BASIC SATELLITE METEOROLOGY COURSE

EUMETSAT

Introduction to Remote Sensing

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Definition

Remote Sensing is the science of obtaining and interpreting information from a distance, using sensors that are not in physical contact with the observed object

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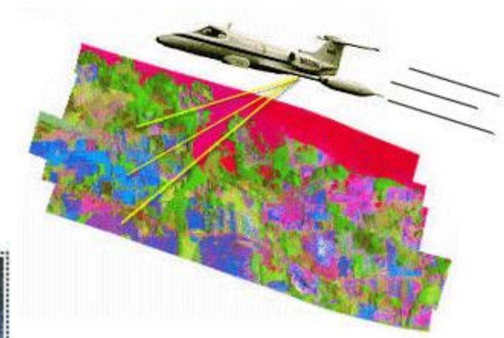
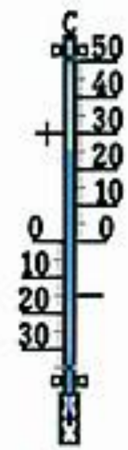


Example:
Aerial, satellite, spacecraft observations of the earth (and other planets / stars / galaxies!)

Opposite

In-situ measurements – the measurement device is in physical contact with the probe

Example:
Thermometer, anemometer, pitot tube, …



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Biological Evolution

You are very familiar with the concept:

- Your eyes detect electromagnetic radiation in the form of visible light
- Your ears detect acoustic information
- Some animals detect the earth's magnetic field (bird migration)

- ……

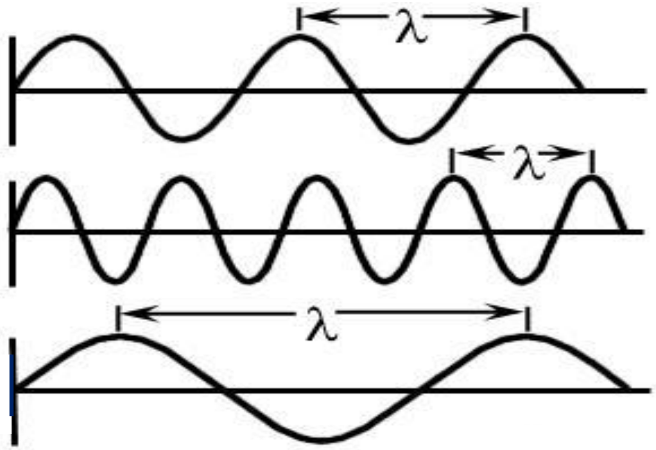
Remote Sensing in Meteorology

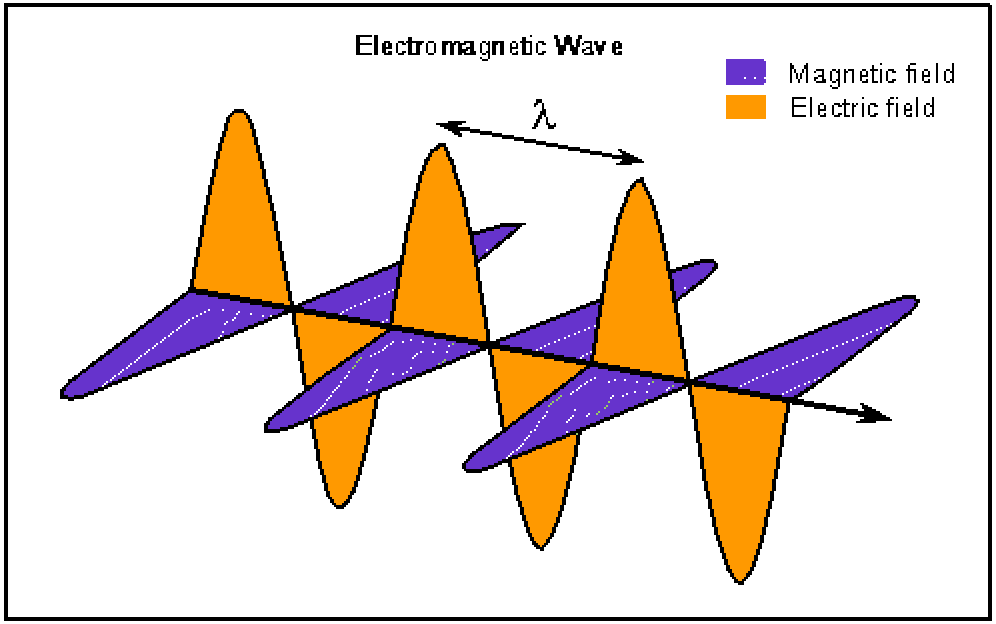
Methods that detect and measure electromagnetic energy

Focus in this course:

- Underlying physical concepts
- Interpretation of remotely sensed images
- Important image characteristics from different sensors

Electromagnetic Waves

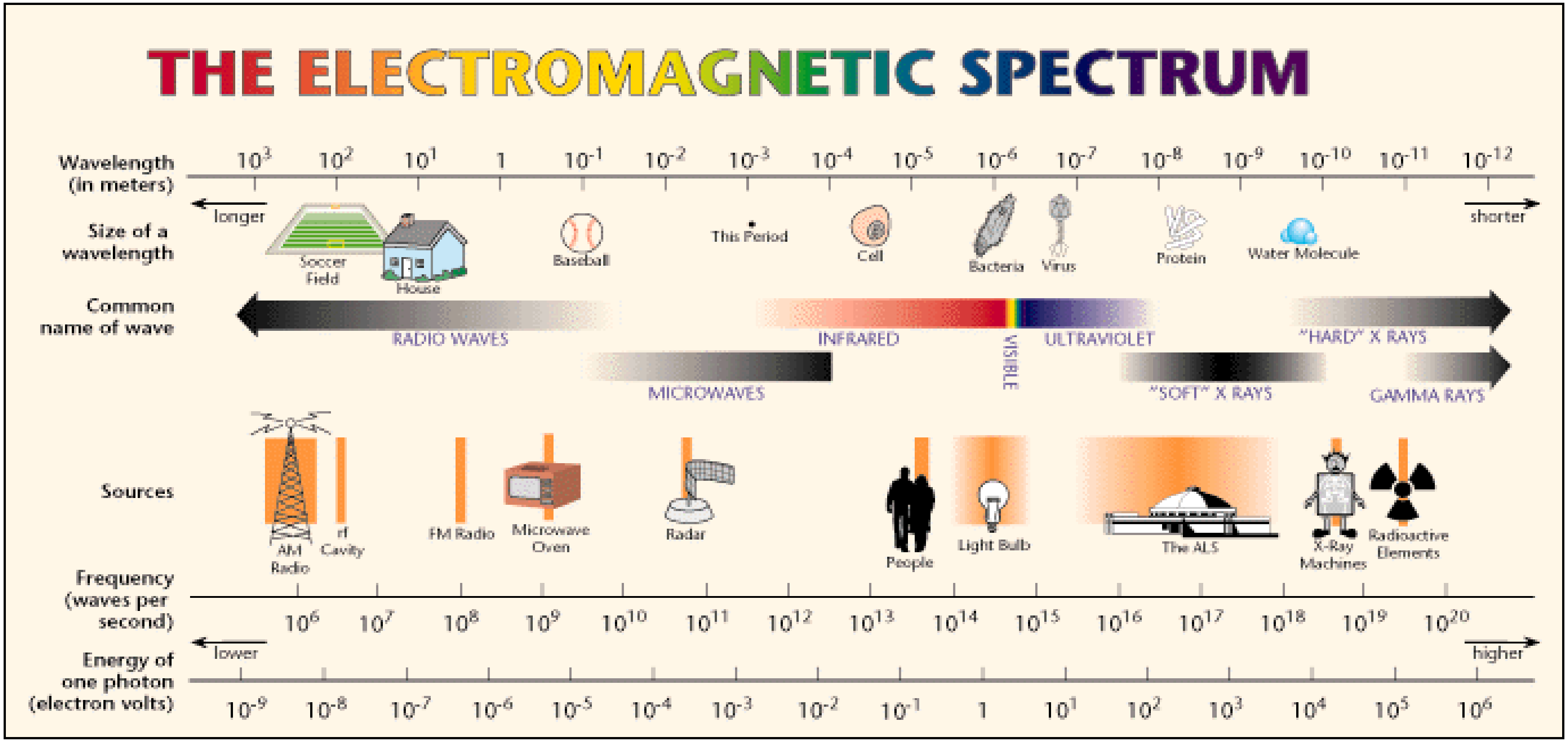




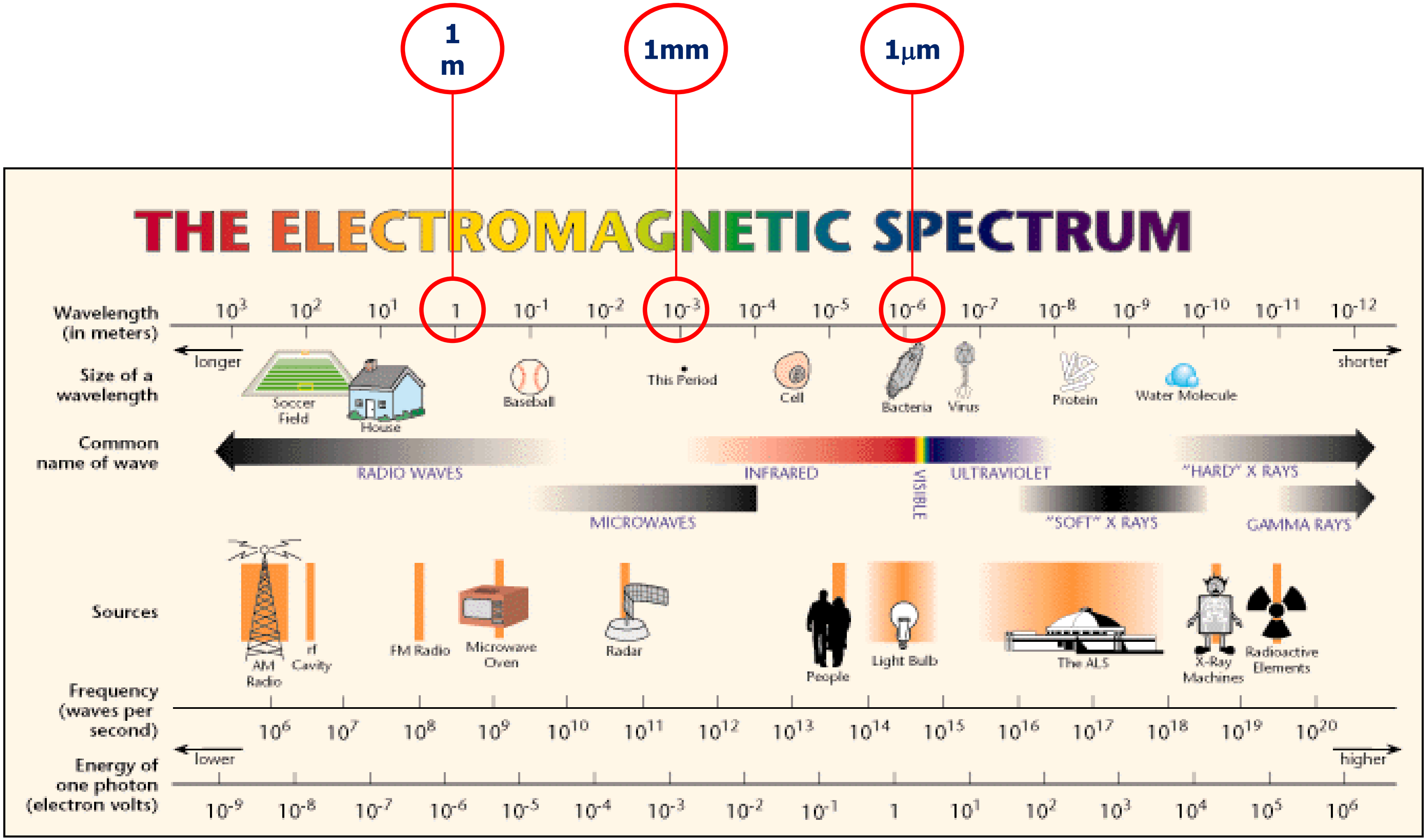
Characteristics:

- Wavelength λ (m or cm or μm)
- Propagation velocity c (m/s)
- Frequency $\nu = c / \lambda$ (s^{-1})
- Wavenumber $=1/\lambda$ (cm^{-1})

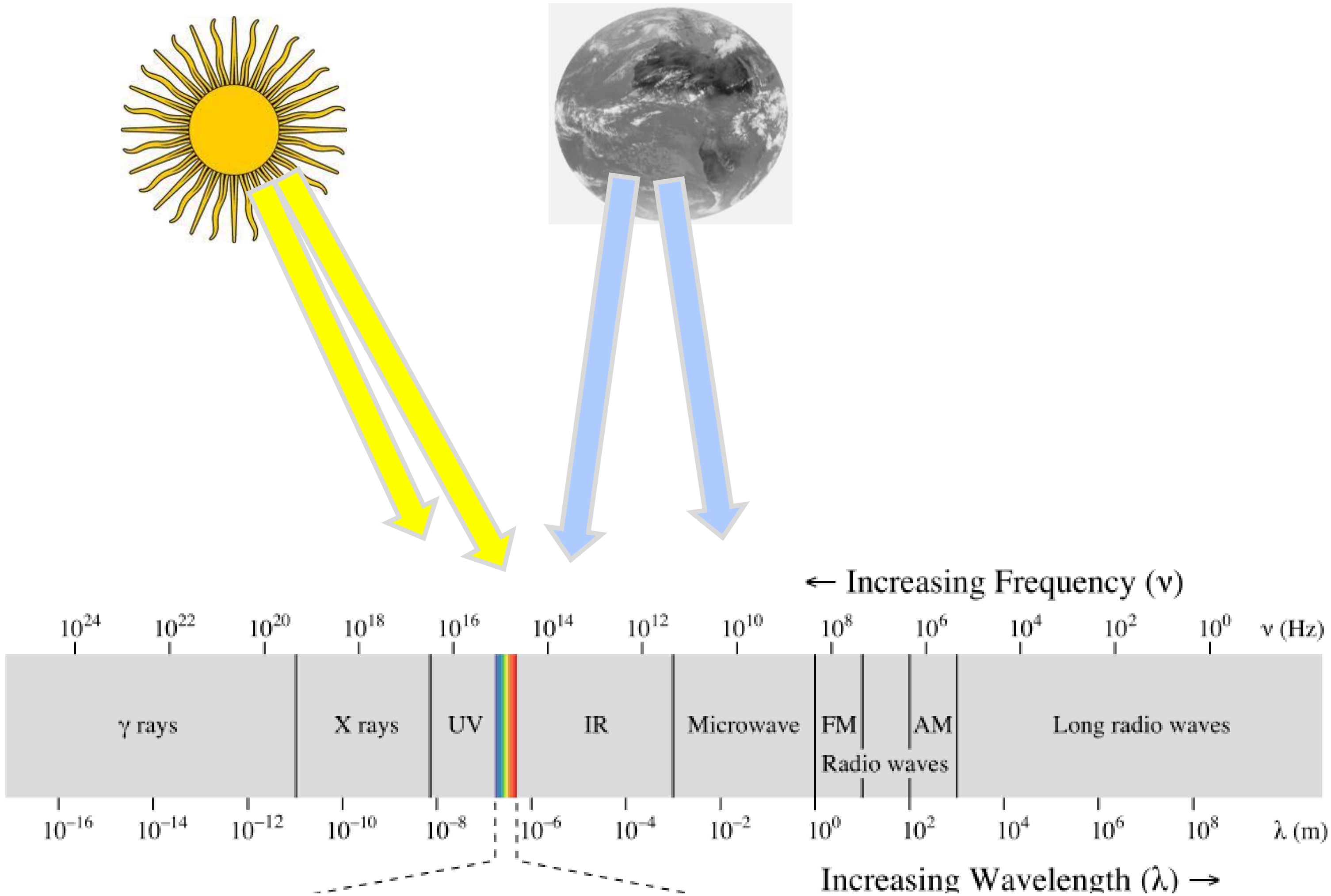
Electromagnetic Spectrum



Electromagnetic Spectrum



Sources of Radiation (Meteorological Applications)



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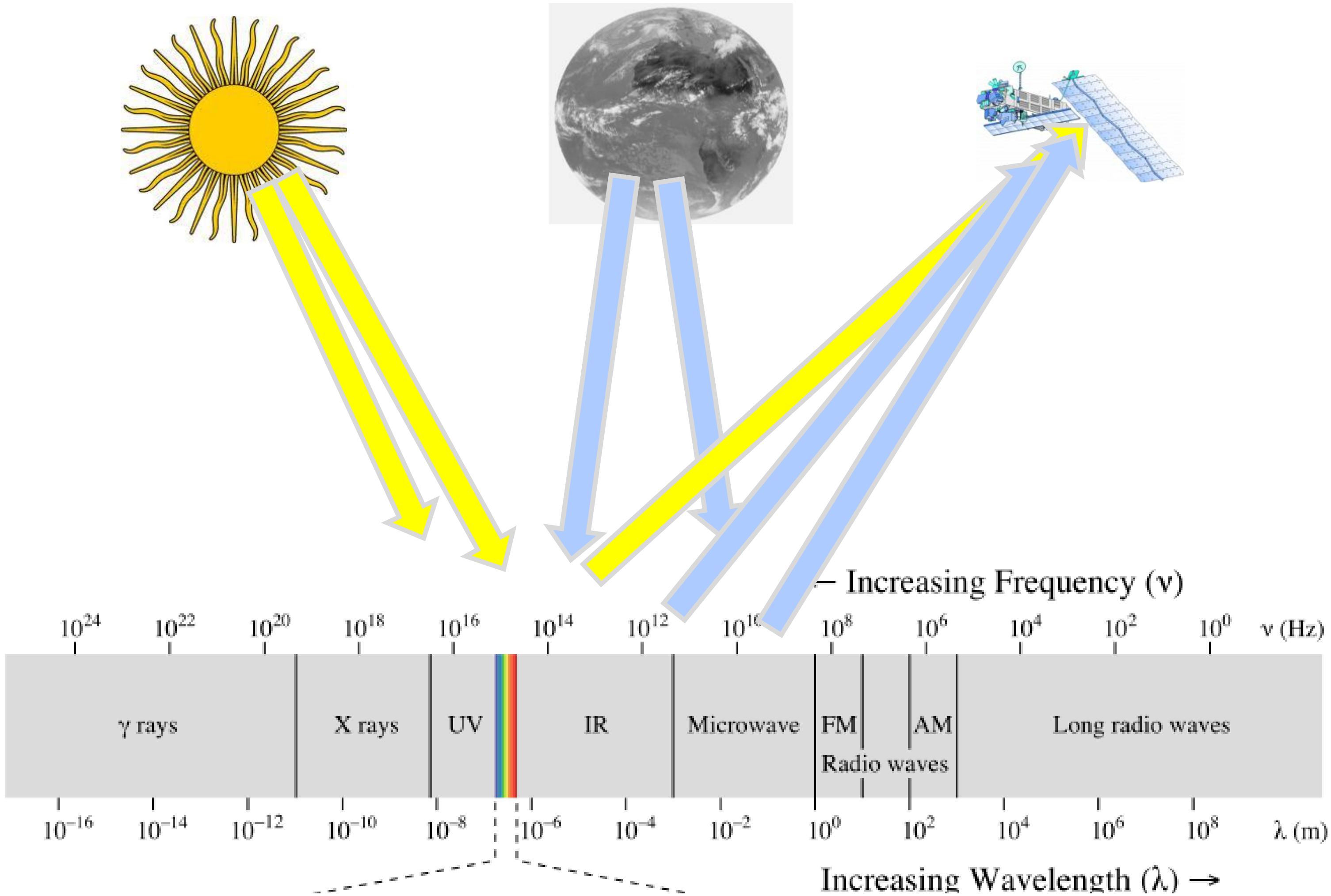
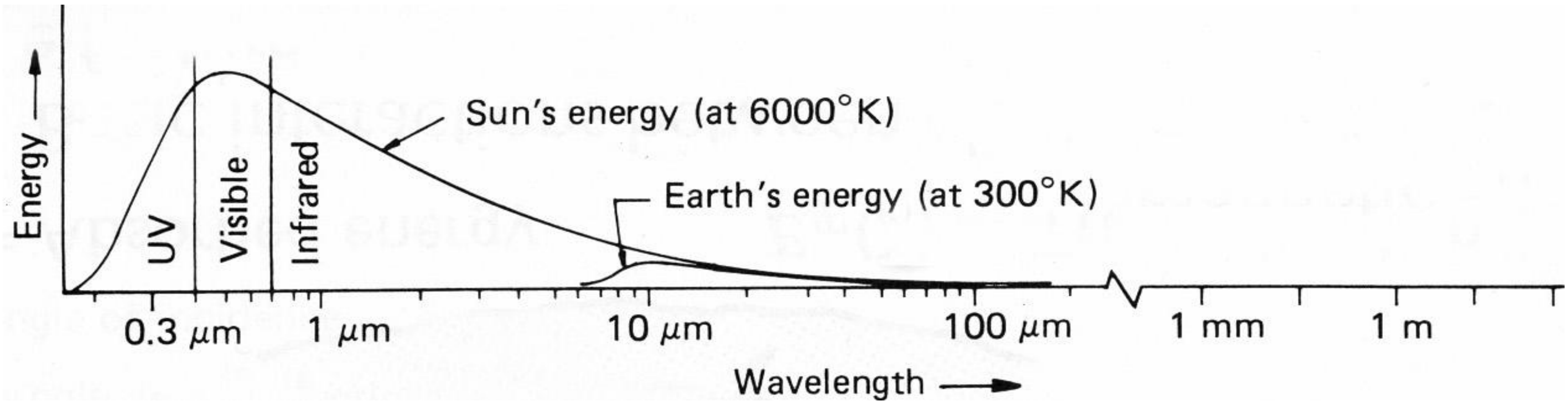
Sources of Radiation (Meteorological Applications)



Fundamental Radiation Law: Planck's Law

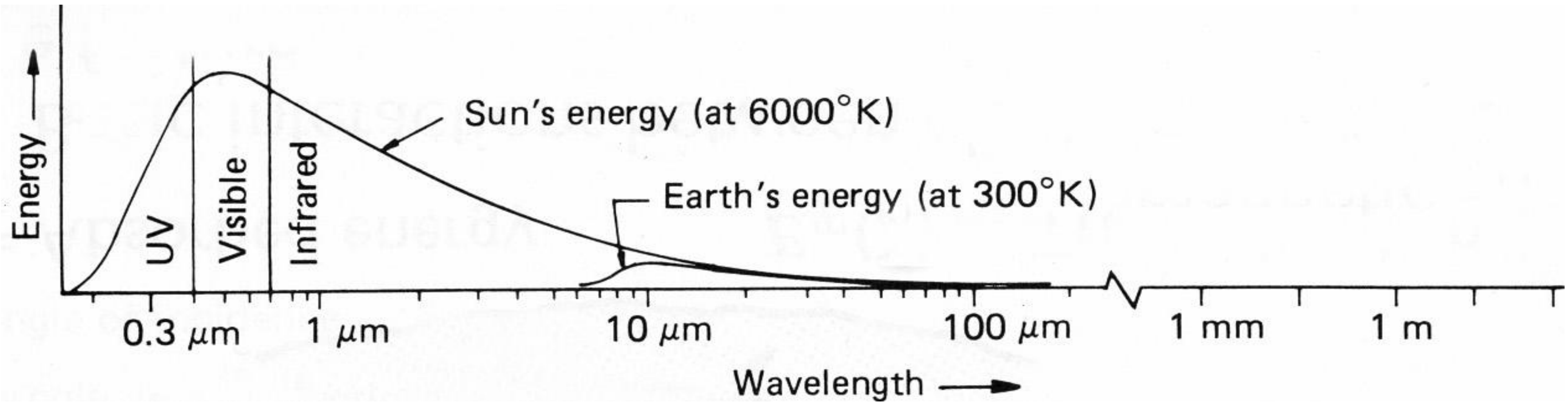


$$B(\nu,T) = \frac{2h\nu^3}{c^2}\,\frac{1}{e^{h\nu/kT} - 1} \qquad B(\lambda,T) = \frac{hc^2}{\lambda^5}\,\frac{1}{e^{hc/\lambda kT} - 1}$$

k = Boltzmann's constant
T = Temperature
h = Planck's constant

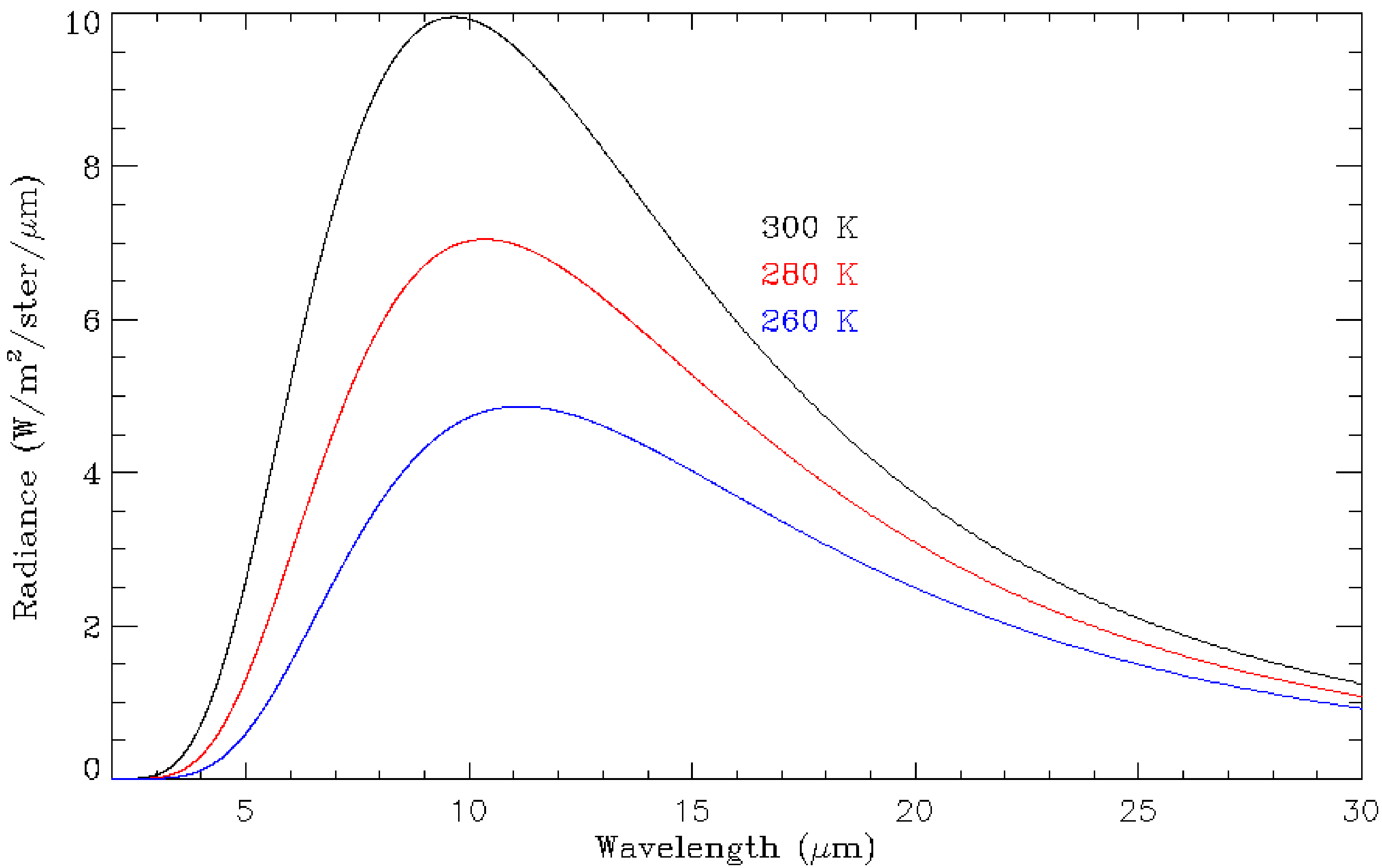
Units:
Watts per unit area, per unit angle, per unit wavelength (or wavenumber), e.g. $W/m^2/ster/cm^{-1}$

Fundamental Radiation Law: Planck's Law



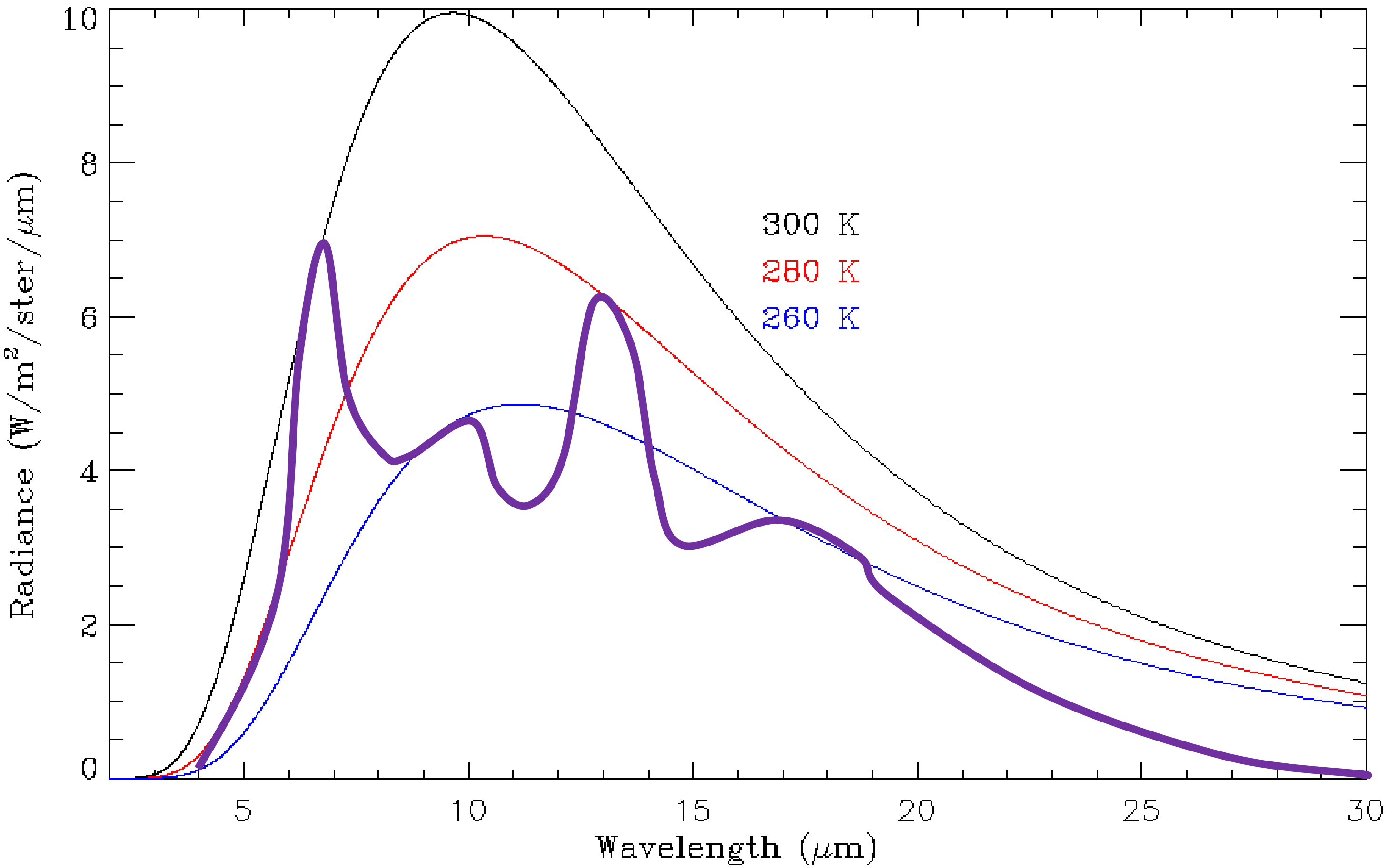
Concept of a Blackbody – Emissivity and Brightness Temperature

A "Blackbody" is an object of temperature T which radiates energy according to Planck's Law.



Concept of a Blackbody – Emissivity and Brightness Temperature

A “Blackbody” is an object of temperature T which radiates energy according to Planck’s Law. Nature does not have perfect blackbodies – physical property of matter is its emissivity (0-1):



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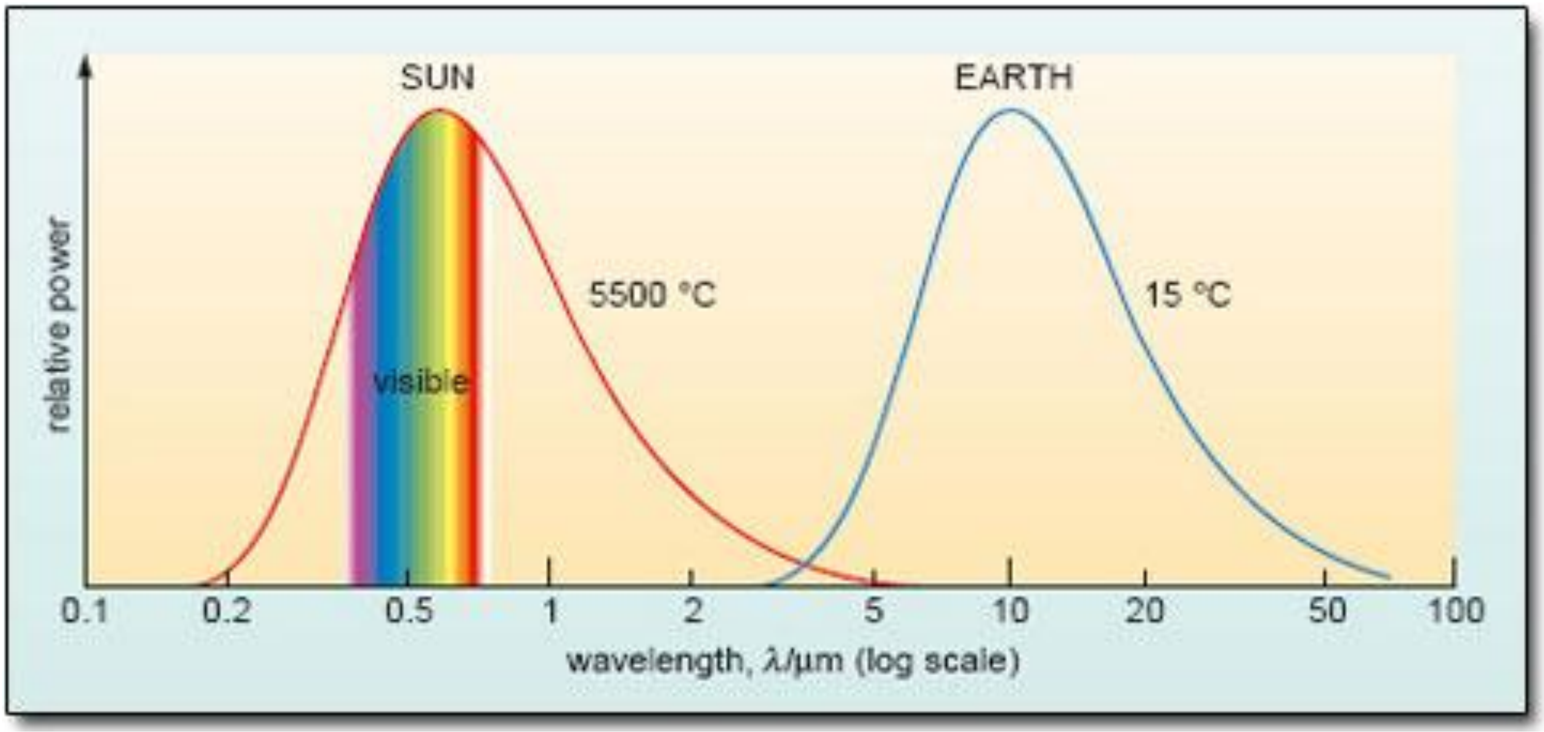
Remote Sensing of the Atmosphere

- What do we measure?
- Solar radiation: reflected by the surface, scattered by molecules, cloud droplets, ice crystals, aerosols, absorbed by the atmosphere
- Thermal radiation: emitted by the earth / clouds / atmosphere,, absorbed by the atmosphere, clouds, aerosols
- What about thermal radiation from the sun???

Explanation

At our Earth's distance from the sun, the radiation received from the sun is approximately on the same energy level as the radiation emitted from the earth/atmosphere



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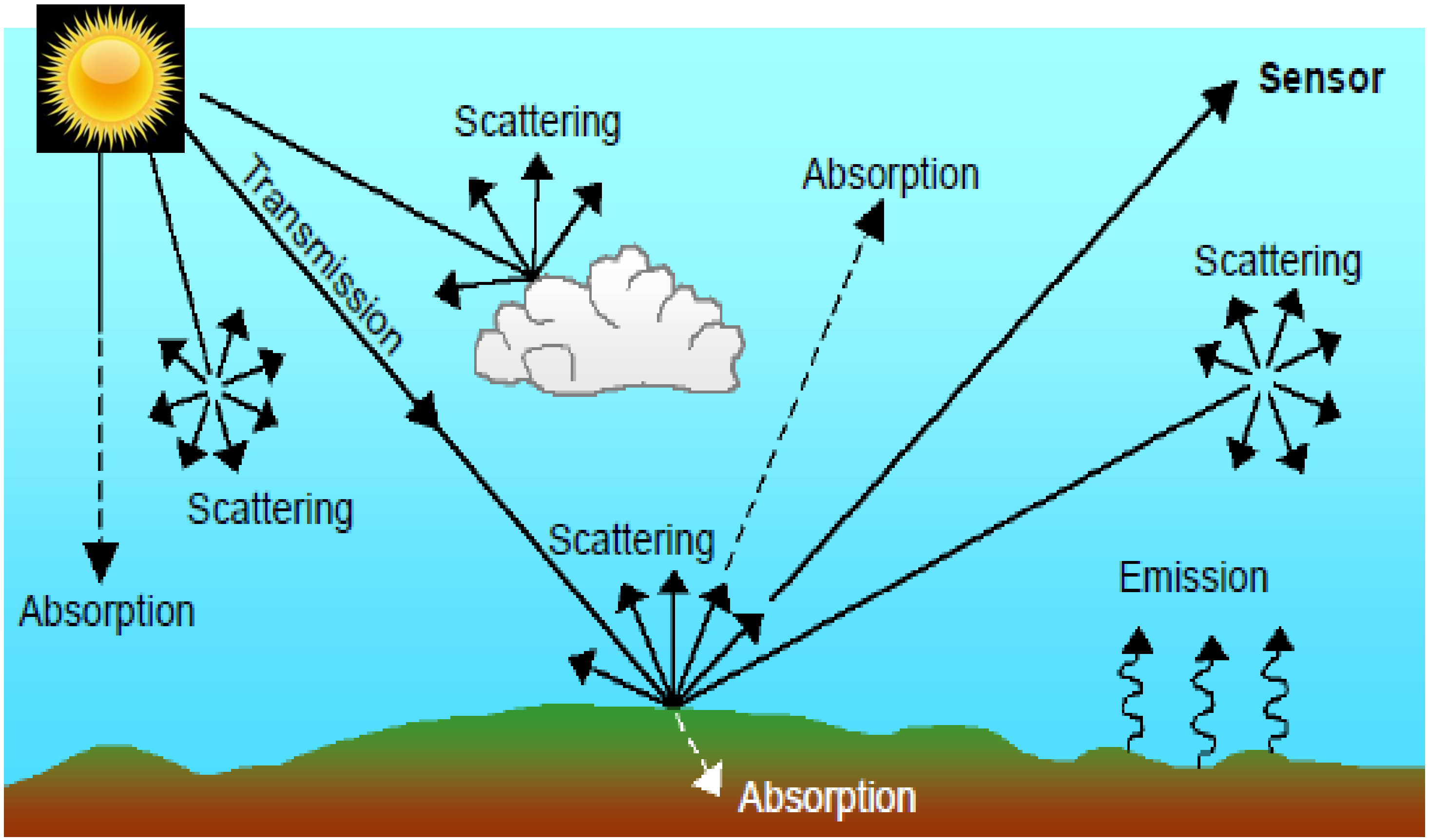
Interaction Processes



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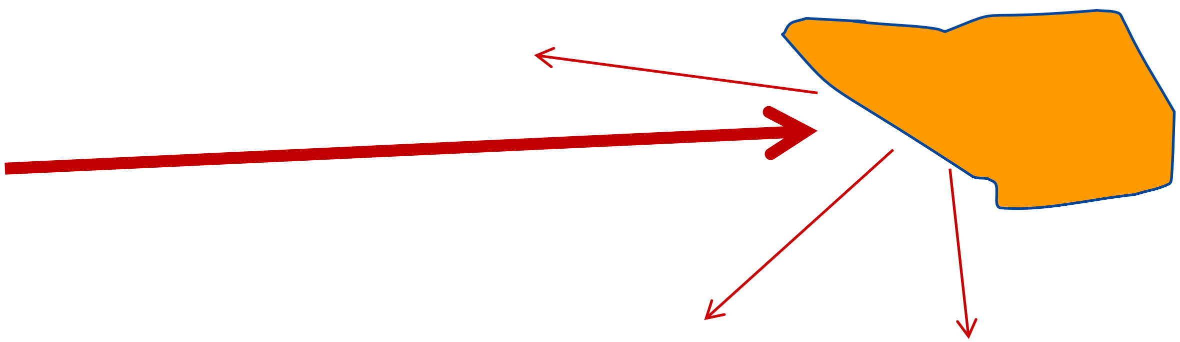
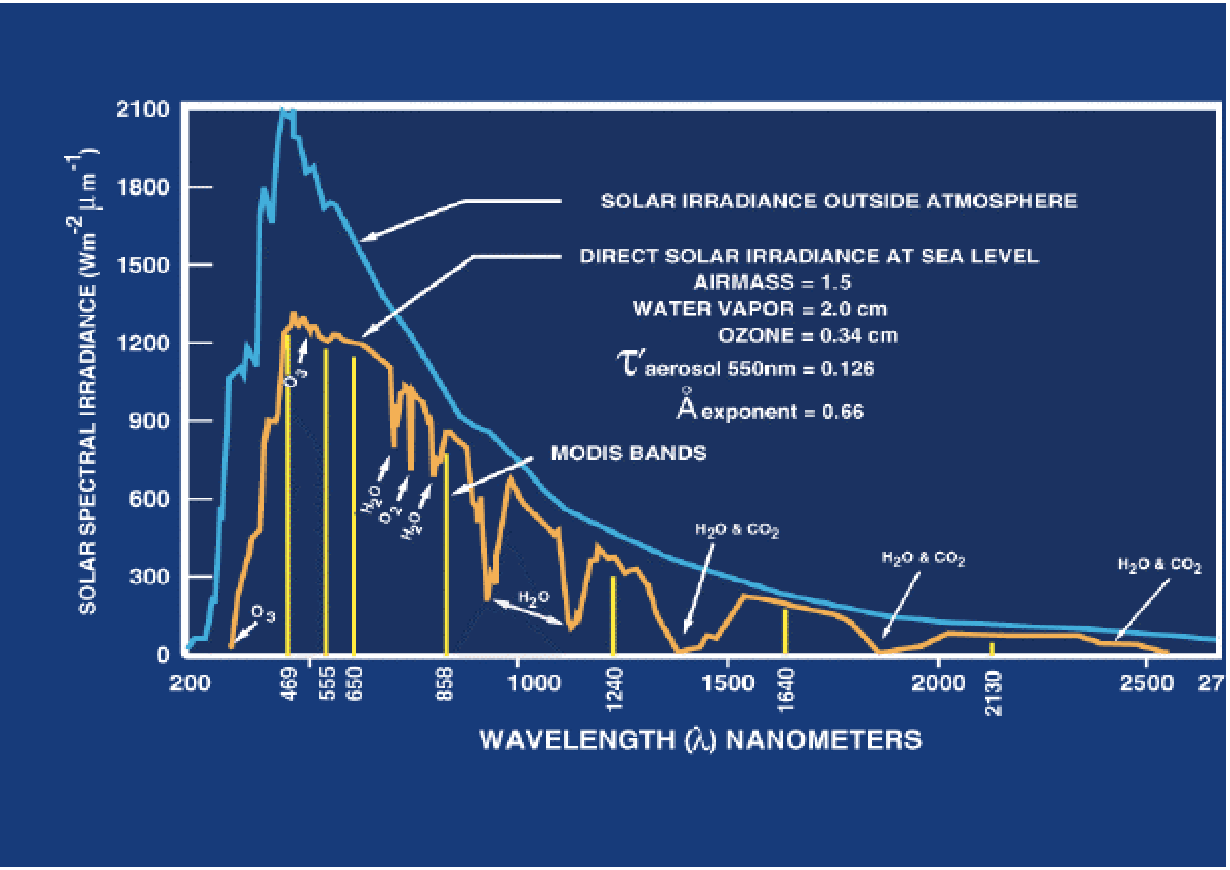
Absorption – Emission - Scattering

- Absorption: Energy of the electromagnetic wave is taken up by matter (e.g. change in atomic state)
- Emission: Energy change in the matter (e.g. change in the atomic state) releases electromagnetic radiation
- Emission = Absorption!!
- Absorption coefficient = property of matter
- Scattering: Radiation is "geometrically' forced to deviate from a straight line (reflection = specific scattering)



Processes for Solar Radiation



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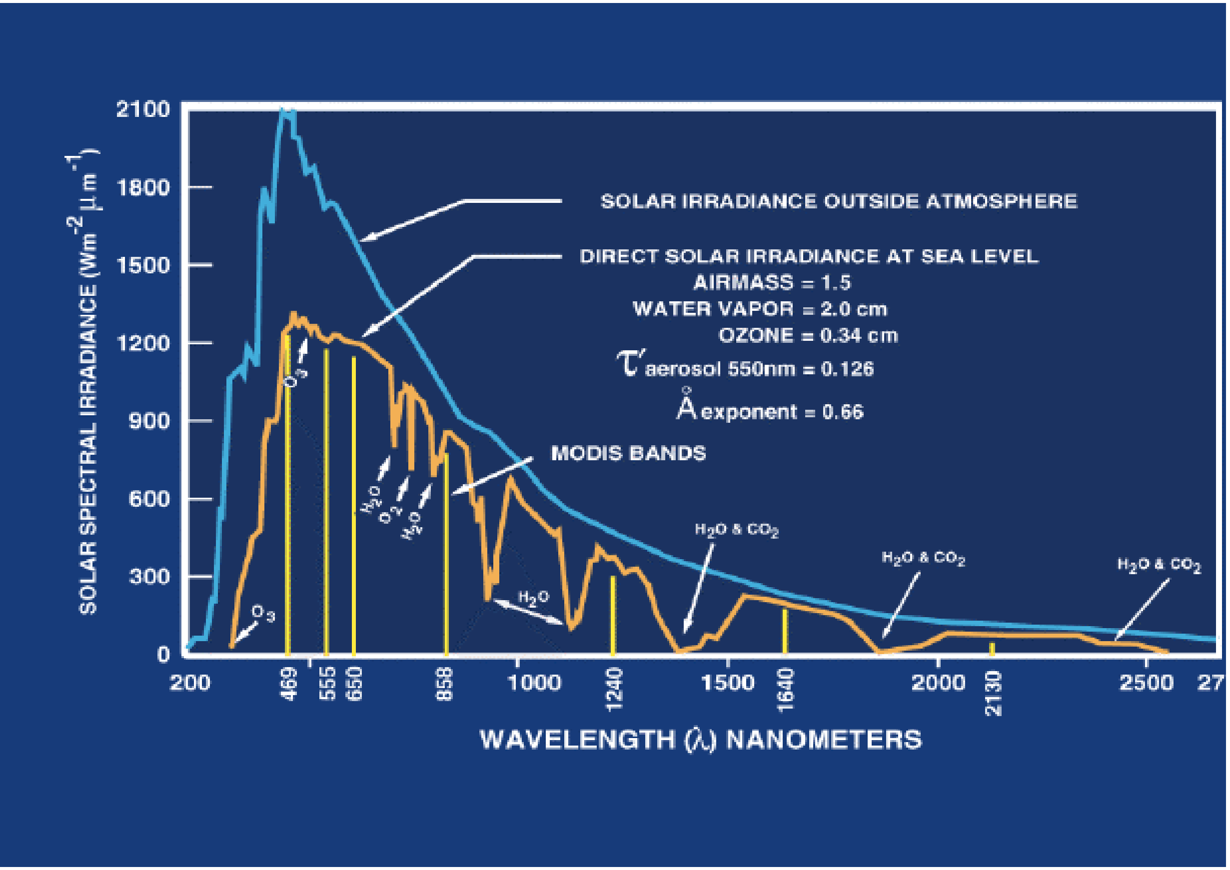
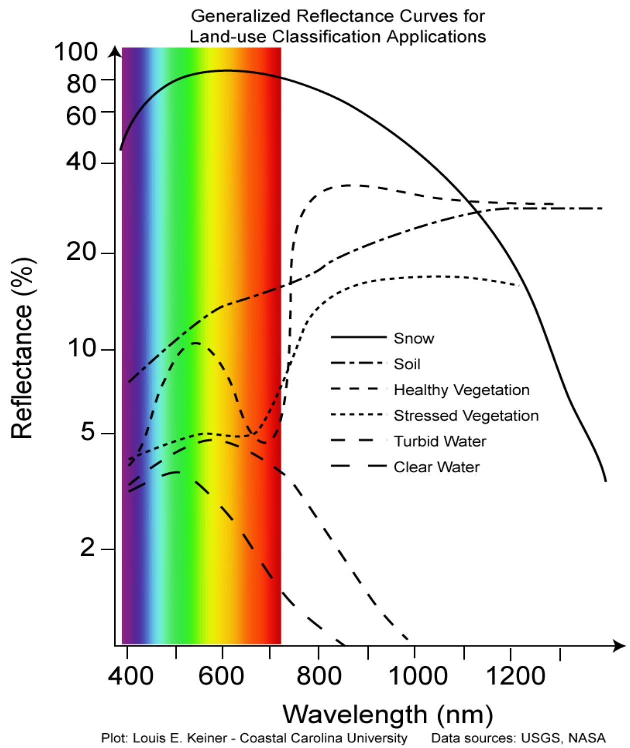
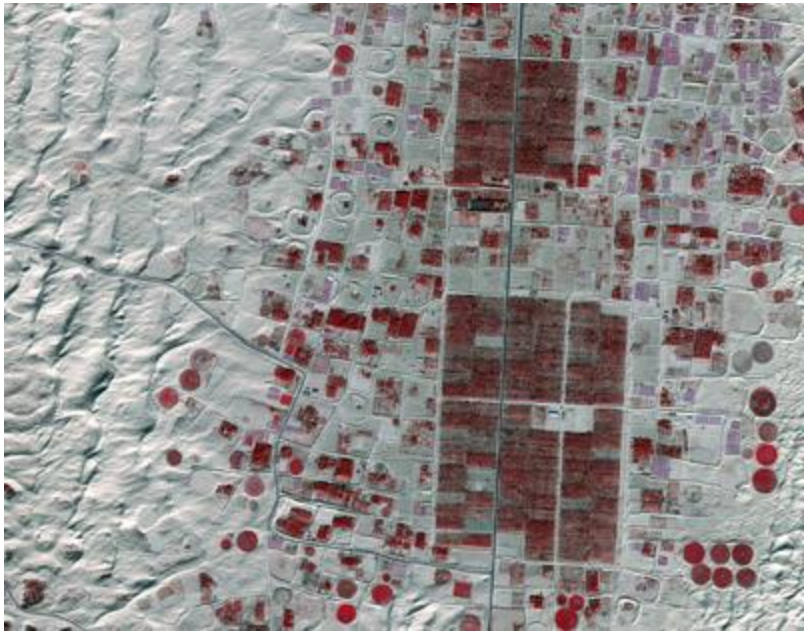


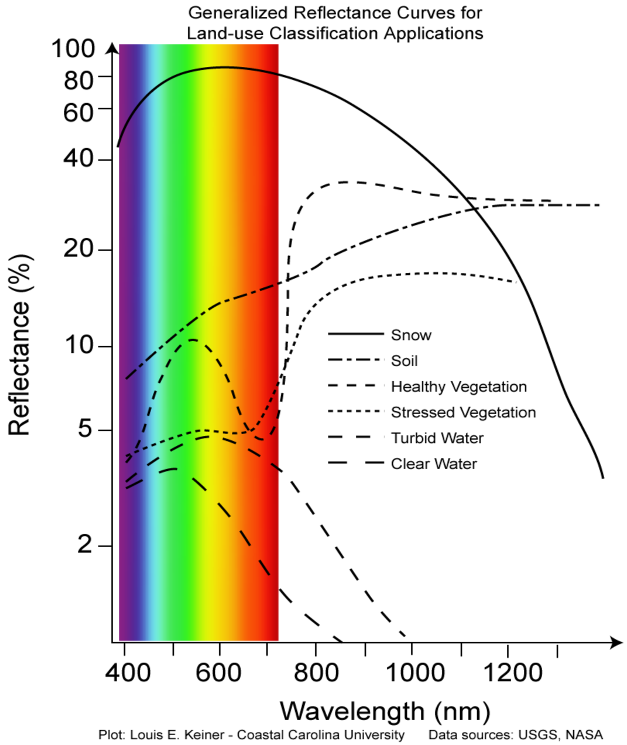


Why is grass green?

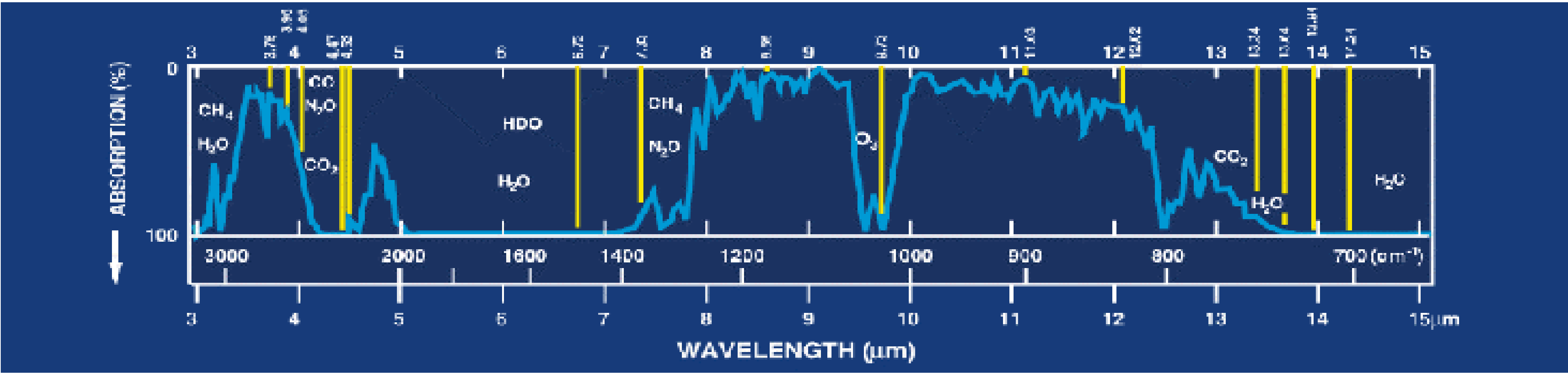
Vegetation Mapping

Vegetation cover is often mapped using near-infrared radiation (~0.8 μm wavelength) because of the high reflectivity here

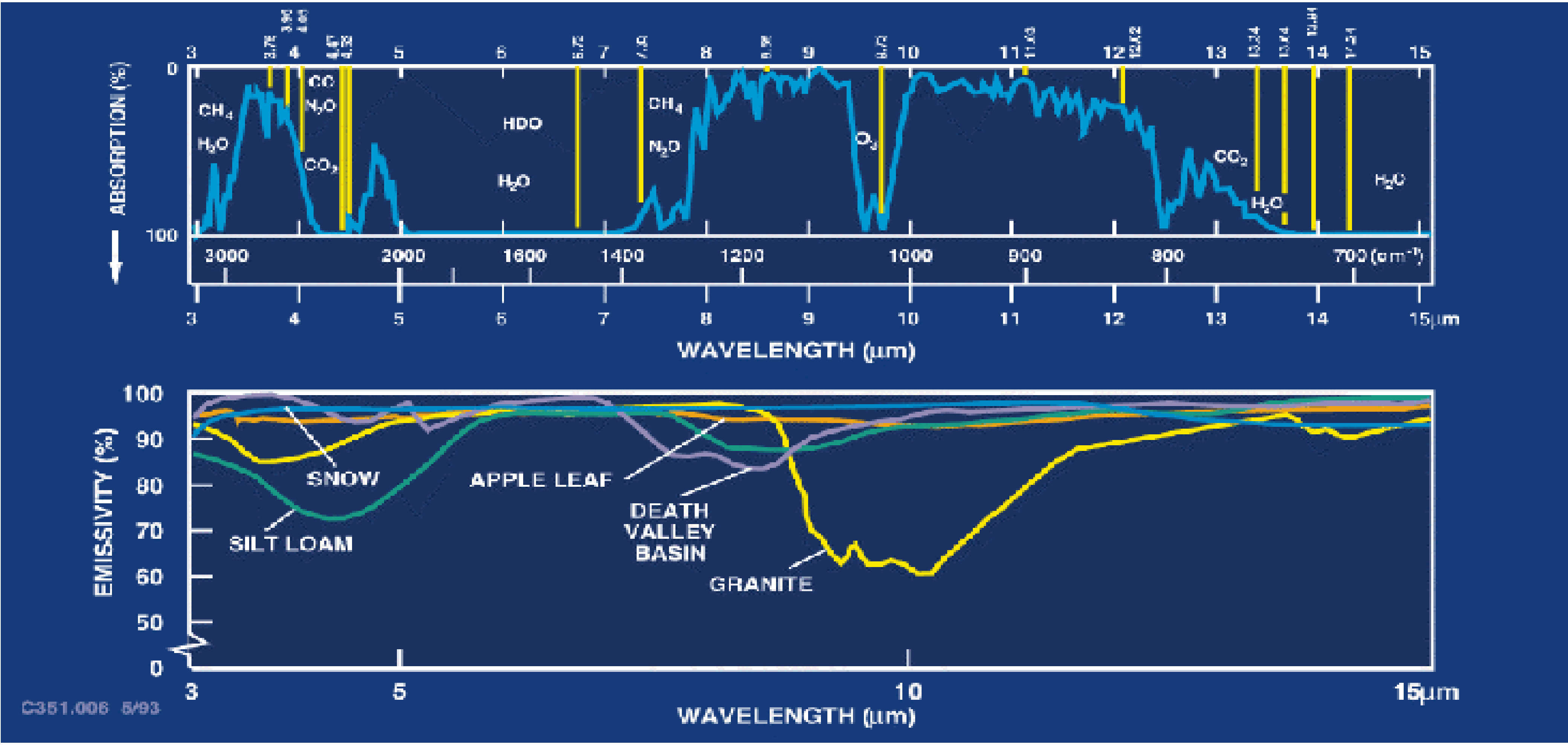




Processes of Thermal Radiation



Processes of Thermal Radiation



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Earth Spectrum and Planck Curves

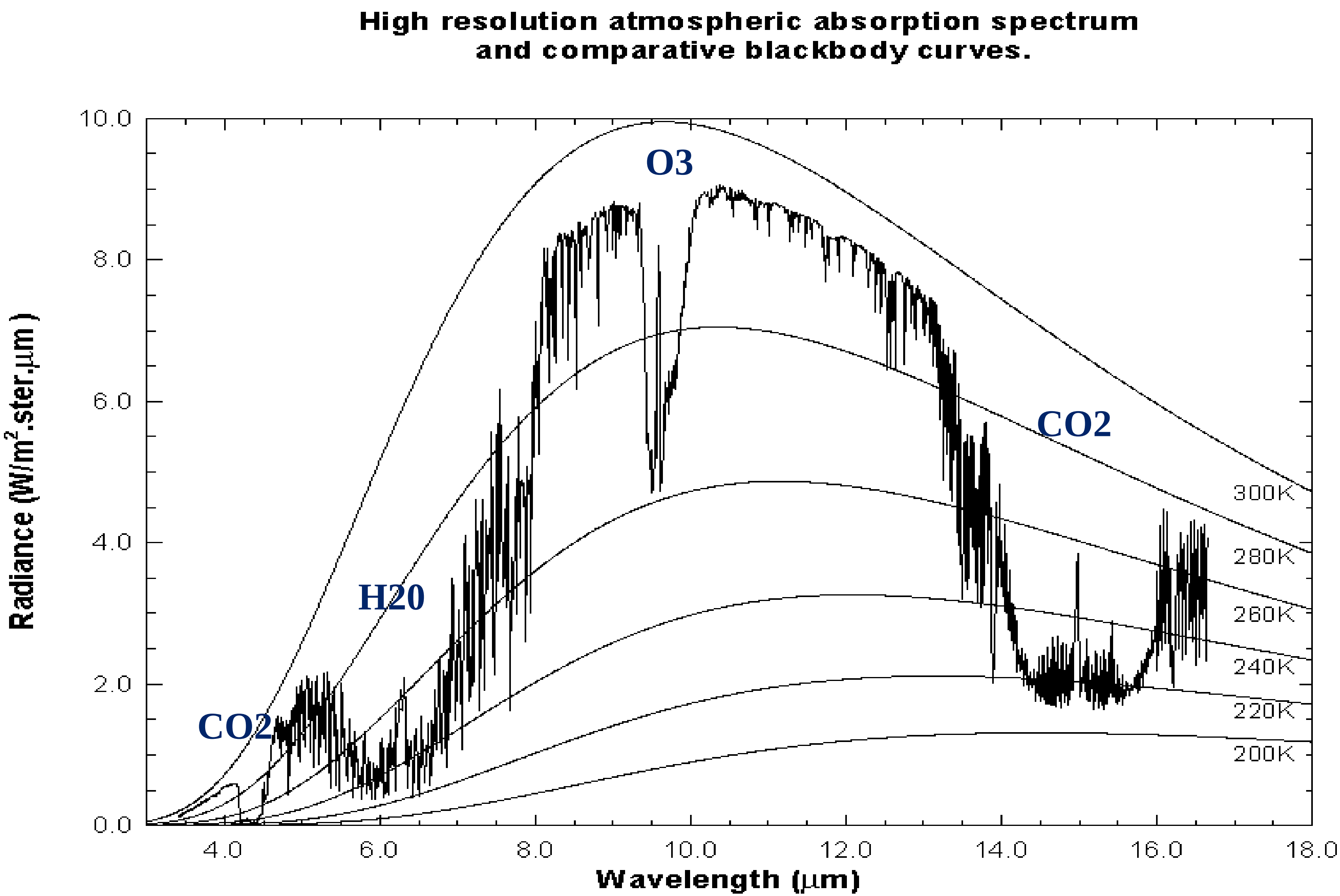


Illustration: Beam at 11 µm wavelength (“Window”)

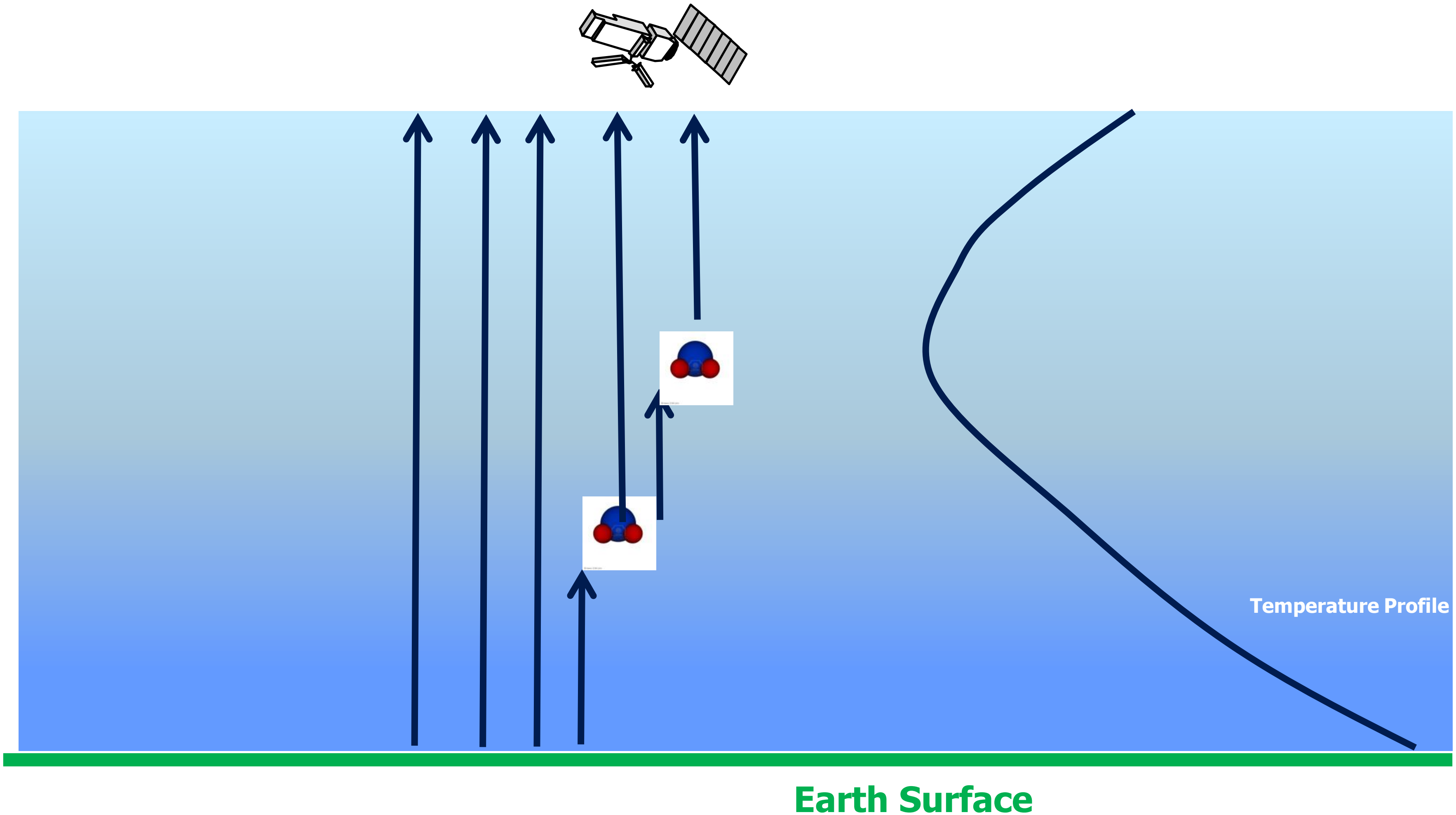
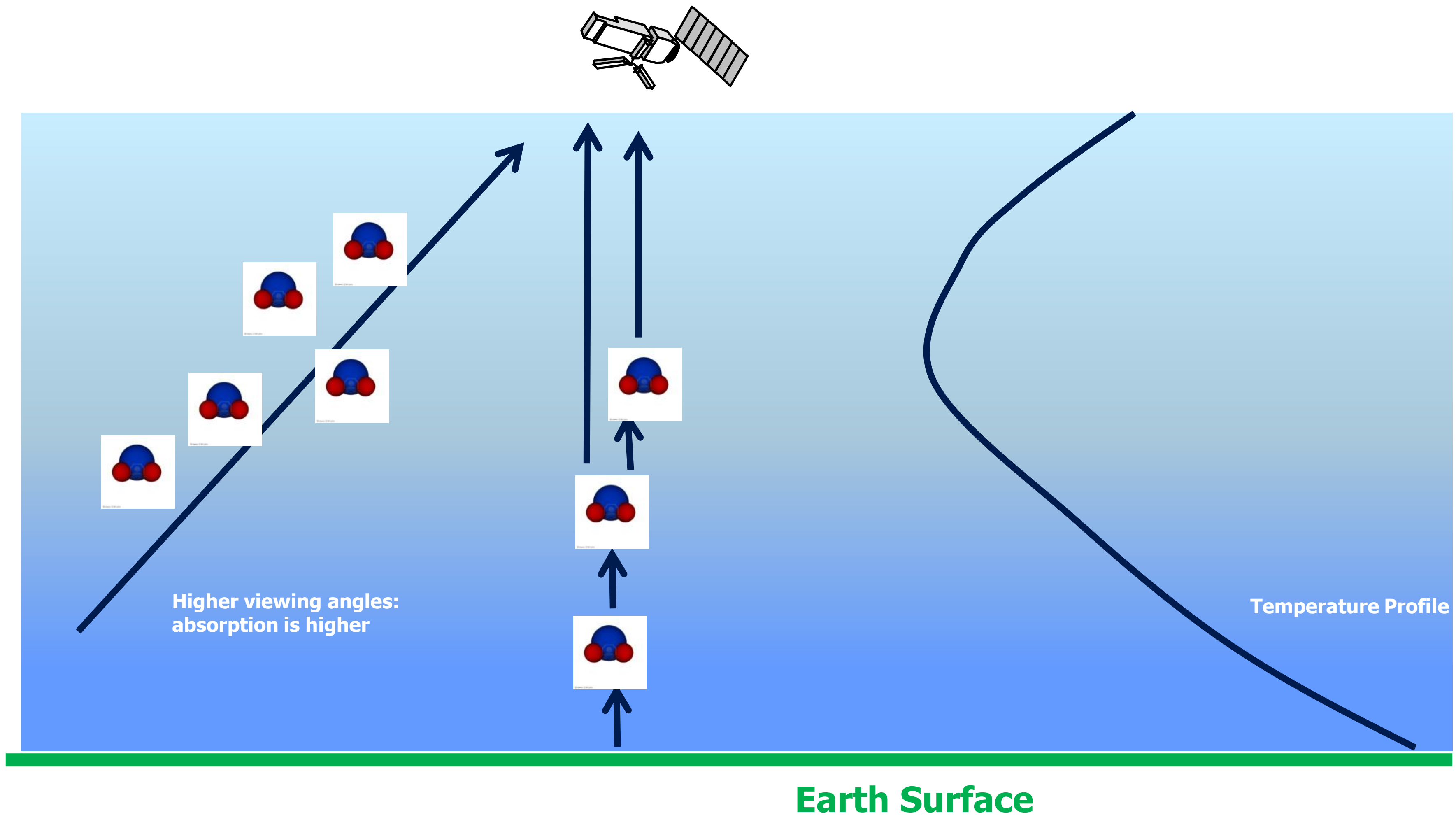
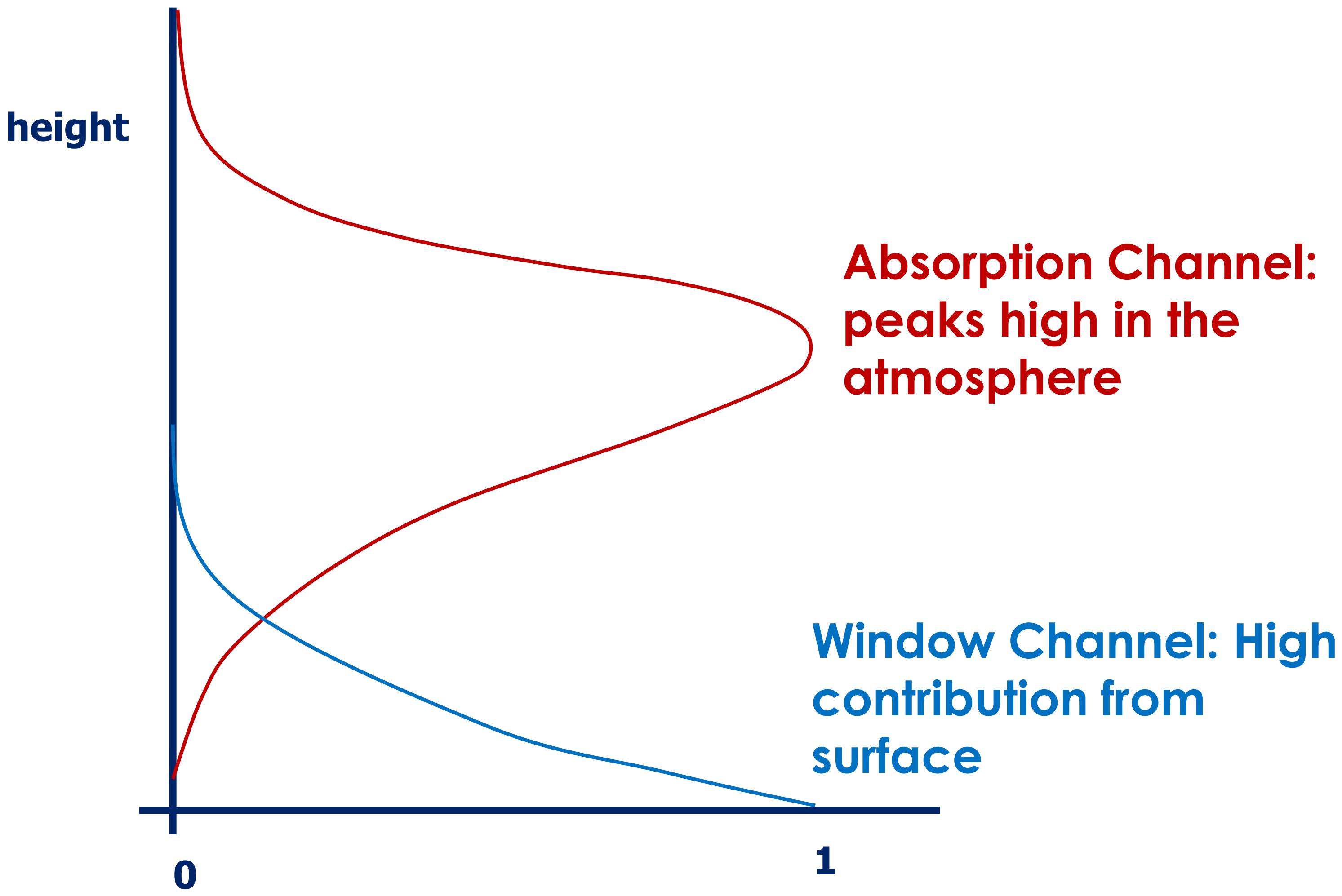


Illustration: Beam at 6.5 µm wavelength (WV Absorption)



Weighting Functions



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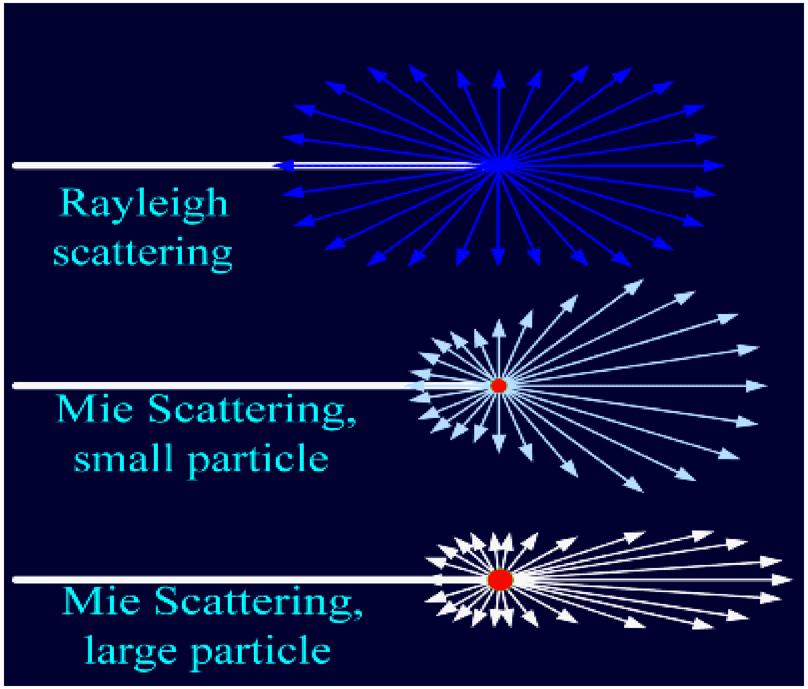
To Remember

Each radiance measured in the VIS or IR or MW part of the spectrum is the result of a number of processes, e.g.

- Source position
- Illumination geometry
- Surface materials
- Passage of energy through the atmosphere

Scattering

- Scattering by particles which are much smaller than the electromagnetic wavelength ("Rayleigh Scattering")
- Scattering by particles which are of same size and larger than the electromagnetic wavelength ("Mie Scattering")

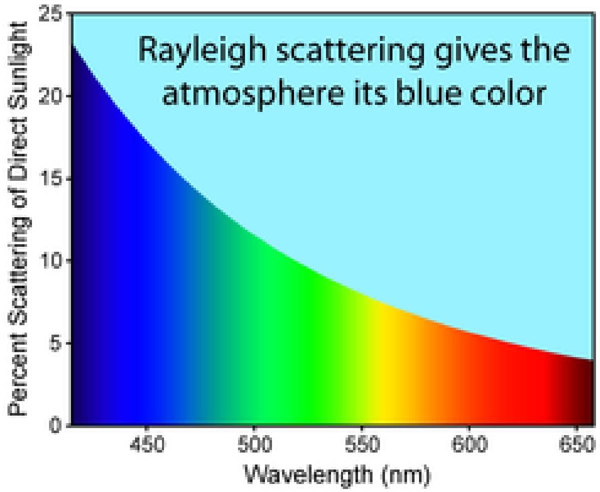


Distribution for all angles: phase function

Rayleigh Scattering

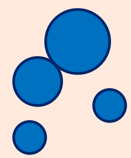
- **Rayleigh scattering**, named after the British physicist Lord Rayleigh, is the elastic scattering of light or other electromagnetic radiation by particles much smaller than the wavelength of the light. The particles may be individual atoms or molecules.

- Scattering is ~ λ^{-4}, i.e. scattering occurs for shorter wavelengths!

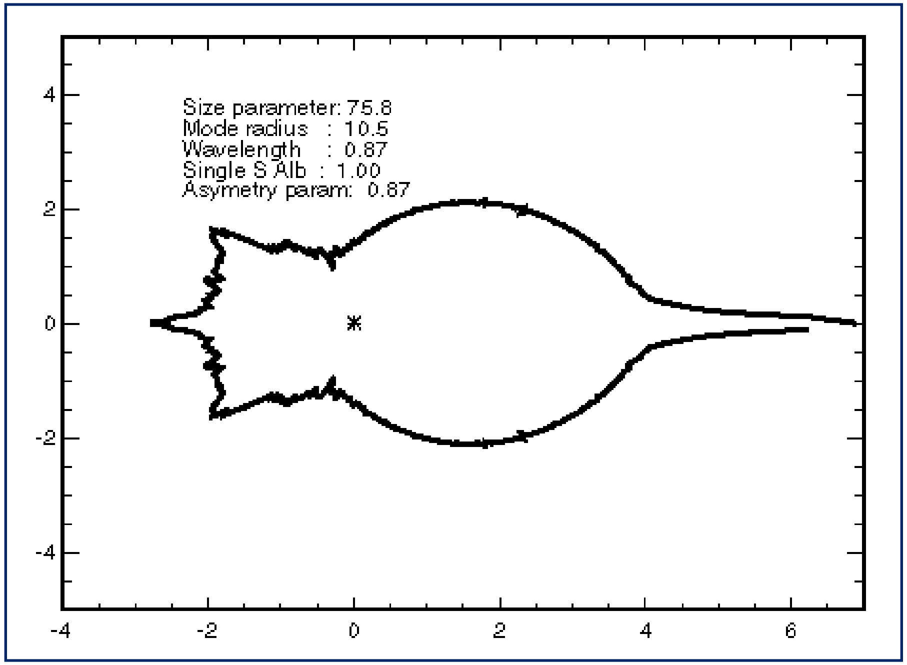


Water Clouds: Scattering on Spherical Particles

Size distribution



Wavelength 0.87 µm
Cloud droplets 1- 10 µm



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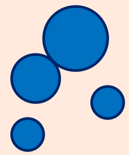

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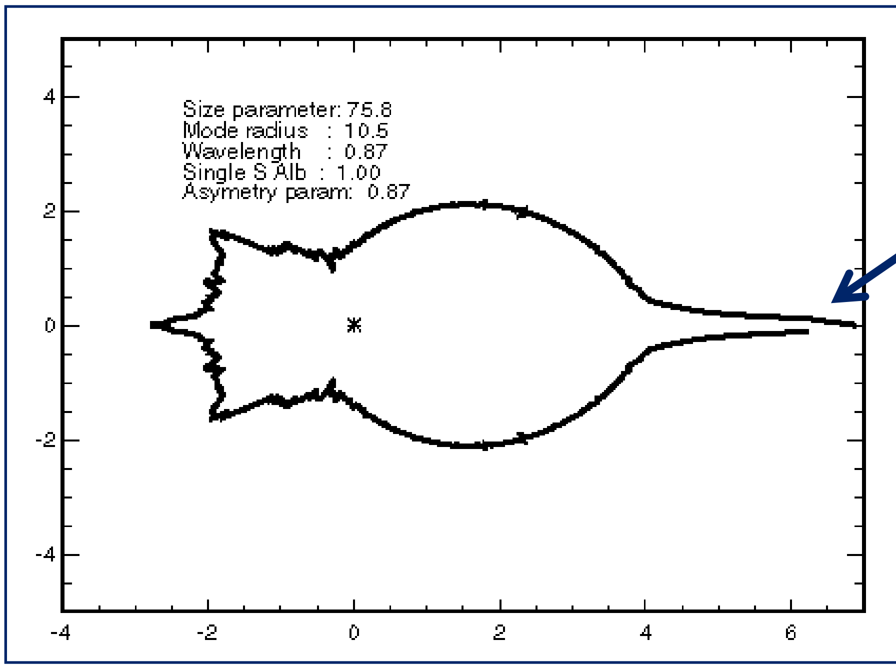
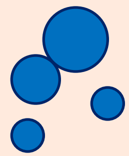


Strong forward scattering

Water Clouds: Scattering on Spherical Particles

Size distribution



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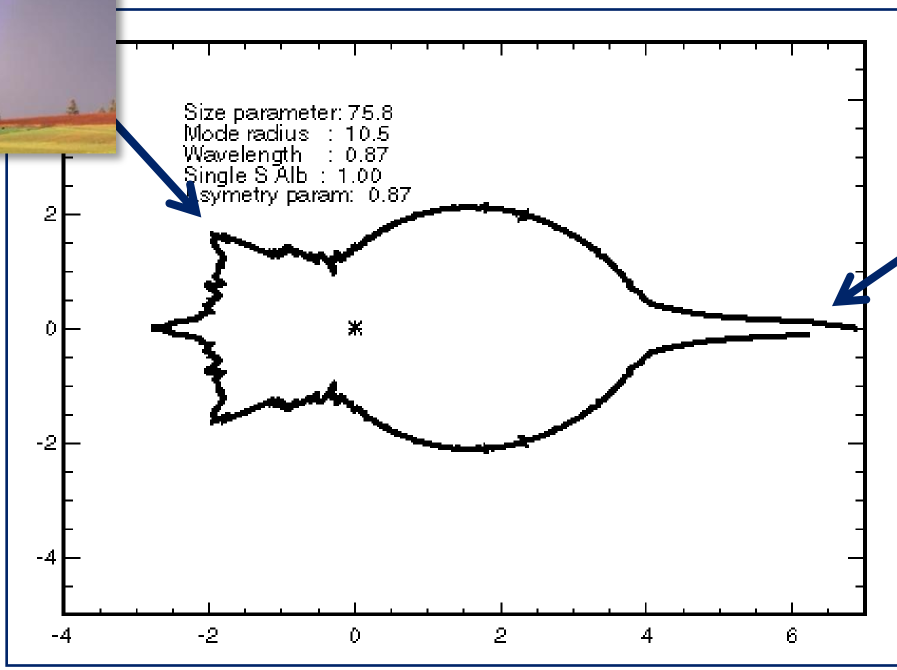
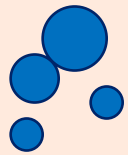


Strong forward scattering

Water Clouds: Scattering on Spherical Particles

Size distribution



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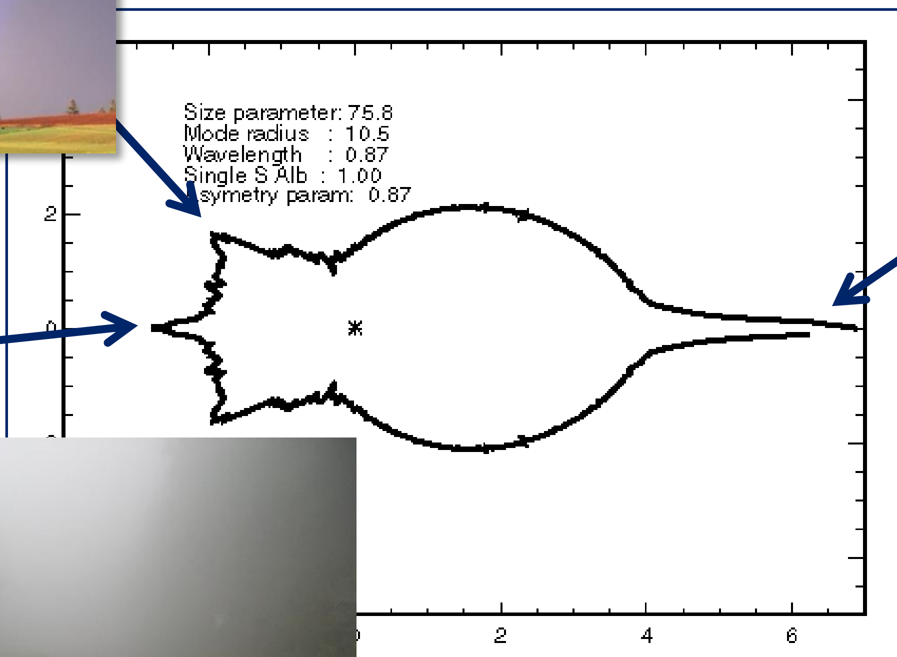

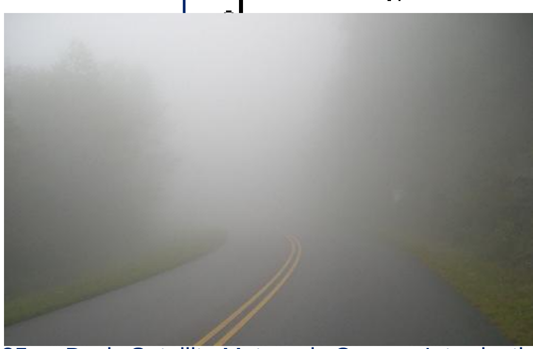

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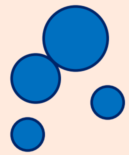

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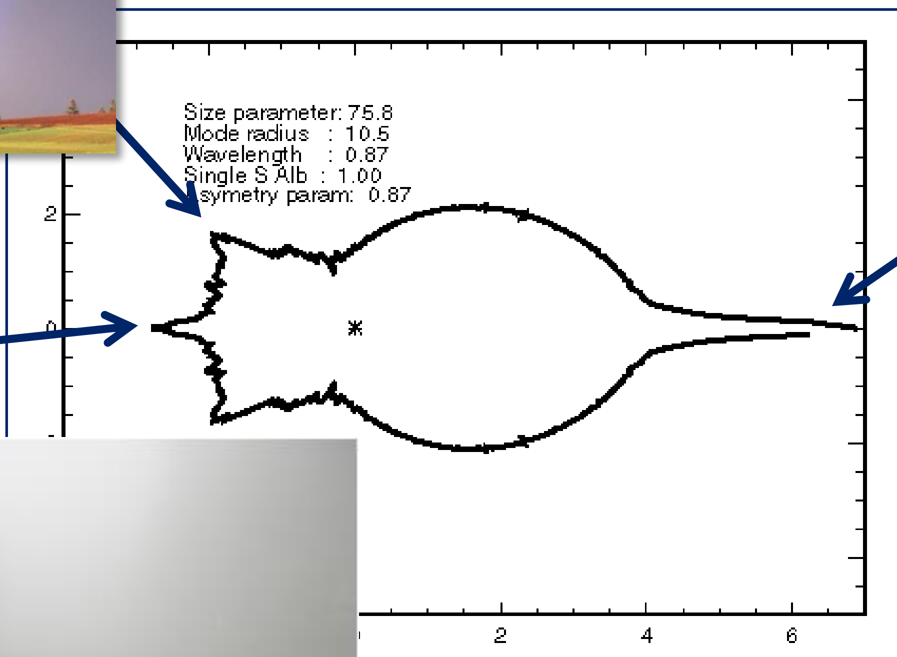

Backscatter

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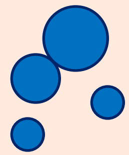
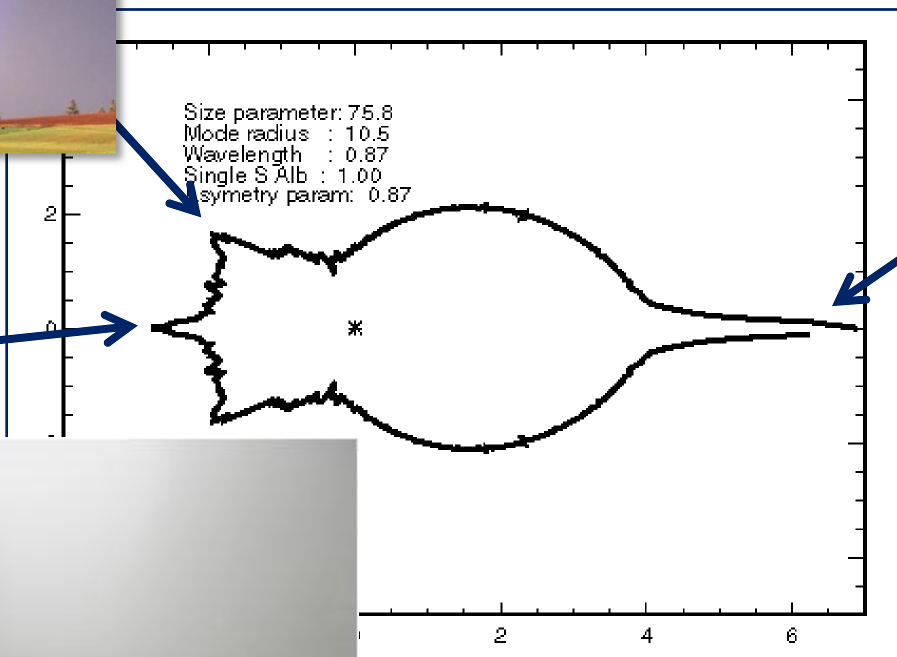
Water Clouds: Scattering on Spherical Particles

Size distribution



Wavelength 0.87 µm
Cloud droplets 1- 10 µm

Strong forward scattering



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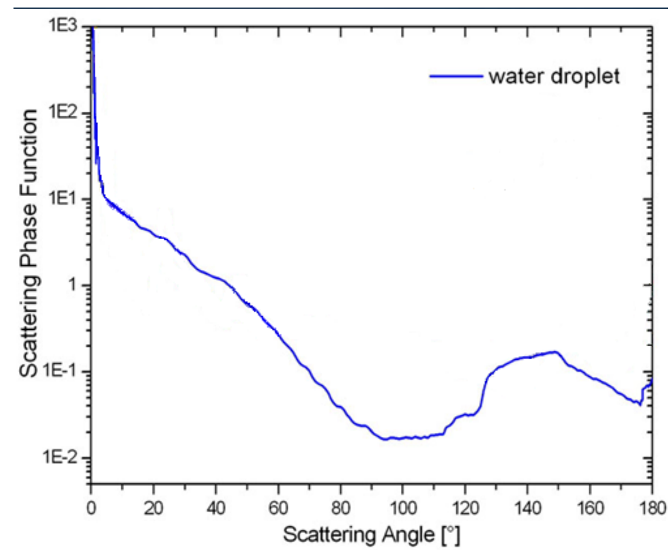
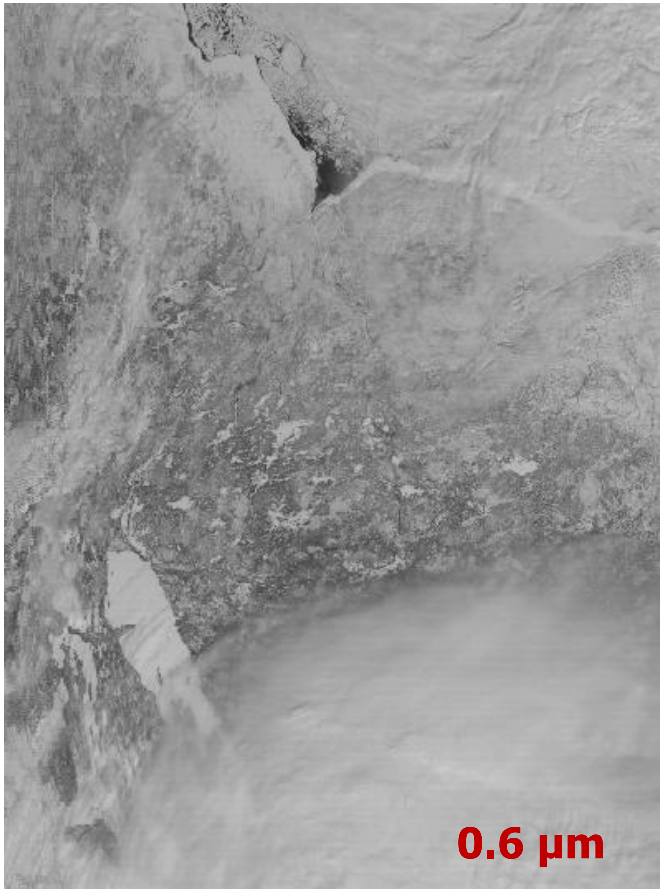
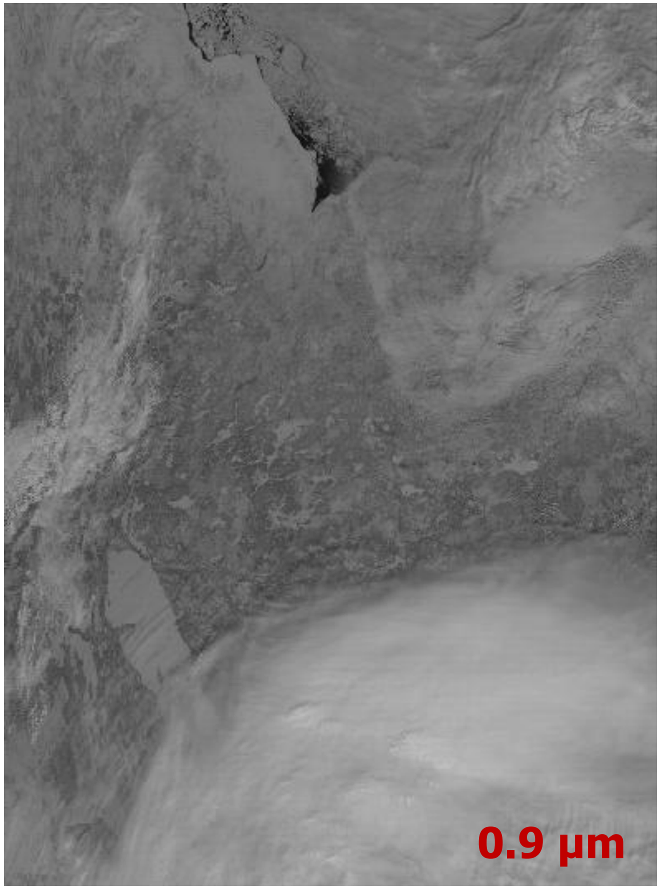
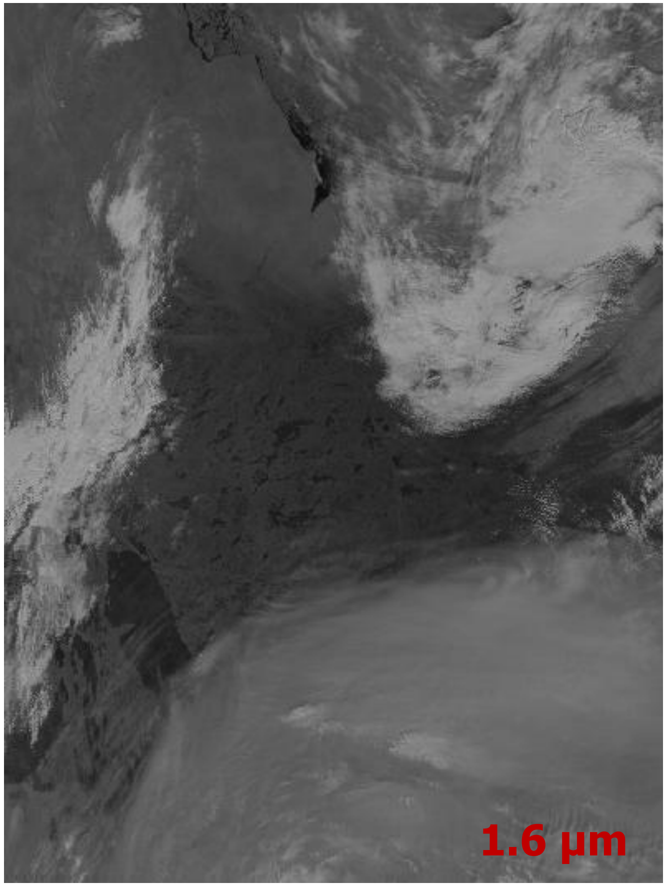


Practical Example: MODIS Imagery, 03 April 2011
Solar Bands







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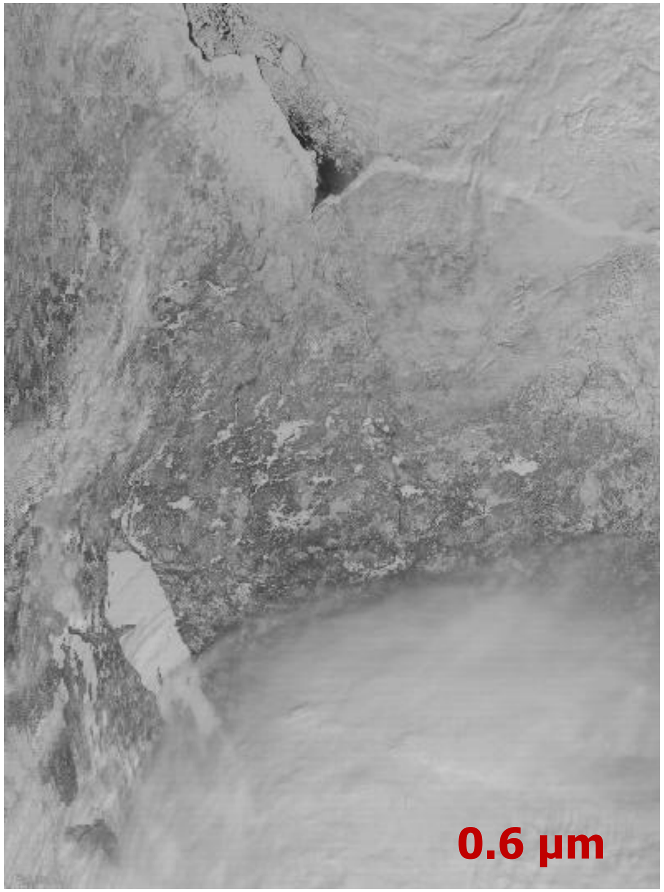

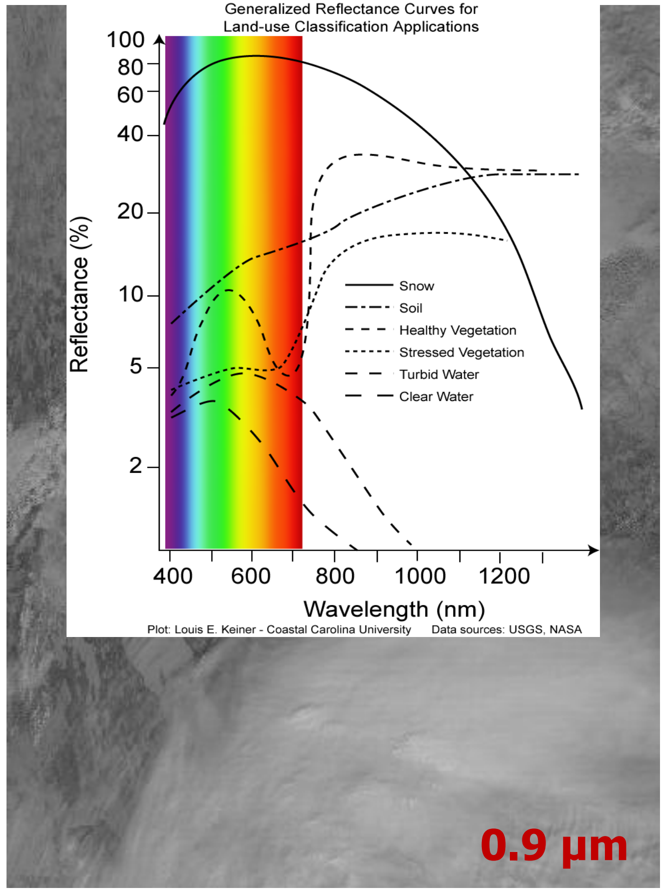

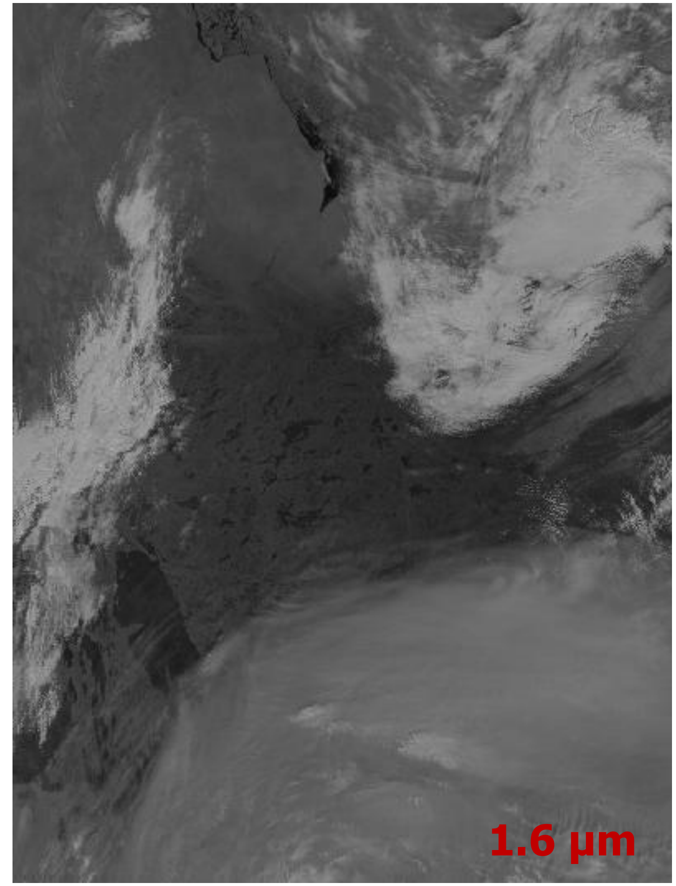

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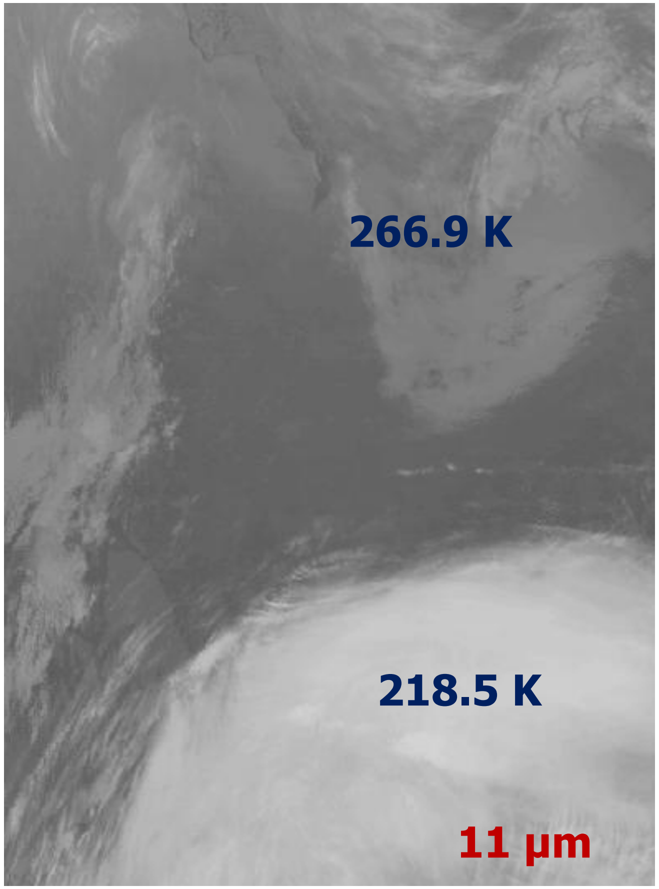
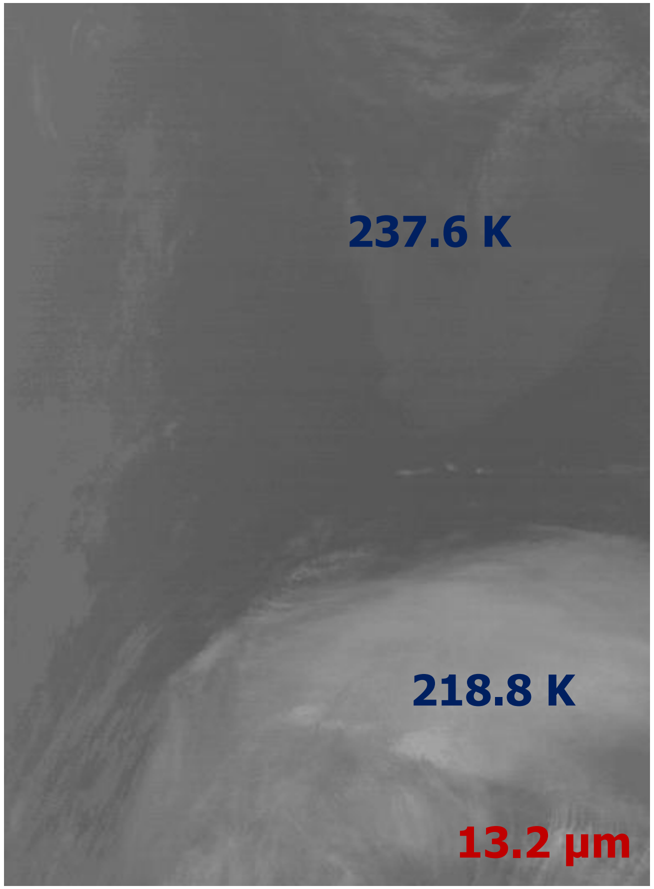
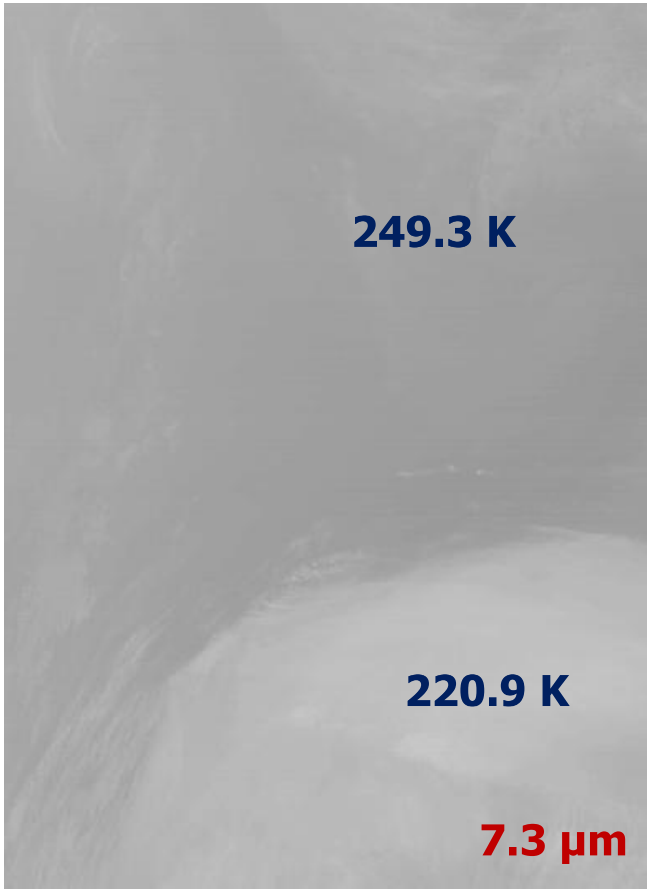
Practical Example: MODIS Imagery, 03 April 2011 Thermal Bands







To Remember

Each radiance measured in the VIS or IR or MW part of the spectrum is the result of a number of processes, e.g.

- Source position
- Illumination geometry
- Surface materials
- Passage of energy through the atmosphere

Radiances at a given wavelength region carry the information of these processes (but not of processes which are not important in this specific wavelength!) – measurement has to be appropriate for what you want to measure!!!!

Example: VIS data carry no temperature information

Radiative Processes Can Be Modelled - RTMs

The equation of radiative transfer simply says that as a beam of radiation travels, it loses energy to absorption, gains energy by emission, and redistributes energy by scattering.

The equation is a differential equation, numerical models exist which provide a solution (Radiative Transfer Models, RTMs).

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Image Acquisition

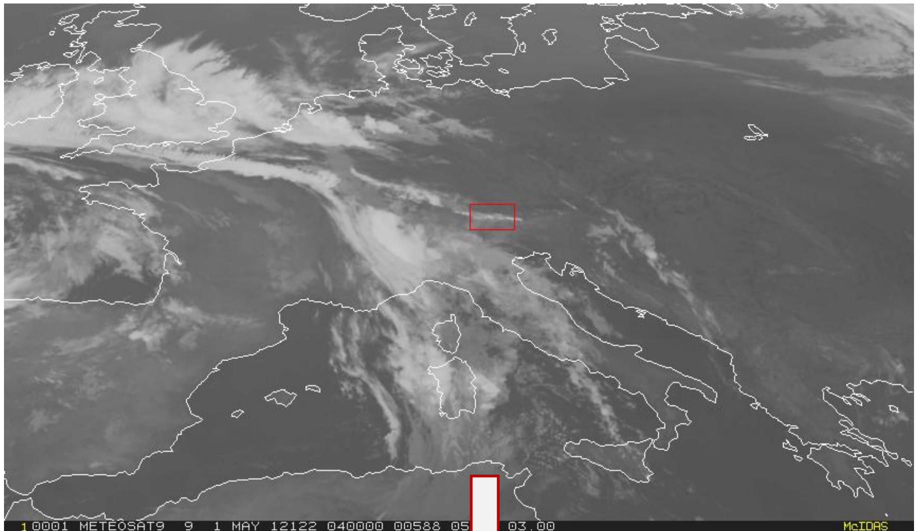
The remote sensing system must first detect and measure the energy signal:

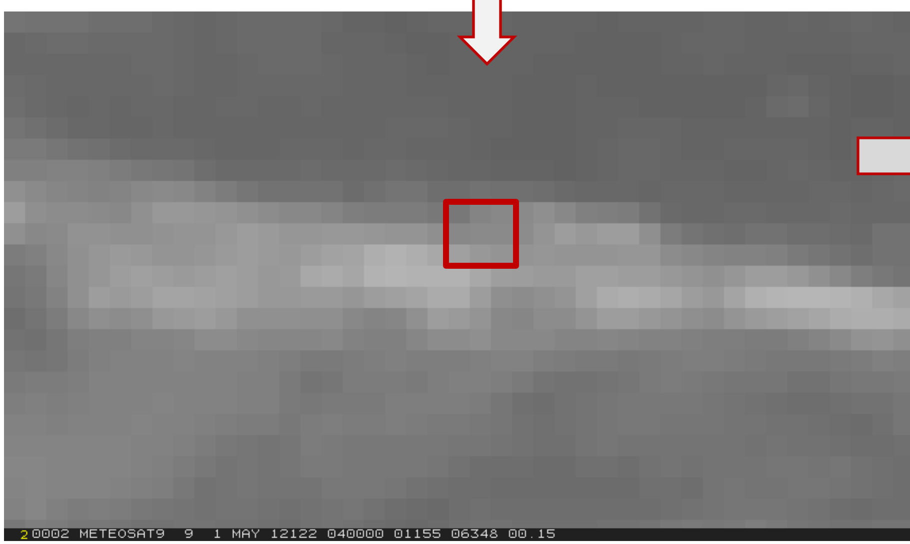
- Light-sensitive film (classical photography)
- Electronic sensors (electrical signal is proportional to the amount of energy received) (digital photography, imaging satellite instruments)

What Is Really Measured?

- The actual measurement on the sensor level is not a radiance (or reflectance or brightness temperature), but some measure of the electric signal (voltage, current) – which is digitized for transmission to the ground station. These digital values are often called “counts”
- Some type of calibration can convert this count to a radiance (and then e.g. to a brightness temperature via Planck’s Law)
- Calibration: on-board (blackbody, solar diffuser), vicarious methods (objects of known temperature/reflectivity)

Spatial Resolution





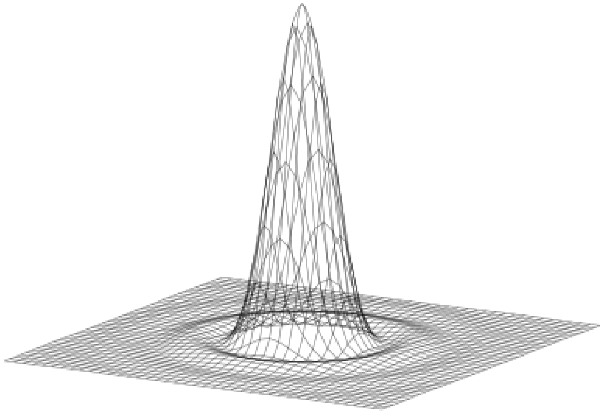
Counts and
Brightness Temperatures

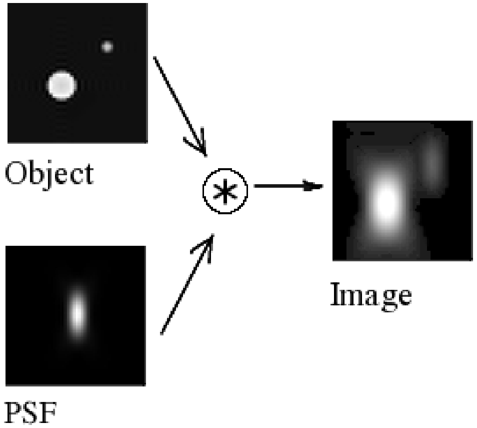
387 270.76	352 264.90	339 262.62
340 262.79	333 261.54	333 261.44
276 250.53	297 254.77	305 256.32

A Pixel is not a Square!

Display systems usually display one measured pixel as one pixel on a monitor – when zoomed this one pixel becomes a square.

The actually measured energy does not equally come from all areas within this square but mostly from the centre (point spread function)





Radiometric Resolution

The digital recording of the energy received by a sensor leads to discrete levels (“counts”) that are recorded as integer values (e.g. 8 bits or 10 bits or 16 bits) – i.e. values between two counts cannot be radiometrically resolved:

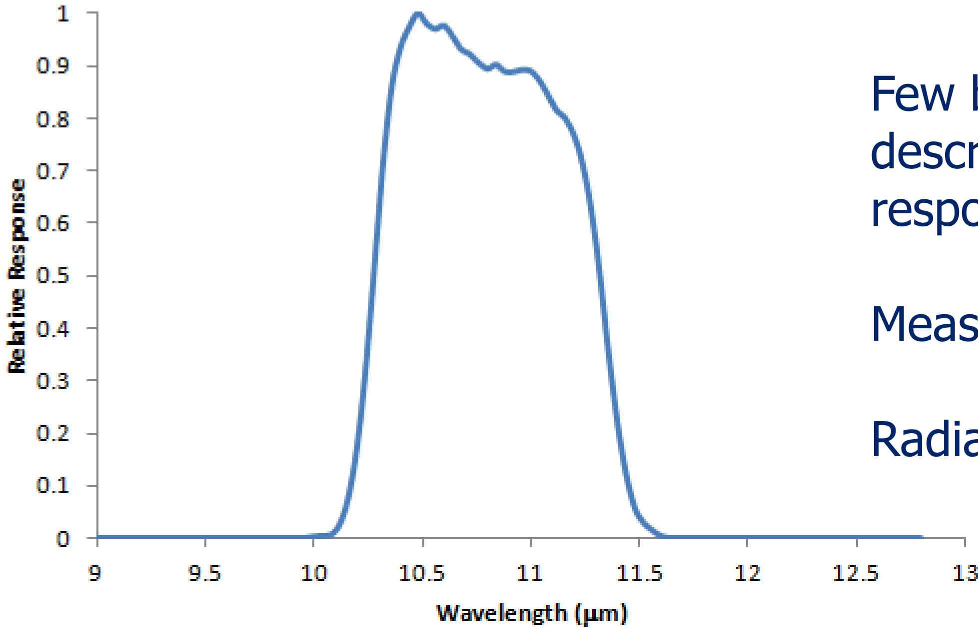
Example (for IR):

Count 333 – 261.54 K
Count 332 - 261.36 K

Temperatures “in between” cannot be measured

Spectral Resolution

The spectral resolution describes the ability of the system to distinguish between different parts of the range of measured wavelengths – important here are the number of wavelength intervals (“bands” or “channels”) and how wide or narrow a band is.



“Imaging” type of instruments:

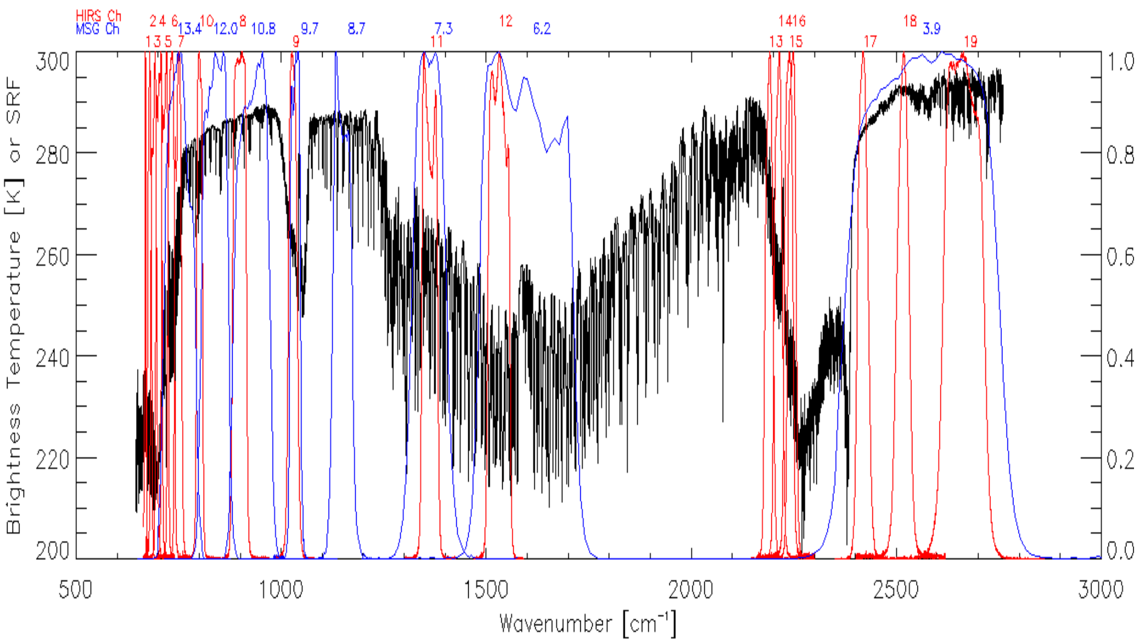
Few broad bands, each described by a filter or response function

Measurement:

Radiance * Filter

Spectral Resolution

The spectral resolution describes the ability of the system to distinguish between different parts of the range of measured wavelengths – important here are the number of wavelength intervals (“bands” or “channels”) and how wide or narrow a band is.

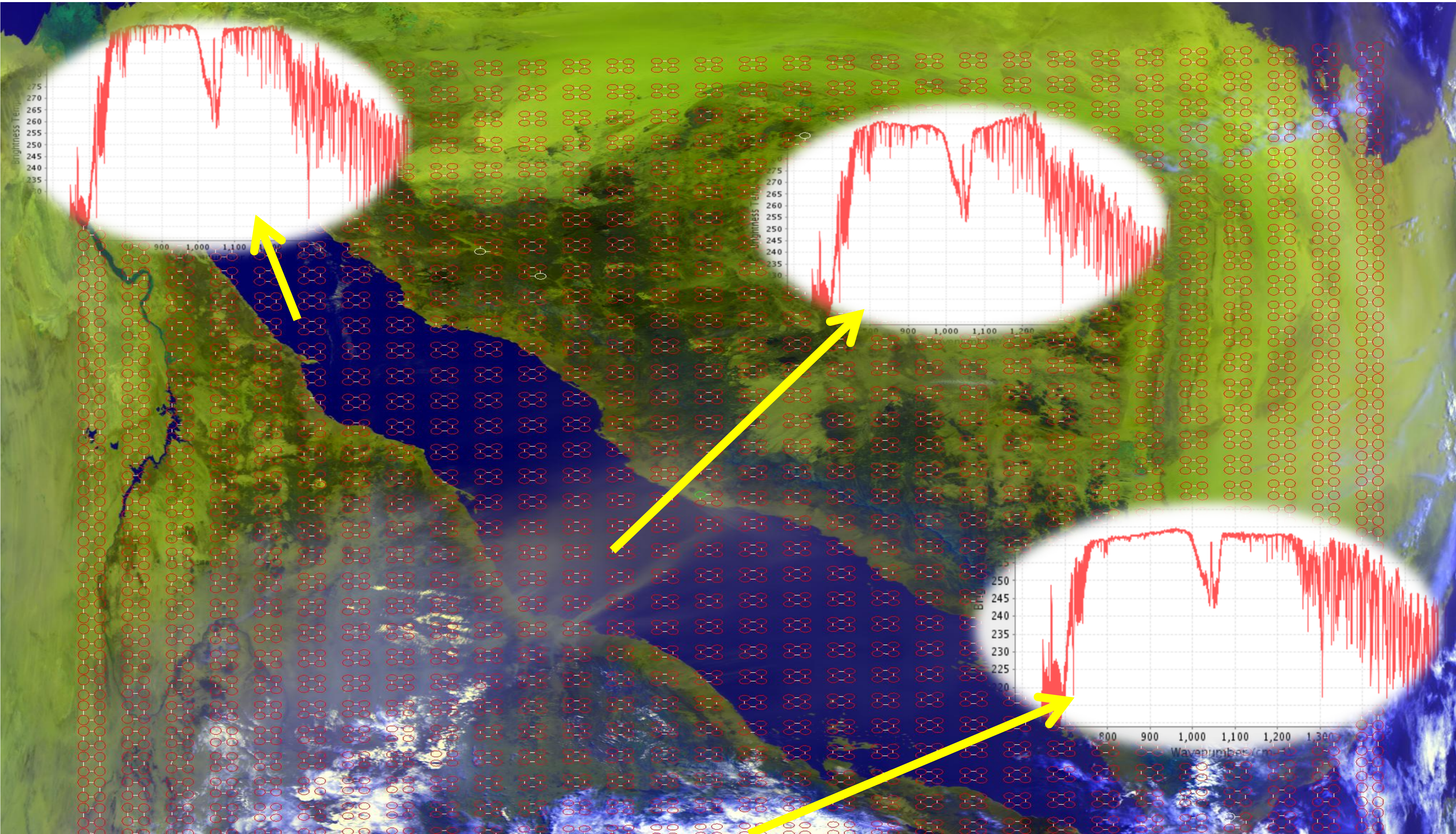


Blue: broad band imager (MSG)
Red: narrow band sounder (HIRS)
Black: hyperspectral instrument (IASI)

“Sounding” type of instruments:

Many narrow bands, each also described by a filter function – but not really used to produce “images” but to obtain information on the vertical structure of the atmosphere.
Most advanced sounders: Hyperspectral instruments with such narrow “bands” that concept of a response function does not apply

IASI Example



Thank you very much!

- Thank you for your attention
- I hope I could give you a basic introduction into what remote sensing is about
- Enjoy the quiz!