Earth System Review. Radiation: Basic Concepts

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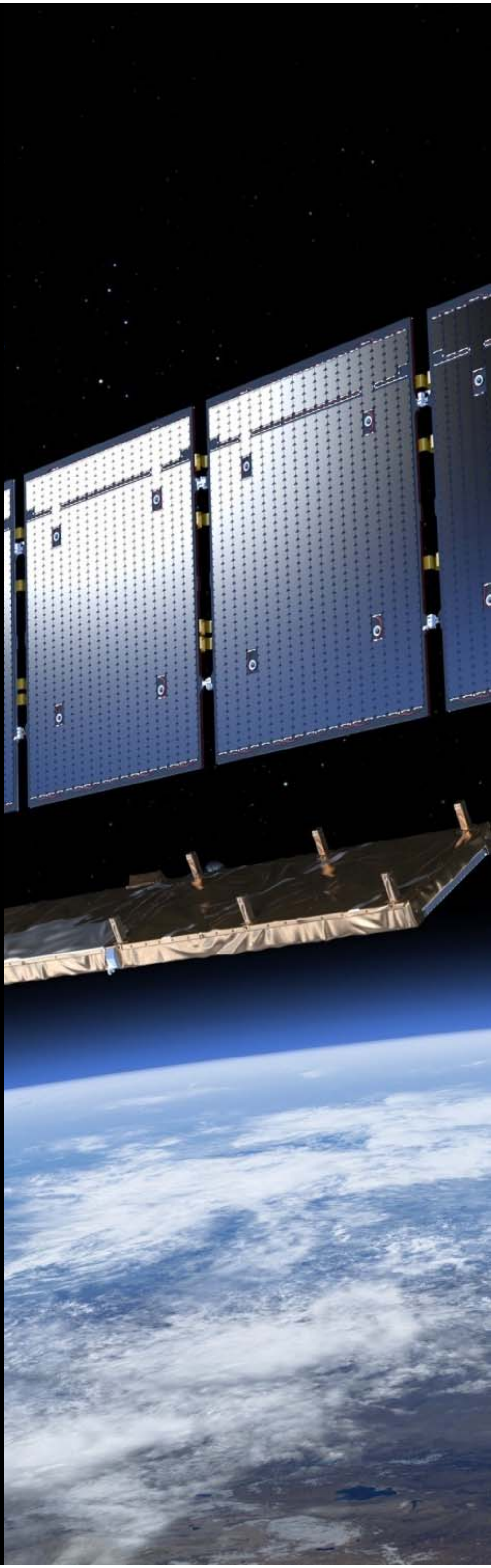


In this lecture:

- Earth and atmosphere system: brief review
- Radiation basics (Spectrum, Units, Laws)
- Radiation processes (scattering, absorption, reflectance)

Earth's System

All of the matter (solid, liquid, and gas) and all of the processes (physical, chemical, and biological) that move energy and materials from one part of the planet to another make up the Earth system.

The Earth system also includes human society.

Earth's Spheres

Atmosphere	The thin layer made up of a mixture of gases and particles suspended in the air that surround the Earth (predominantly N_2, O_2, Ar, CO_2, and H_2O)
Hydrosphere	A sphere that includes the liquid ocean, inland water bodies, and groundwater
Cryosphere	A subset of the Hydrosphere that consists of frozen water
Geosphere	A sphere that includes the solid Earth; the core, mantle, crust, and soil layers
Biosphere	A sphere that Includes all of Earth's organisms, including humans, and matter that has not yet decomposed

Earth’s Land and Ocean

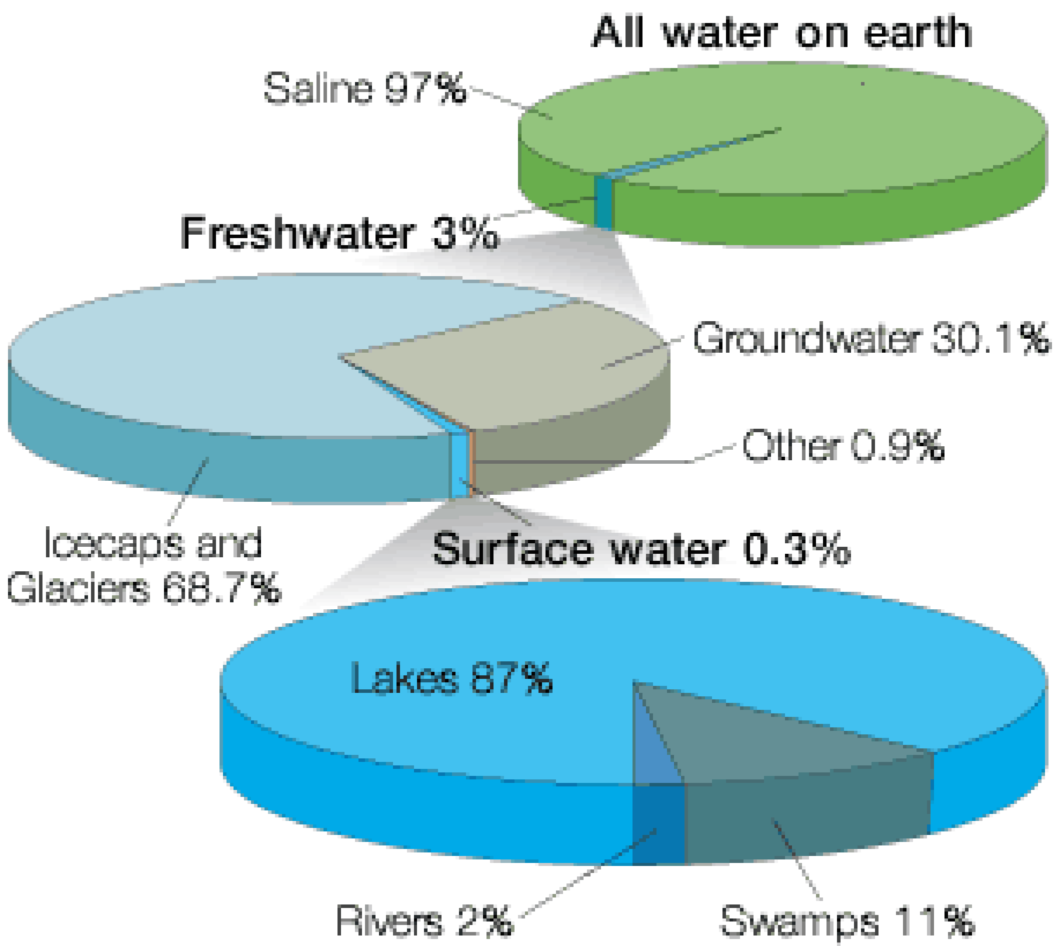
Earth’s surface area:

Water 71%

Land: 29%

Earth's Water

Where it is….



Oceans : 97%

Glaciers: ~2%

Ground water: ~0.9%

Surface water: ~0.01%

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Atmosphere: ~ 0.001%

Earth’s Cryosphere

Sea Ice: Affects ~15% of the ocean surface,

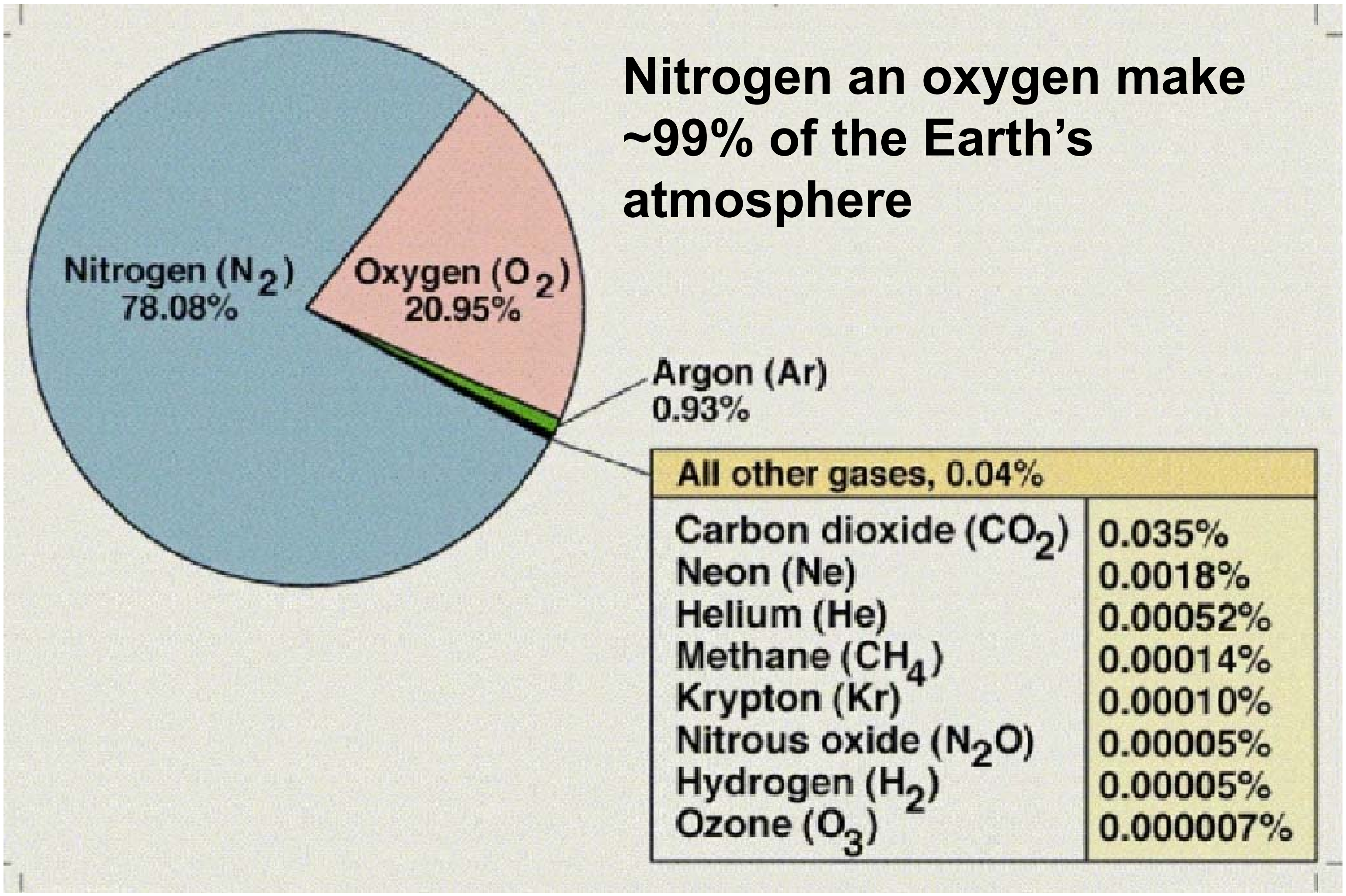
Glaciers: Cover ~ 11% of Earth’s land area

Seasonal snow: Affects up to ~32% of Earth’s land area

Sea ice and snow extent changes with season and with time (climate)

Earth's Atmosphere

What we are breathing with….



Other Gases

Which of them are "greenhouse" gases ?

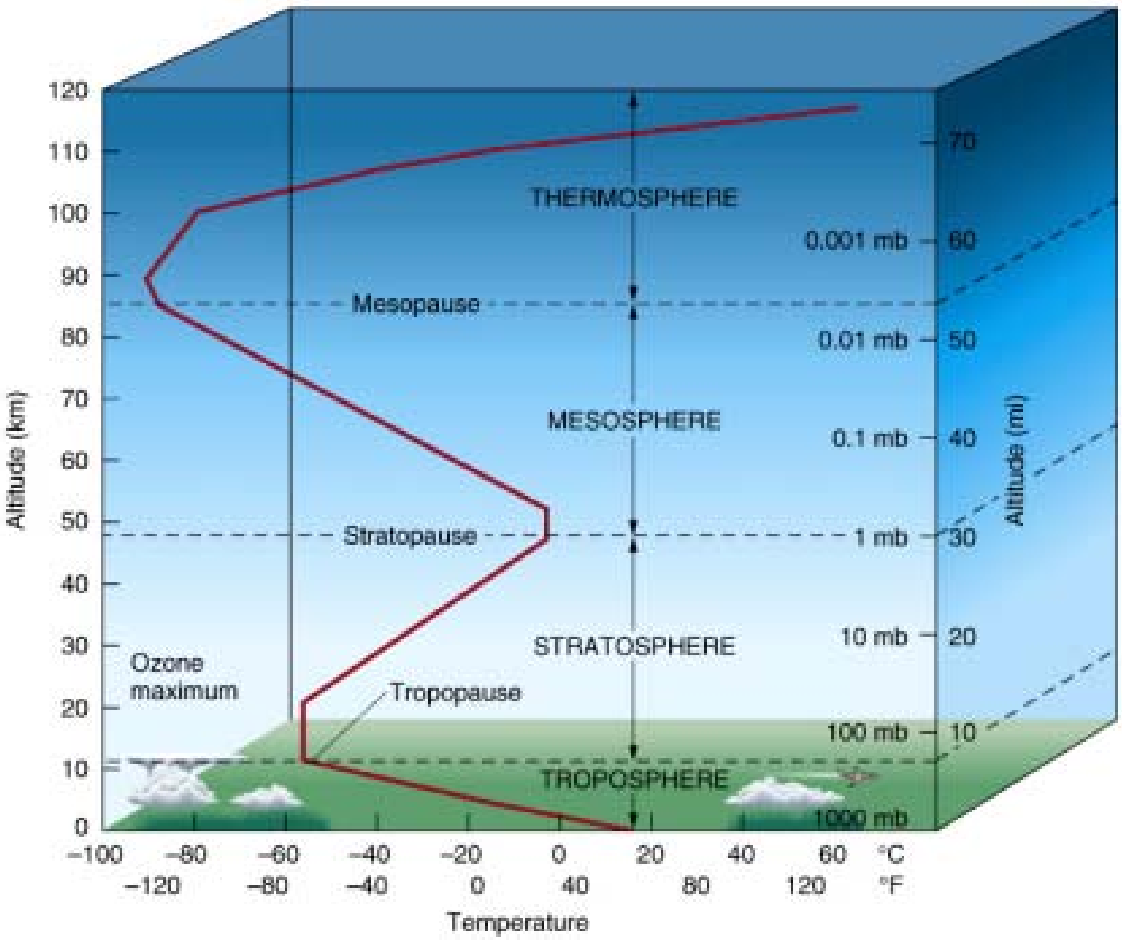
All other gases, 0.04%	
Carbon dioxide (CO_2)	0.035%
Neon (Ne)	0.0018%
Helium (He)	0.00052%
Methane (CH_4)	0.00014%
Krypton (Kr)	0.00010%
Nitrous oxide (N_2O)	0.00005%
Hydrogen (H_2)	0.00005%
Ozone (O_3)	0.000007%

Greenhouse gases absorbing thermal radiation, may contribute to global warming

Water Vapor: 0 – 0.04% by volume

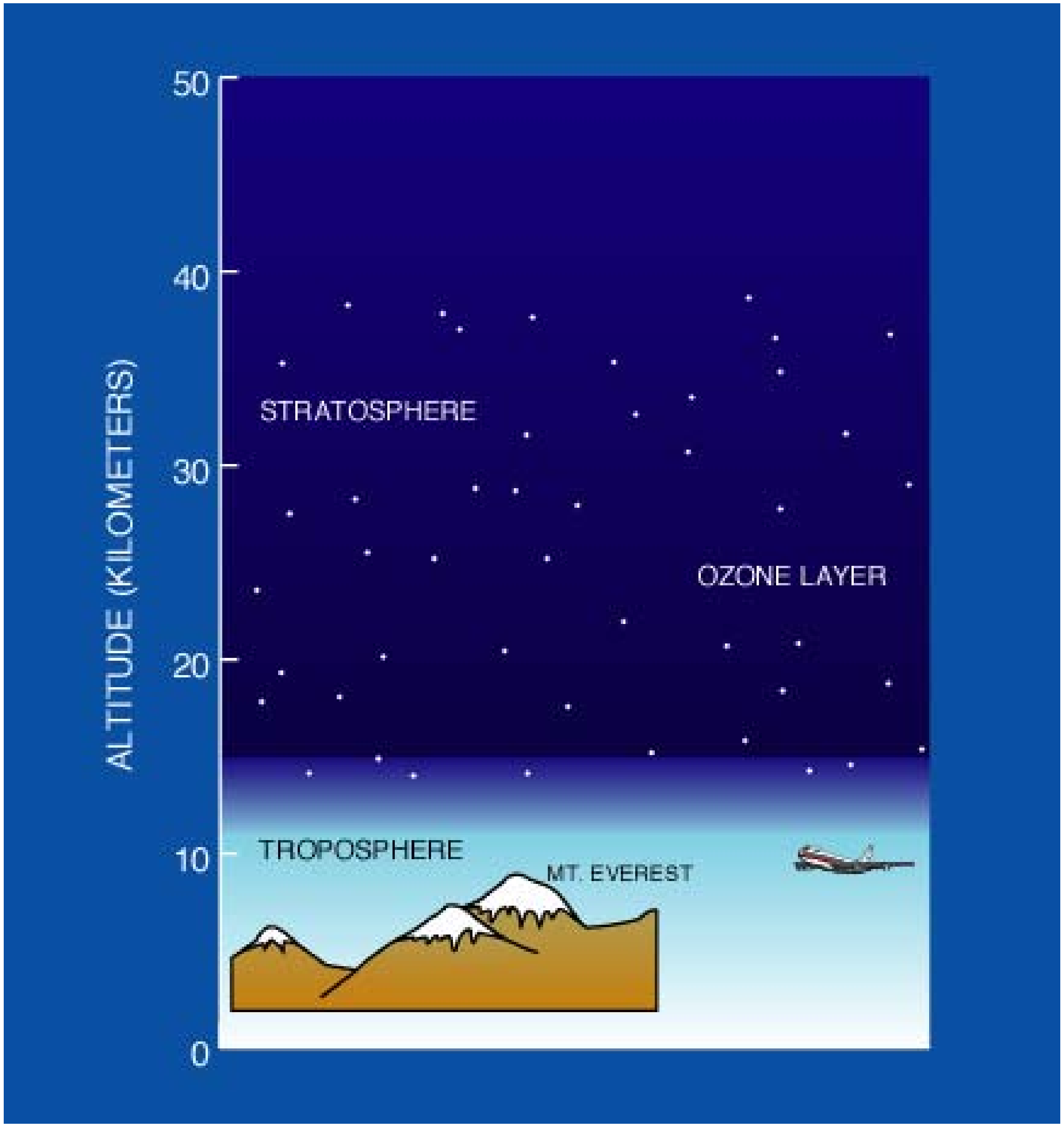
Provides the strongest greenhouse effect

Atmosphere: Vertical Structure



- Mean temperature gradient in the troposphere is -6.5K/km
- Temperature increase in the stratosphere is due to ozone layer absorption

Most weather processes occur in troposphere, within 10-12 km from the ground surface



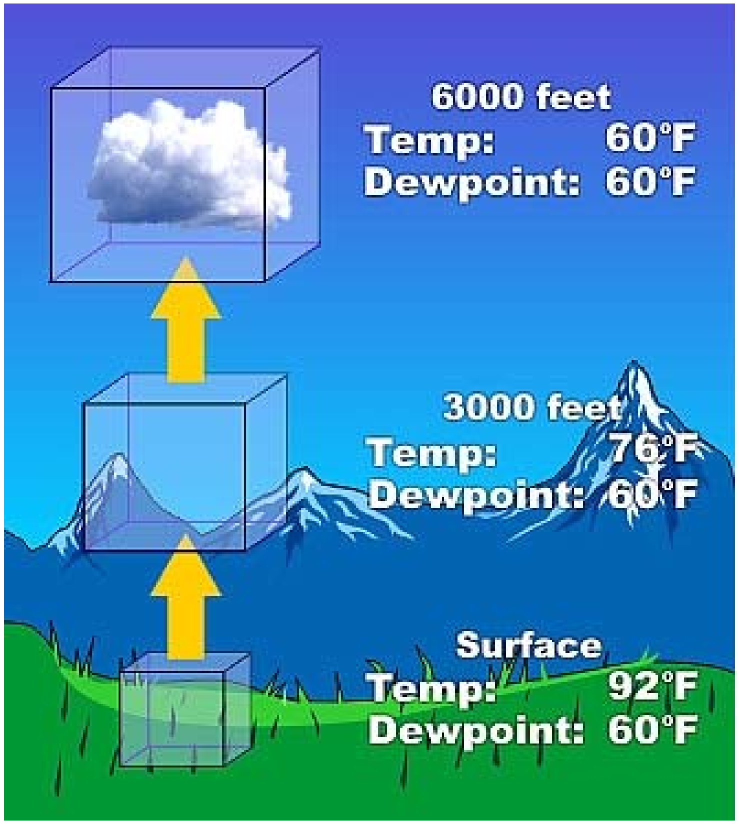
Clouds in the Atmosphere

At any time about 60% of the Earth's surface is covered with clouds.

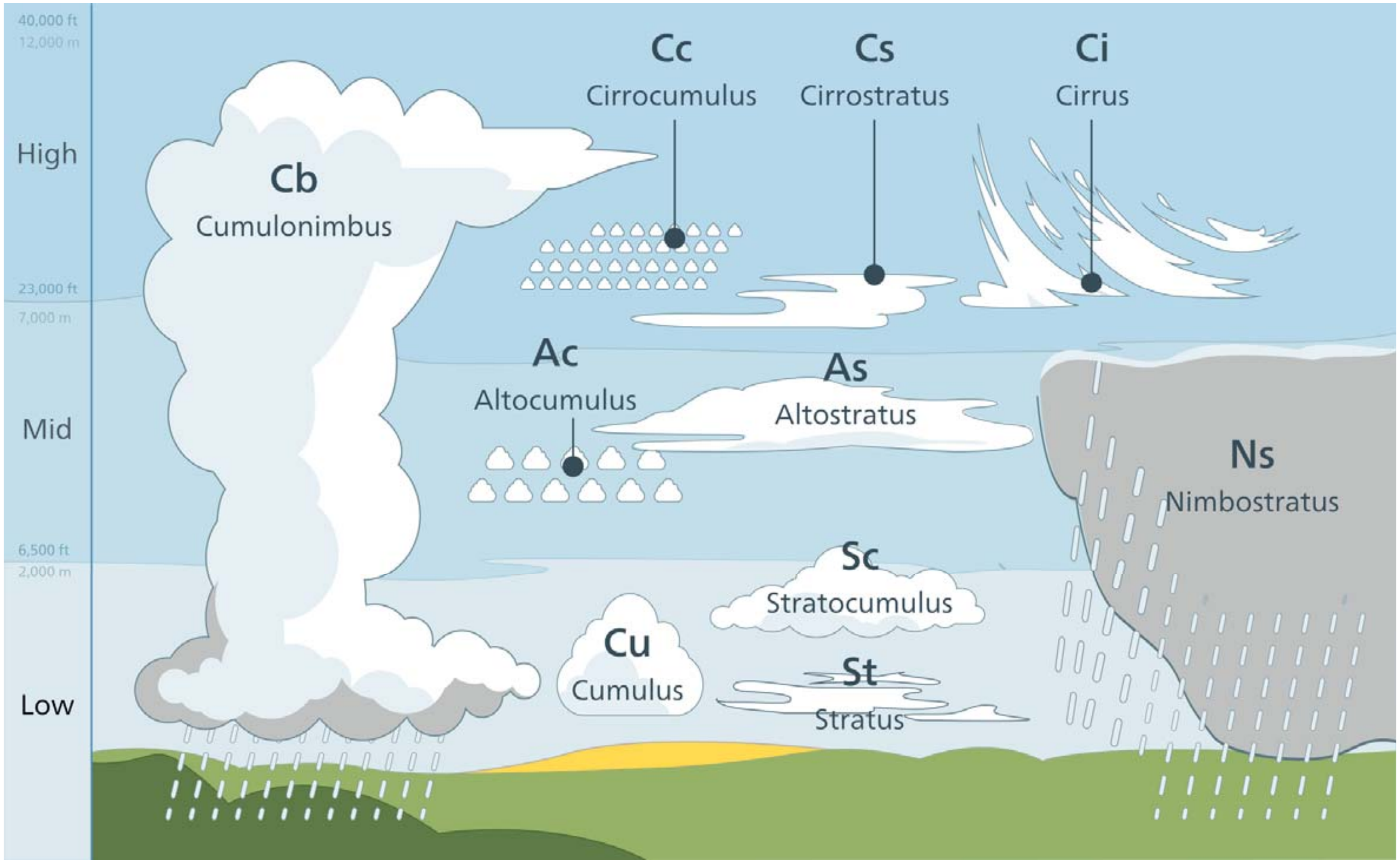
Clouds consist of small water droplets or ice crystals

Clouds form when rising moist air cools to the dew point temperature and condensation occurs

Clouds are an important factor for satellite remote sensing



Cloud Types



Three levels. Ten basic types. Names have Latin roots.

Cumulus: Heap, Stratus: Layer, Cirrus: Curl

Nimbus: Rain, Alto: High

Cloud Types


Cirrocumulus


Cirrus


Cirrostratus


Cumulonimbus


Altocumulus


Altostratus


Cumulus (fair weather)

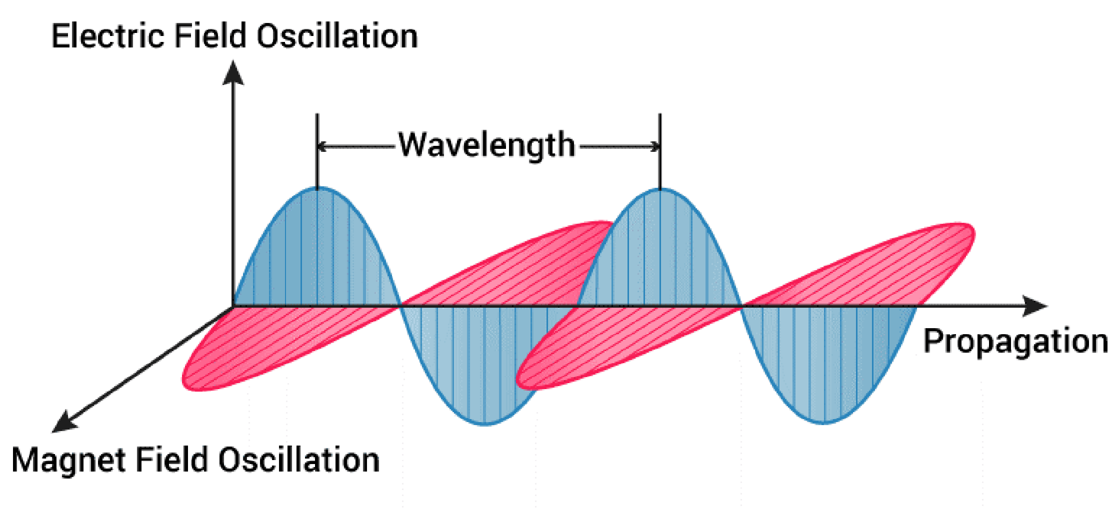

Stratus


Cumulus (with development)

Radiation Basics

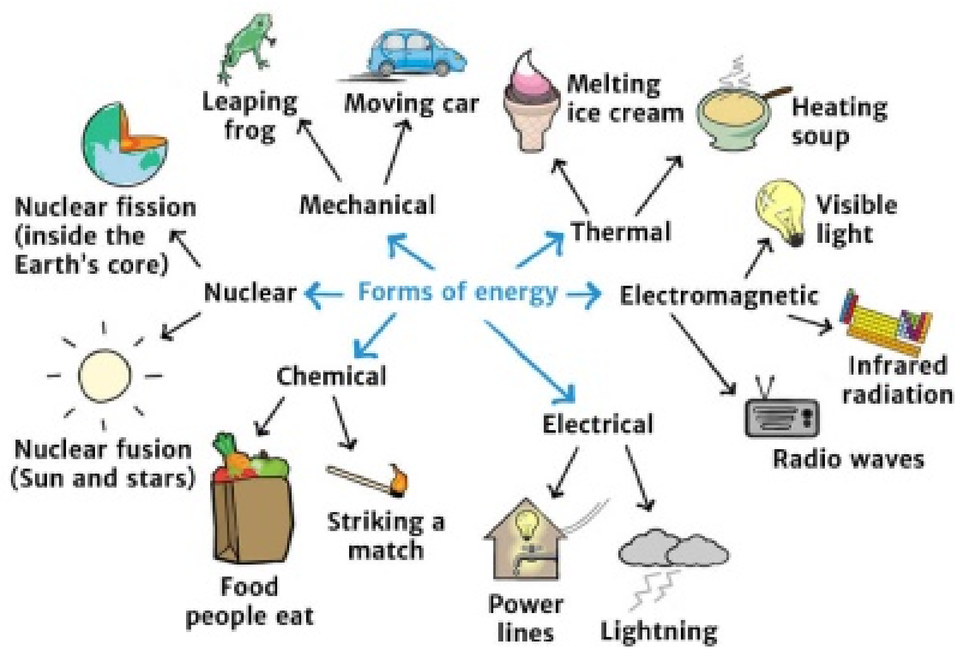
Electromagnetic radiation

- Electromagnetic radiation can be described in terms of a stream of particles with no electrical charge, called photons.
- They travel in a wave-like pattern at the speed of light. Each photon contains a certain amount of energy.
- The different types of radiation are defined by the amount of energy found in the photons, starting with radio waves with low energies.
- Microwave photons have a little more energy, infrared photons have still more, then visible, ultraviolet, X-rays, and, the most energetic of all, gamma-rays.



Electromagnetic radiation

- Photons are elementary particles, meaning that they are the smallest piece of light possible.
- In physics, energy is the property that is transferred to an object in order to perform work, such as creating heat.
- Common forms of energy include the kinetic energy of a moving object, the potential energy stored by an object's position in gravitational, electric or magnetic forces, the elastic energy stored by stretching solid objects, the chemical energy released when a fuel burns, the radiant energy carried by light, and the thermal energy of an object's temperature.



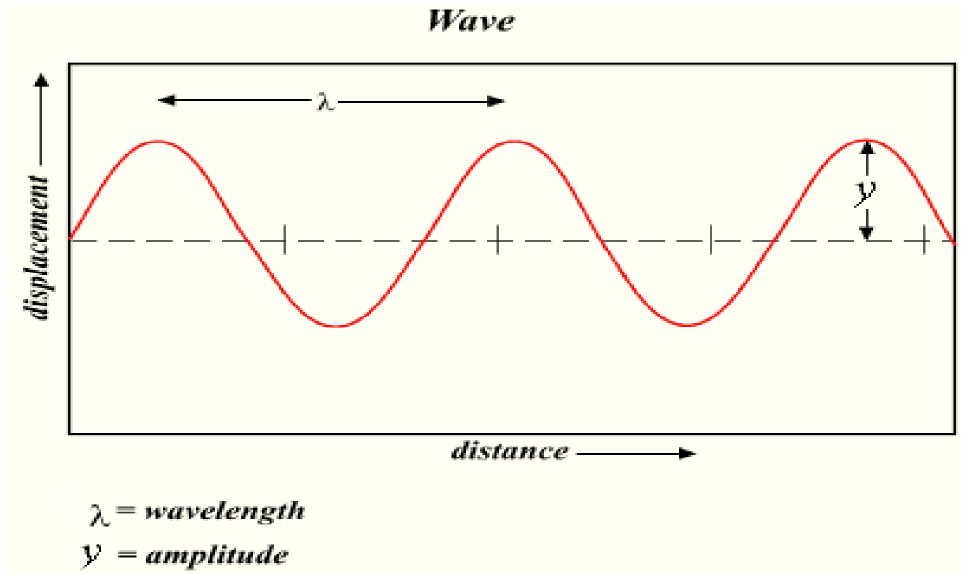
Wavelength and Frequency

Wavelength (*λ*): Distance between successive crests of a wave

Frequency (*f*): Number of oscillations per unit of time

$$\lambda = c/f$$

where ***c*** is the speed of light



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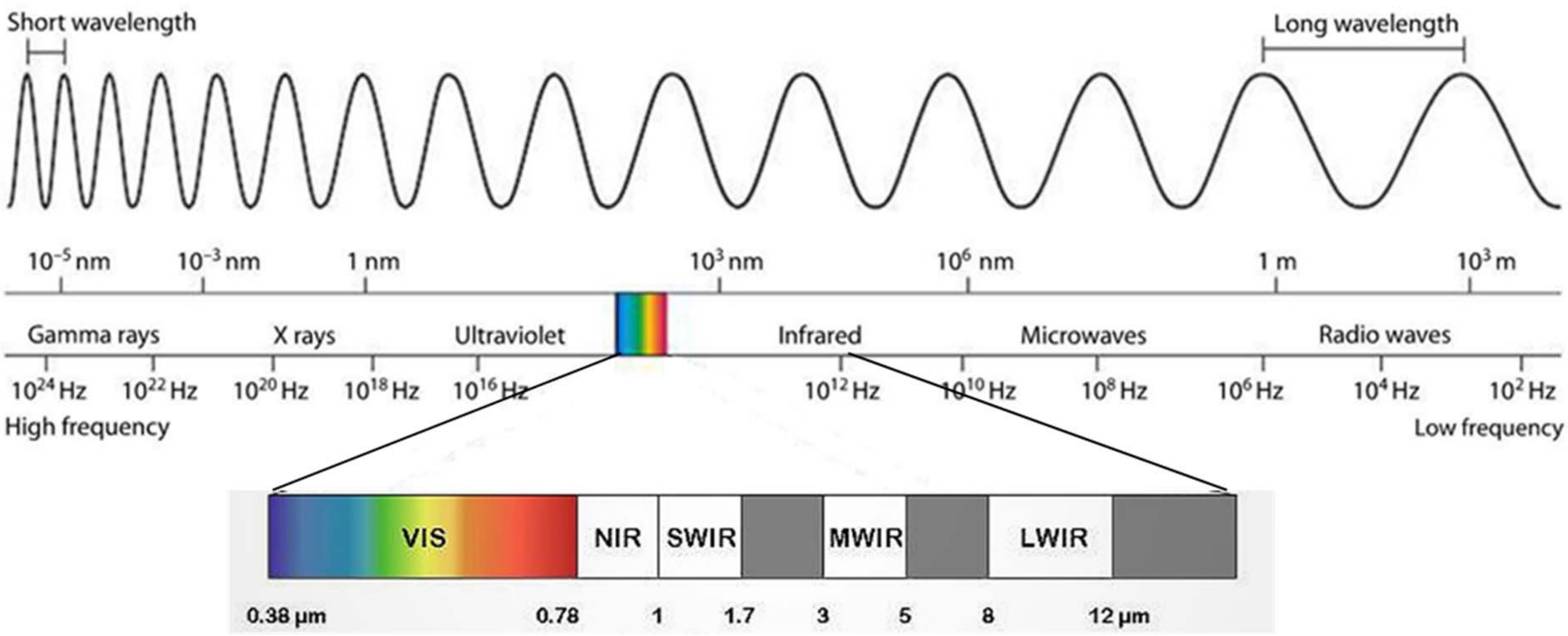
Wavelength units: meters (m), centimeters, (cm, 10^{-2}m, micrometers (µm, 10^{-6}m), nanometers (nm, 10^{-9}m)

Frequency units: Hz (sec^{-1}), MHz (10^6 sec^{-1}), GHz (10^9 sec^{-1})

Frequency and wavelength are inversely related.

Electromagnetic spectrum



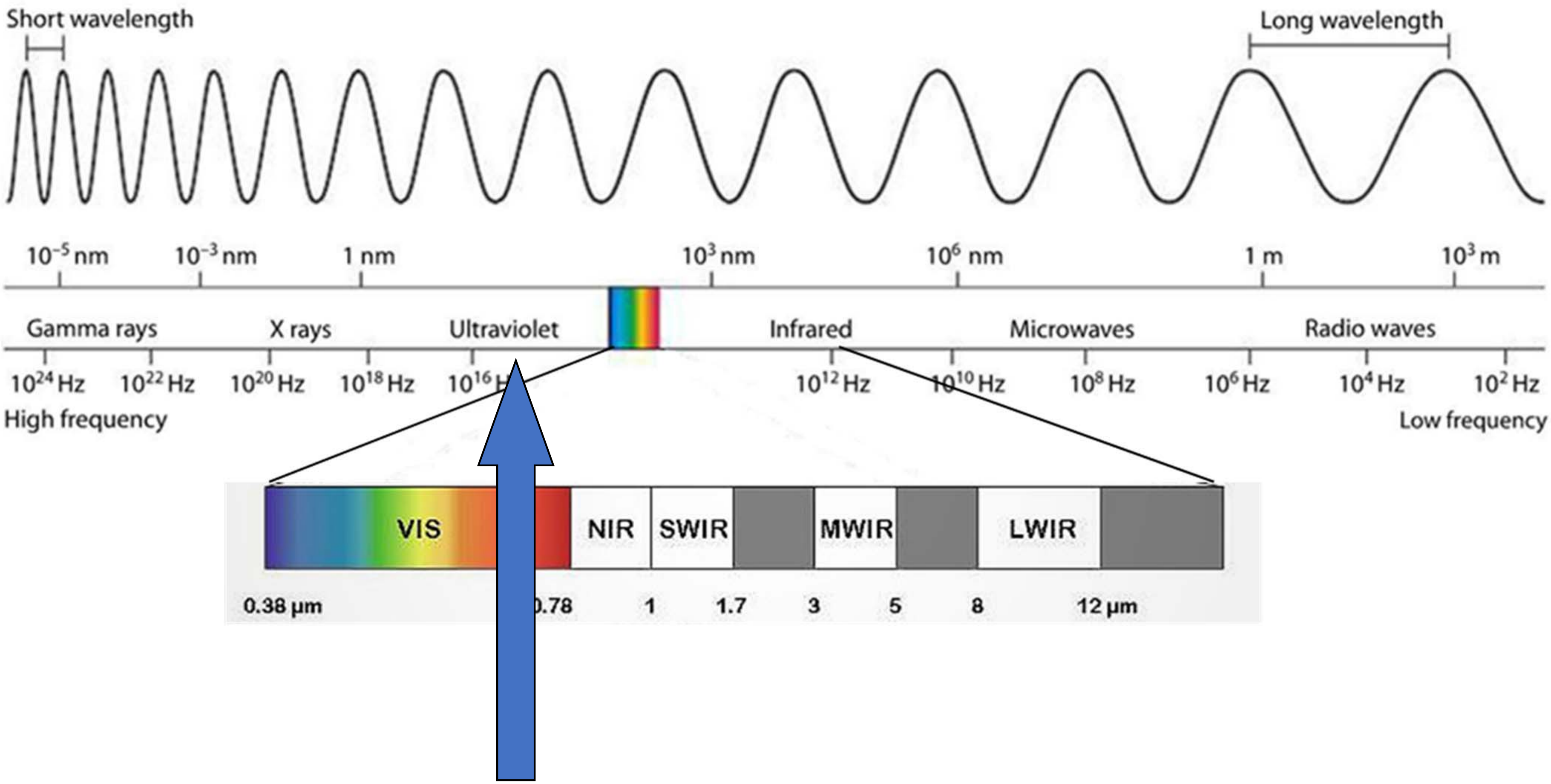
For Earth's remote sensing purposes most interesting is the range from 0.35 µm to 10 cm

Electromagnetic waves with higher frequencies, X-rays and gamma-rays, have shorter wavelengths. Consequently, electromagnetic waves like radio waves and microwaves have lower frequencies and longer wavelengths.

Shorter wavelengths: Full absorption at high altitudes in the atmosphere

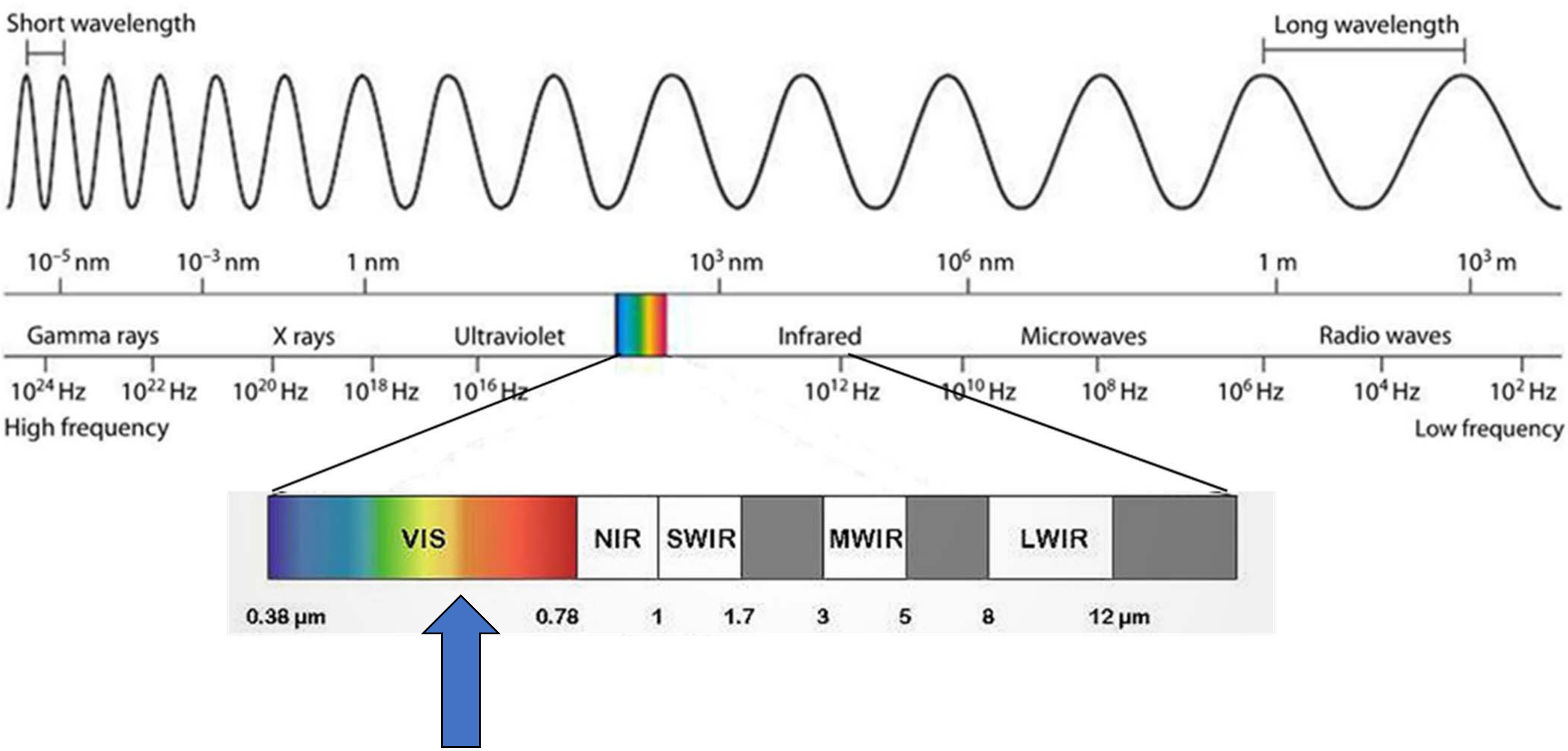
Longer wavelengths: High commercial use

UltraViolet Range



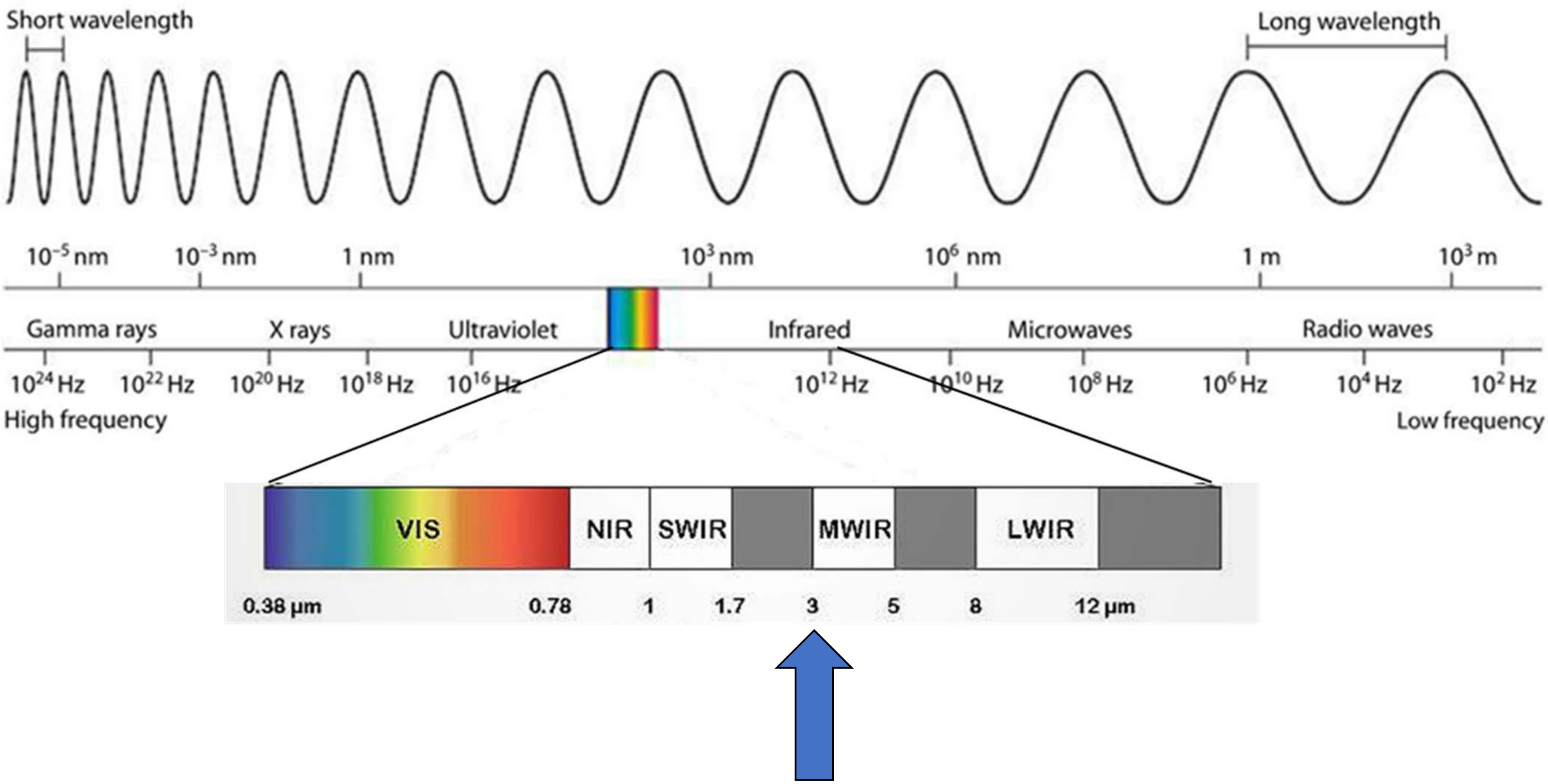
Near UV (0.35-0.40µm) :The shortest wavelengths which are practical for remote sensing.

Visible Range



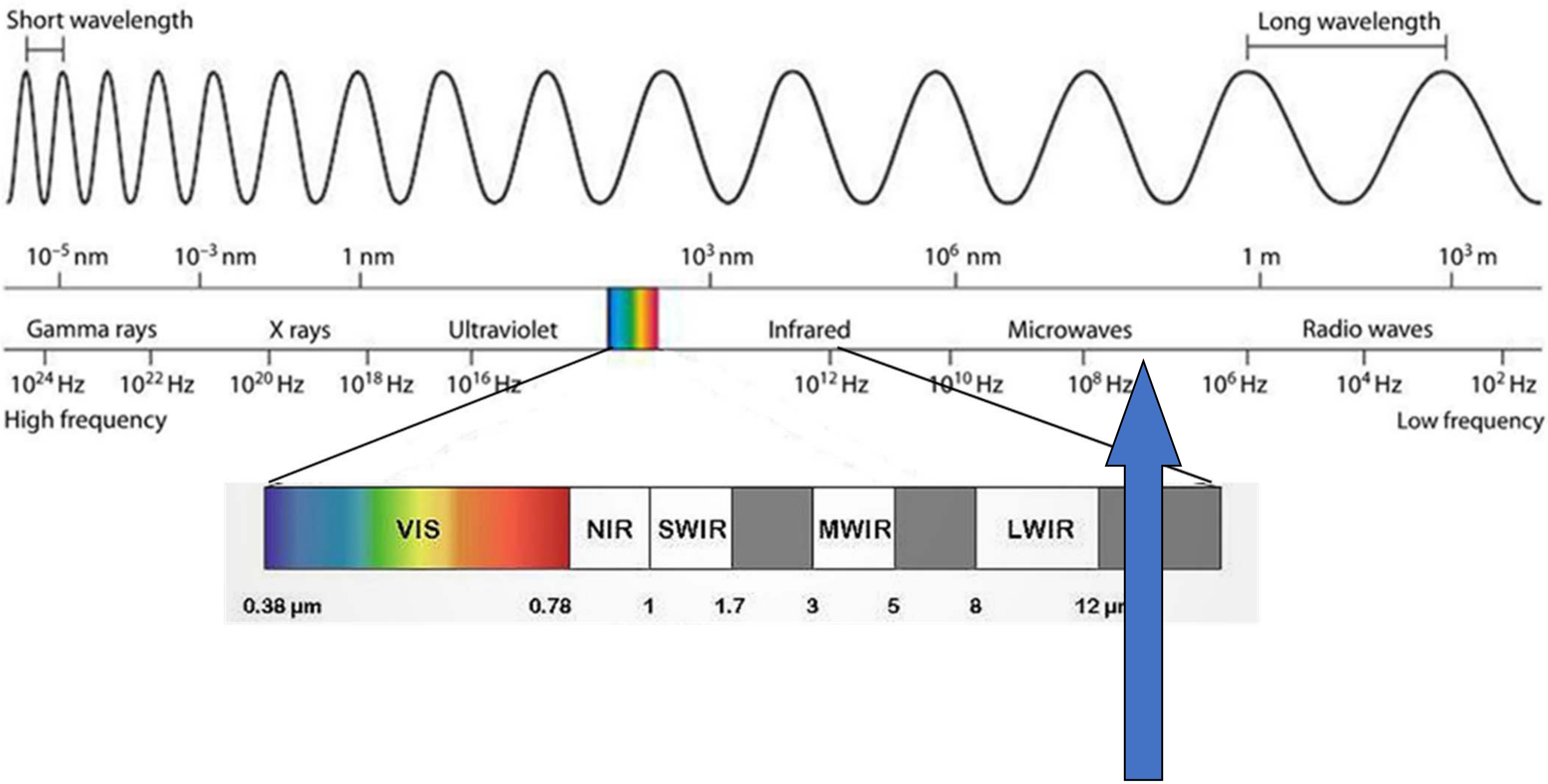
Violet: 0.4 - 0.446 μm
Blue: 0.446 - 0.500 μm
Green: 0.500 - 0.578 μm
Yellow: 0.578 - 0.592 μm
Orange: 0.592 - 0.620 μm
Red: 0.620 - 0.78 μm

Infrared Range



NIR: Near-Infrared (0.78-1µm)
SWIR: Shortwave Infrared (1-3µm)
MWIR: Middle Infrared (3-8 µm)
LWIR: Longwave or Thermal
or Far infrared (8-100µm)

Microwave Range



Microwave: 0.1 cm to 10 cm

These are the longest wavelengths used for remote sensing.

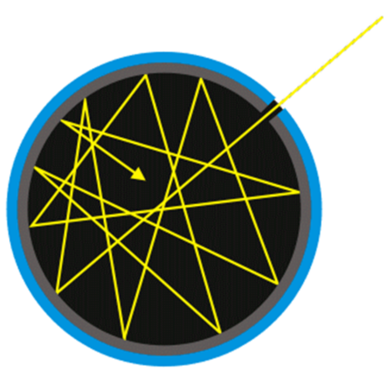
Radiation, Absolute Temperature and Black Body

All bodies with a temperature above absolute zero (-273° C) radiate heat in the form of longwave, infrared **radiation.**

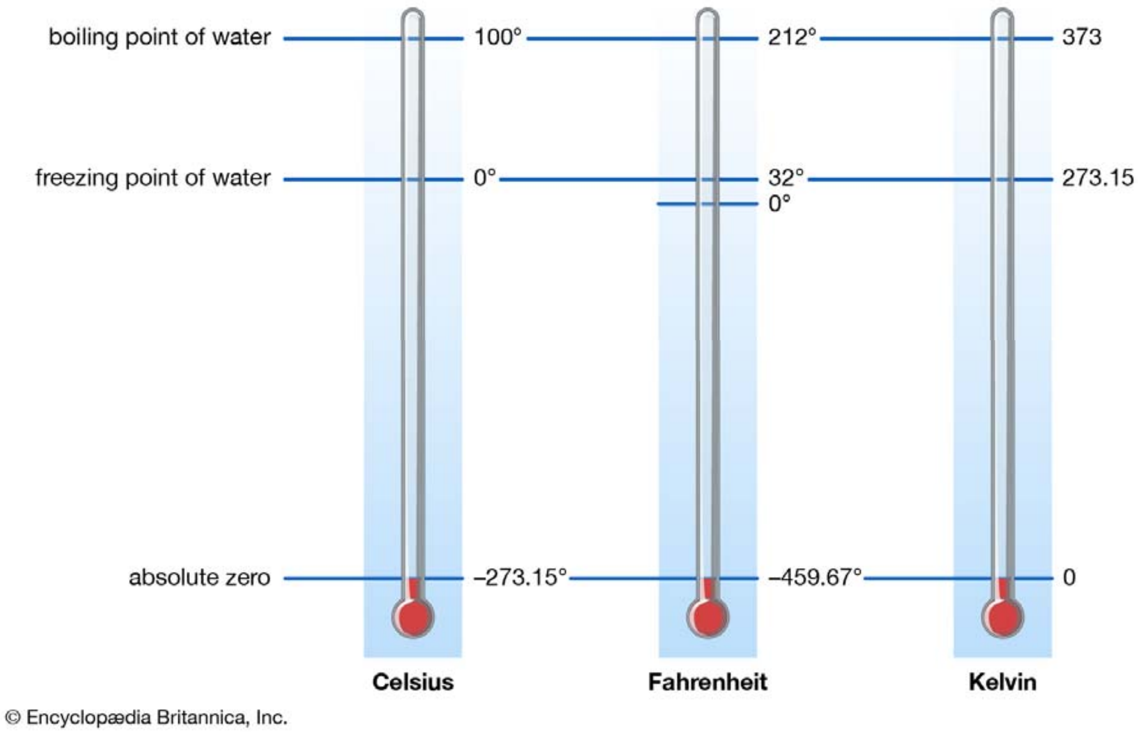
Absolute temperature in deg K is related to the temperature in deg C as

$$T[K] = T[C] + 273.15$$

Blackbody is a body whose absorbs all radiation incident upon it.



Conceptual Black Body



Properties of blackbody radiation

- Radiation emitted by a blackbody is isotropic, homogeneous and unpolarized
- Blackbody radiation at a given wavelength depends only on the temperature
- Any two blackbodies at the same temperature emit precisely the same radiation
- A blackbody emits more radiation than any other type of an object at the same temperature.

Stefan-Boltzmann Law

The total blackbody emission radiance is proportional to the fourth power of the temperature:

$$\boldsymbol{E = \sigma T^4}$$

$$P = e\sigma A(T^4 - T_C^4)$$

P	= net radiated power		e	= emissivity (=1 for ideal radiator)
A	= radiating area		T	= temperature of radiator
σ	= Stefan's constant		T_C	= temperature of surroundings

$$\sigma = 5.6703x10^{-8}\, watt\, /\, m^2 K^4$$

Human body radiation

The human body radiates energy as infrared light. The net power radiated is the difference between the power emitted and the power absorbed:

$$P_{\text{net}} = P_{\text{emit}} - P_{\text{absorb}}.$$

Applying the Stefan–Boltzmann law,

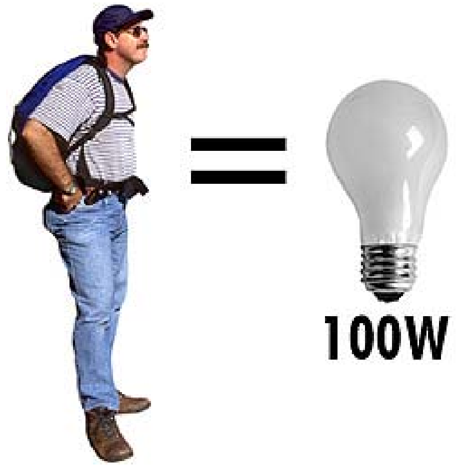
$$P_{\text{net}} = A\sigma\varepsilon \left(T^4 - T_0^4\right),$$

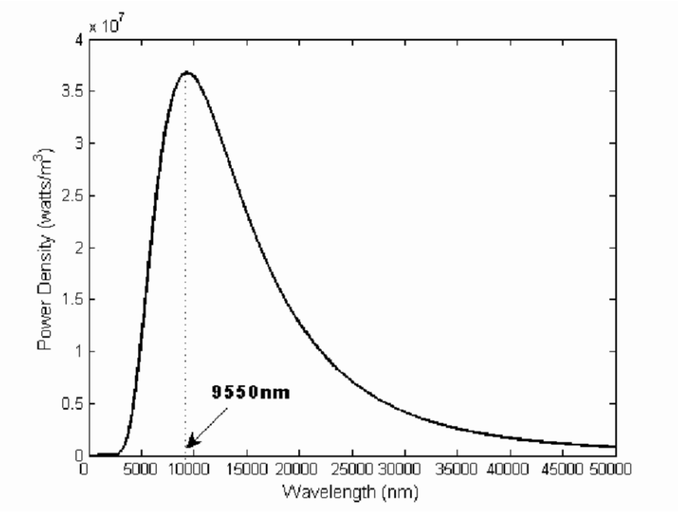
where A and T are the body surface area and temperature, ε is the emissivity, and T_0 is the ambient temperature.

The total surface area of an adult is about 2 m^2, and the mid- and far-infrared emissivity of skin and most clothing is near unity, as it is for most nonmetallic surfaces. Skin temperature is about 33 °C, but clothing reduces the surface temperature to about 28 °C when the ambient temperature is 20 °C. Hence, the net radiative heat loss is about

$$P_{\text{net}} = 100\ \text{W}.$$

The total energy radiated in one day is about 8 MJ, or 2000 kcal (food calories).

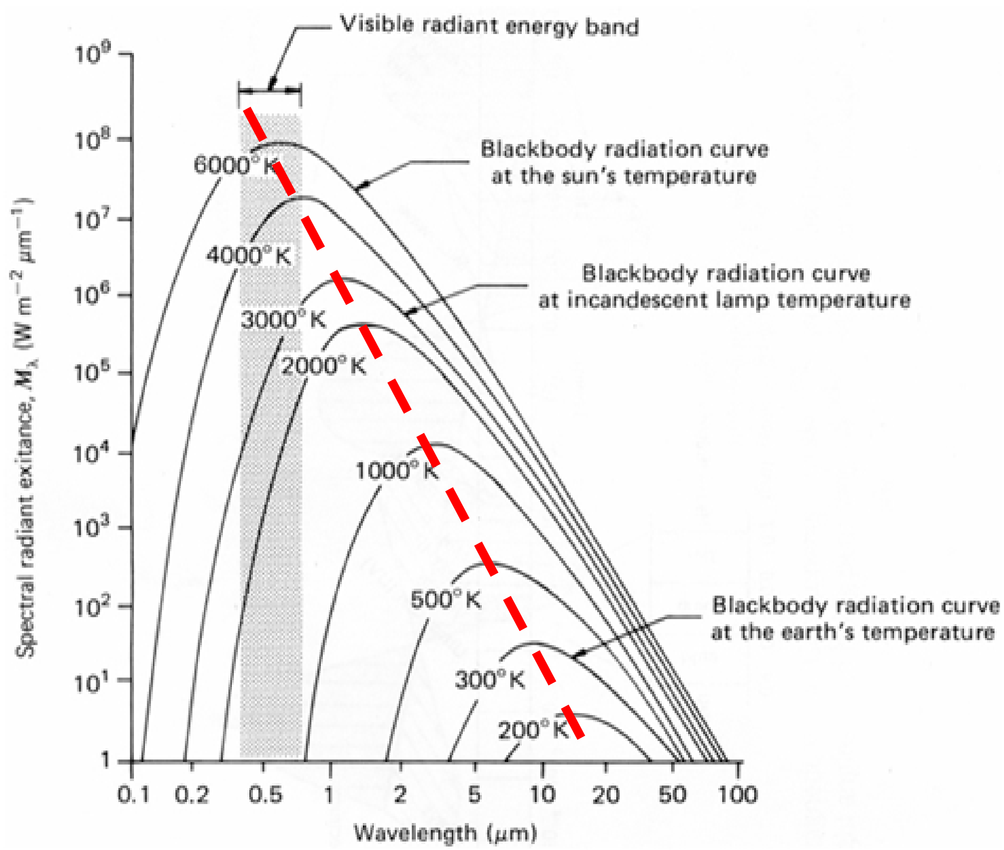




Planck's Law

- Radiation depends on the temperature and wavelength
- Planck's Law characterizes the intensity of monochromatic radiation emitted by a black body.

Planck's law describes the spectral density of electromagnetic radiation emitted by a black body in thermal equilibrium at a given temperature T, when there is no net flow of matter or energy between the body and its environment.



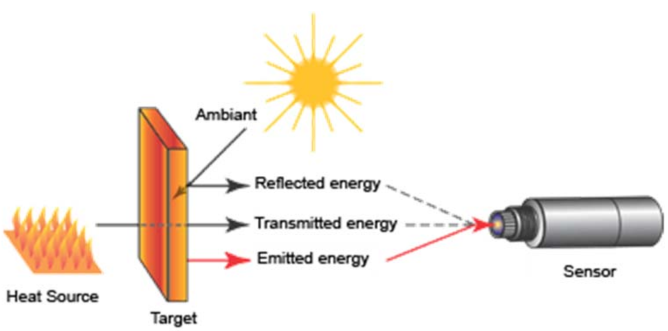
Further watching:

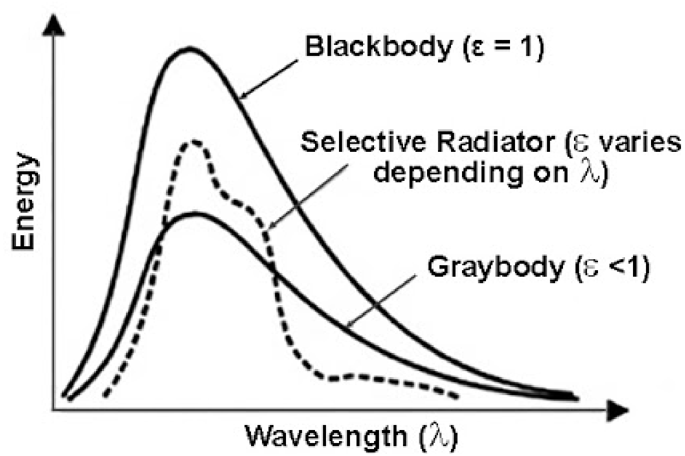
https://www.youtube.com/watch?v=7BXvc9W97iU

Emissivity

- Emission from natural surfaces generally differs from the emission of the black body.
- Emissivity (**ε**) characterizes the difference between the actual body radiation (***R***) and radiation of the ideal black body (***B***)

$$R_\lambda = \varepsilon_\lambda B_\lambda$$





Material	Emissivity
Polished silver	0.02
Polished copper	0.03
Polished gold	0.03
Aluminum foil	0.07
Wood	0.85
Asphalt pavement	0.9
White paint	0.9
Vegetation	0.94
White paper	0.94
Water	0.95
Black paint	0.98

For most natural surfaces in the infrared $\varepsilon_\lambda = 0.9$ to 1.0, "black body" presents a relatively good approximation

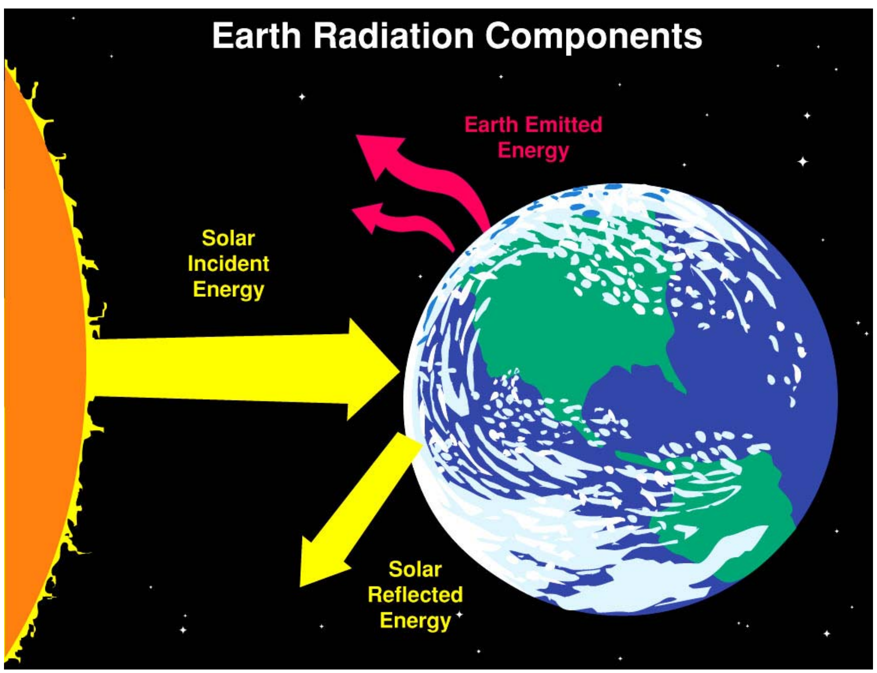
Solar and Earth Radiation

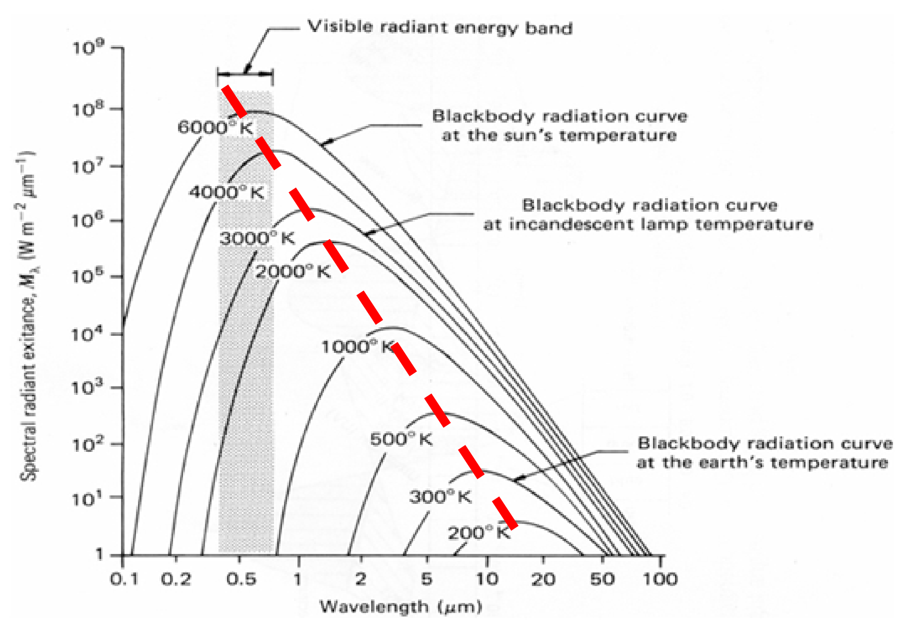
Both Sun and Earth emit radiation

- **Solar temperature: 6000K,**

  Solar emitted radiation peaks at 0.6μm (visible band)
- **Earth temperature: ~300K,**

  Earth emitted radiation peaks at ~10 μm (infrared band)





Brightness Temperature

Brightness temperature: Temperature of the blackbody which emits the same amount of radiation as the given natural body.

$$T_b = \varepsilon T_{kin}$$

Thus, passive microwave brightness temperatures can be used to monitor temperature as well as properties related to emissivity

Microwave radiometer ***Brightness temperature*** are considered a fundamental climate data record and are the values from which we derive ocean measurements of wind speed, water vapor, cloud liquid water, rain rate, and sea surface temperature.

Radiation Interactions

Energy Interactions in the Atmosphere-Land Surface System

Three mechanisms which modify the incoming solar radiation in the Earth-Atmosphere system

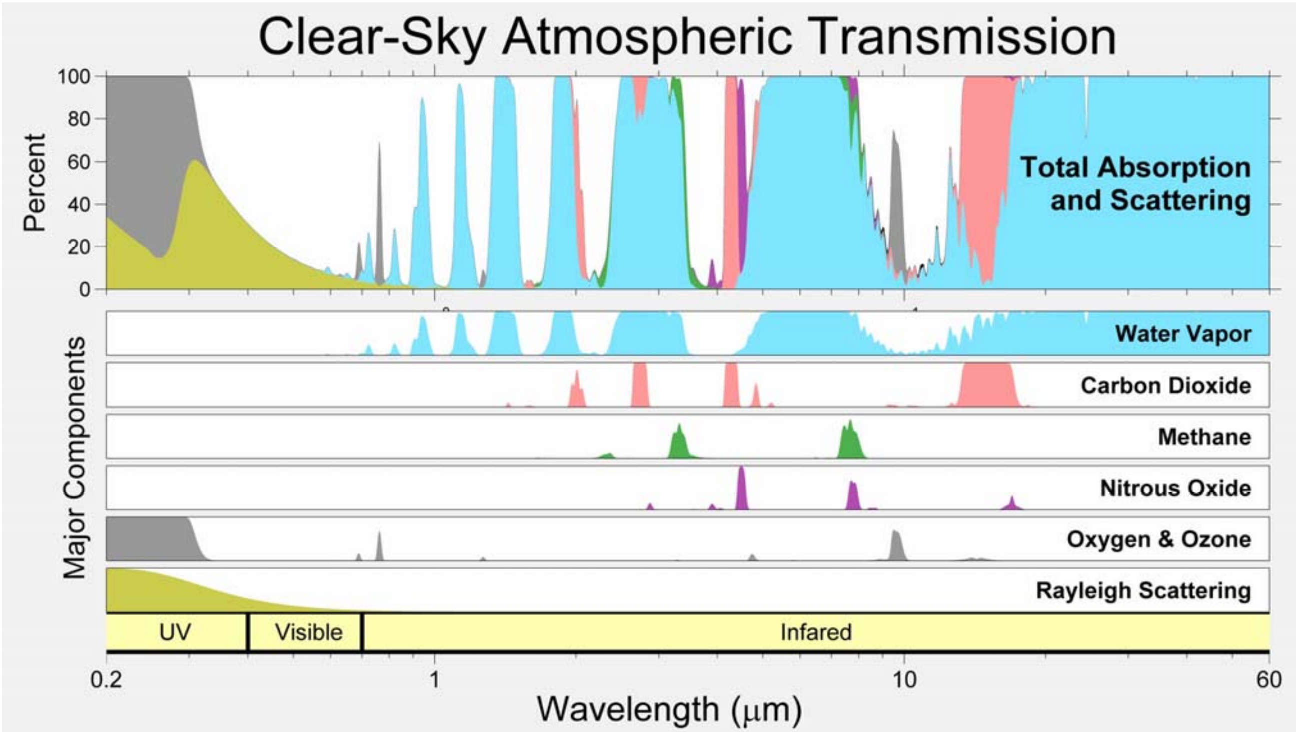
Absorption: By atmospheric gases, ground surface

Scattering: On air molecules, aerosol particles, cloud droplets

Reflection: From ground surface, water

Absorption by Gases

Gases absorption depends on the wavelength (selective absorption)
Strongest absorption is in the infrared and ultraviolet bands.



The most abundant and most significant greenhouse gas in the atmosphere is water vapor (H_2O). The second-most significant in carbon dioxide (CO_2). Man-made increases in carbon dioxide, methane (CH_4), and nitrous oxide (N_2O) are major sources of global warming.

Most absorption caused by: H_2O, CO_2 , O_2 ,O_3, NH_4, NO_2

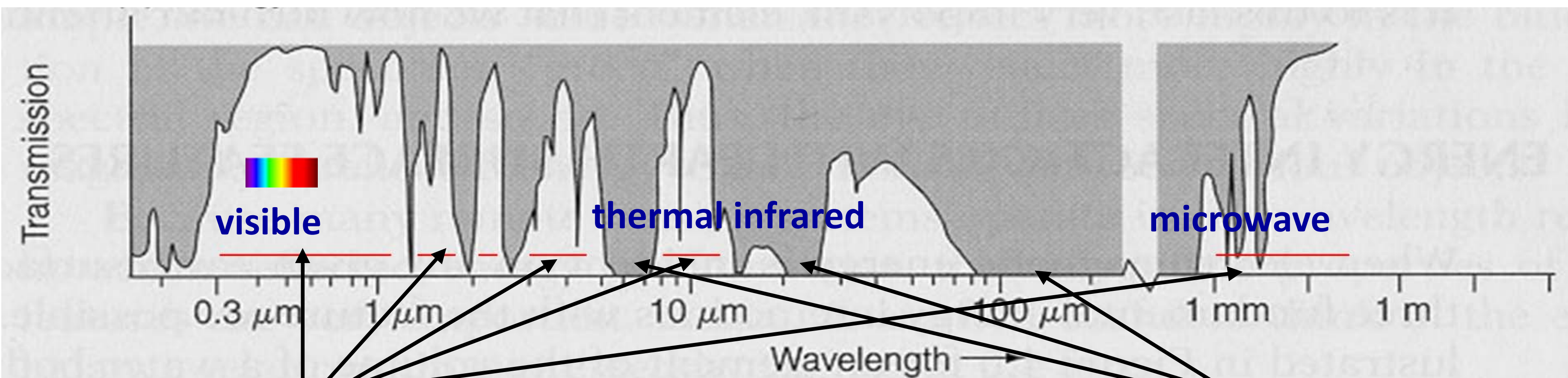
Atmospheric “Windows”

Atmospheric “windows” are spectral bands where atmospheric absorption is small and therefore atmosphere is mostly transparent.

Reflected/scattered solar radiation

Thermal/microwave emission of the Earth’s surface, clouds or atmosphere

Atmospheric absorption and transmittance



Atmosphere is mostly “transparent” at these wavelengths. Spectral bands can be used for land surface observations.

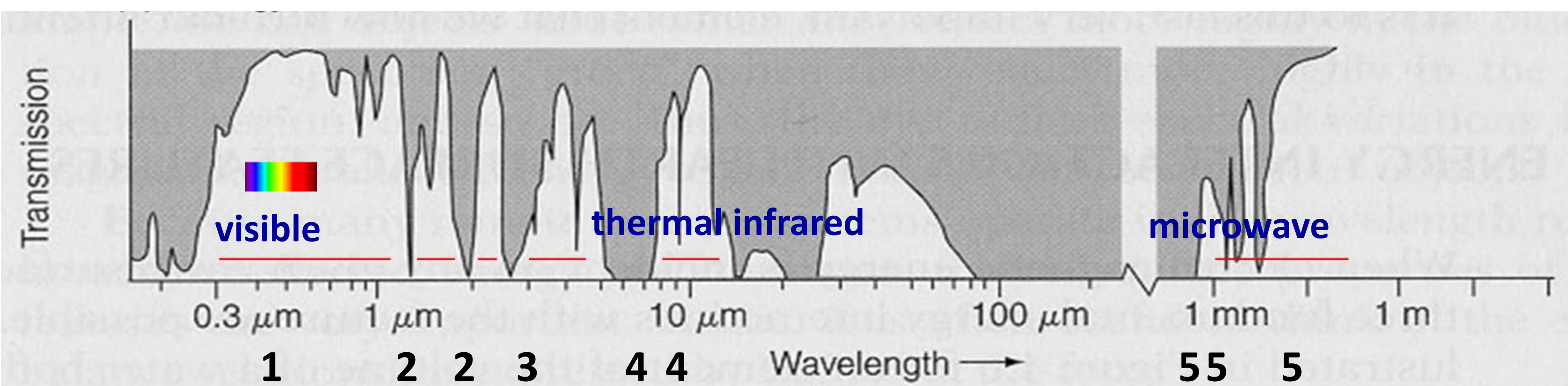
Atmosphere is opaque at these wavelengths due to gases absorption. Bands are used for atmospheric soundings

Atmospheric “Windows”

Most transparent atmospheric “windows” are :

1) Visible-Near Infrared (0.40 -0.9 µm);
2) Shortwave Infrared (1.55-1.75 µm, 2.05-2.4 µm)
3) Mid-IR (3.5 - 4.16 µm);
4) Thermal IR (8 - 9.2 µm and 10.2-12.4 µm);
5) Microwave (2.06-2.22 mm, 7.5-11.5 mm, 20+ mm).

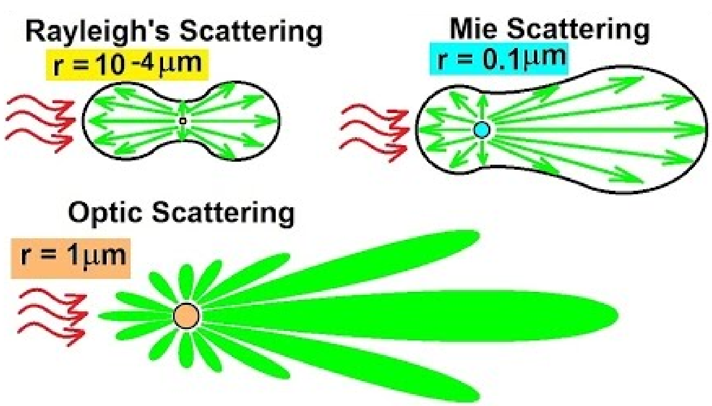
Satellite observations in these bands are most often used for the land surface and ocean monitoring



Atmospheric Scattering

Types of scattering

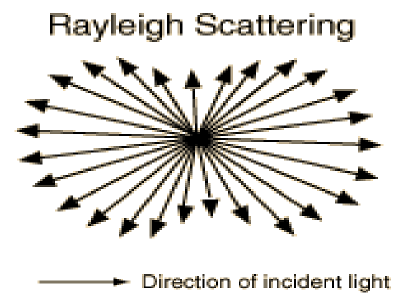
- Rayleigh scattering
- Mie scattering
- Geometric/Optic scattering

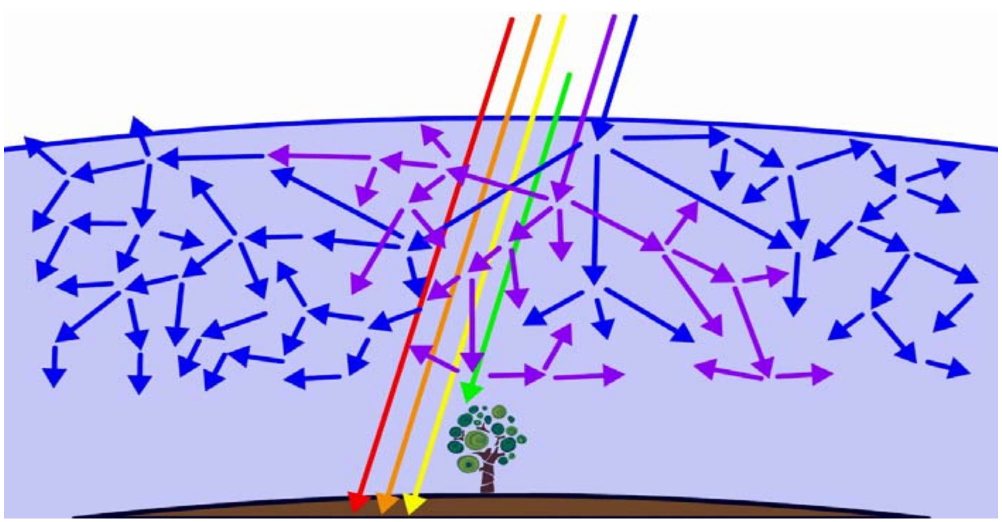


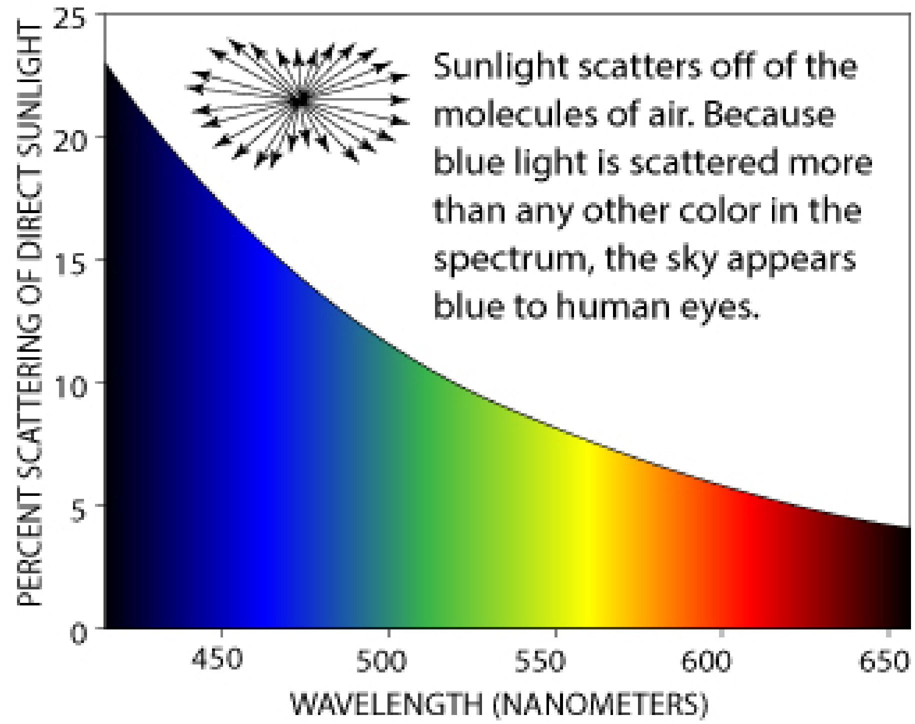
Rayleigh Scattering

Defines the type of scattering when **the size of particles is much smaller than the wavelength**.

- Occurs on air molecules
- Radiation scattered both in forward and backward direction
- Scattering strongly increases with decreasing wavelength (proportional to $1/\lambda^4$)
- In the “blue” band the scattering is 4-5 times stronger than in the “red” band



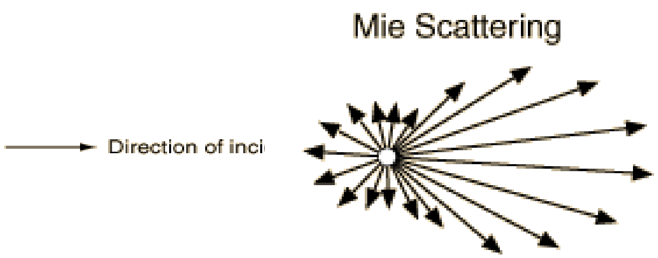




Mie Scattering

Defines the type of scattering when **the size of particles is comparable to the wavelength**.

- Occurs on atmospheric aerosols
- Forward scattering dominates
- Scattering slowly increases with decreasing wavelength (~ $1/\lambda$)
- Aerosols scatter 3-5% (clear atmosphere) to 20% (very turbid atmosphere) of the solar radiation



Geometric or Non-Selective Scattering

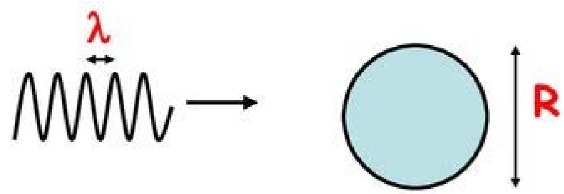
Defines the type of scattering when **the particle size is much larger than the wavelength.**

- Occurs on cloud/Rain droplets
- Radiation is scattered equally in all directions
- Scattering is independent of the wavelength. This causes whitish color of sky under heavy haze conditions

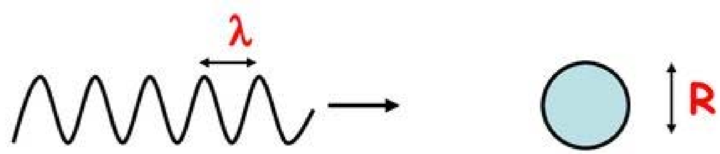
Scattering of light

- The scattering of light in the atmosphere depends on the size of the scattering particles, **R**, and on the wavelength, λ, of the scattered light.

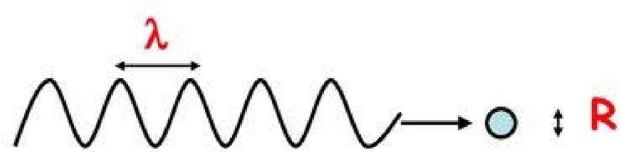
- Geometric scattering: R>>λ
  - Rain drops (R~10-100 μm)
  - All wavelengths equally scattered
  - Optical effects: white clouds

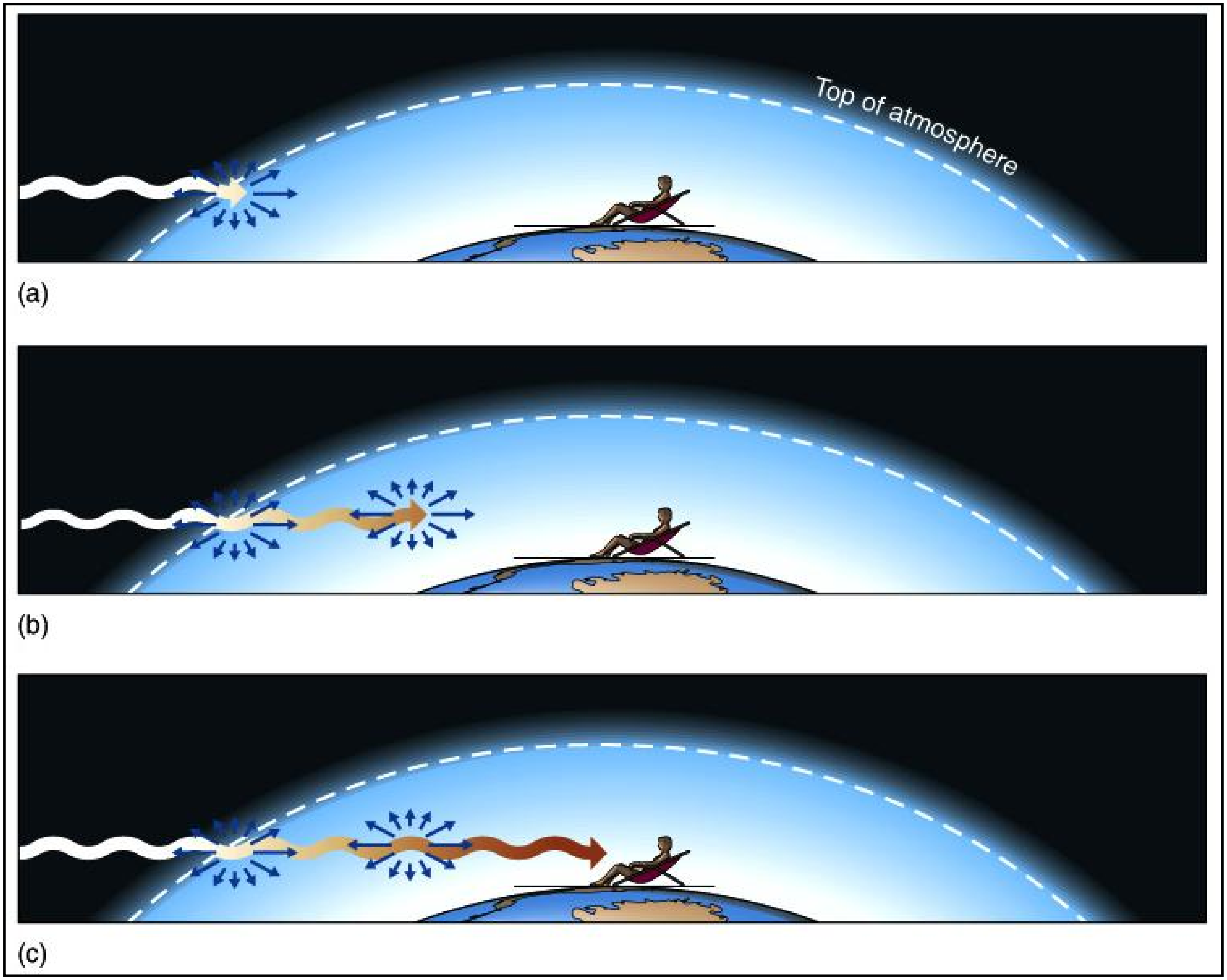


- Mie scattering: R~λ
  - Aerosols (R~0.01-1 μm)
  - Red scattered better than blue
  - Blue moon, blue sun



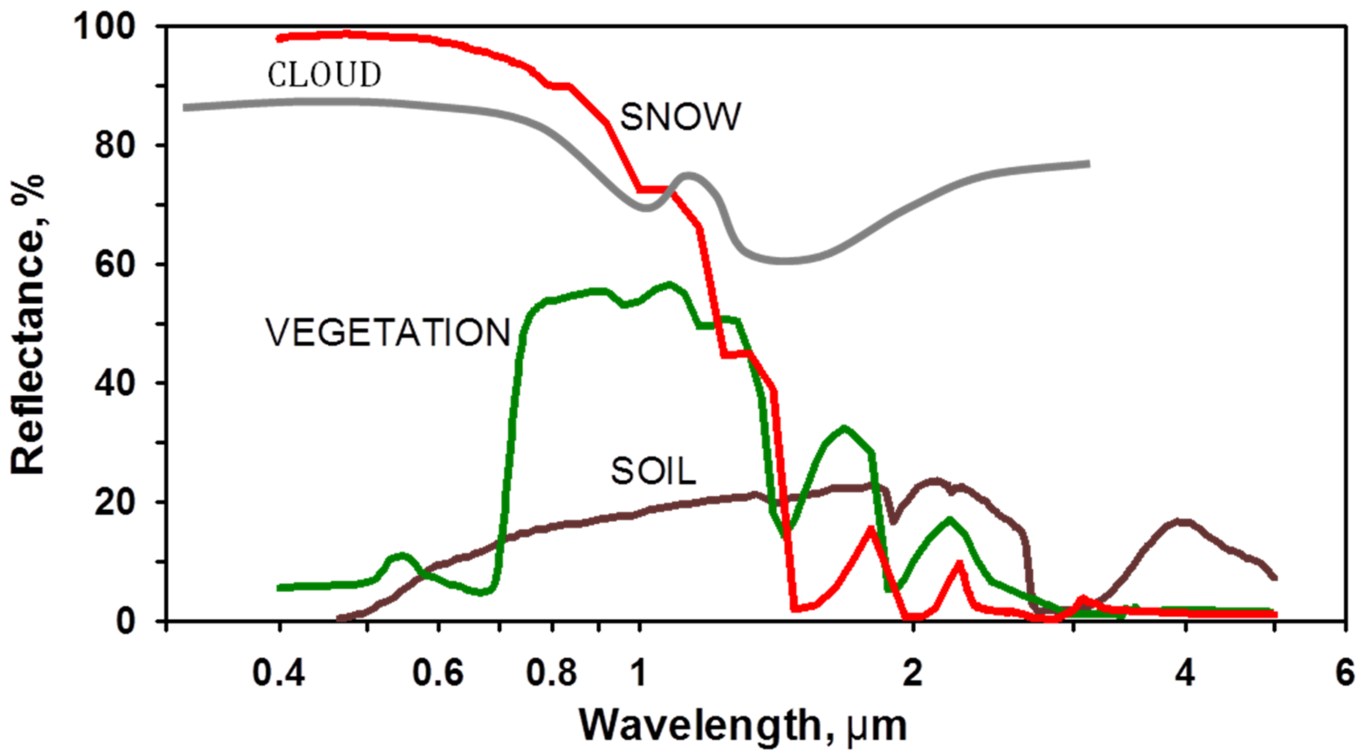
- Rayleigh scattering: R<<λ
  - Air molecules (R~0.0001-0.001 mm)
  - Blues scattered better than red
  - Blue sky, blue mountains, red sunsets





Sunrises and sunsets appear red because sunlight travels a longer path through the atmosphere. This causes a high amount of scattering to remove shorter wavelengths from the incoming beam radiation. The result is sunlight consisting almost entirely of longer (e.g., red) wavelengths.

Surface Reflectance



The smaller reflectance, the larger absorption

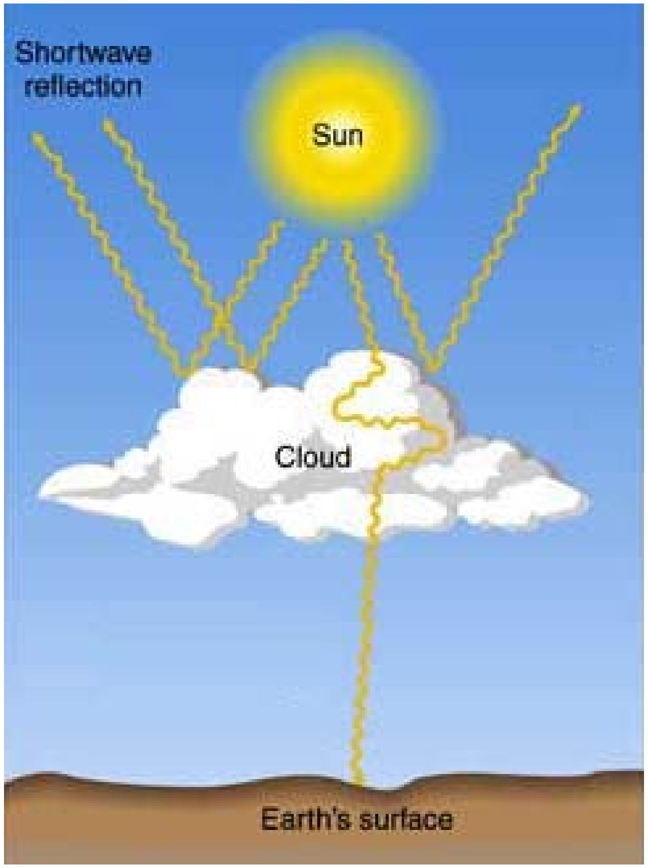
- Reflectance varies with wavelength and the surface cover type.
- In thermal infrared reflectance of most natural surfaces is very small
- Different spectral reflectance allows for discriminating between surface cover types in satellite imagery

Typical Reflectance in the Visible Range

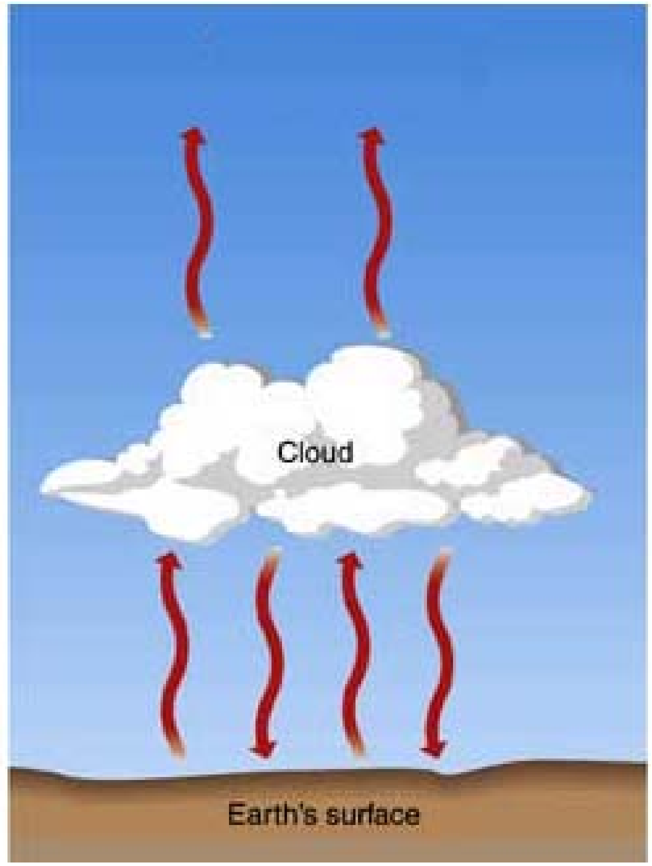
Material	Percent Reflected
Fresh snow	80–95
Old snow	50–60
Thick cloud	70–80
Thin cloud	20–30
Water (sun near horizon)	50–80
Water (sun near zenith)	3–5
Asphalt	5–10
Light soil	25–45
Dark soil	5–15
Dry soil	20–25
Wet soil	15–25
Deciduous forest	15–20
Coniferous forest	10–15
Crops	10–25
Earth system	35

Reflectance varies within each surface type !

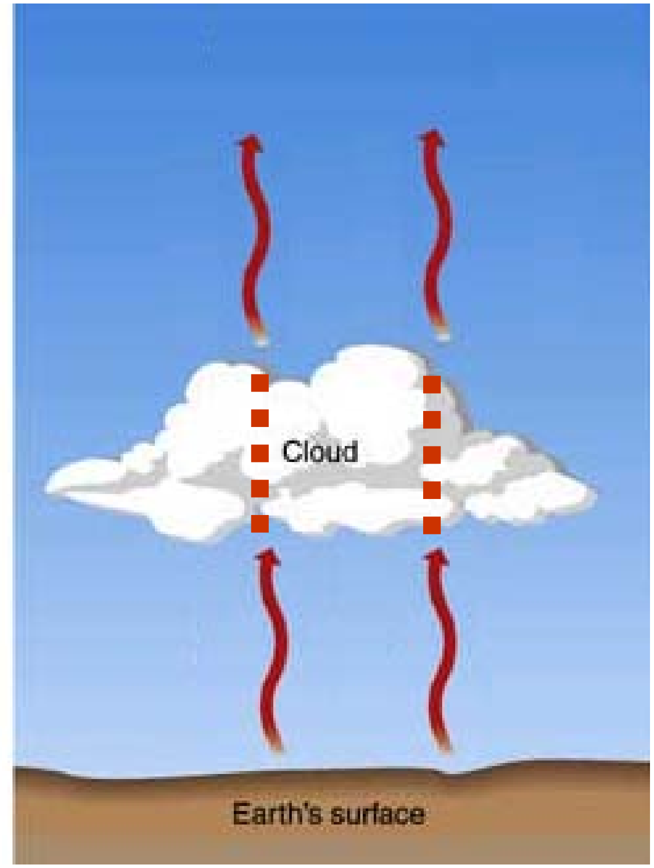
Cloud Effects on the Radiation



Visible: Clouds are mostly opaque and scatter and reflect most of incoming solar radiation

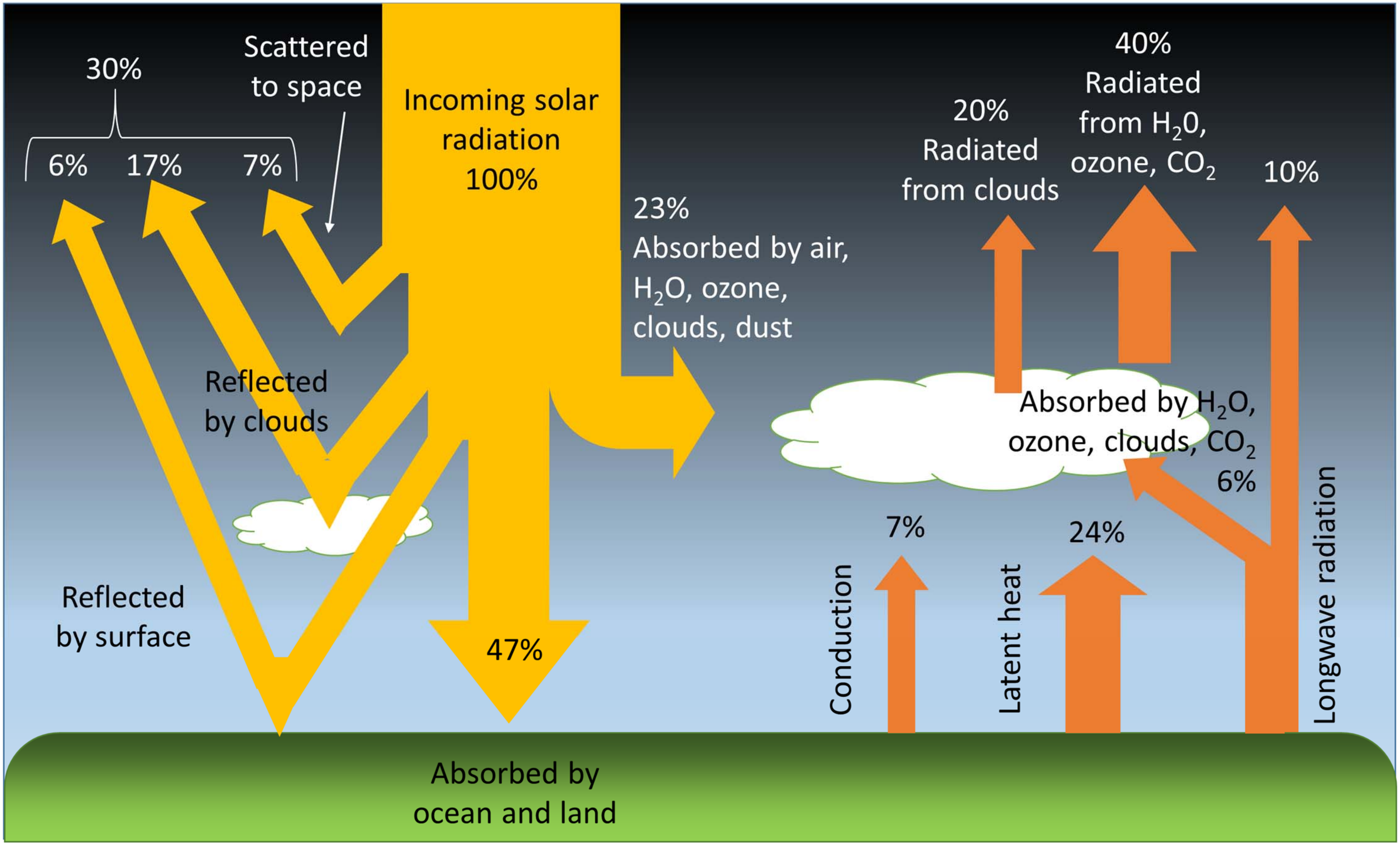


Infrared: Clouds are mostly opaque. They absorb Earth-emitted radiation and emit their own radiation corresponding to the temperature of their tops



Microwave: Clouds are mostly transparent. They transmit Earth-emitted radiation leaving it practically unchanged

Earth's Heat Budget: Radiation Fluxes



SUMMARY

Radiation observed from satellite is determined by the source of radiation (Sun or Earths or clouds)) as well as radiation scattering, absorption, reflection and emission in the Earth-atmosphere system

Observations of the Earth's surface is possible in atmospheric spectral "windows" where absorption of radiation by atmospheric gases is small.

Emission of thermal radiation by the Earth's surface is is determined by the surface temperature and its emissivity. Most natural surfaces are "gray" bodies with emissivity of less than 1.

Reflectance of most natural surfaces changes with the wavelengths. This provides the physical basis for discriminating between different surface types using multispectral observations from satellites.

READING

- **Remote Sensing Applications with Meteorological Satellites by W. Paul Menzel**, https://cimss.ssec.wisc.edu/rss/benevento/source/AppMetSat06.pdf
- Chapters 2-3.

- **Fundamentals of Remote Sensing. Canada Center for Remote Sensing** http://www.ldeo.columbia.edu/res/fac/rsvlab/fundamentals_e.pdf
- Chapter 1.1

- **Remote sensing Tutorial. Federation of American Scientists (FAS)** . http://fas.org/irp/imint/docs/rst/. Introduction