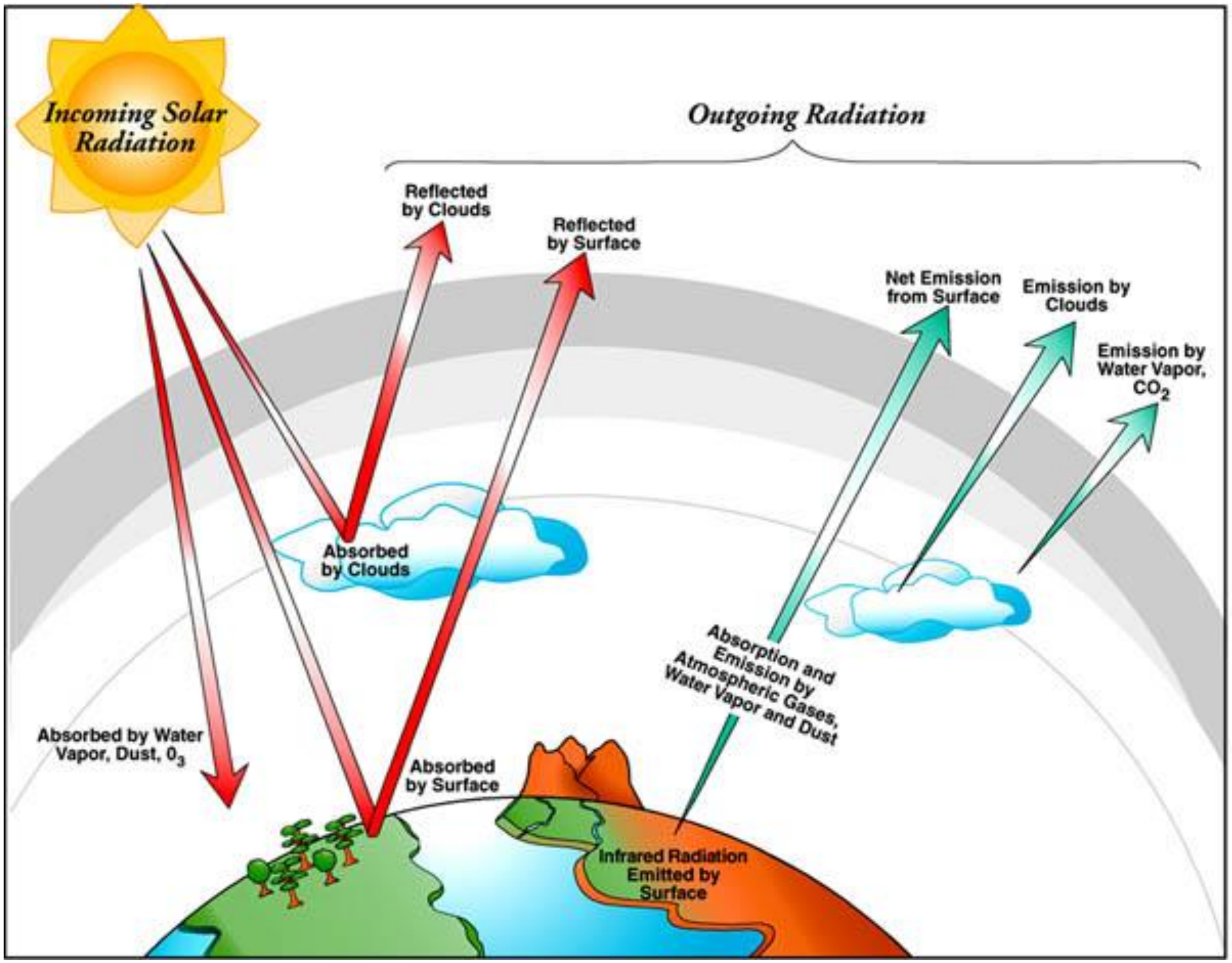
The tranfer of heat trought a fluid caused by molecular motion



Radiation

Energy that is radiated or transmitted in the form of rays or waves or particles

What Can Happen to Solar Radiation?


Incoming Solar Radiation
Outgoing Radiation
Reflected by Clouds
Reflected by Surface
Net Emission from Surface
Emission by Clouds
Emission by Water Vapor, CO2
Absorbed by Clouds
Absorption and Emission by Atmospheric Gases, Water Vapor and Dust
Absorbed by Water Vapor, Dust, 03
Absorbed by Surface
Infrared Radiation Emitted by Surface

Absorption

The ability of an object to assimilate (take up or hold) energy from the electromagnetic waves that strike it (incident to it)

Different objects vary in their capabilities to absorb radiant energy (and thus increase in temperature)

A general rule is that good radiators are good absorbers, and poor radiators are poor absorbers

Minerals materials (rocks and soils) are good absorbers; snow and ice are poor absorbers; water surfaces vary in their absorbing efficiency

Carbon dioxide and water vapor are efficient absorbers of certain wavelengths of radiation, while nitrogen, the most abundant gas in the atmosphere, is not

Color also plays a role in an object's absorption ability; dark-colored surfaces more efficiently absorb the visible portion of the electromagnetic spectrum than light-colored surfaces

Reflection

The ability of an object to repel waves without altering either the object or the waves

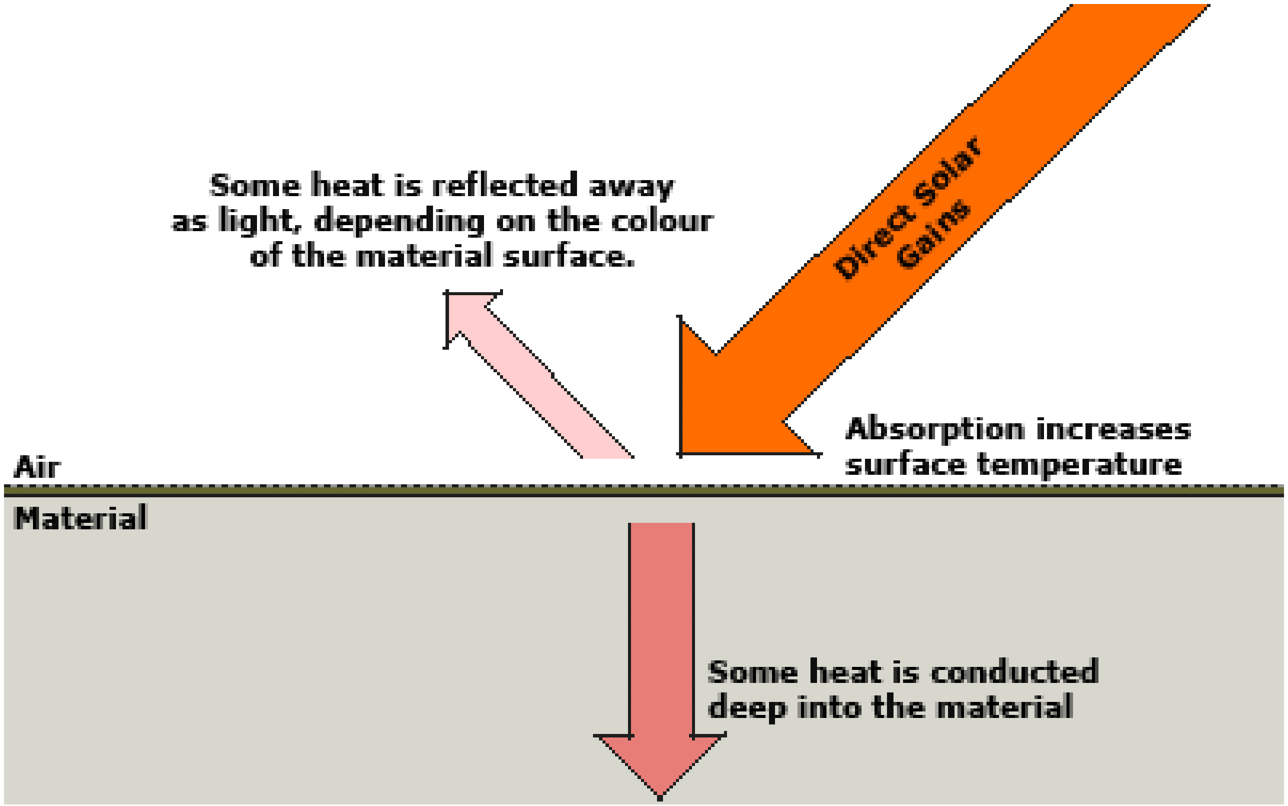
When insolation is reflected by the atmosphere or the surface of the Earth, it is deflected away, generally in the same or opposite angle of incidence

In a sense, reflection is the opposite of absorption – if the wave is reflected, it cannot be absorbed

Generally, an object that is a good absorber is a poor reflector, and vice versa.

E.g. unmelted snow on a sunny day – despite the temperature being above freezing, does not melt rapidly because its white surface reflects rather than absorb a large share of solar energy.

Absorption and Reflection

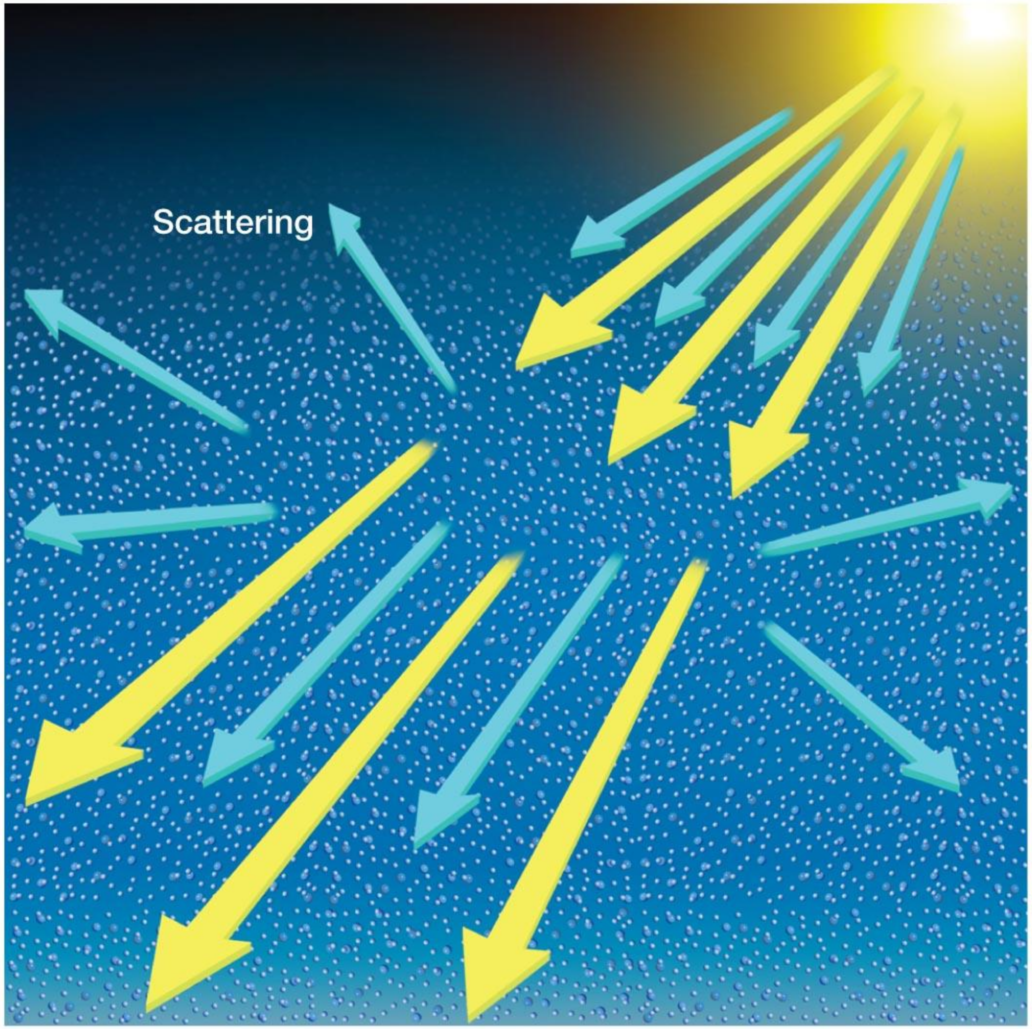


Scattering

The process by which light waves changes direction (deflected), as they come into contact with gas molecules and particulate matter in the atmosphere.

Can be thought of a type of reflection, but in this case wavelengths are deflected and redirected into many directions, rather than only in the direction from which they originated.

Amount of scattering depends on wavelength of energy and the size, shape, and composition of the molecule or particulate that deflected them.


Scattering

Scattering

Scattering is the reason why we see the sky as being blue

- Rayleigh scattering:
  - Scatters shorter wavelengths of visible light
  - Violets and blues in the visible part of the spectrum are shorter in wavelength than the oranges and reds.
  - Shorter waves (like violets and blues) are more readily scattered by the gases in the atmosphere, so they are more likely to be redirected.
  - There is a greater prevalence of blue wavelengths in solar radiation PLUS our eyes are more sensitive to blue than violet, hence we see the sky as blue when solar radiation is scattered!
  - The Sun appears reddish at sunrise and sunset because the path of light through the atmosphere is longer, so most of the blue light is scattered out before the light waves reach Earth's surface.

Scattering

Mie scattering

- When the atmosphere contains large quantities of larger particles, such as suspended aerosols, all wavelengths of visible light are more equally scattered.
- Dust, pollen, smoke and water vapor are common causes of Mie scattering.
- Mie scattering tends to scatter longer wavelengths than those affected by Rayleigh scattering.
- Mie scattering occurs mostly in the lower 4.5 km of the atmosphere where larger particles such as smoke and dust are abundant.
- E.g. Dust particles (including pollution from our cars) scatter away violet and blue leaving behind orange and red light to reach our eyes.
- Pollution contributes to beautiful sunsets and sun rises.

Transmission

The process by which electromagnetic waves pass completely through a medium, as when light waves are transmitted through a pane of clear, colorless glass.

Ability of objects to transmit varies greatly based on their makeup; also, transmission depends on the wavelengths themselves:

Shortwave radiation is transmitted "better" than longwave radiation

Earth materials are poor transmitters; sunlight is absorbed at the surface of rock or soil and does not penetrate at all.

Water on the other hand, transmits sunlight very well: even in very murky water, light can penetrate great distances.

Greenhouse Effect

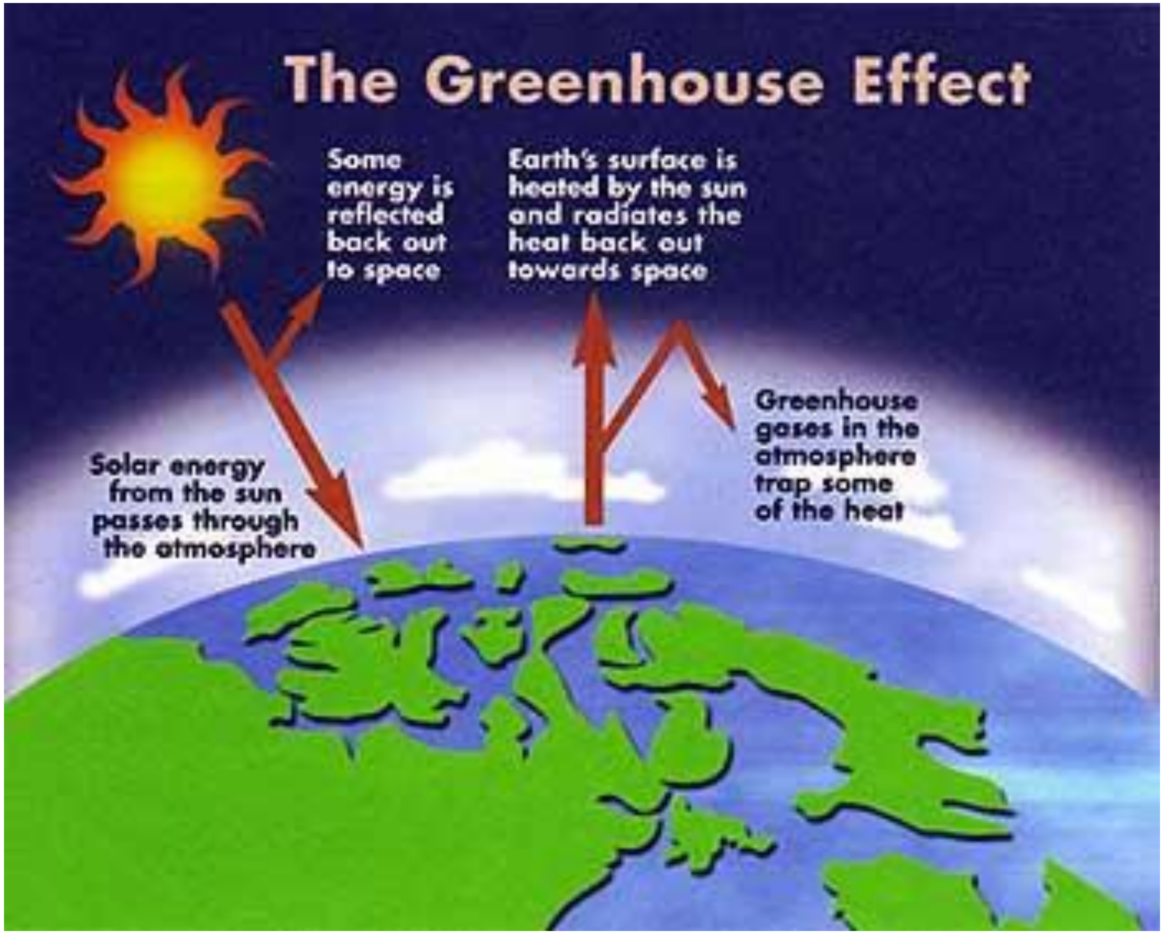
The greenhouse effect is directly related to how different wavelengths of insolation are transmitted through objects

The warming up of the atmosphere is more similar to what occurs in a closed automobile parked in the sunlight.

In the atmosphere, atmospheric gases, known as greenhouse gases, transmit the incoming solar shortwave radiation, which is absorbed by Earth's surface. They do not transmit the outgoing longwave terrestrial radiation, but instead absorb it, then reradiate the terrestrial radiation back toward the Earth surface.

Heat is then trapped in the lower troposphere (more in next class).

Enhanced greenhouse effect: Anthropogenic Addition of Greenhouse gases to the atmosphere



Greenhouse Effect

The most important greenhouse gas is water vapor, followed closely by carbon dioxide, then to a lesser degree by methane, ozone and other trace gases and some kinds of clouds.

The gases in the atmosphere ‘trap’ longwave radiation and reradiate them toward the surface, hence delaying energy loss to space.

Greenhouse effect is one of the most important heating processes in the troposphere.

Without the greenhouse effect, the average temperature of Earth would be –15ºC as compared to its present average of 15ºC.

Introduction of greenhouse gases such as Carbon dioxide and ozone could therefore lead to a heating up of the Earth surface.

What are some common greenhouse gases?

Greenhouse Gases

Carbon dioxide CO_2

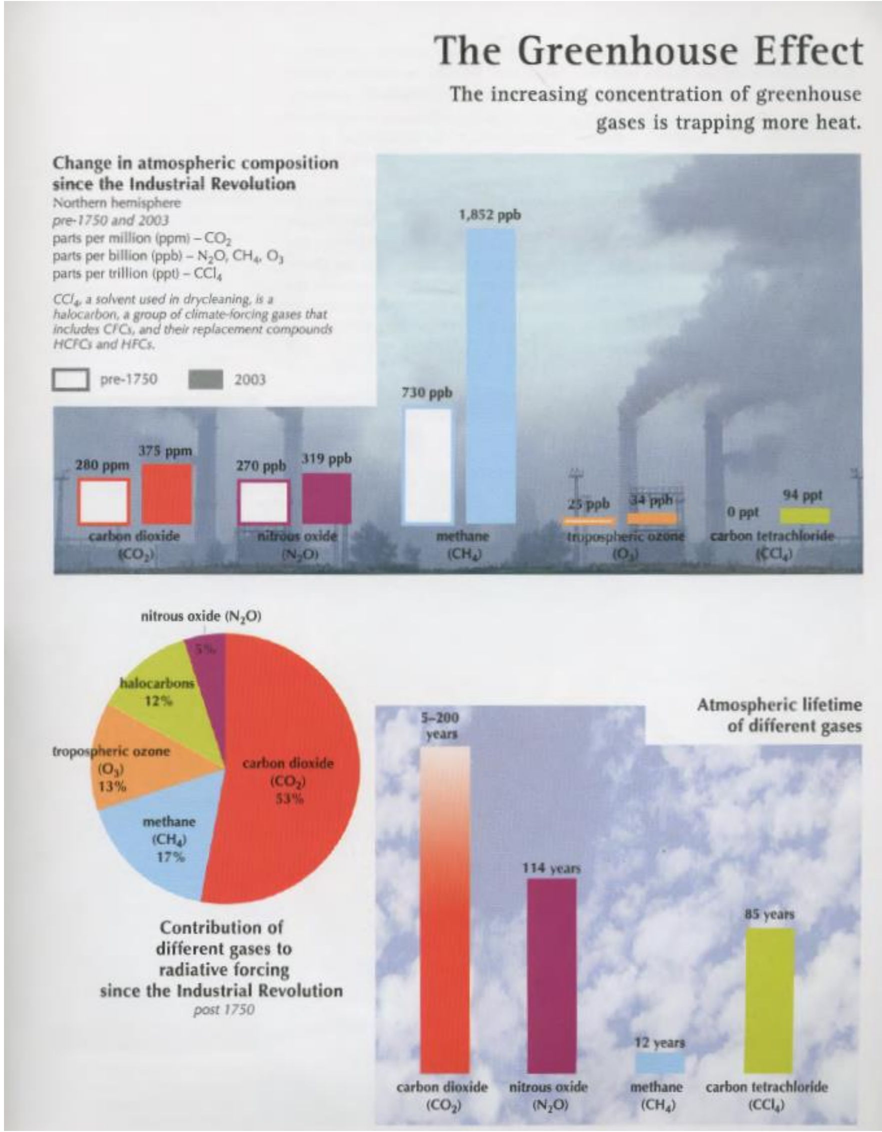
Methane CH_4

Nitrous oxide N_2O

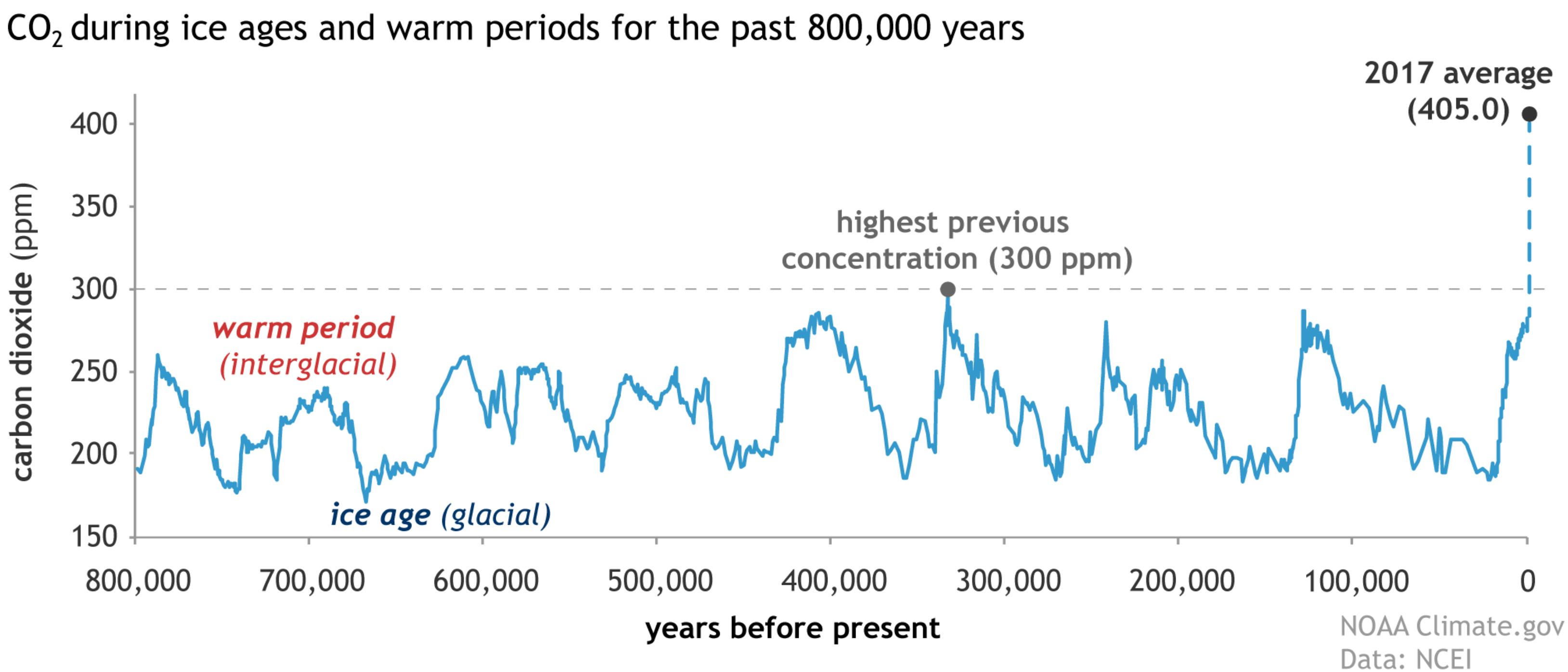
Halocarbons (including CFCs)

Tropospheric ozone

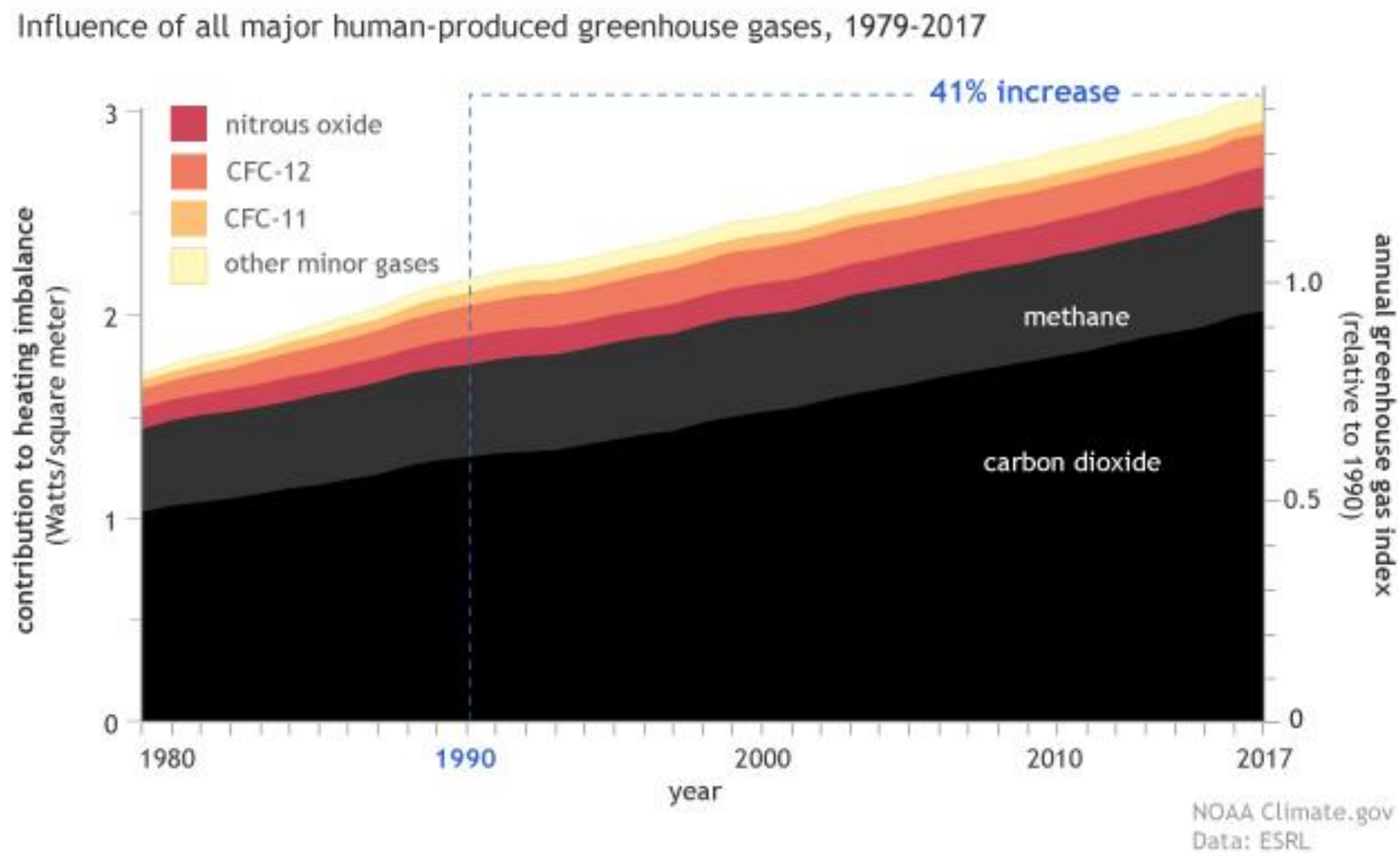
Water vapor



Dow and Downing, 2007



https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide



https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

What drives the enhanced greenhouse effect?

Enhanced greenhouse effect

Carbon dioxide

- The increase in CO_2 is partly caused by fossil-fuel burning, cement manufacture, land clearing, forest harvesting and changes in agricultural practice.

Methane

- Emissions from landfill, biomass burning, increased agricultural production in rice fields, digestive fermentation (burps and farts) from cattle and other livestock, and leaks from natural gas pipelines and coal mines have lead to a steady increase in methane emissions.
- Scientists are concerned that global warming will result in the release of even more methane if permafrost melts

Nitrous oxide

- There are many small sources of this gas both natural and manufactured that are difficult to quantify. The main sources created by human activity are from agriculture (especially the development of pastures in tropical regions), biomass burning and number of industrial processes.

Enhanced greenhouse effect

Halocarbons

- Chlorofluorocarbons (CFCs) are halocarbons which were widely used for propellants, refrigerants, and foaming agents. Their use rapidly increased after their invention in the 1930s
- The realization that they were responsible for ozone depletion in the stratosphere has led to their phasing out under the 1987 Montreal Protocol.
- Perfluorocarbons, another type of halocarbon, are produced during aluminium production
- (Despite their small concentrations, halocarbons have a significant greenhouse effect.)

Water vapor

Land conversion

Irrigation

Important Due Dates:

Quiz 4: 06/09/2021 by 11:59 PM

Exam 1: 06/12/2021 by 11:59 PM
- Covers everything from 05/24/2021 to 06/07/2021
- 20 questions – 30 minutes
  - 16 Multiple choice
  - 1 matching
  - 3 short answers (one line)
- Each question worth 5 points, total 100 points
- Password will be given in class

Exercise 3: 06/16/2021 by 10:00 AM