Course Remote Sensing and Climate

Summer 2026
University of Frankfurt

2. Day (R. Hollmann)

- ➔ Content and Structure of Course
- ➔ Motivation and background
- ➔ **A short introduction in Physics**
- ➔ Radiative Transport and retrieval basics
- ➔ Satellite orbits and instruments
- ➔ Climatologies based on satellite instrument and usage

Notes to PDF-Version

This PDF is based on the presentation given in the summer term 2025 of University Frankfurt as part of the course „remote sensing and climate“.

It is meant to recall the content the content of the lecture and is for the personal use of the participants of the course and <u>not</u> for a wider audience.

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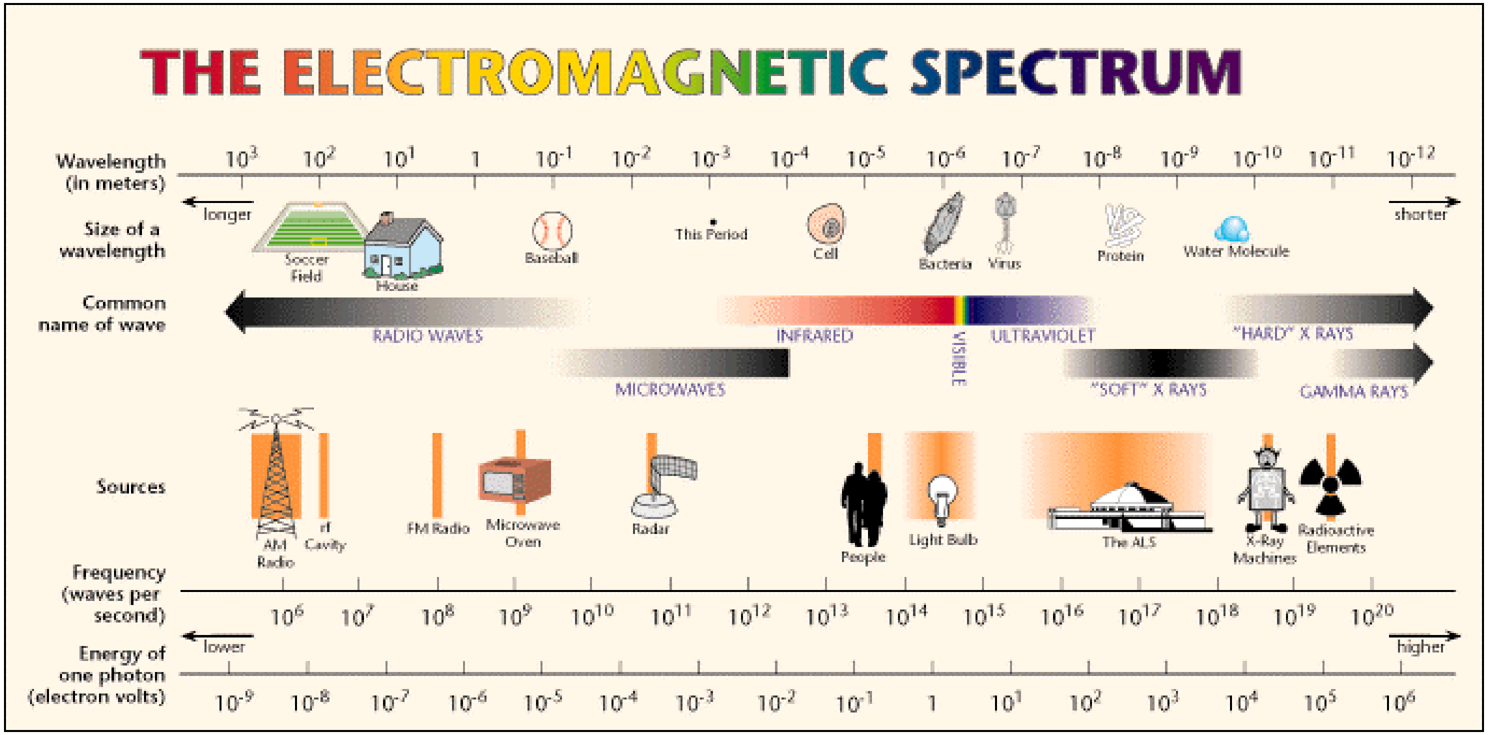
A short introduction in Physics

Content

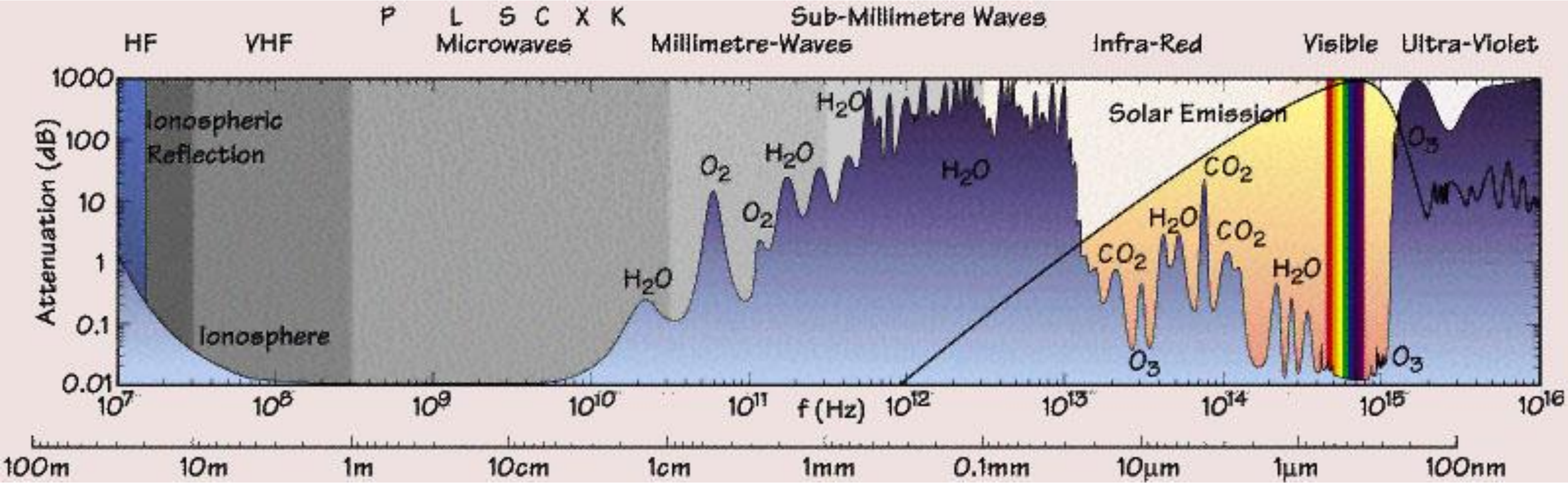
- electromagnetic spectrum
- Solid angle, Radiance, Flux
- Black body and Planck function
- Reflection, Emission

Electromagnetic Spectrum (I)

- Electromagnetic radiation is a form of energy propagation. It can be understood as a wave, i.e. as a periodically changing electromagnetic field. It is characterized by the frequency or wavelength.
- The entirety of the wavelengths occurring in electromagnetic radiation is represented in the electromagnetic spectrum:



Electromagnetic Spectrum (II)



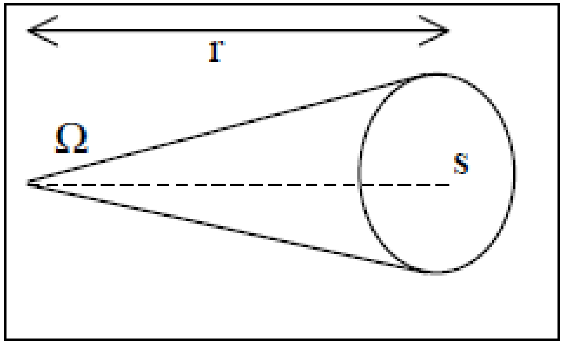
Radio-window

Optical window

Which parts are often used in satellite remote sensing?

Solid Angle Ω

Solid Angle (often Steradian) is defined as ratio of an area s of a cone to the radius r of this cone:
$\Omega = s / r^2$.



Expressed as differential d Ω and using

$$ds = (r\, d\theta)\ (r \sin(\theta)\, d\phi)$$

(sphere co-ordinates!) we yield :

$$d\Omega = \frac{ds}{r^2} = \sin(\theta)\, d\theta\, d\phi$$

Radiance

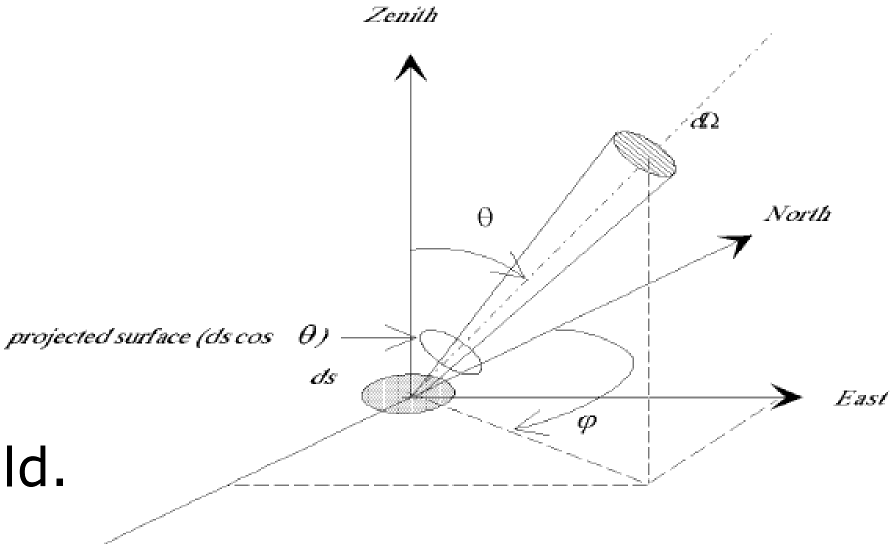
The **radiance L** or intensity (I) is the radiant energy in one direction per unit of time, wavelength and solid angle (perpendicular to the axis) and is defined as:

$$L_\lambda = \frac{dE_\lambda}{ds\cos(\theta)d\Omega\,dt\,d\lambda}$$

Unit: W / (m² sr μm).

L (or I) is monochromatic

The radiance as a function of direction enables a complete description of the radiation field.



Characteristics of radiance

In general, L is a function of
- direction
- location
- wavelength
- time

= 7 independent variables

The integration of L over solid angle provides the radiation flux density.

Special cases:

L independent of direction: **ISOTROP**

L independent of location: **HOMOGEN**

radiant flux and **radiance flux density Φ**

The **radiant flux Φ** describes the radiant energy that is transported, received or emitted per unit of time. It provides neither information about the directional distribution nor about the spatial distribution of the radiation.

$$\Phi_\lambda = \frac{dE_\lambda}{dt\, d\lambda}$$

Unit is Watt.

The **radiance flux density or irradiance** describes the radiation flux through a certain area (dA) and thus provides information about the area distribution of the radiation:

$$F_\lambda = \int_\Omega I_\lambda \cos(\theta) d\Omega = \frac{dE_\lambda}{ds\, dt\, d\lambda} = \frac{d\Phi_\lambda}{ds}$$

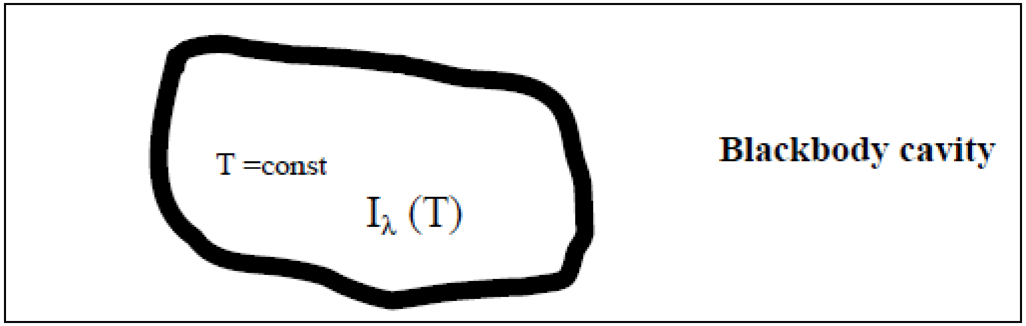
Unit is Watt / (m² μm).

Blackbody and **Thermodynamic equilibrium**

A **blackbody** is a body that absorbs all incident radiation.

Thermodynamic equilibrium describes the state of radiation and the body within an isolated environment at constant temperature.

Blackbody temperature
The blackbody radiation is the radiation field within a body in thermodynamic equilibrium.



Characteristcs of blackbody radiation

The **emitted radiation** of a blackbody is

- **Isotropic**
- **homogeneous**
- **not polarized**
- **depends only on the temperature and wavelength**

Two **blackbodies** with the **same temperature** emit exactly the **same radiatio**n

A **blackbody** emits **more radiation** than **all other objects** / **types** at the **same temperature**

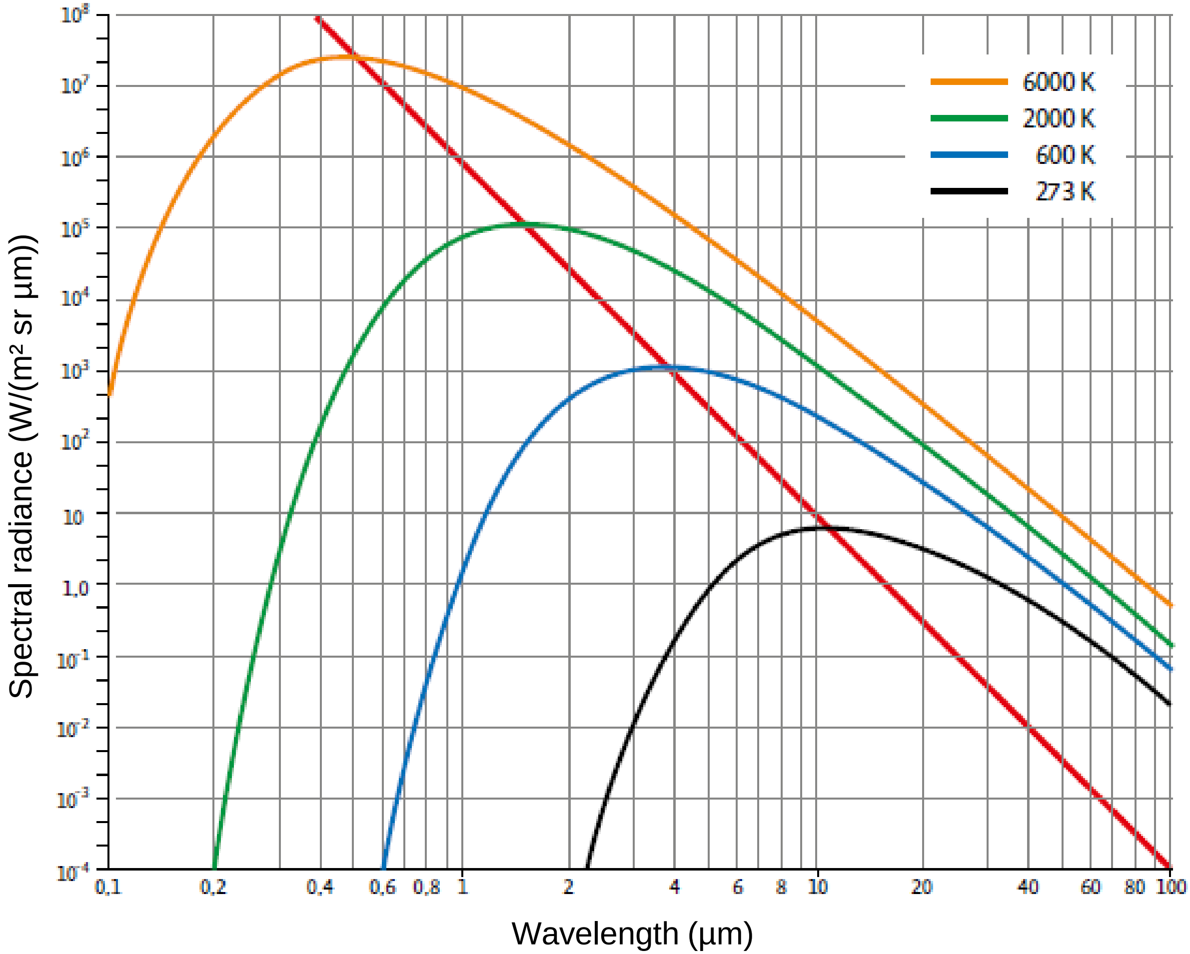
The **Planck function** describes the **radiance** of the **blackbody**.

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5 (\exp(hc / k_B T\lambda) - 1)}$$

Planckfunction

What about the Planckfunction for the Earth?

What about the Planckfunction for the Sun?

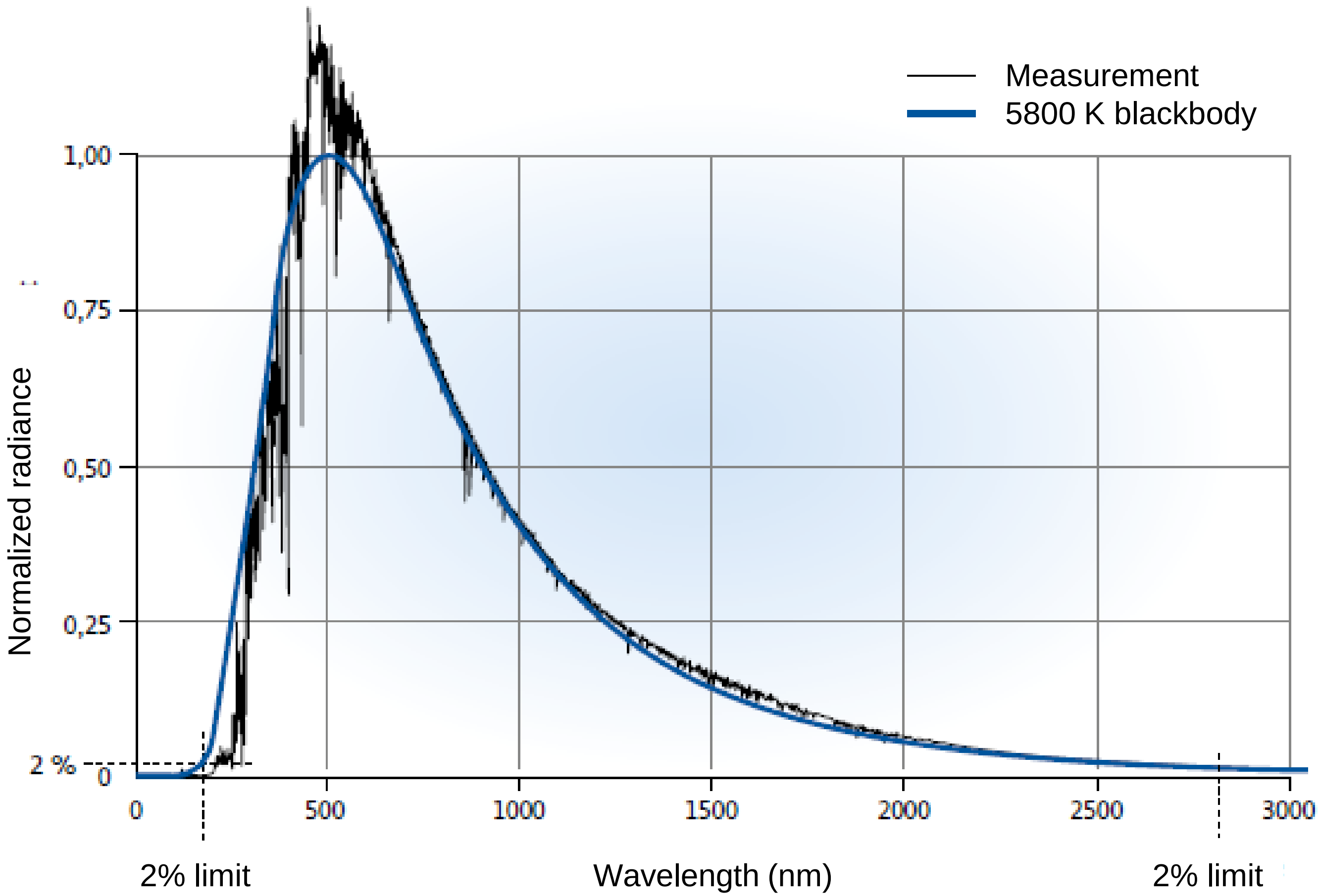


Planckfunction for different temperatures

Spectral radiance of blackbodies with 6000, 2000, 600 and 273 K.
Red line indicates the respective radiation maximum.

Köpcke et al. (2012), adapted

What about the Planckfunction for the Sun?



Köpcke et al. (2012)

Planckfunction

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5(\exp(hc/k_B T\lambda) - 1)}$$

For large Wavelengths (Rayleigh-Jeans Law):

$$\lambda \to \infty \Rightarrow B_\lambda(T) = \frac{2k_B c}{\lambda^4} T$$

Linear Approximation is important for passive microwave

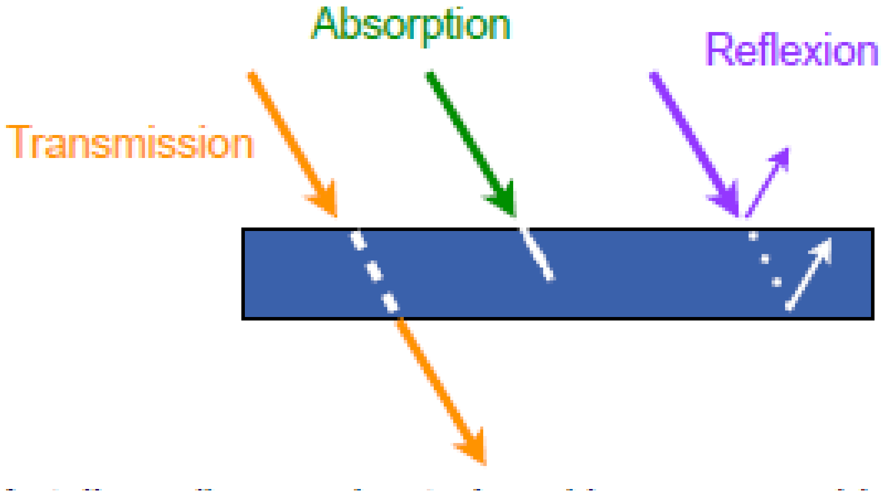
Stefan Boltzmann Law:

$$F = \sigma T_B^4, \quad \sigma = 5.67\,10^{-8}\, W/(m^2 K^4)$$

Interaction of electromagnetic radiation

Part of the electromagnetic radiation hitting a body is **reflected**, another part is **absorbed** and the rest penetrates the body which is called **transmission**.

The **individual proportions** vary greatly and **depend** on both the **characteristics** of the body and the **wavelength** of the radiation in question.



Extinction and Emission

Electromagnetic radiation **in the atmosphere** is influenced by gases, aerosols and cloud particles:

extinction (“attenuation”) leads to a reduction in radiance

absorption: Transformation of electromagnetic energy into other energy

scattering: Redistribution of electromagnetic energy in a different direction

(a) elastic -> constant wavelength
(b) inelastic (Raman) -> wavelength changes

Emission leads to an increase in radiance
- essentially in the thermal range

Emission and Reflection of surfaces

Energy conservation: Absorption + Transmission + Reflection = 1

Emissivity of surface:
Generally, depends on

- Direction
- surface temperature
- Wavelength
- Surface properties

Thermal IR (4µm < λ < 100µm) all surface with an emission larger than 0.8 are nearly independent of direction :

$$L_\lambda = \varepsilon_\lambda B_\lambda(T_S), \quad F = \varepsilon\sigma T_S^4$$

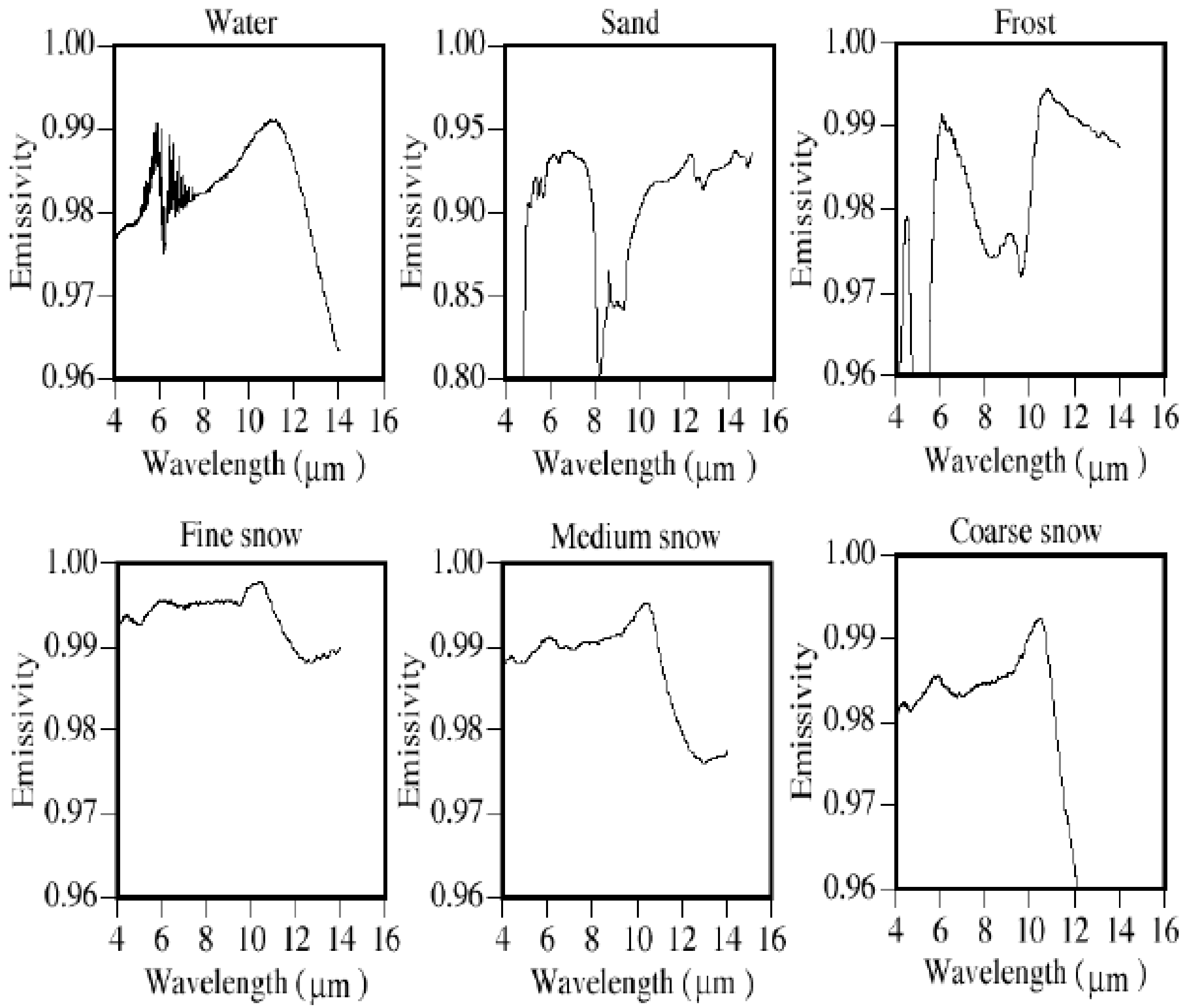
Solar: (0.1 µm < λ < 4 µm), emission negligibly small
Microwave (0.1 cm < λ < 100 cm), emission depends strongly on type and surface state (e.g. ice/water)

Emissivity of surface types (3)

Surface	Emissivity
Water	**0.993-0.998**
Ice	**0.98**
Green grass	**0.975-0.986**
Sand	**0.949-0.962**
Snow	**0.969-0.997**
Granite	**0.898**

Emissivity of surfaces types (10-12 µm domain)

Emissivity of surface types (2)



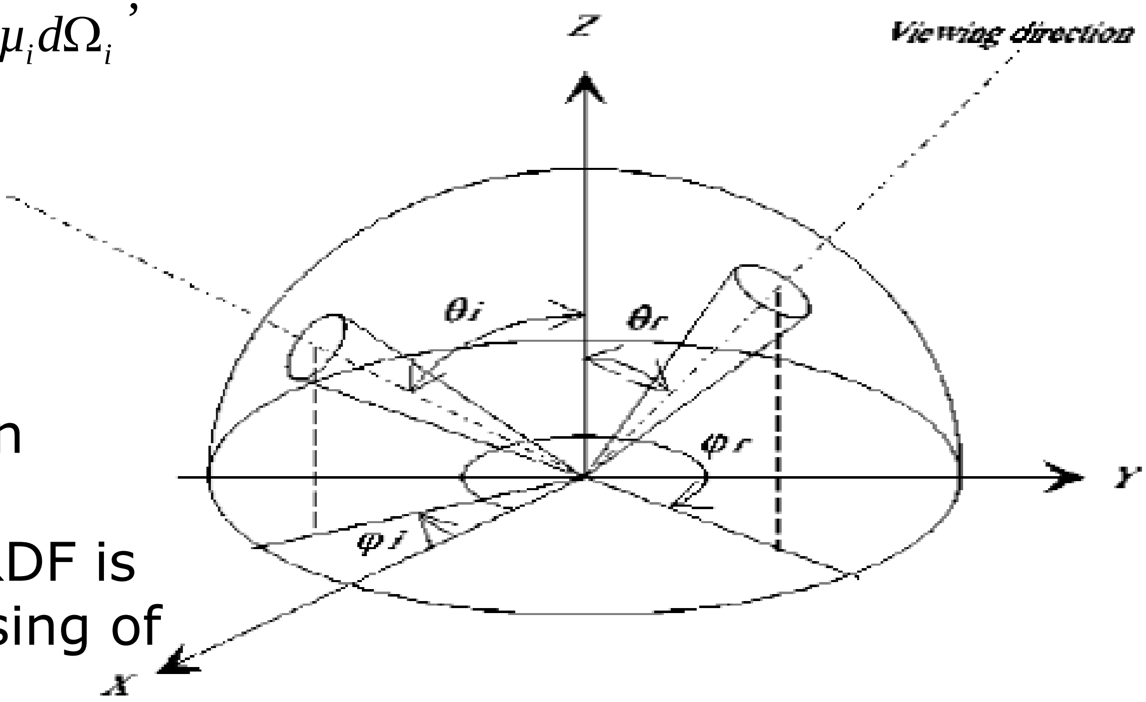
Spectral emissivity of surface types

Reflection of Surfaces

Surfaces are anisotropic, which is why a **BRDF (bi-directional reflectance distribution)** is introduced. It characterizes the angular dependence of the ground reflection:

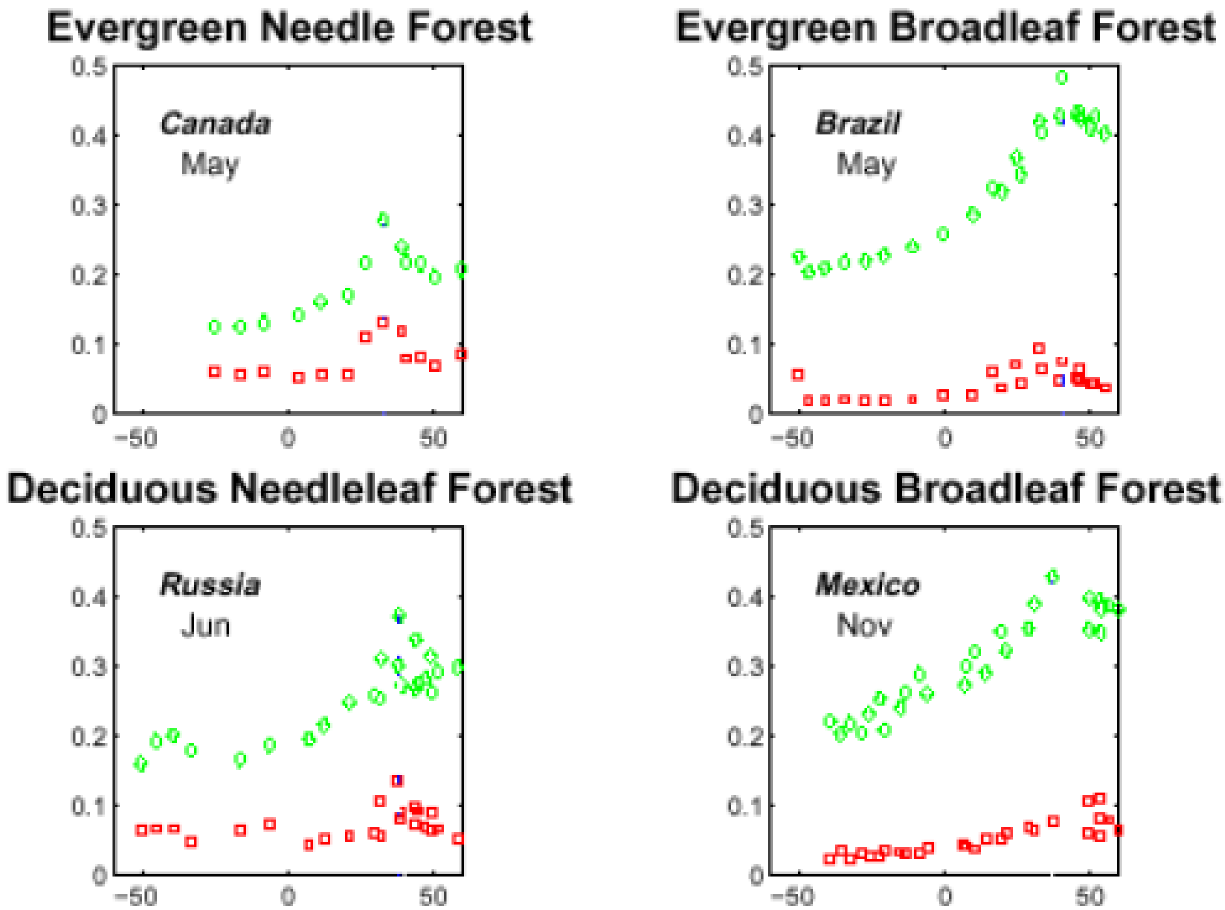
$$R(\mu_i,\varphi_i,\mu_r,\varphi_r) = \frac{\pi dI^{\uparrow}(\mu_r,\varphi_r)}{dI^{\downarrow}(\mu_i,\varphi_i)\mu_i d\Omega_i},$$

$$\mu_i = \cos(\theta_i),\ \mu_r = \cos(\theta_r)$$



- the BRDF depends on wavelength.
- Knowledge of the BRDF is needed in remote sensing of land surfaces

BRDF



Example of the BRDF for 4 land surface types.
For two different visible channels 0.6 µm (green), 1.6 µm (red).