Radiation Transfer in Environmental Science

with emphasis on aquatic and vegetation canopy media

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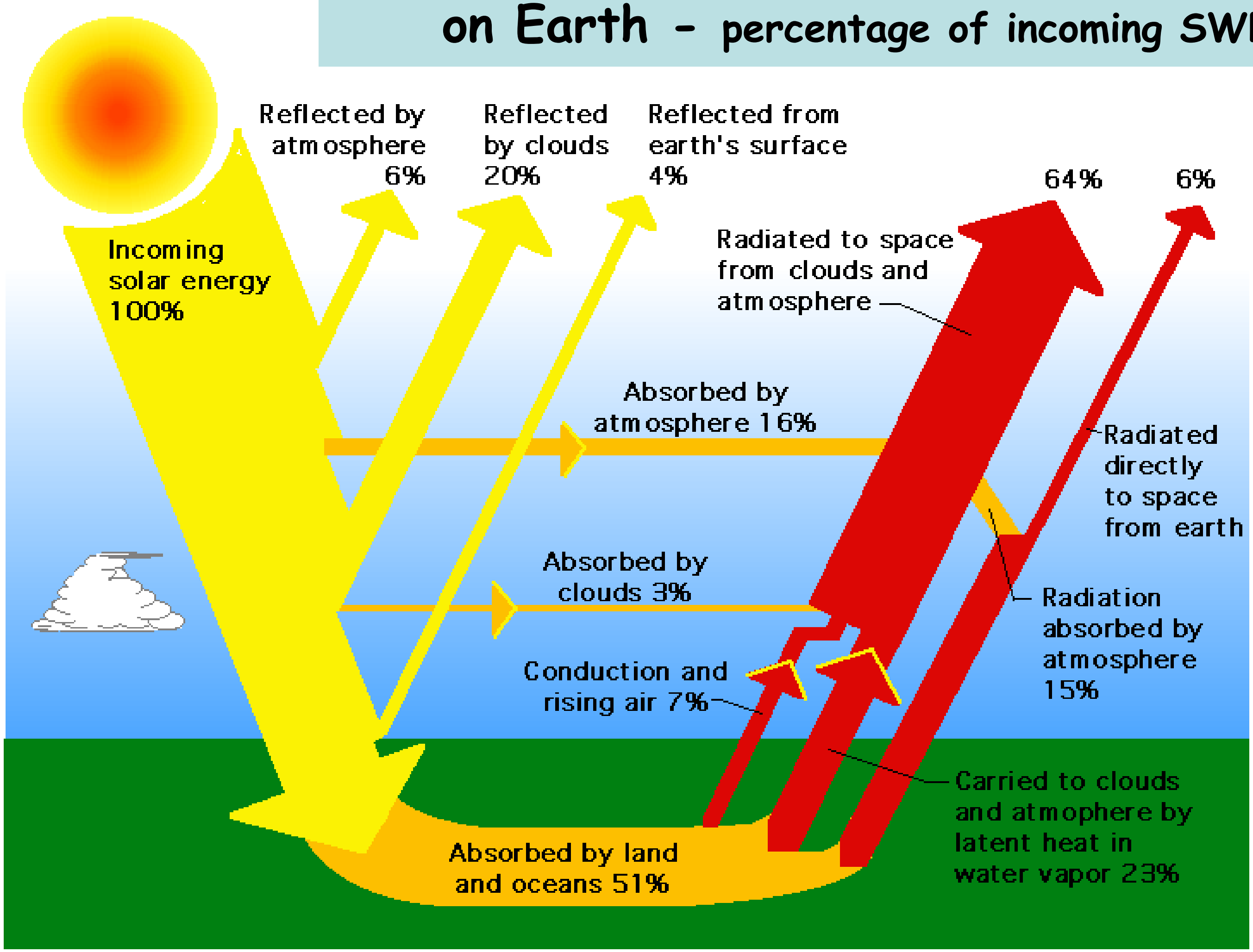
Introduction
Radiation in Environmental sciences

- **Most of the energy for processes on Earth is coming from the sun** (>99% of total energy) **and is delivered in the form of radiation.**
- **The sun is the energy source for the wind to blow and clouds formation, for sea waves, for plants to grow and for the animals to live on.**
  Even most of the energy sources for human consumptions come originally from converting sun energy to biochemical energy (e. g., fusil fuel).
- **The radiation coming from the sun is transferred through the atmosphere interacting with the air molecules and aerosols, part of the radiant beams are absorbed, part is reflected back to space and part is transferred through and arrives to the Earth surface.**
- **At the Earth surface part of the incident radiation is back reflected to the sky and again interact with the atmosphere. The other part is absorbed and then released back to the atmosphere at different energy forms, including re-radiation at longer wavelengths.**
- **The light interactions with the environment which greatly affects conditions and life on Earth are with: the atmosphere, the vegetation cover and the oceans. These interactions are the topic of this course.**

How the solar radiation is distributed on Earth - percentage of incoming SWR



Yellow – solar radiation

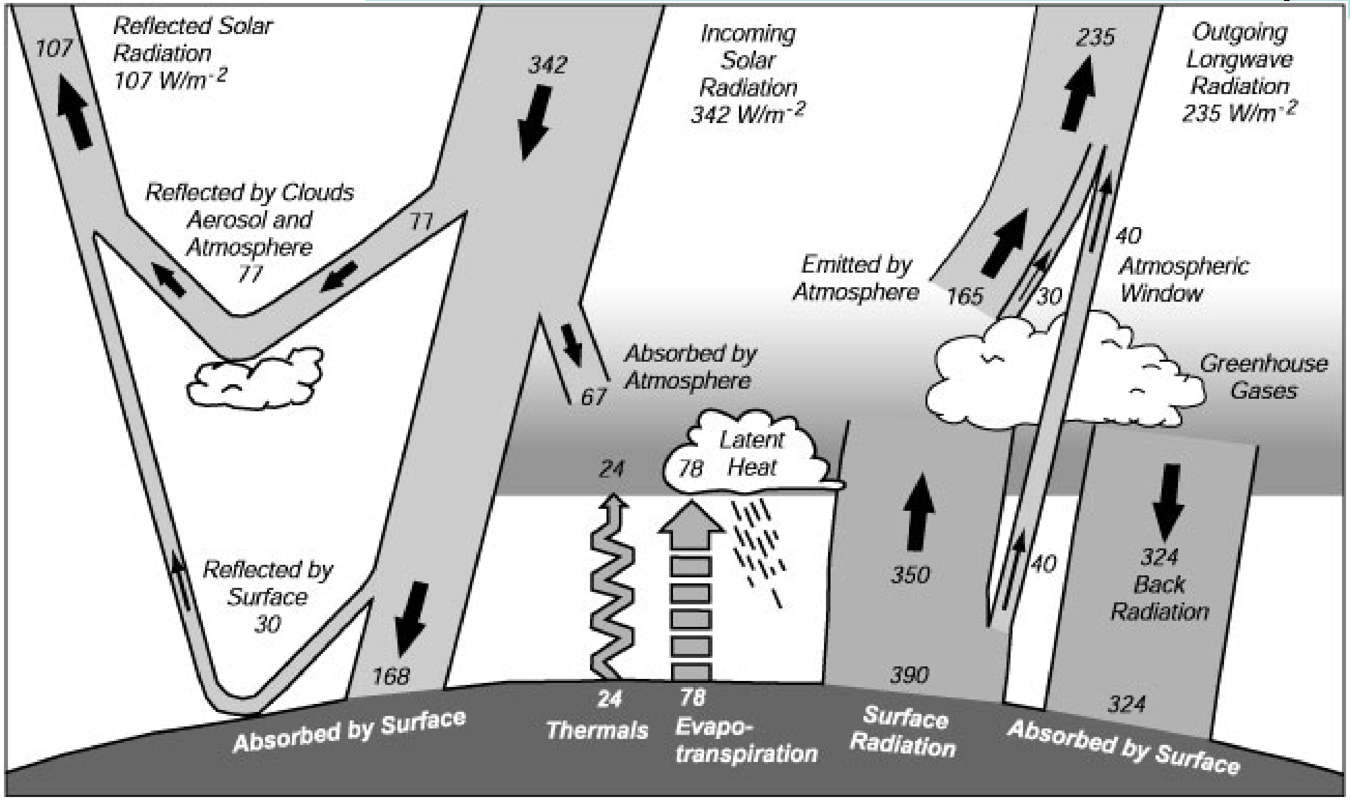
Red- Long wave (or Thermal) radiation

These are annual and global mean values.

30% of incoming SWR is back reflected to space, that is the Earth albedo at the atmosphere top. It is lower at the surface.

To keep the Earth in thermal balance the same amount of incoming energy should be emitted back to space, and it can returned only in a radiation form (as LWR).

Annual mean of Earth radiation balance – absolute values [W/m²]



Keihl &Trenberth, 1997

- Annual average incoming SWR at the top of the atmosphere - 342 W/m²
- The solar constant – 1366 W/m²
- Note the size of LWR fluxes compared with the solar fluxes – that is the green house effect (On long terms the Earth should be in equilibrium)
- Means of sensible and latent heat fluxes
- Global warming means net SWR at the atmosphere top is smaller than LWR to space, till a new steady-state been reached.

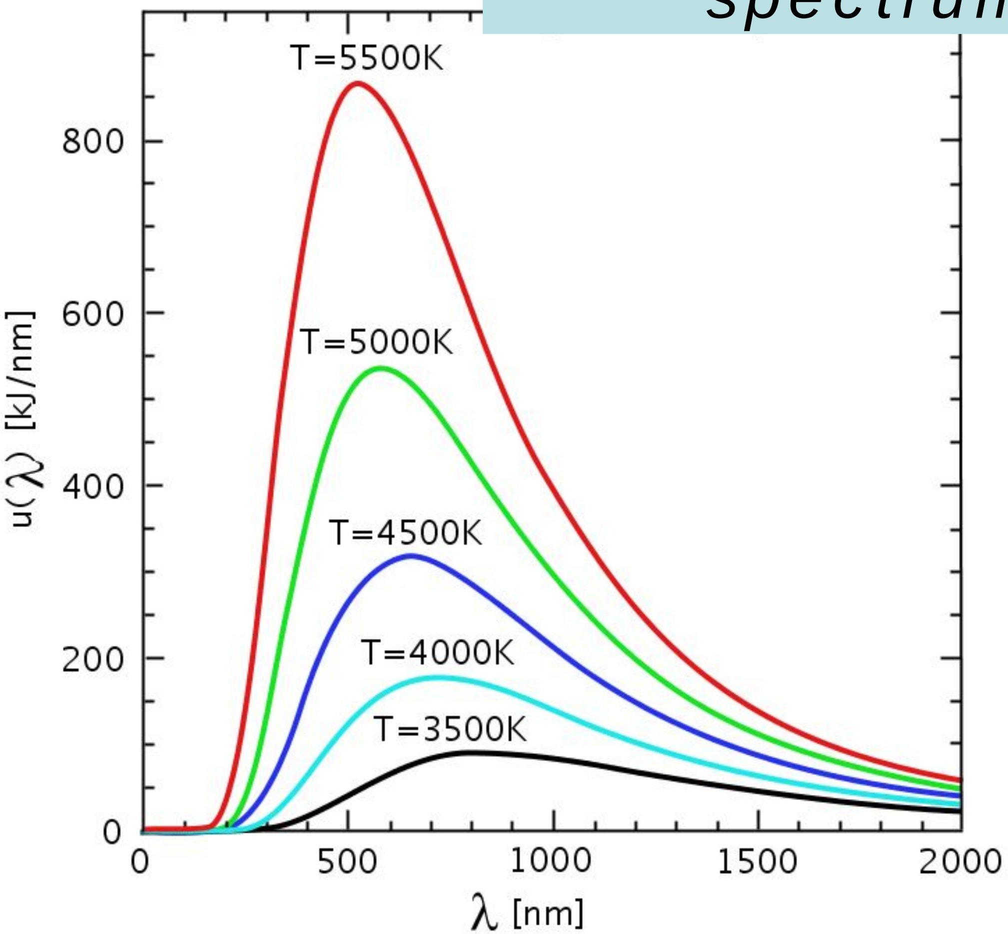
The nature of electromagnetic radiation

- All bodies emit radiation to the surroundings according to their temperature.
- The spectral radiance of the emitted radiance at all wavelenghts and from ideal element (black body - BB) at surface temperature *T*, as a function of frequency ν is givan by Planck's law as:

$$I(\nu,T)=\frac{2h\cdot\nu^{3}}{c^{2}}\cdot\frac{1}{e^{\frac{h\nu}{kT}}-1} \qquad (1.1)$$

- This function represents the emitted readiation (power) (*I*) coming from unit area (*A*) of the emitting surface, per unit solid angle (θ), and per unit frequency. Integration of *I* over all frequencies and for given direction (cf. to a sphere, arc…) gives the total emitted radiation from a unit surface per unit time.
- *h* – Planck's constant and *k* – Boltzmann's constant
- Planck equation may be represented as function of the wavelength.

Planck's black body spectrum



1000 nm = 1 μm

Planck distribution of different surface temperatures:

Emitted radiance function of wave length ($\lambda = c/\nu$). (c- speed of light).

Area under the curve – total emitted radiance (u)

<u>Note:</u>

The strong decay of u with temperature.

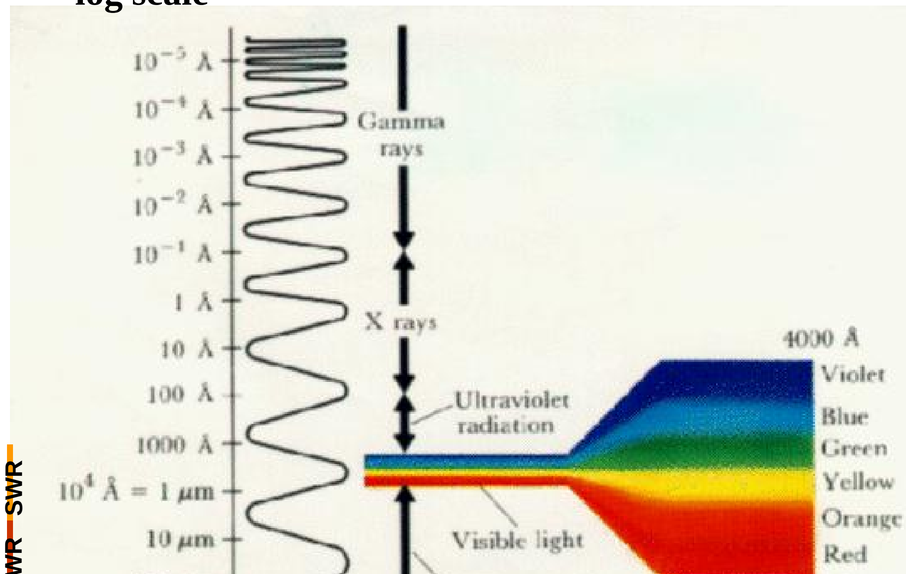
Sun surface is almost an ideal BB, emits solar radiation at effective temperature of ~5800K.

Most emitted radiation concentrated around the peak.

The peak of the curves are shifted with wavelength

The spectrum of light

Wave length (λ) log scale



The Earth receives EM radiation the wavelength range between 0.3 to 100 μm.

It is common to divide this spectrum to the followings ranges:

UV(0.29-0.38 μm) – effect on genes, biodegradations, photochemistry in air and others; <4% of solar range (=SWR, short)

PAR (0.38-0.71 μm) – the visible range, photosynthetic activities, morphology and others; 20-46% of SWR.

NIR (0.71-4.0 μm – 10^{-6} m) – thermal, metabolism, morphological and other effects; 50-80% of SWR.

FIR – (4.0-100 μm) – Mainly thermal effect and mostly originates from the earth (soil, veg', air..). Also called the thermal or the long wave range (LWR)

Nature of radiation:

- Radiation exhibits the properties of both waves (e. g. diffraction) and of particles. Energy is transferred as districted units termed quanta or photons).
- The energy (noted as E) of a photon is related to wavelength or frequency:

$$E = hc/\lambda = h\nu \qquad (1.2)$$

h the Planck constant =$6.63*10^{-34}$ Js, c = $3*10^{8}$ ms^{-1} (in vacuum)

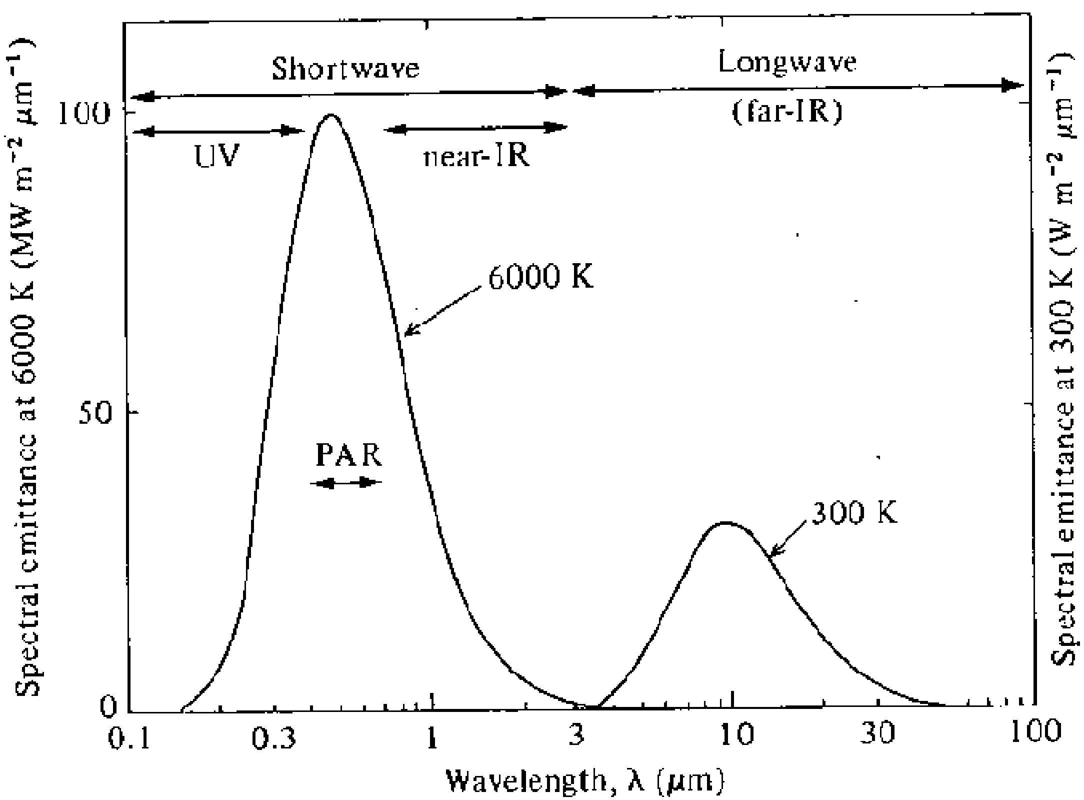
- Emission or absorption of radiation requires a corresponding change in the potential energy of the material. For a single atom, exchange energy could perform only in district wavelengths but energy transitions by complex body may have infinity number of wavelengths.
- The peak wavelength (λ_m) of the Planck distribution is a function of temperature given by Wien's low:

$$\lambda_m = 2897/T \qquad (T\ [K]) \qquad (1.3)$$

- λ_m of the solar radiation (~5800 K) is at about 0.483 μm, within the visible range (blue color). Element radiating at 300 K (27 °C), typical terrestrial temperature, emits with λ_m of 9.65 μm well in the LWR range.
- At the surface of the Earth there is small overlap between the two fluxes:

Black body emitted radiation spectrums

at temperature approximate to the sun (6000 K) and the Earth (300K)



- Left axis is for the 'solar' spectrum with units of [MW m^{-2}]; Right axis is for the 'terrestrial' spectrum with [W m^{-2}] units.
- The intensity of radiation decrease per unit area by the square root (R^2) of the distance thus and Solar and Earth fluxes have similar magnitudes at the Earth's surface
- ~1% is the solar originate LWR that reaches the Earth surface.
- The green house effect is mainly concerned with absorption of LWR by the atmosphere.

Radiant Emittance

- Total energy emitted (emitted flux density, *E*) by a unit surface area is found by integrating the Planck equation (1.1) over all wavelengths and the result is given by the Stefan-Boltzmann low (for black body):

$$E_{BB}(T) = \sigma \cdot T^4 \quad [Wm-2] \qquad (1.4)$$

With σ - the Stefan-Boltzmann constant = $5.67 \cdot 10^{-8}$ W m^{-2} K^{-4}

- For non-black body (common surface), the emitted flux density is lower than that of a black body and be given by:

$$E\,(T) = \varepsilon \cdot \sigma T^4 \qquad (1\text{-}5)$$

- ε is the emissivity factor, usually function of the surface temperature and the emitted wavelength ($\varepsilon(\lambda)$).
- When ε is not function of λ, we say that the surface has a gray emissivity.
- $\varepsilon = E/E_{BB}$ and $0 < \varepsilon < 1$.
- Equation 1-5 is highly applied in environmental sciences when calculating the radiation fluxes at the thermal range.
- For many surfaces the emissivity at the thermal range is $\varepsilon > 0.95$.
- ε values: water – 0.96, soil 0.8 – 0.96, leaves – 0.94 – 0.98.
  Emissivity of a clear sky is ~0.8 and for overcast sky ~0.97

Units and definitions:

- Terms in radiation transfer are quite complicated and one can find different terms and notation convention in books.
- Radiation is either originate from emitted element or it received by another object which add to the difficulties.
- Terminology (partially list):

Term	Units	Symbol	definition
Radiant energy	J (Joule)	E	Electromagnetic energy
Radiant flux	Js^{-1} = W (Watt)		Amount of energy emitted, transfer or received per unit time
Radiant flux density	W m^{-2}	Φ	Radiant flux per unit area
Radiance	W m^{-2} sr^{-1}	N; E	Radiant flux density emanating from a surface per unit solid angle
Irradiance	W m^{-2}	I	Radiant flux density incident on a surface
Emittance	W m^{-2}		Radiant flux density emitted by a surface
Photon flux	mol s^{-1}		Number of photons emitted or absorbed by a area per unit time