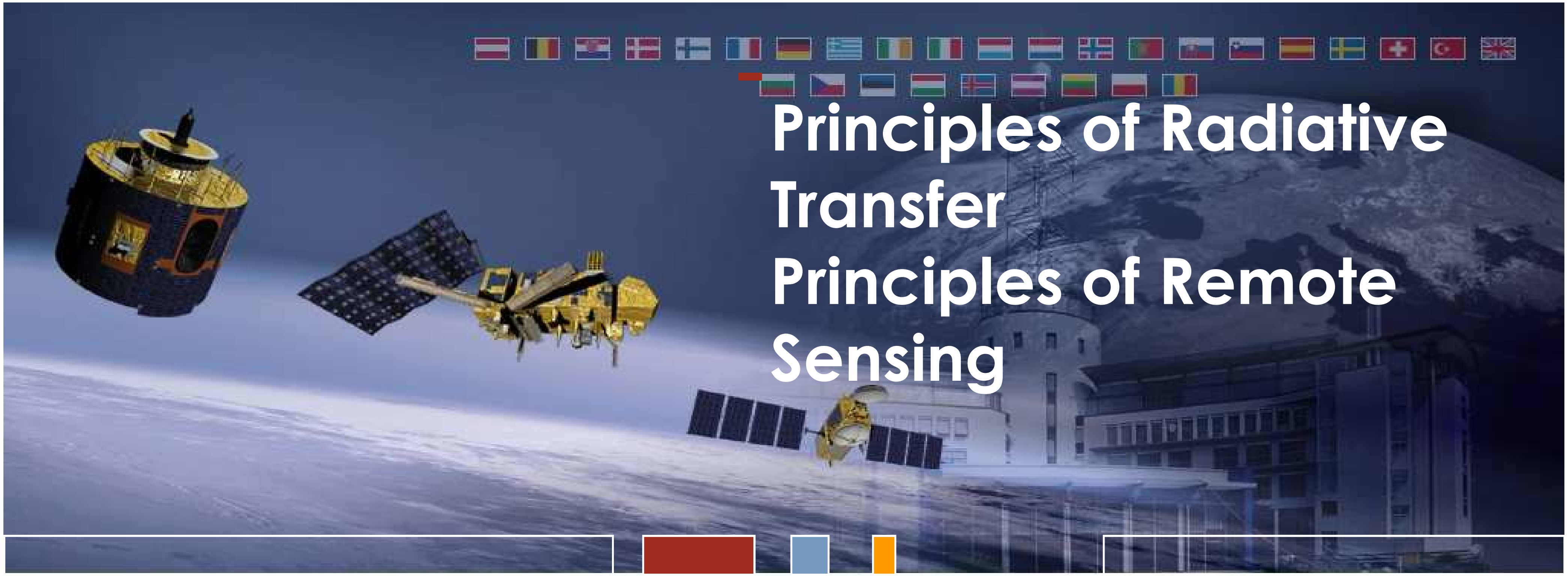

Principles of Radiative Transfer
Principles of Remote Sensing

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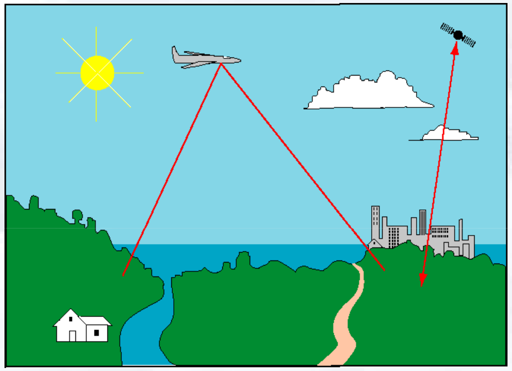
Remote Sensing

All measurement processes which perform observations/measurements of parameters which carry information about properties at the location of interest, far from the location of interest



Opposite: ***In-situ*** measurements, i.e. at the location of interest

For Meteorology: most remote sensing relies on electromagnetic waves

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Remote Sensing

"Remote Sensing" is for us
not such a strange principle – we have several remote sensing devices (which?)

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Remote Sensing - Principle

In order to obtain meaningful information from remote sensing images, the probed radiation field must have some interaction with the parameter of interest

Example:

A fish seen in "visible" wavelengths (by humans)

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Remote Sensing - Principle

In order to obtain meaningful information from remote sensing images, the probed radiation field must have some interaction with the parameter of interest

Example:

A fish seen in "visible" wavelengths (by humans)

And seen by x-rays

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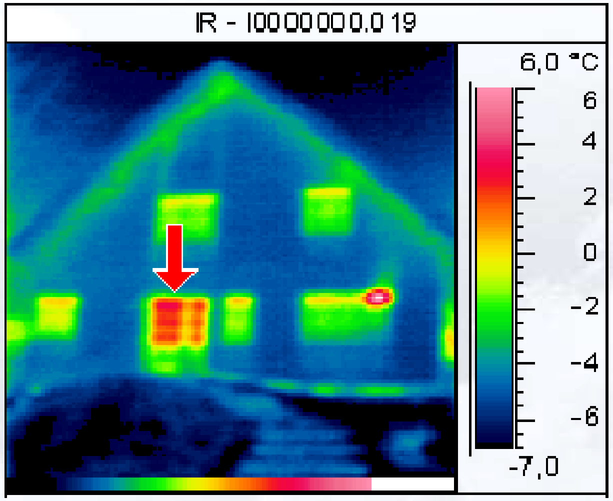
Remote Sensing - Principle



Another example: photograph and infrared picture of a house

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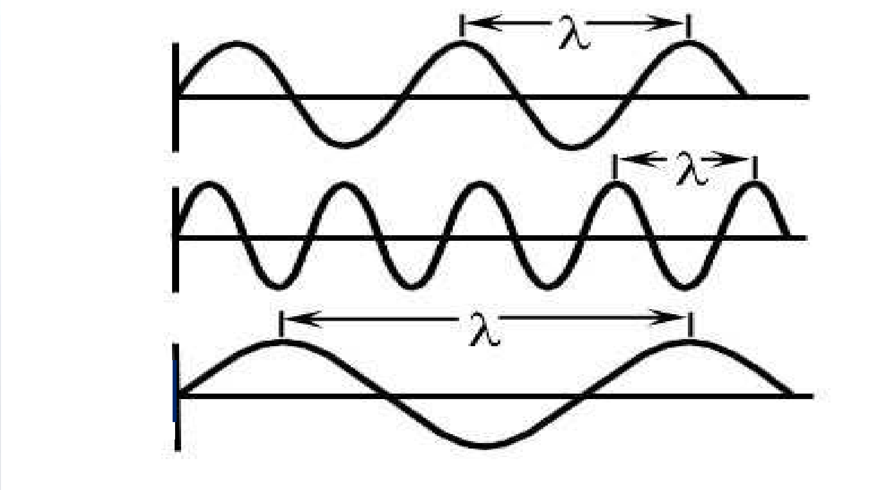
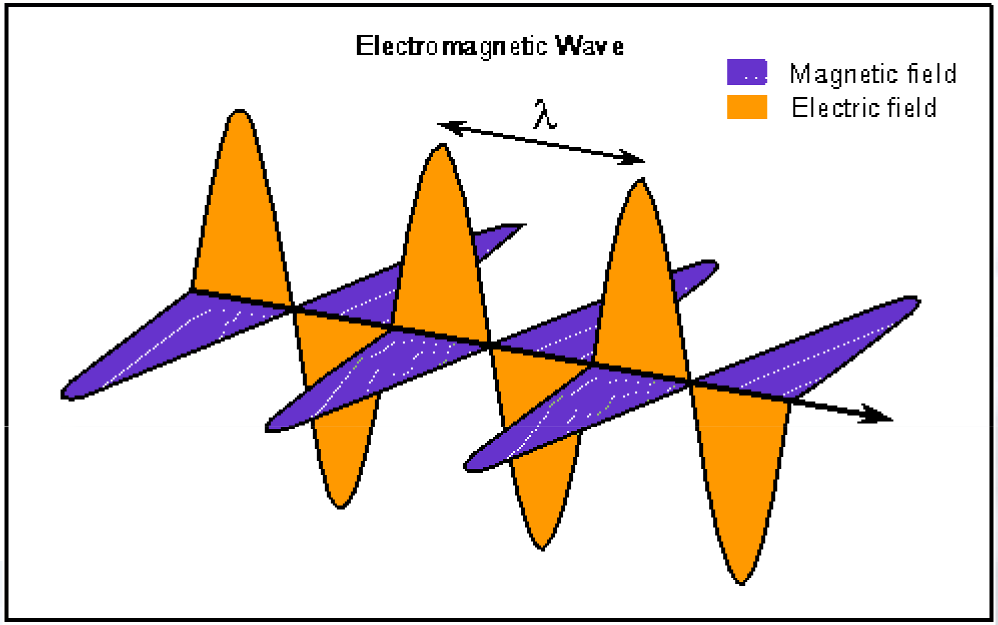
Electromagnetic Waves





Characteristics:

- Wavelength λ
- Propagation velocity c
- Frequency ν = c / λ
- Wavenumber =1/ λ (cm^{-1})

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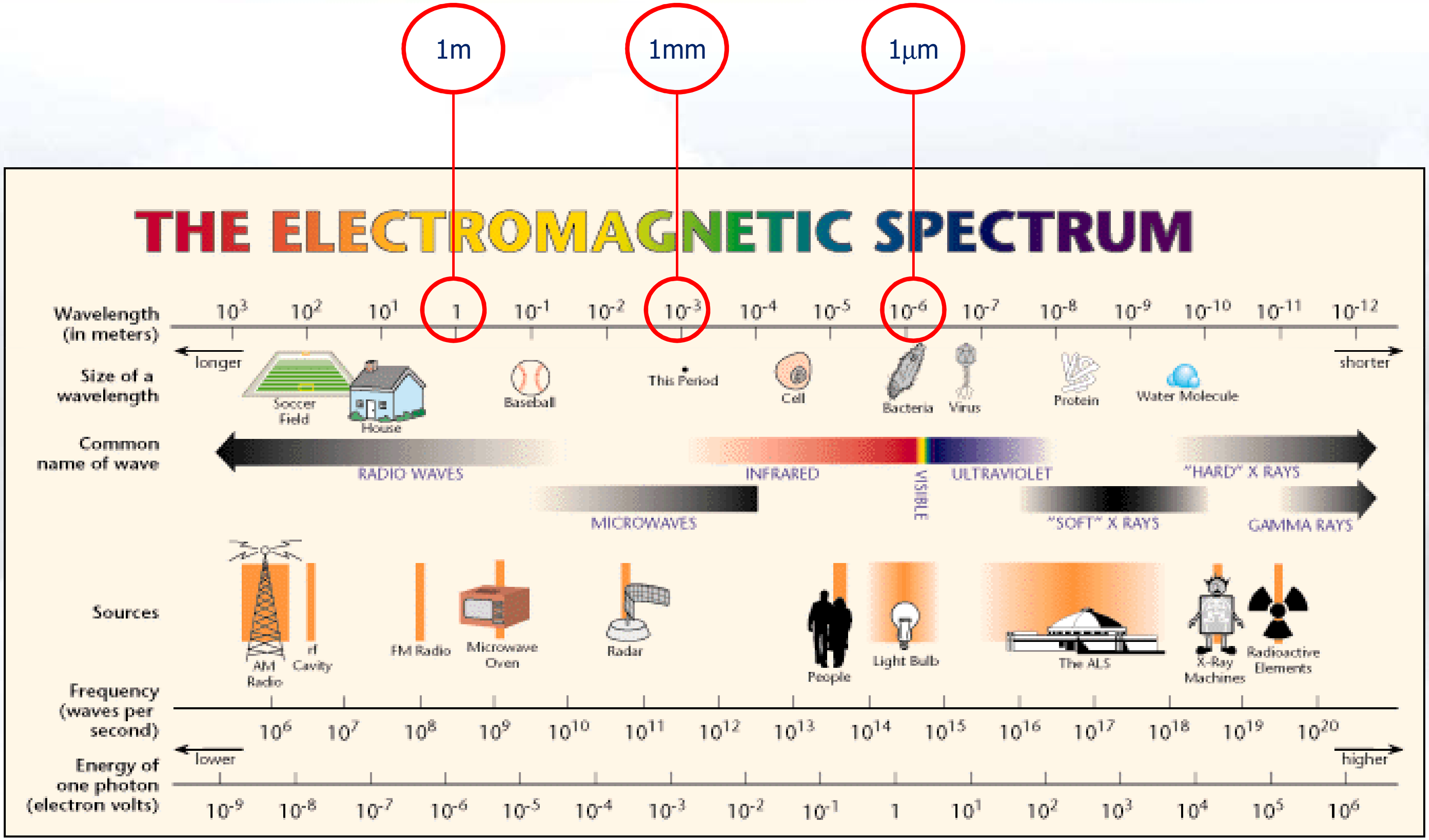
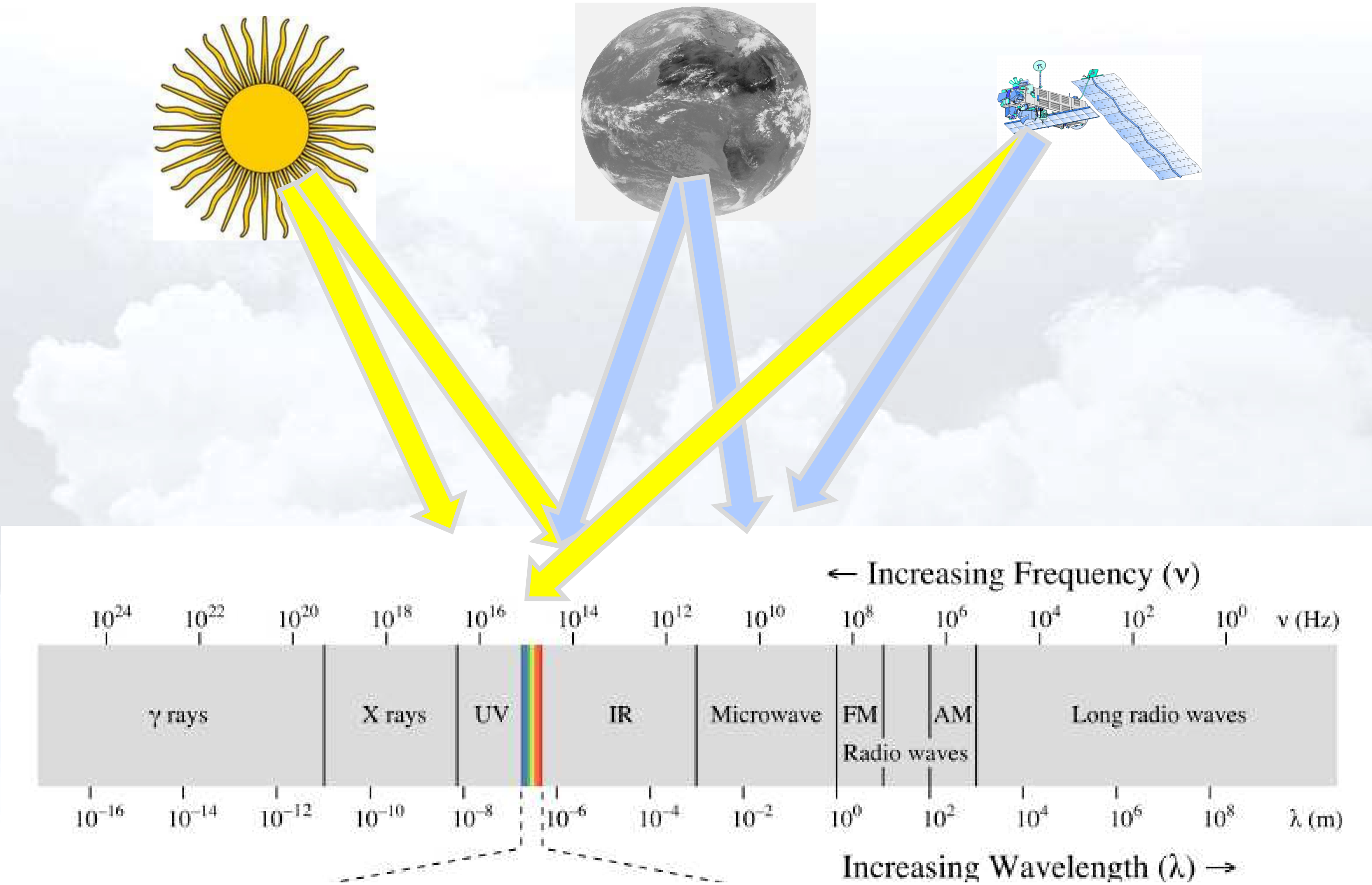
Electromagnetic Spectrum



Sources of Radiation (Met Applications)



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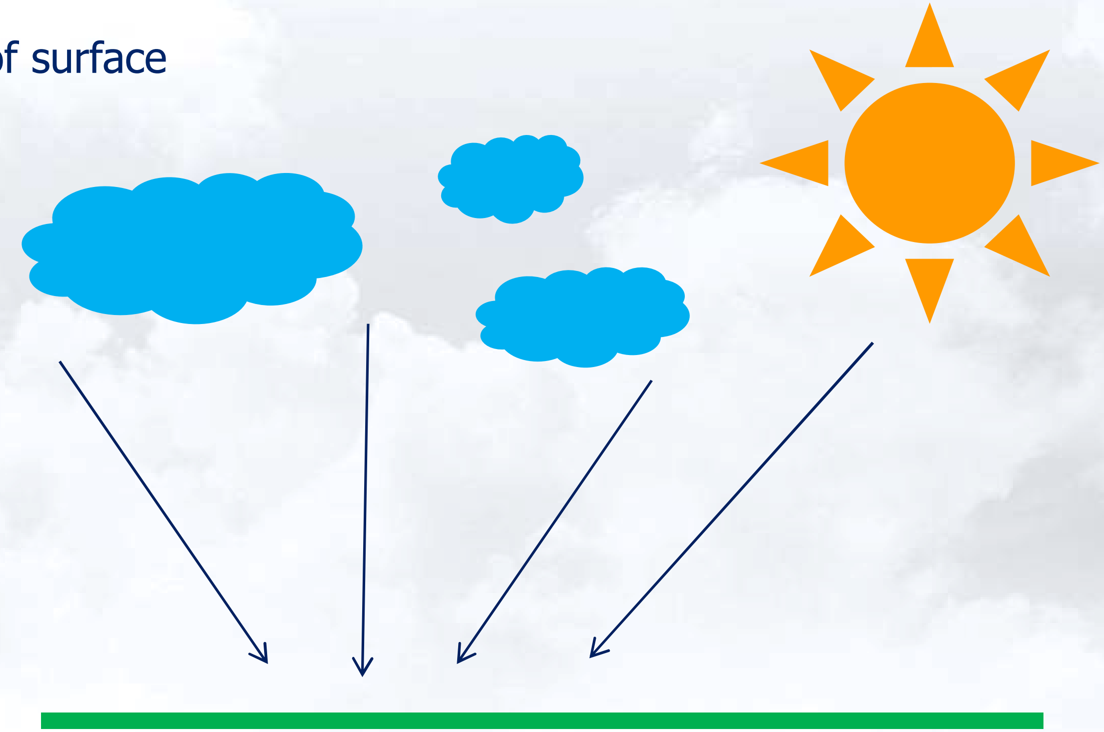
Electromagnetic Radiation – Units and Concepts

Irradiance Watts/meter^2

Total energy which falls onto 1 sqm of surface



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Electromagnetic Radiation – Units and Concepts

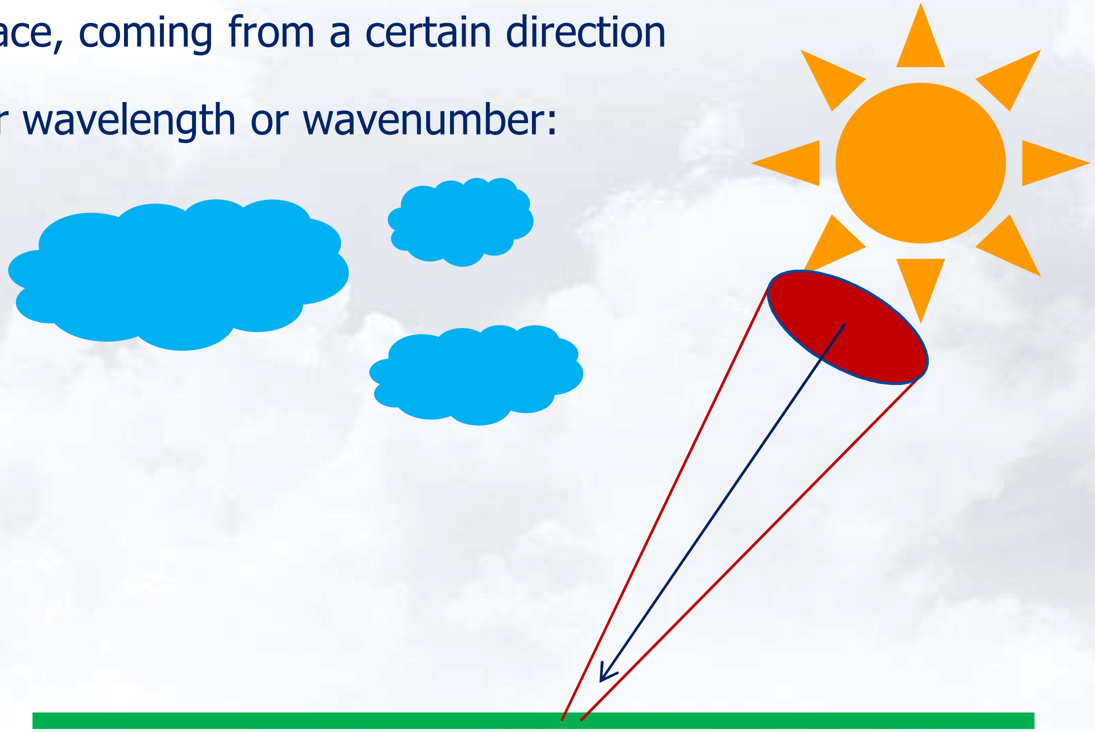
Radiance Watts/meter^2/ster (W/m^2/ster)

Energy which falls onto 1 sqm of surface, coming from a certain direction

Can also be expressed as radiance per wavelength or wavenumber:

W/m^2/ster/µm

W/m^2/ster/cm^{-1}



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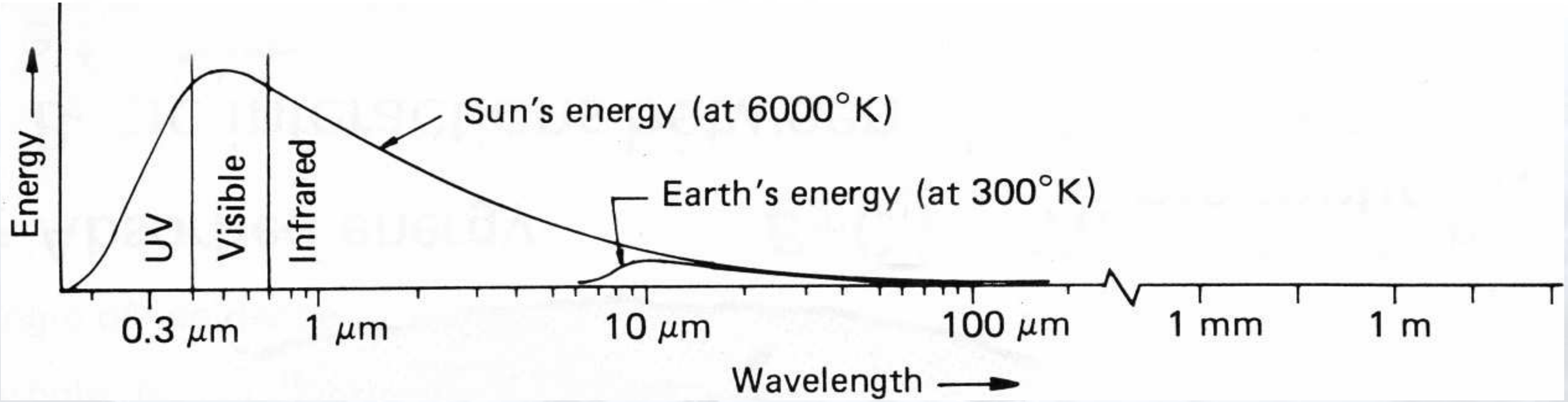
Fundamental Radiation Law: Planck's Law



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

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

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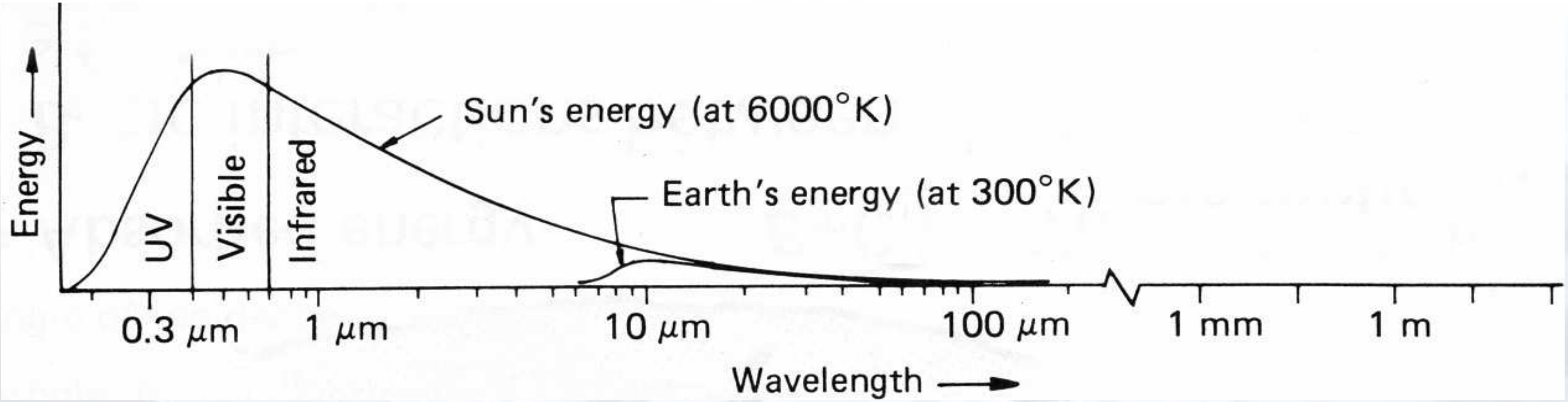
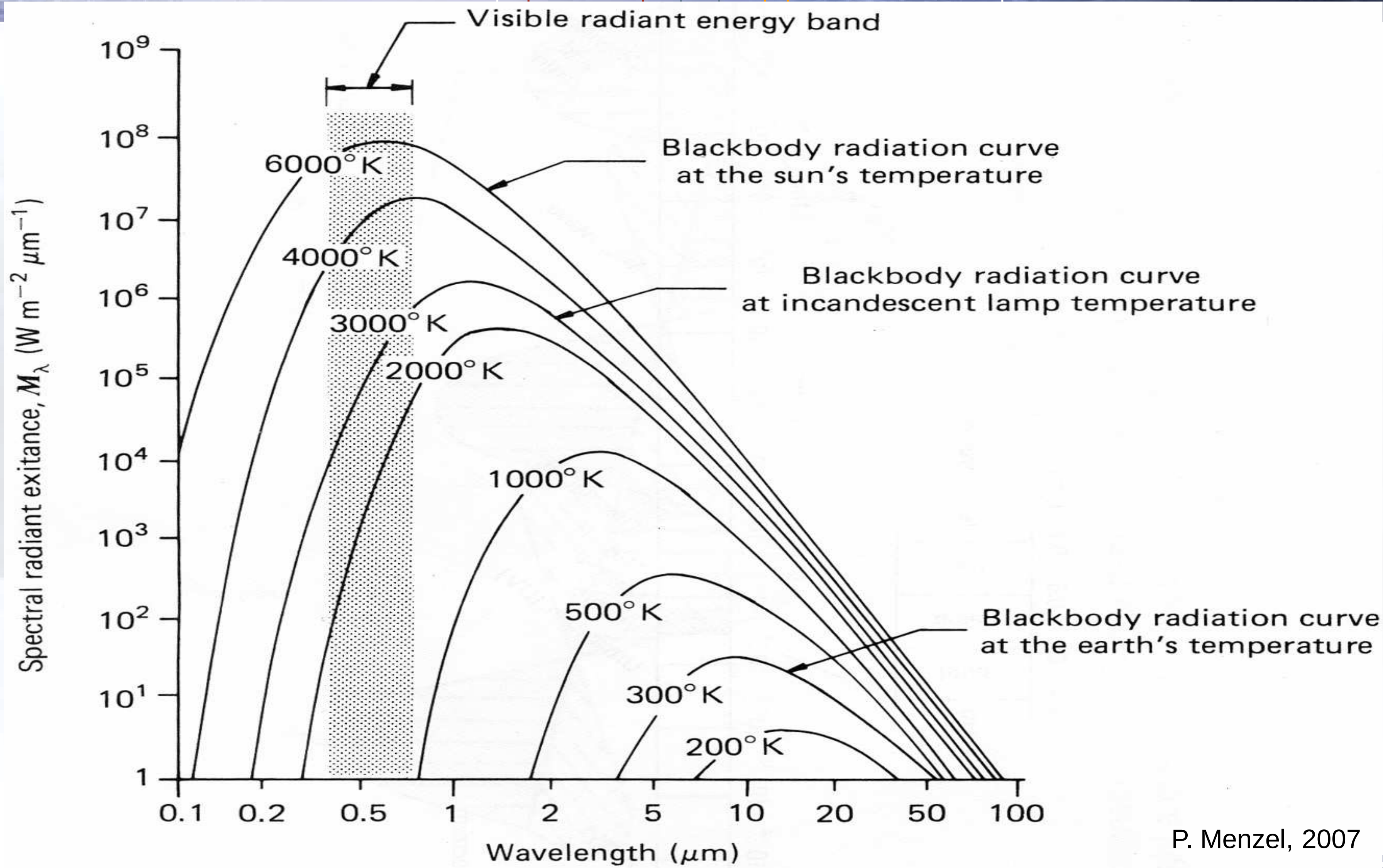
Fundamental Radiation Law: Planck's Law



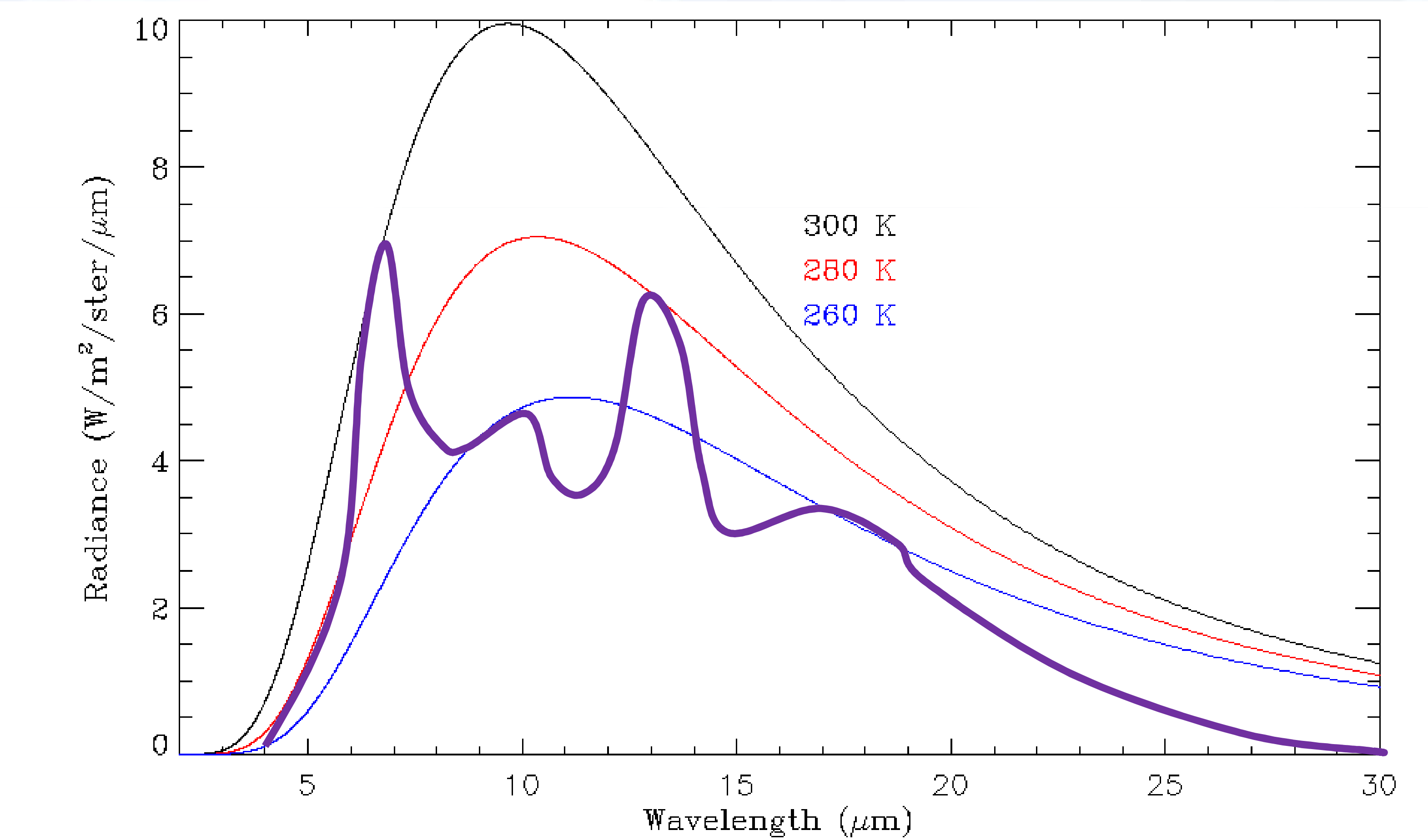
Spectral Distribution of Energy Radiated from Blackbodies at Various Temperatures



P. Menzel, 2007

Concept of a Blackbody – Concept of Emissivity

A “Blackbody” is an object of temperature T which radiates energy according to Planck’s Law. Nature does not have perfect blackbodies:



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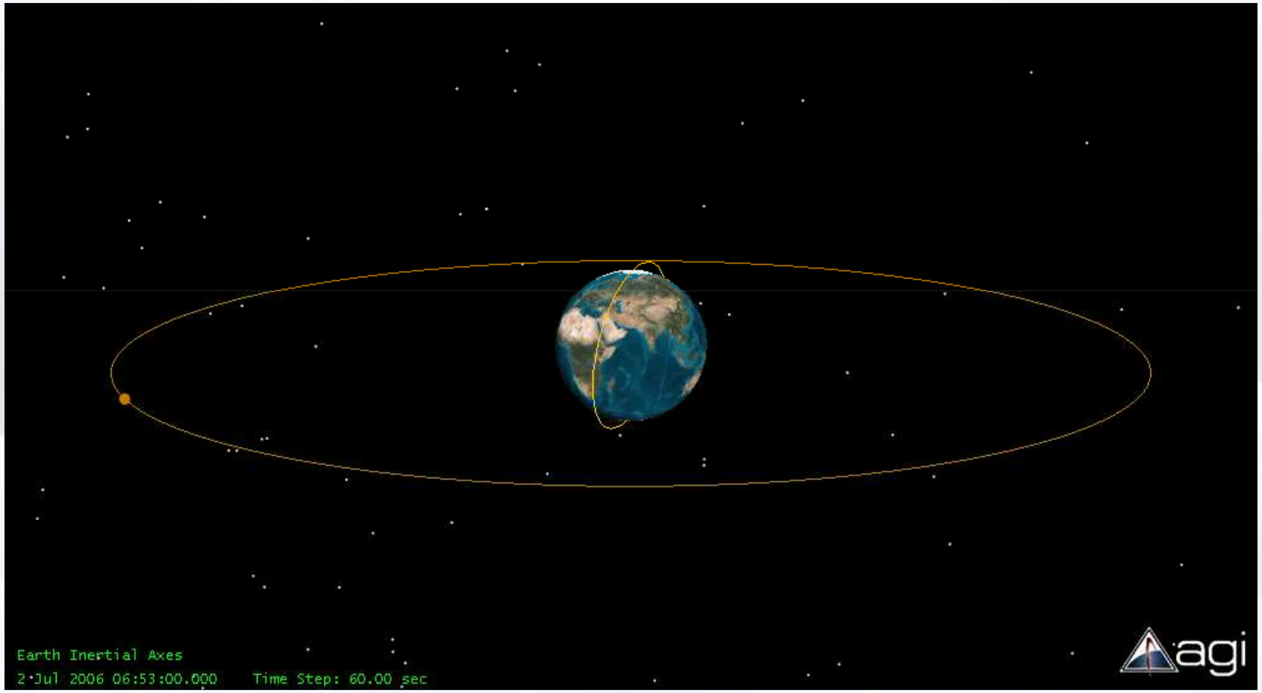
Satellite Orbits – What Can We Measure?



Geostationary orbit:
36000 km height
Usable energy in solar and infrared bands

Low earth / polar orbit:
~800-900 km height
Usable energy in solar, infrared and microwave bands

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Remote Sensing of the Atmosphere

What do we measure?

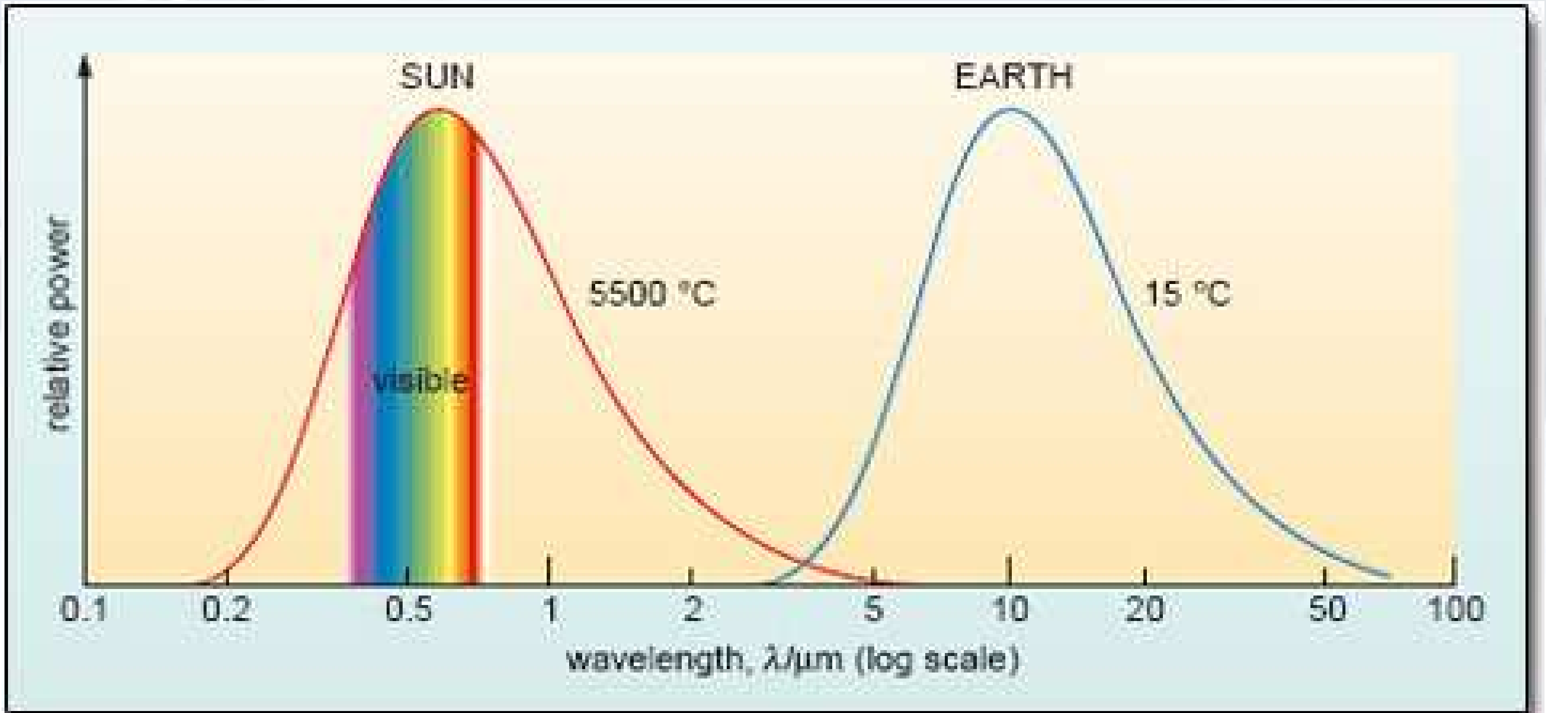
Solar radiation: reflected by the surface, by clouds, scattered by molecules …   (wavelengths?)

Thermal radiation: emitted by the earth / clouds / atmosphere … (wavelengths?)

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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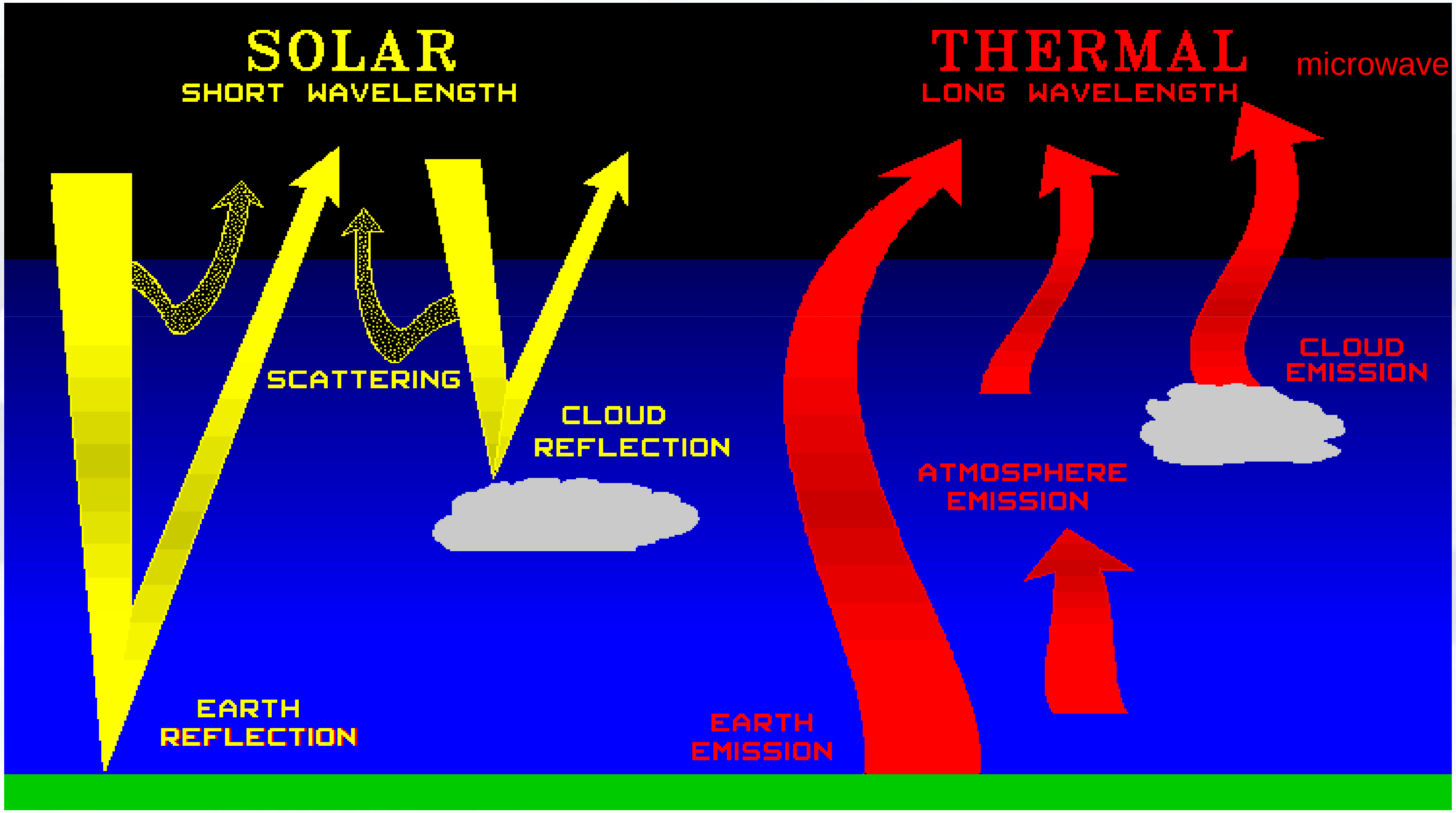
Visible (Reflective Bands)

Infrared / microwave (Emissive Bands)



P. Menzel, 2007

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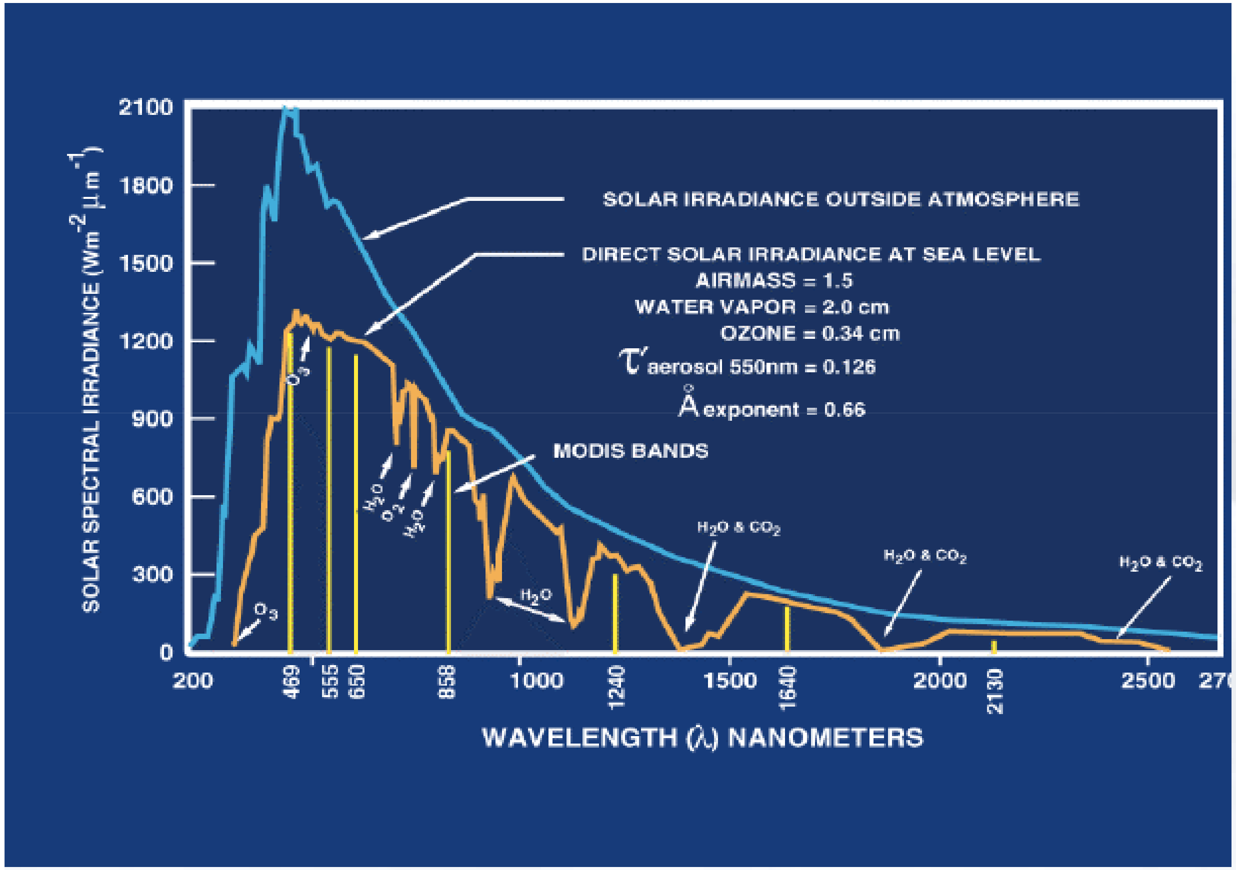
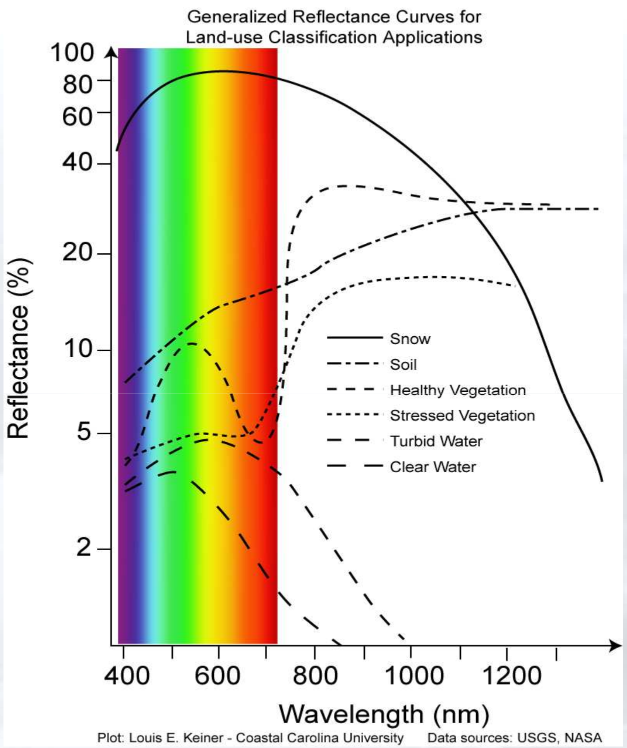
Processes for Solar Radiation





Why is grass green?

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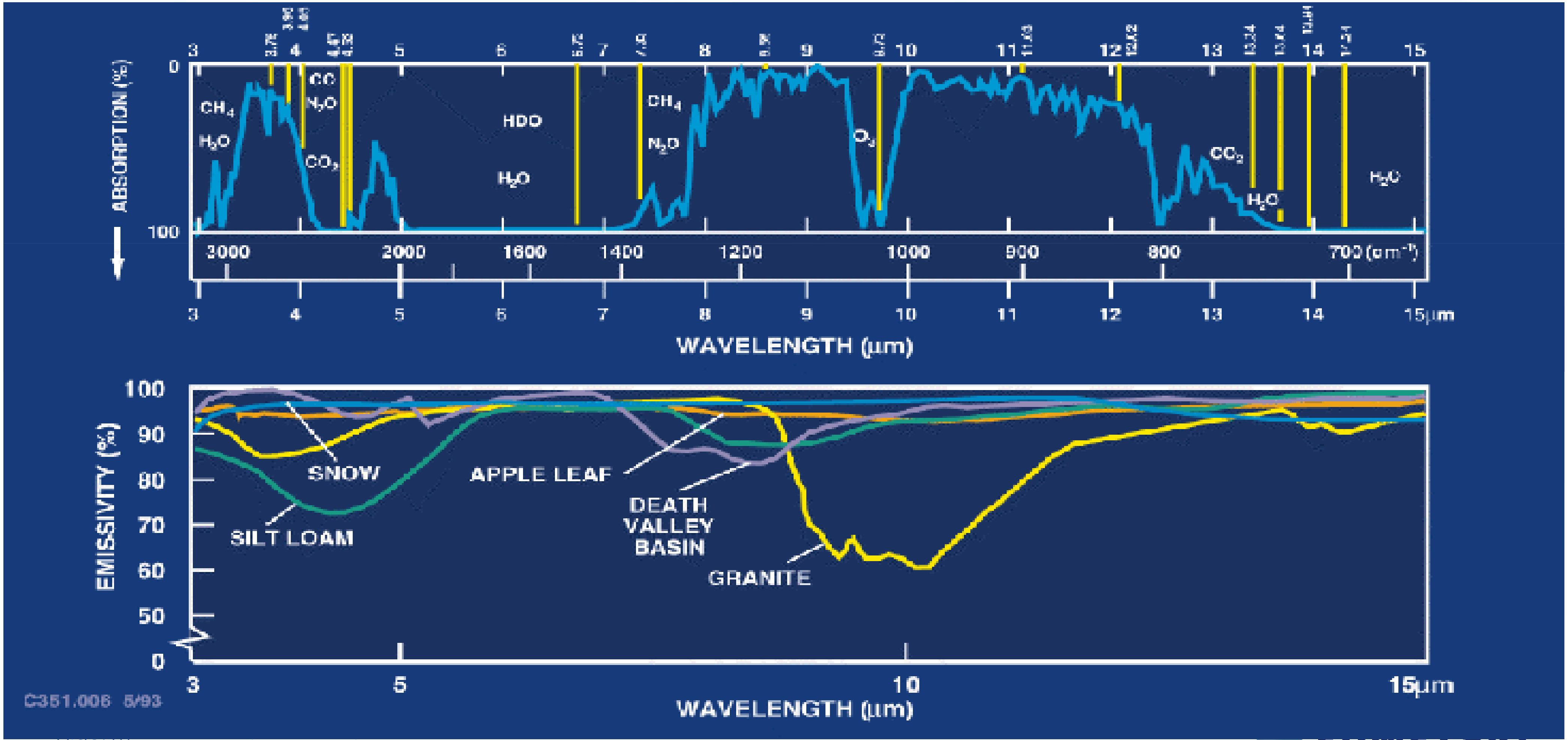
Processes of Thermal Radiation



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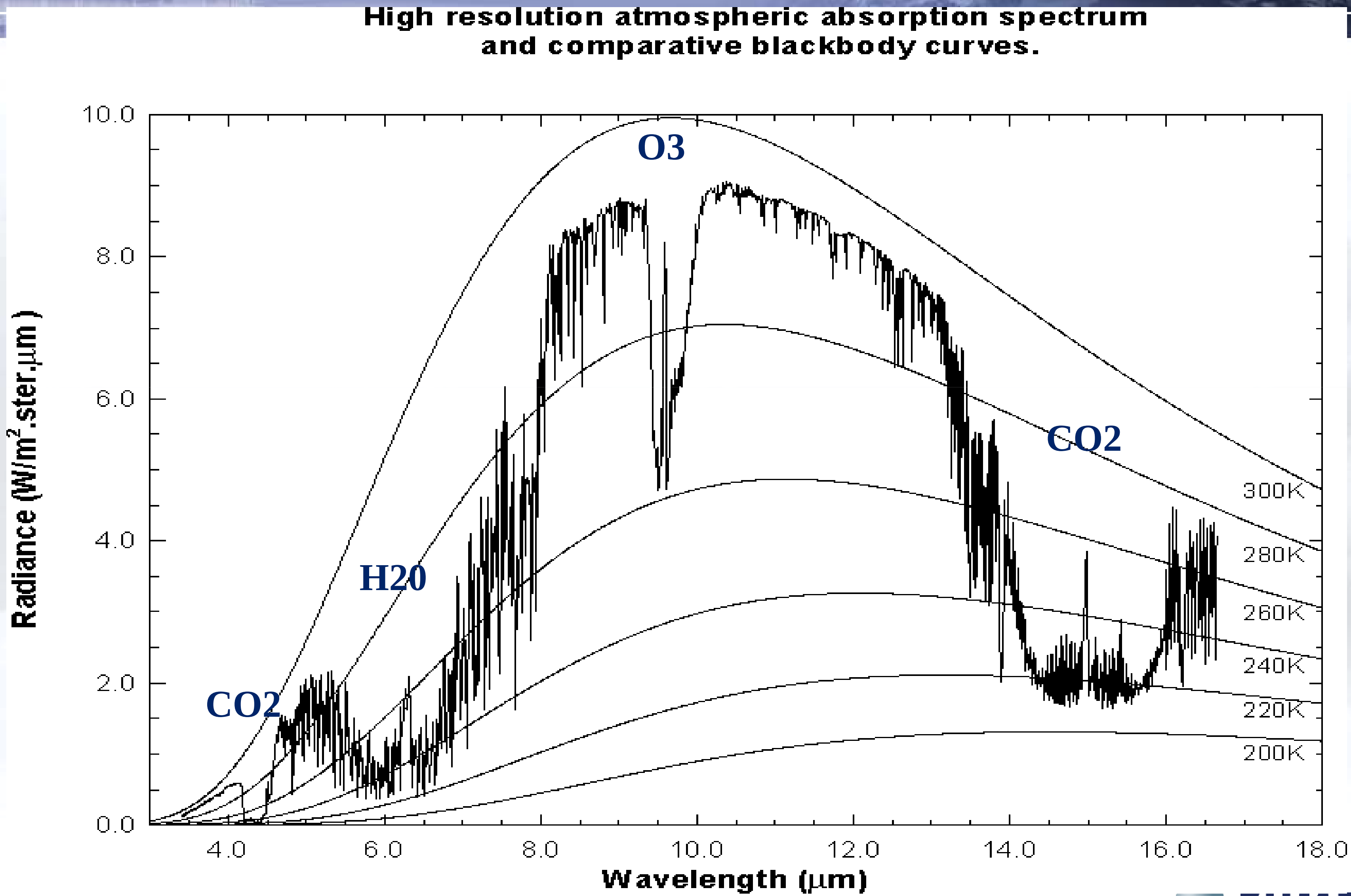
Earth Spectrum and Planck Curves



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Radiative Processes

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

Radiative Processes

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/reflection: Radiation is "geometrically" forced to deviate from a straight line

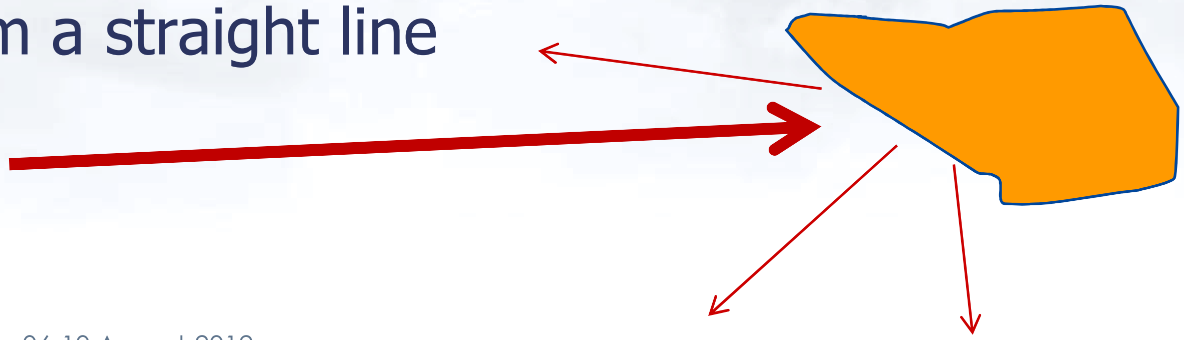

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Illustration: Beam at 11 µm wavelength (“Window”)

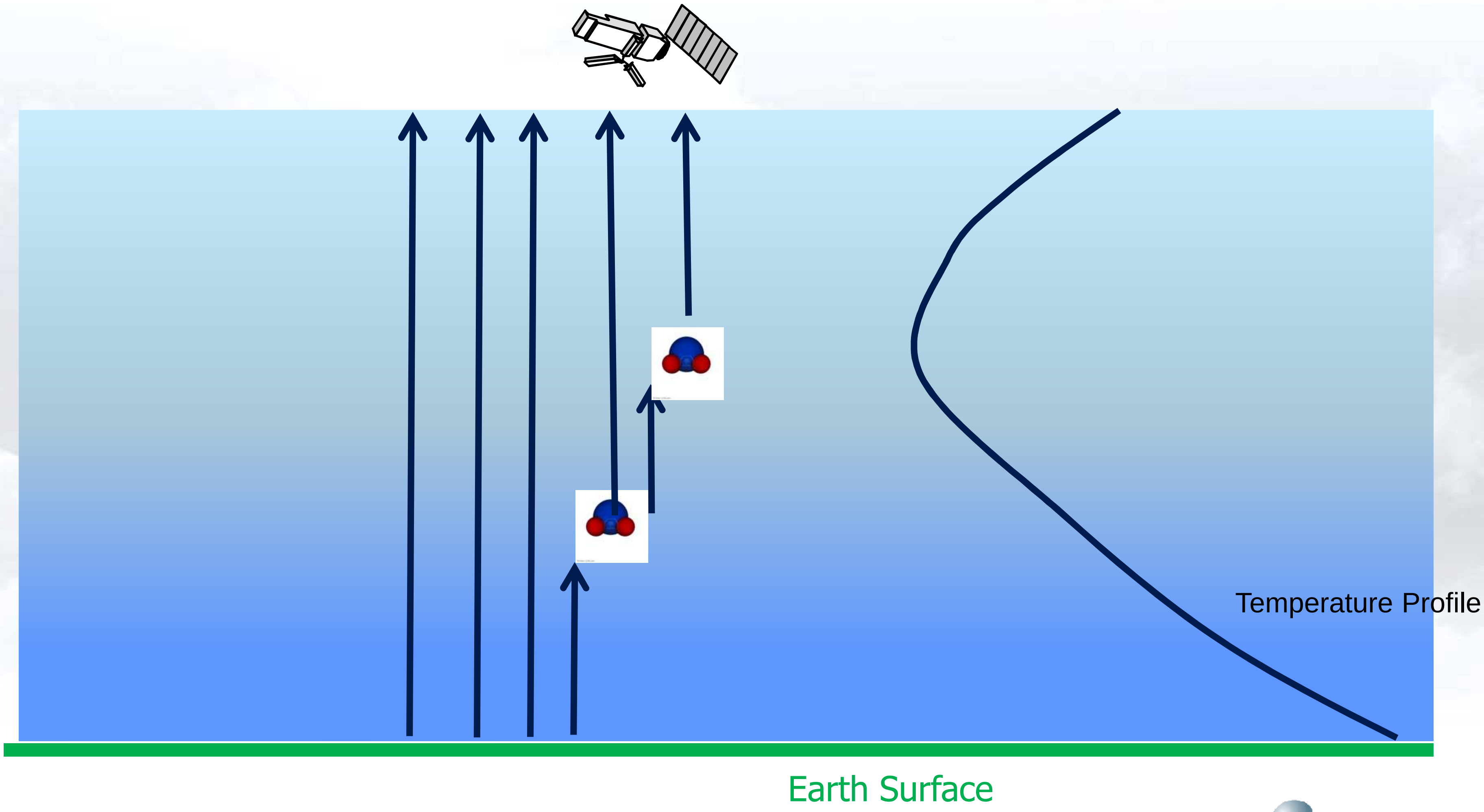

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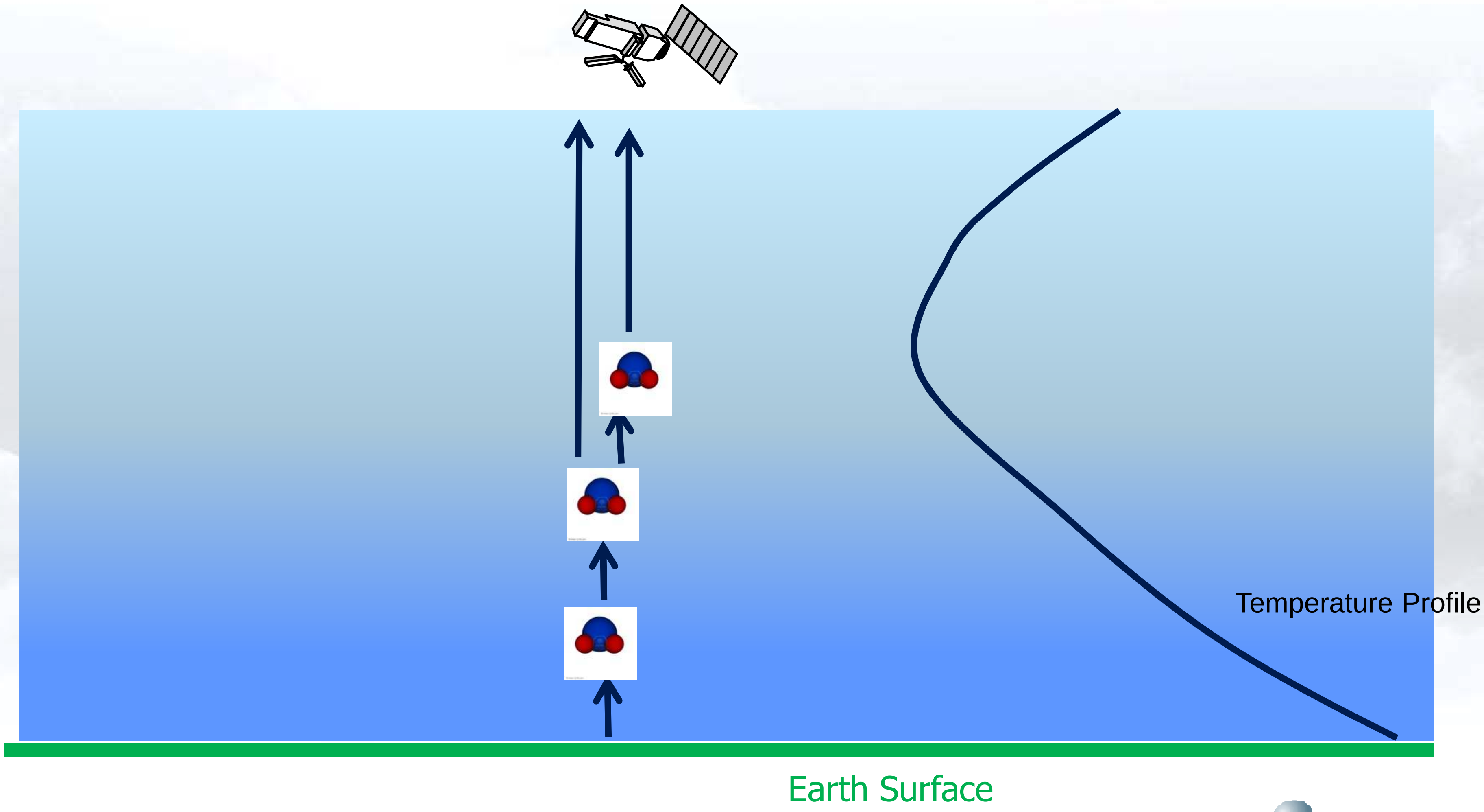
Illustration: Beam at 6.5 µm wavelength (WV Absorption)



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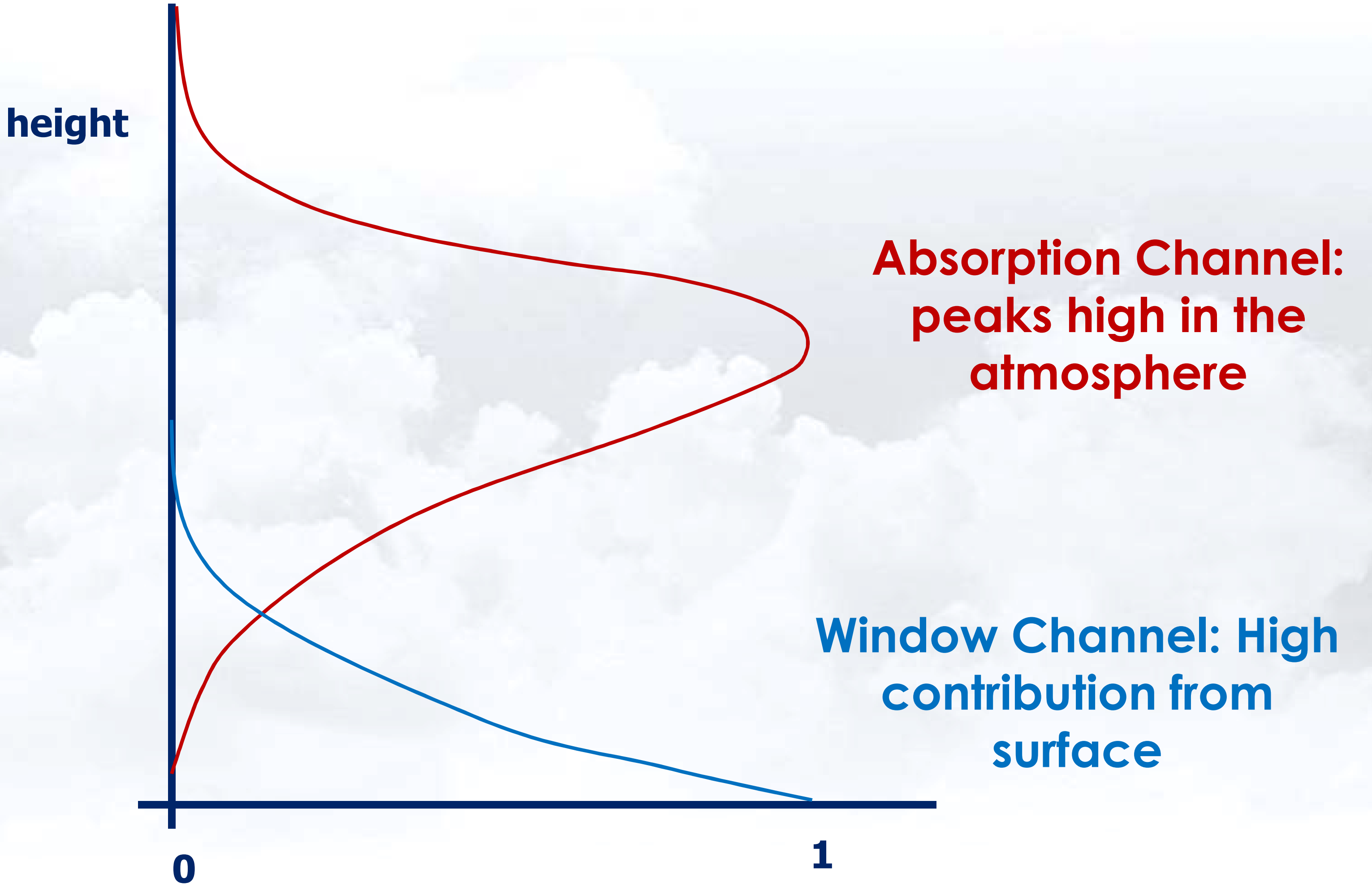
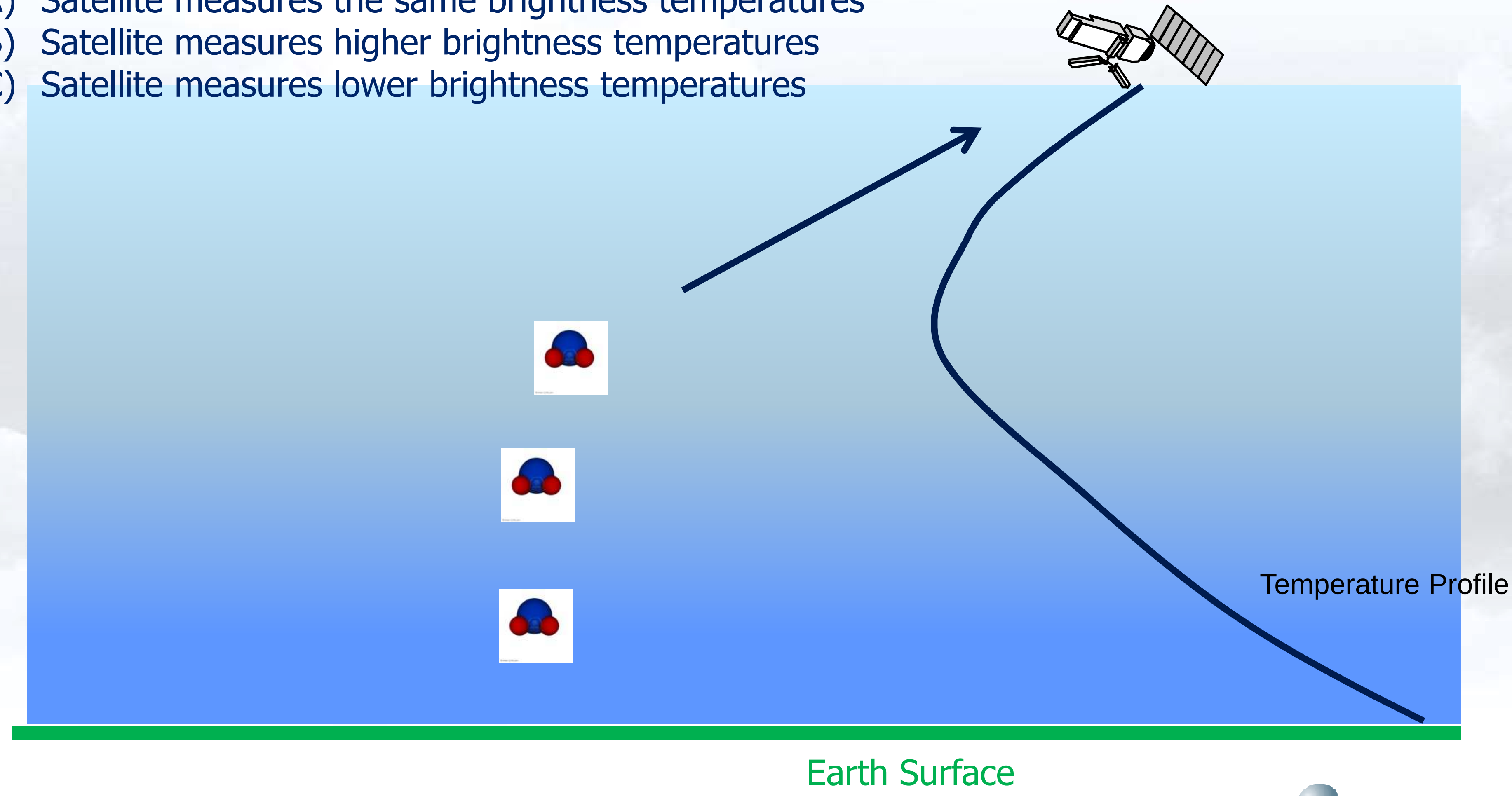
Weighting Functions



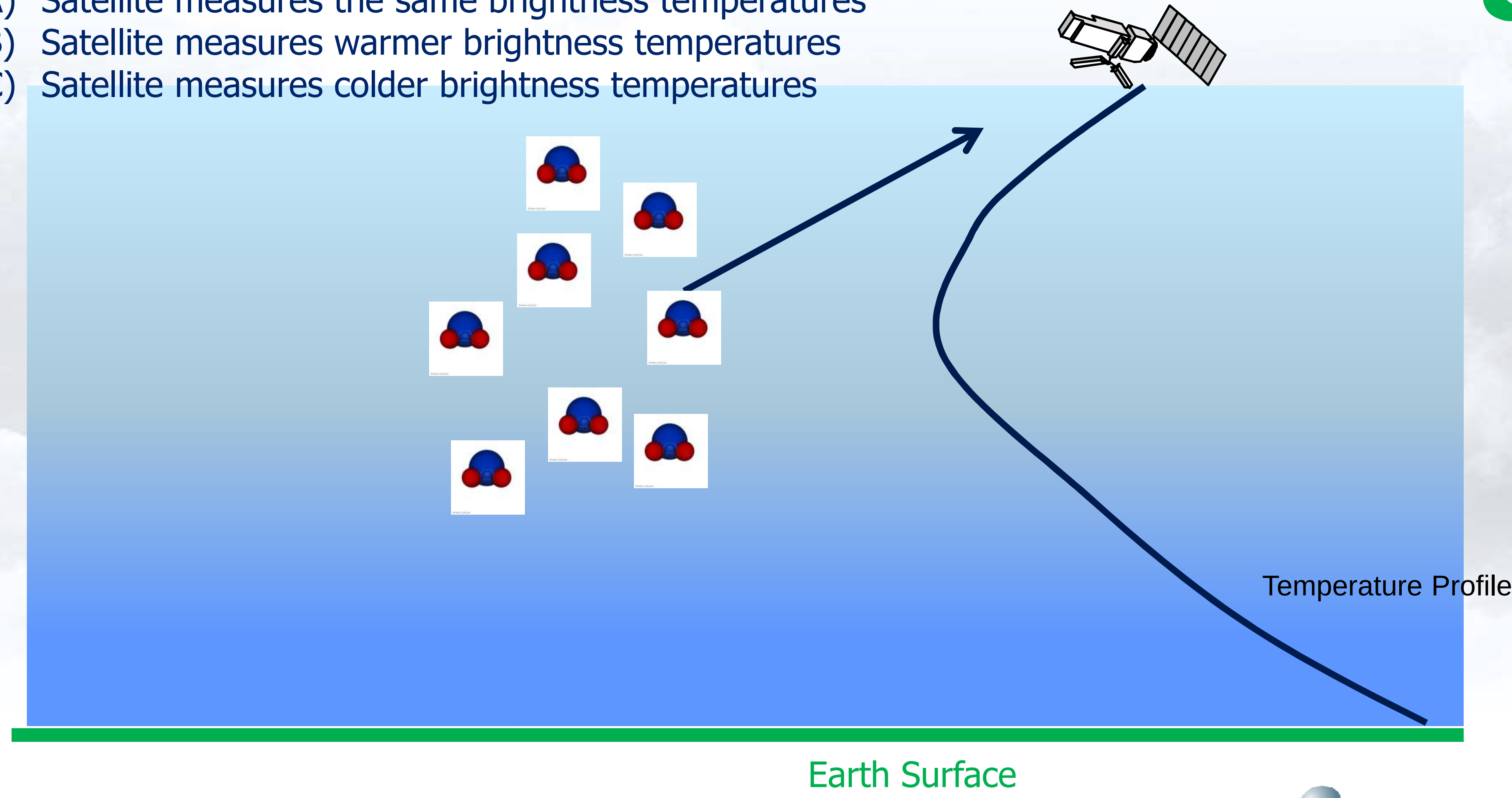
Question: What happens for higher viewing angles?

A) Satellite measures the same brightness temperatures
B) Satellite measures higher brightness temperatures
C) Satellite measures lower brightness temperatures



Question: What happens for strong absorption channels, at higher viewing angles?

A) Satellite measures the same brightness temperatures
B) Satellite measures warmer brightness temperatures
C) Satellite measures colder brightness temperatures

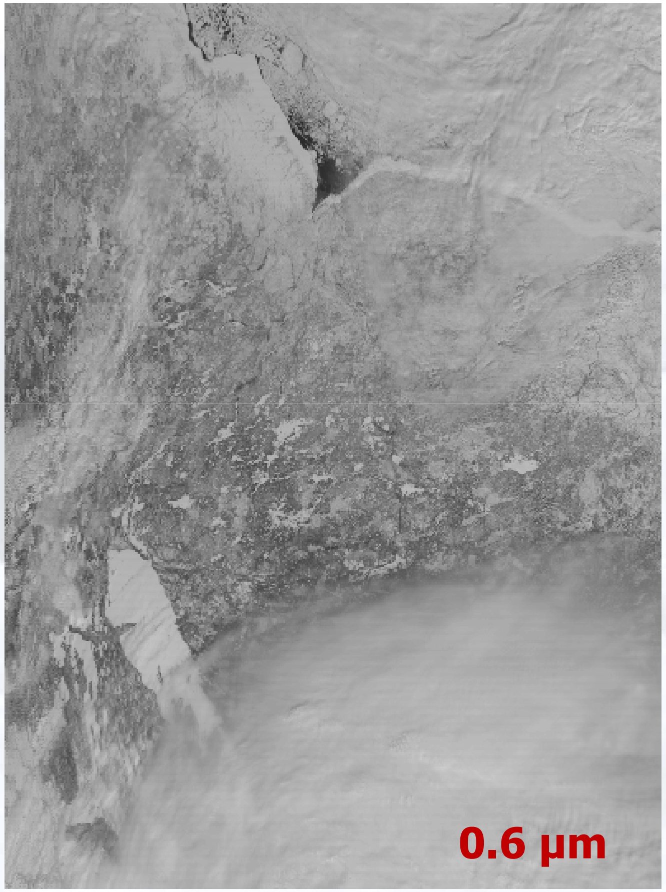


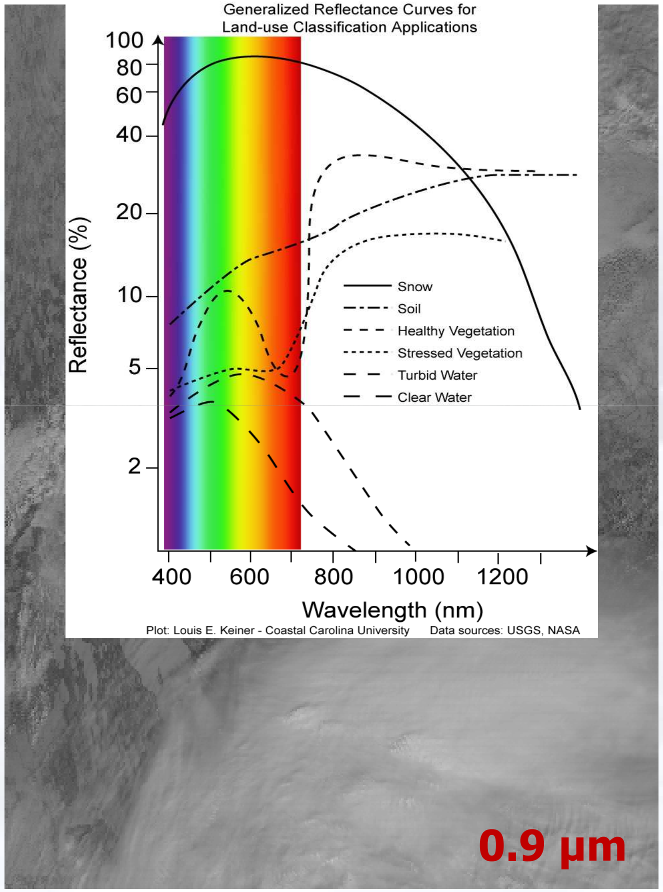
Radiative Processes Can Be Modelled - RTMs

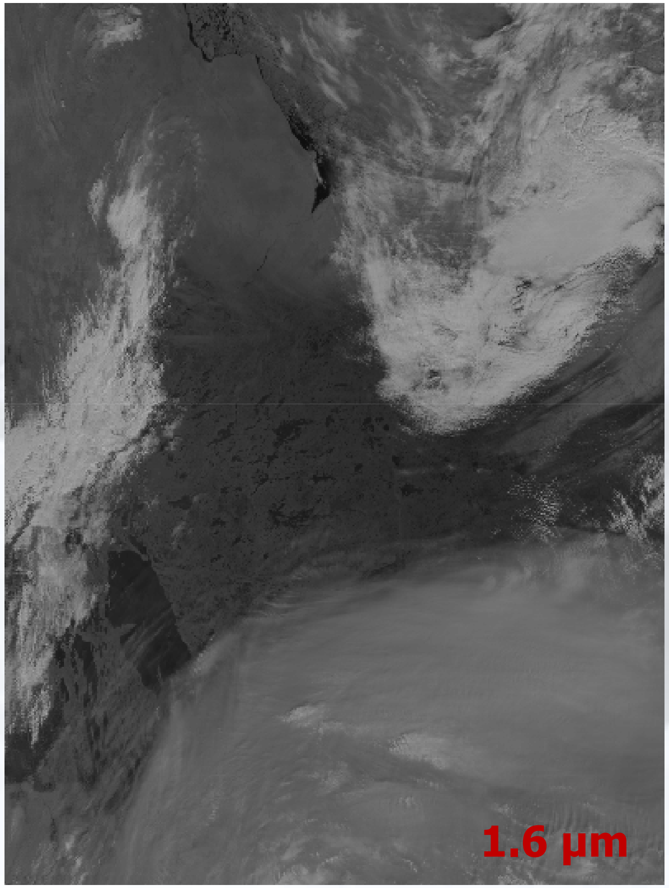
The equation of radiative transfer simply says that as a beam of radiation travels, it loses energy to absorption, gains energy by emission, and redistributes energy by scattering.

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

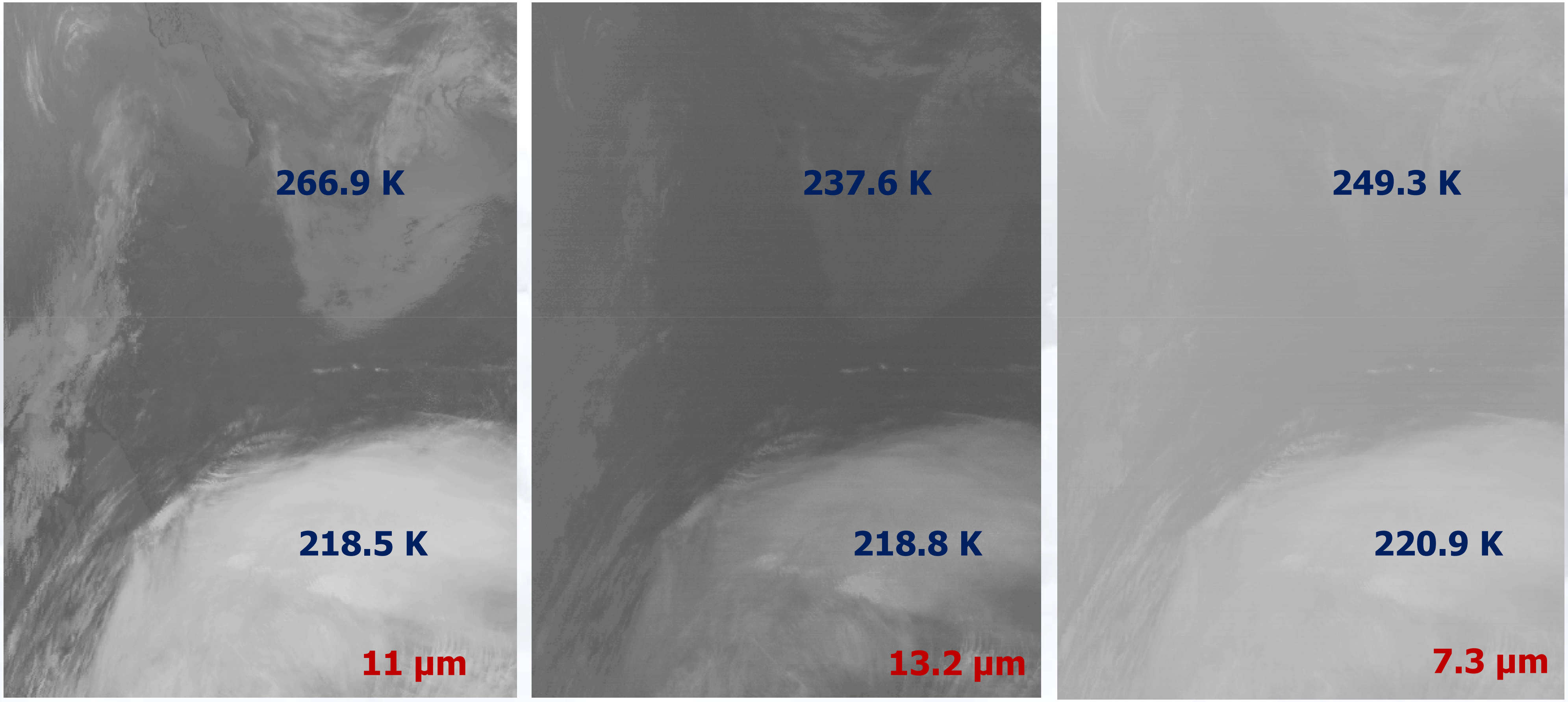
Practical Example: MODIS Imagery, 03 April 2011
Solar Bands





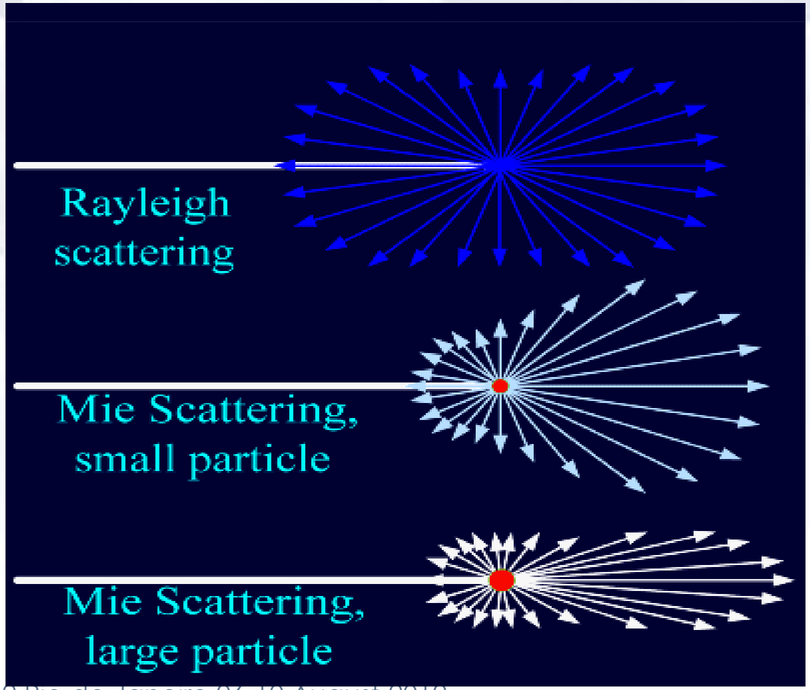


Practical Example: MODIS Imagery, 03 April 2011
Thermal Bands



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

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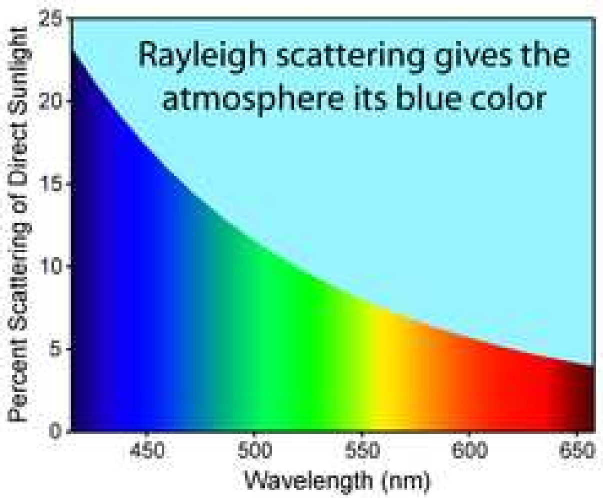
Rayleigh Scattering

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!



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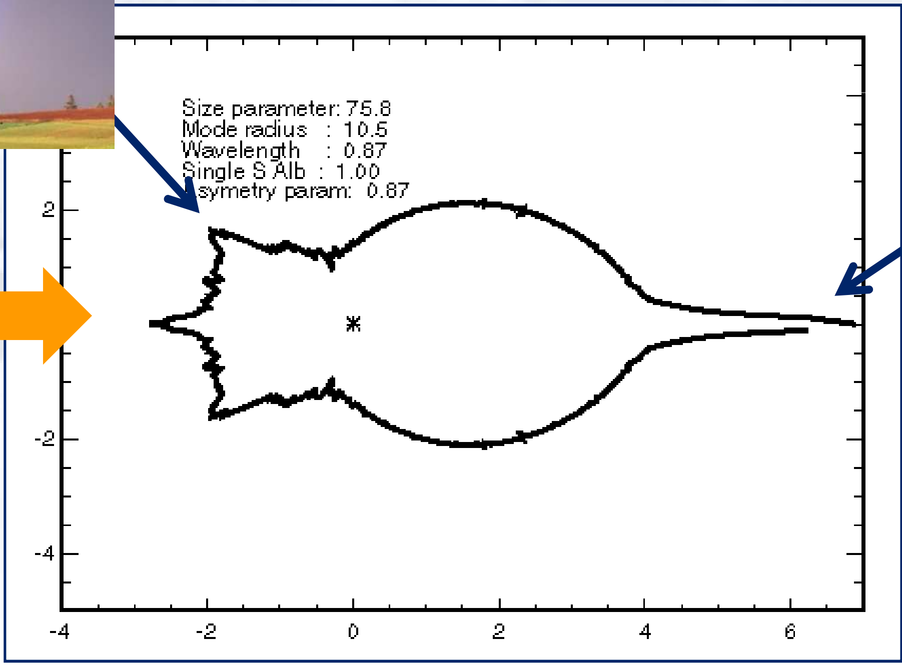
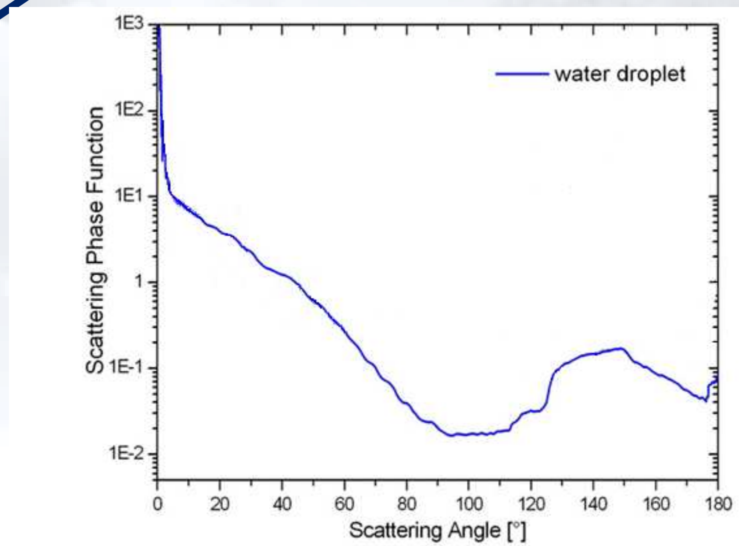
Water Clouds: Scattering on Spherical Particles

Size distribution

Wavelength 0.87 µm
Cloud droplets 1- 10 µm



Strong forward scattering



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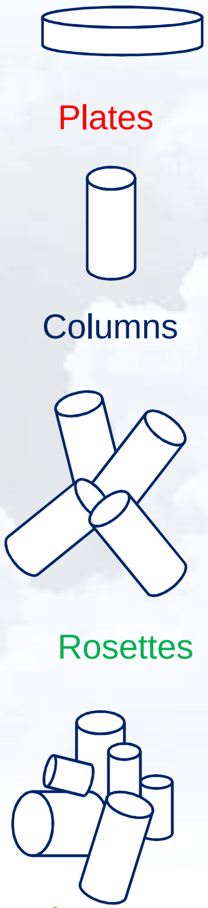
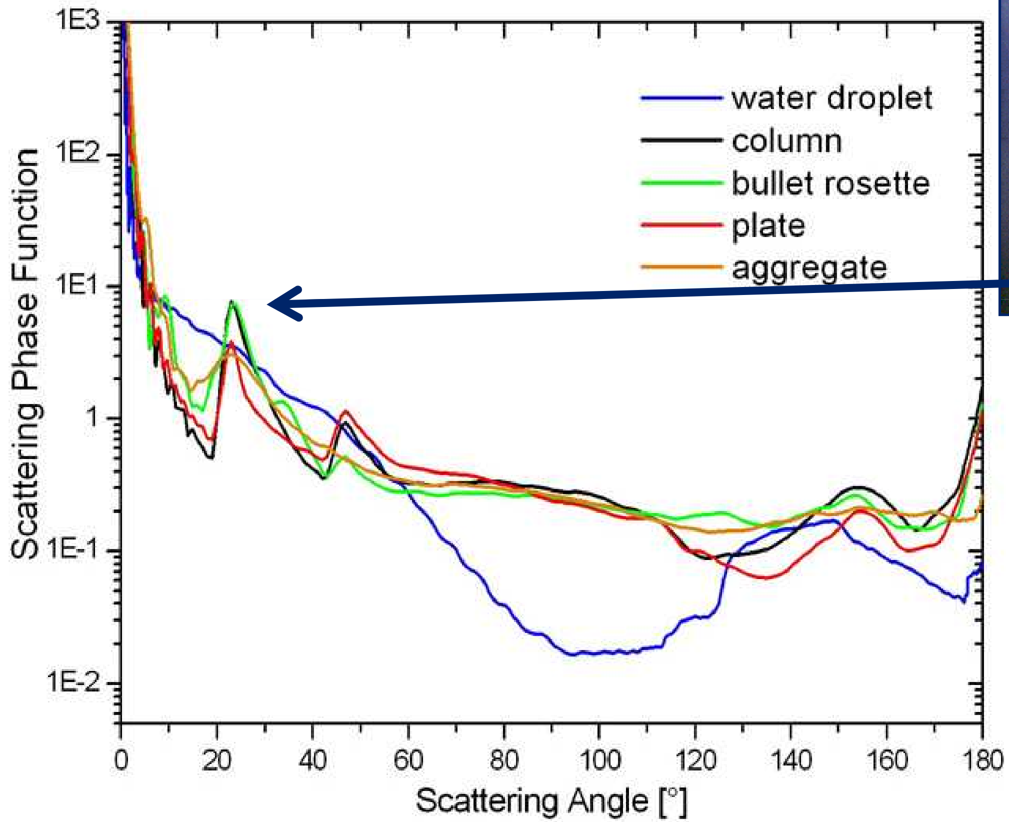
Ice Clouds: Complex Scattering Depending on Ice Crystals' Shape





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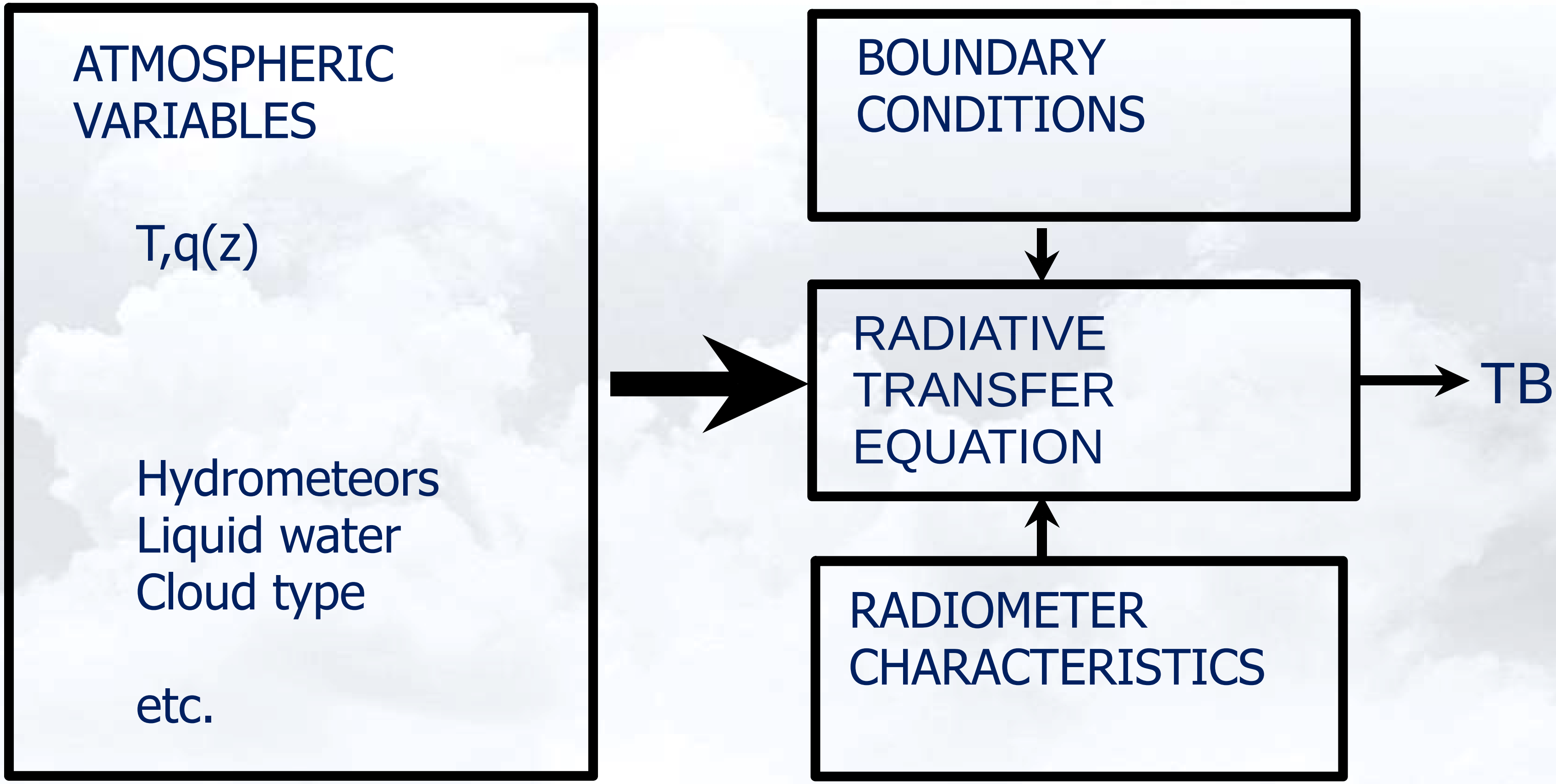
Radiative Transfer Theory: Forward Problem



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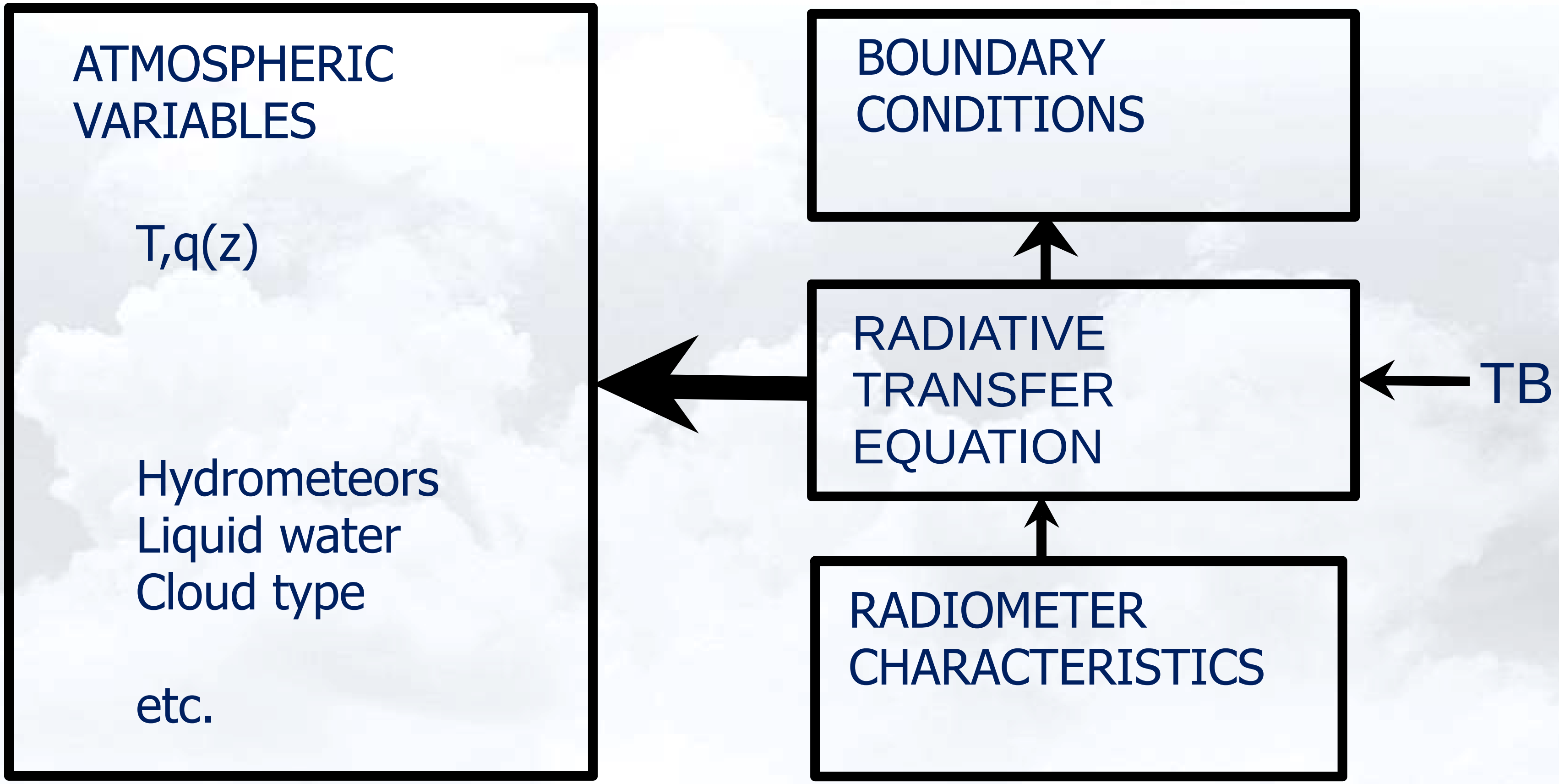
Radiative Transfer Theory: Inverse Problem



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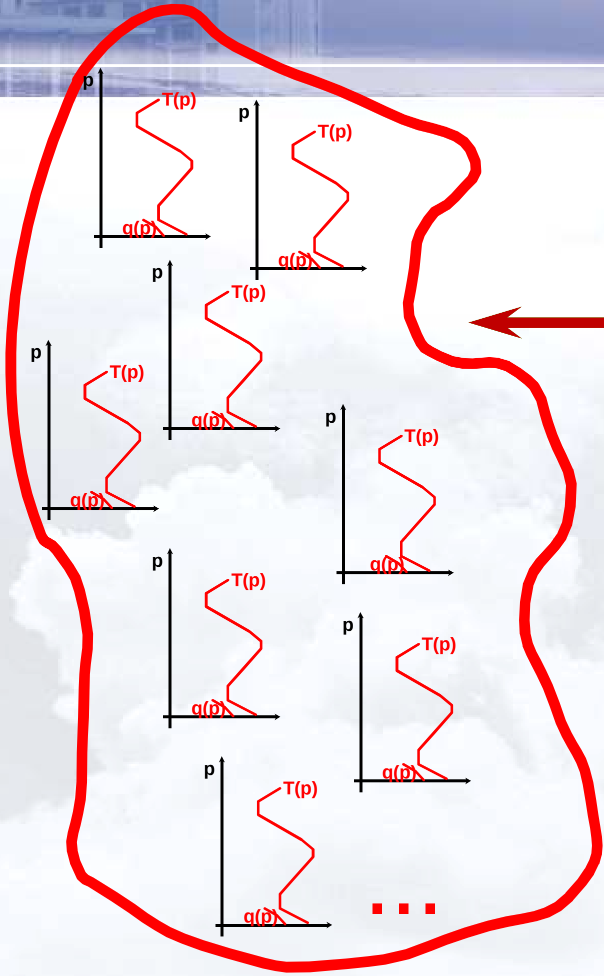
Inversion Problem



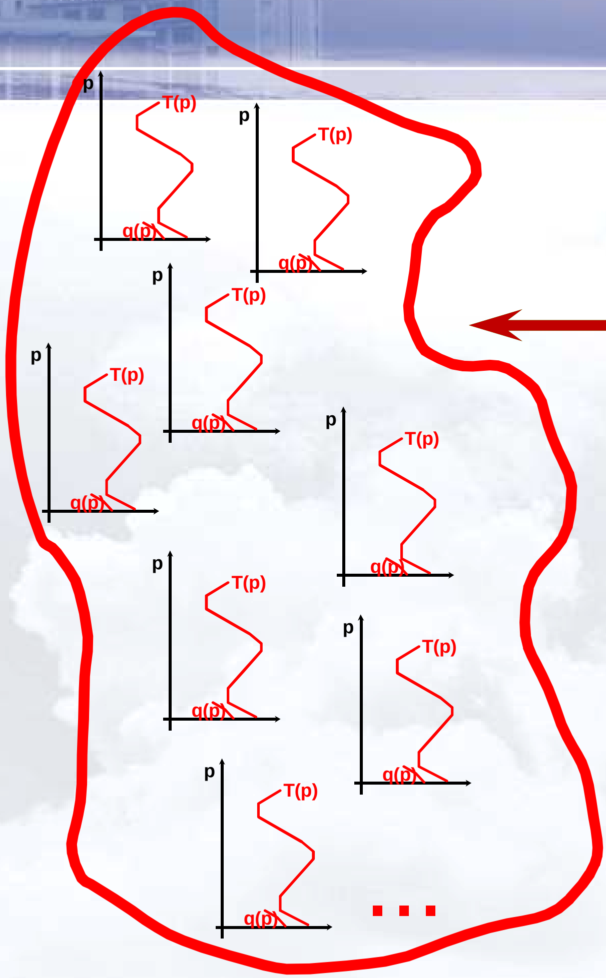
Retrieval/ Inversion Scheme

TBs in different wavelengths

ILL POSED PROBLEM

Many possible states of
Temperature
Water vapour, etc.
(or cloud parameters,
aerosol information ….)

Inversion Problem



Retrieval/ Inversion Scheme

Many TBs in many different wavelengths

More channels = more information!

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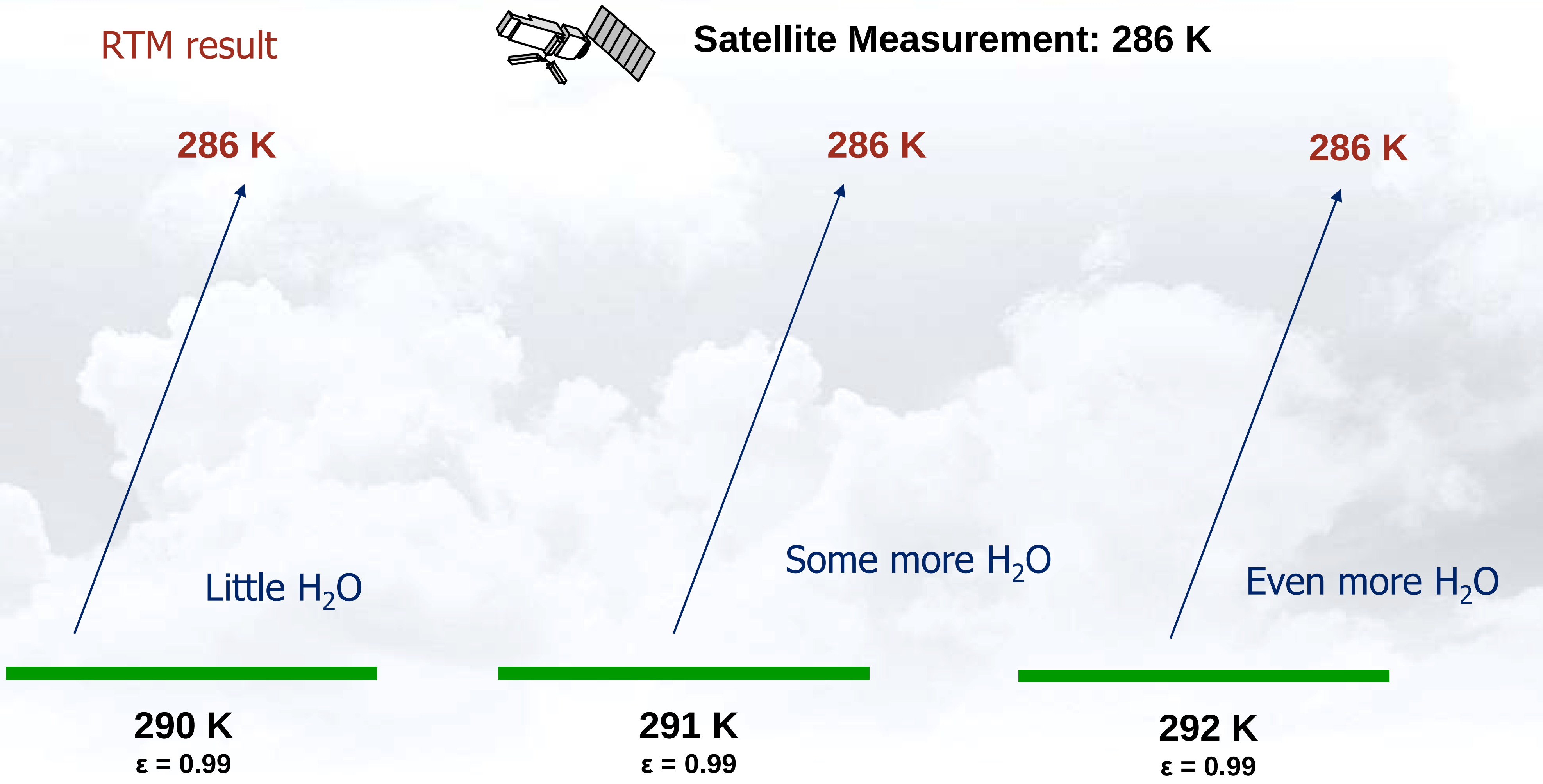
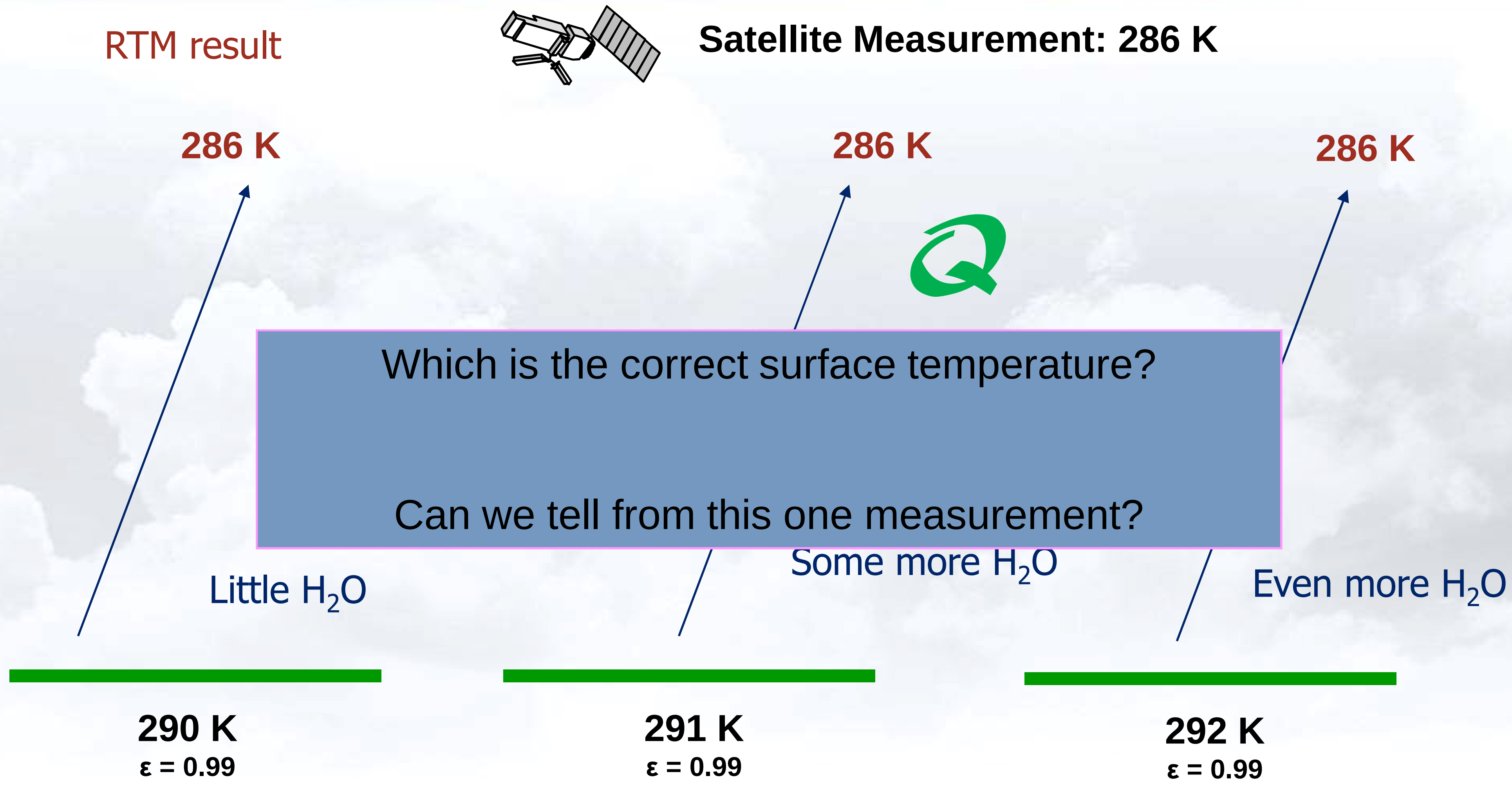
Inversion Problem: Practical Example, 11µm



Inversion Problem: Practical Example, 11µm



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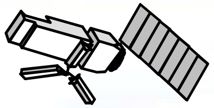
Inversion Problem: Practical Example, 11µm

RTM result



Satellite Measurement: 286 K

286 K | **286 K** | **286 K**

No, we cannot tell!

Possible: constrain humidity by forecast profile

Or: combine with another channel that is sensitive to surface temperature and humidity

Lit ... ven more H_2O

290 K
ε = 0.99

291 K
ε = 0.99

292 K
ε = 0.99

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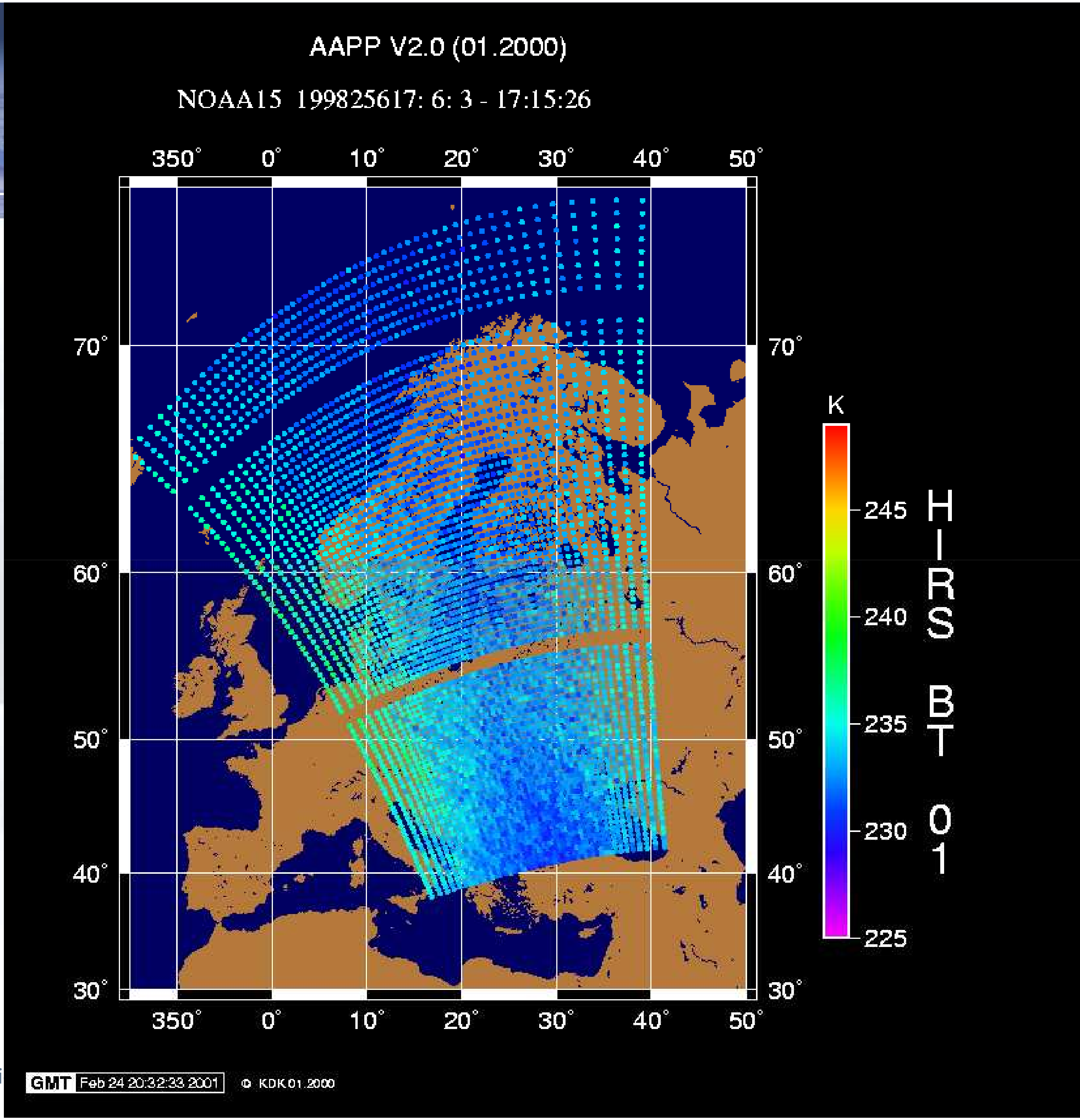

HIRS Ch01

ca. 23 km

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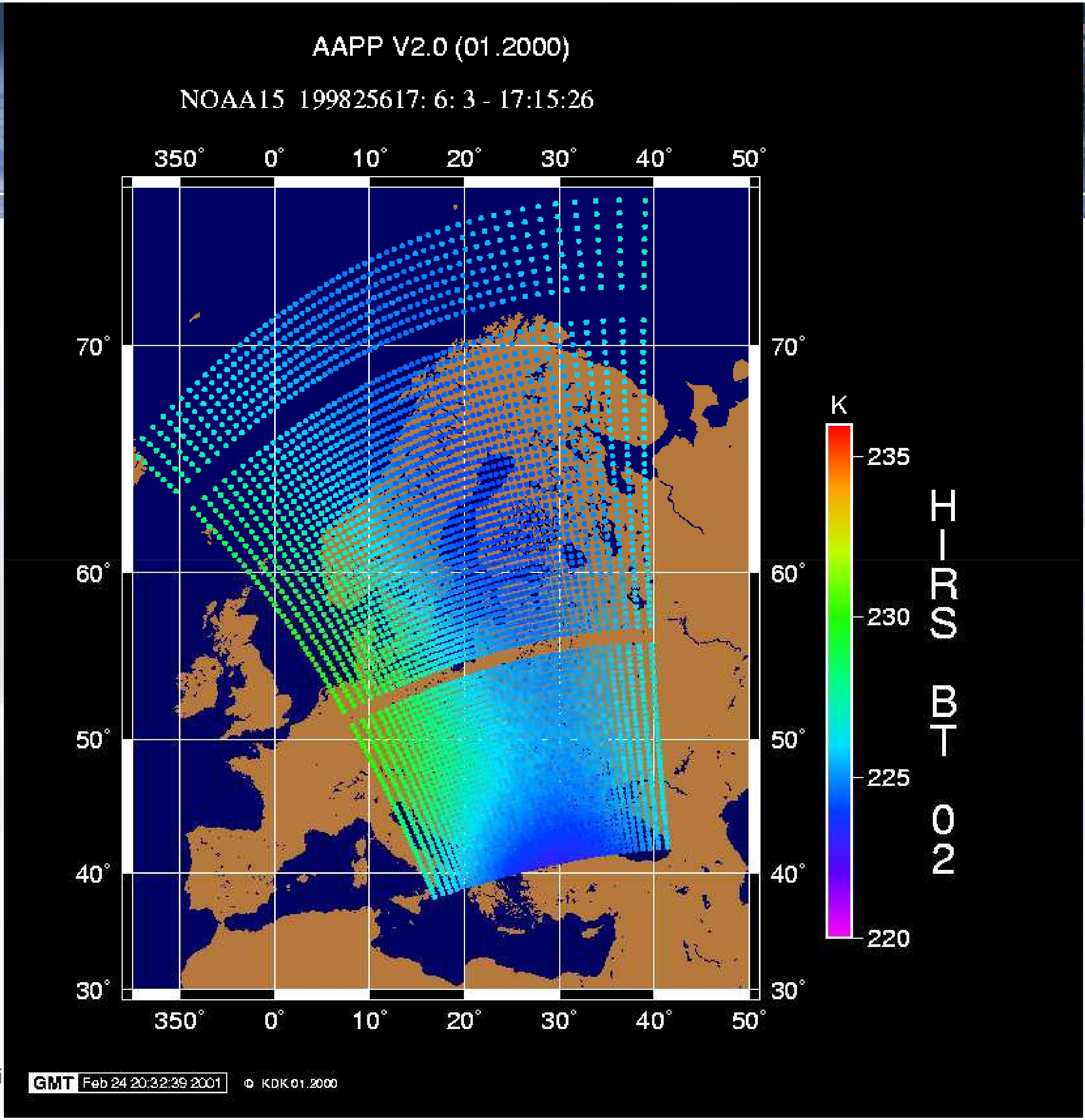

HIRS Ch02

ca. 19 km

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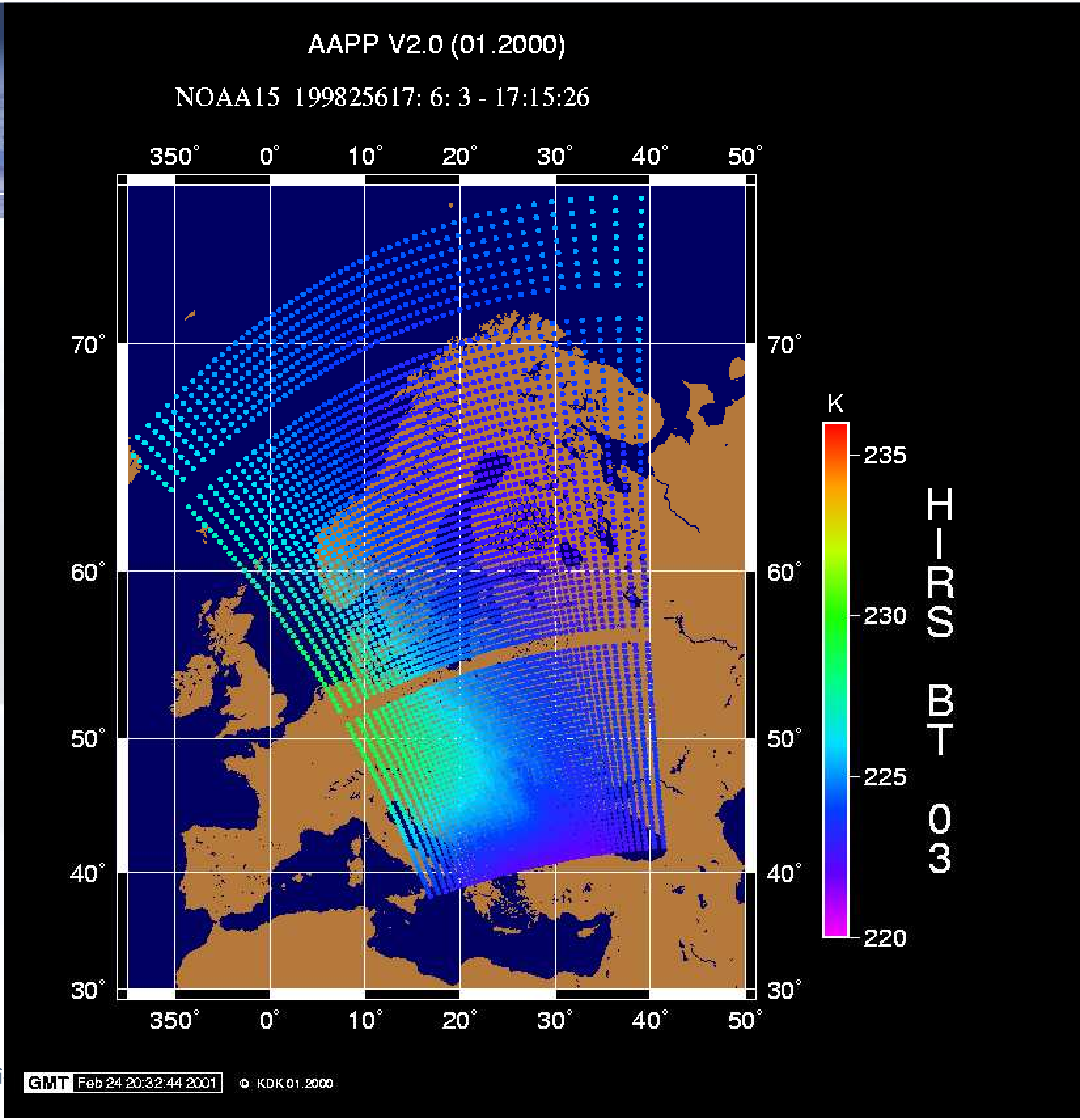
HIRS Ch03

ca. 17 km



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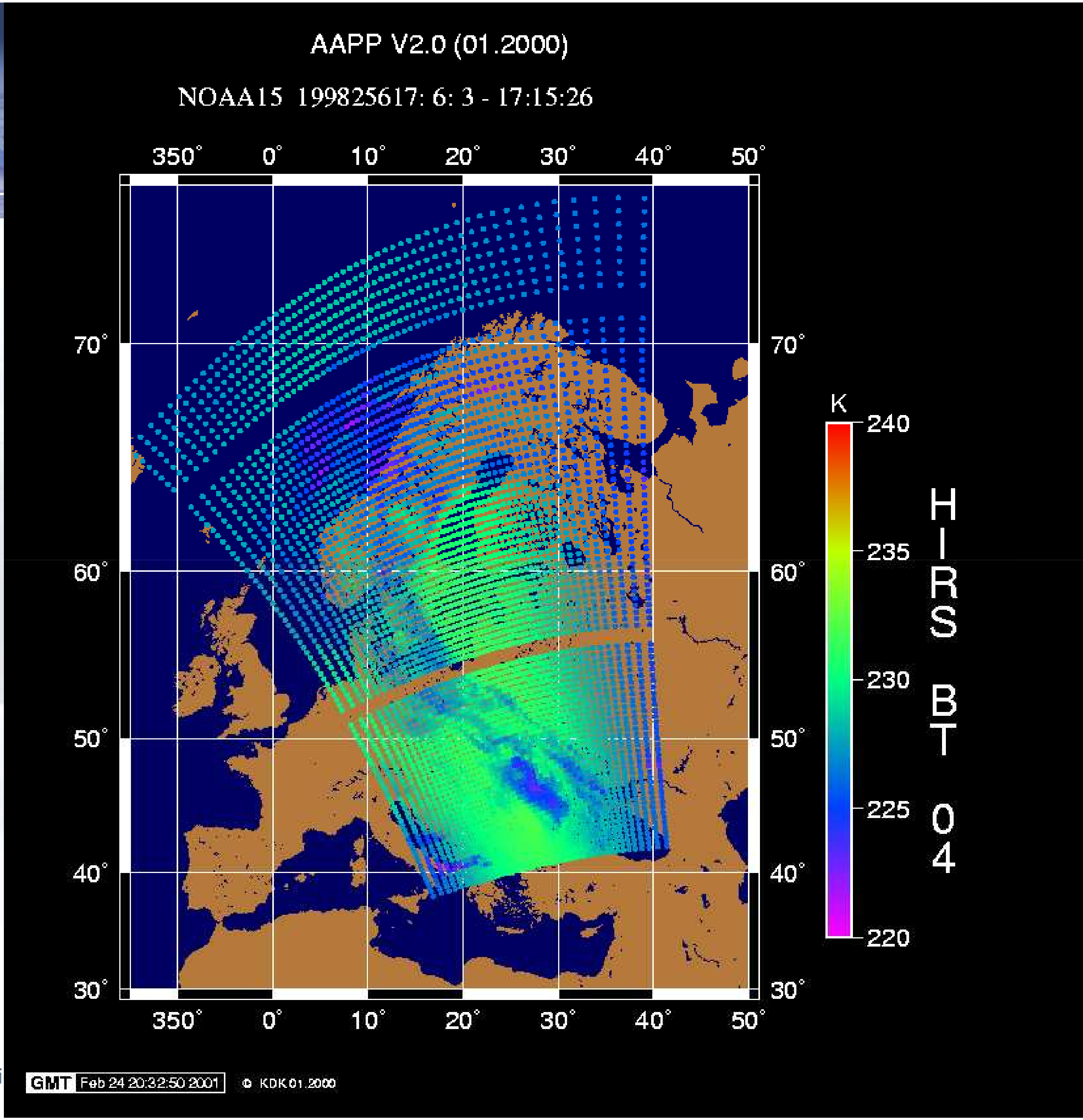
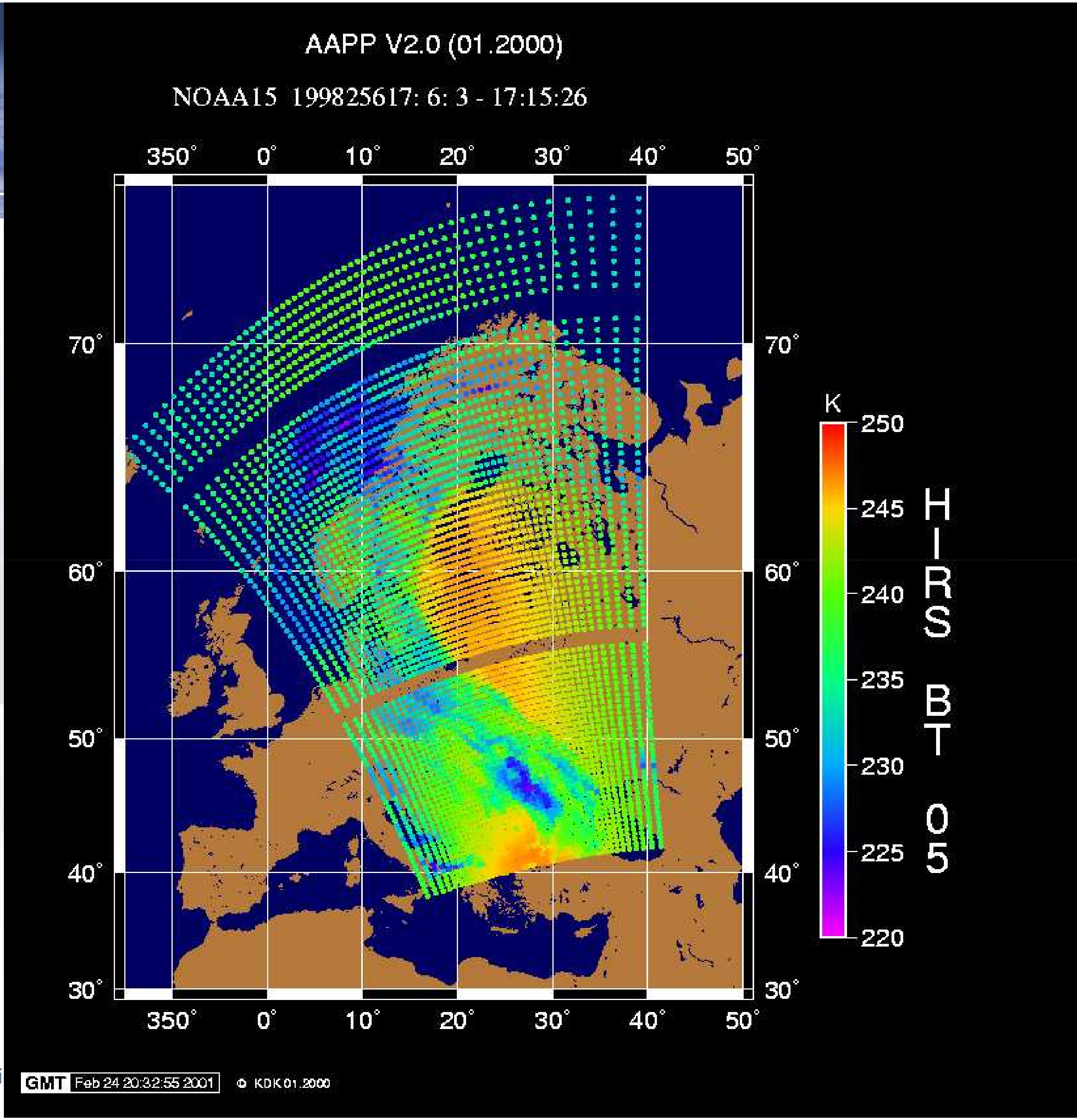


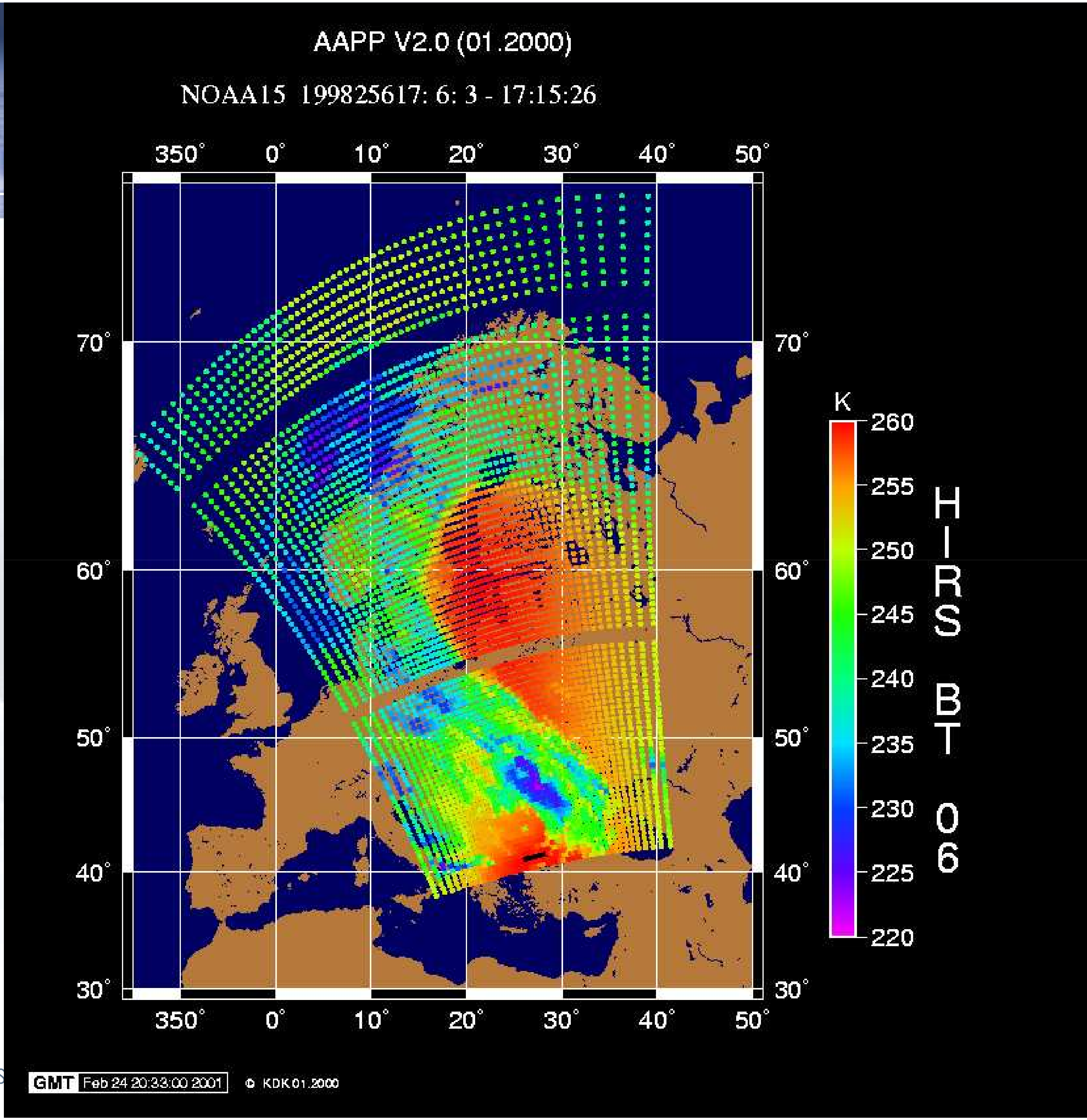
HIRS Ch04

ca. 7 km



HIRS Ch05

ca. 4 km



HIRS Ch06

ca. 2 km

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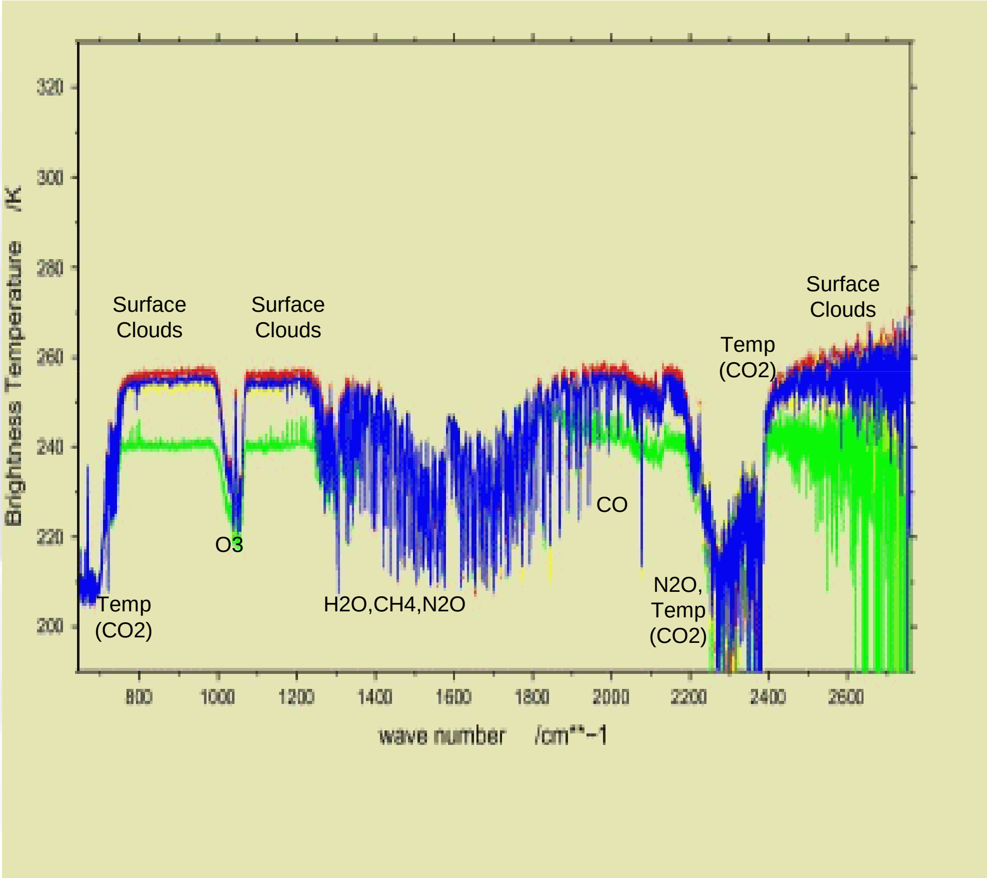
Outlook: Hyperspectral Measurements



Instruments like IASI measure the IR spectrum in 8461 different samples

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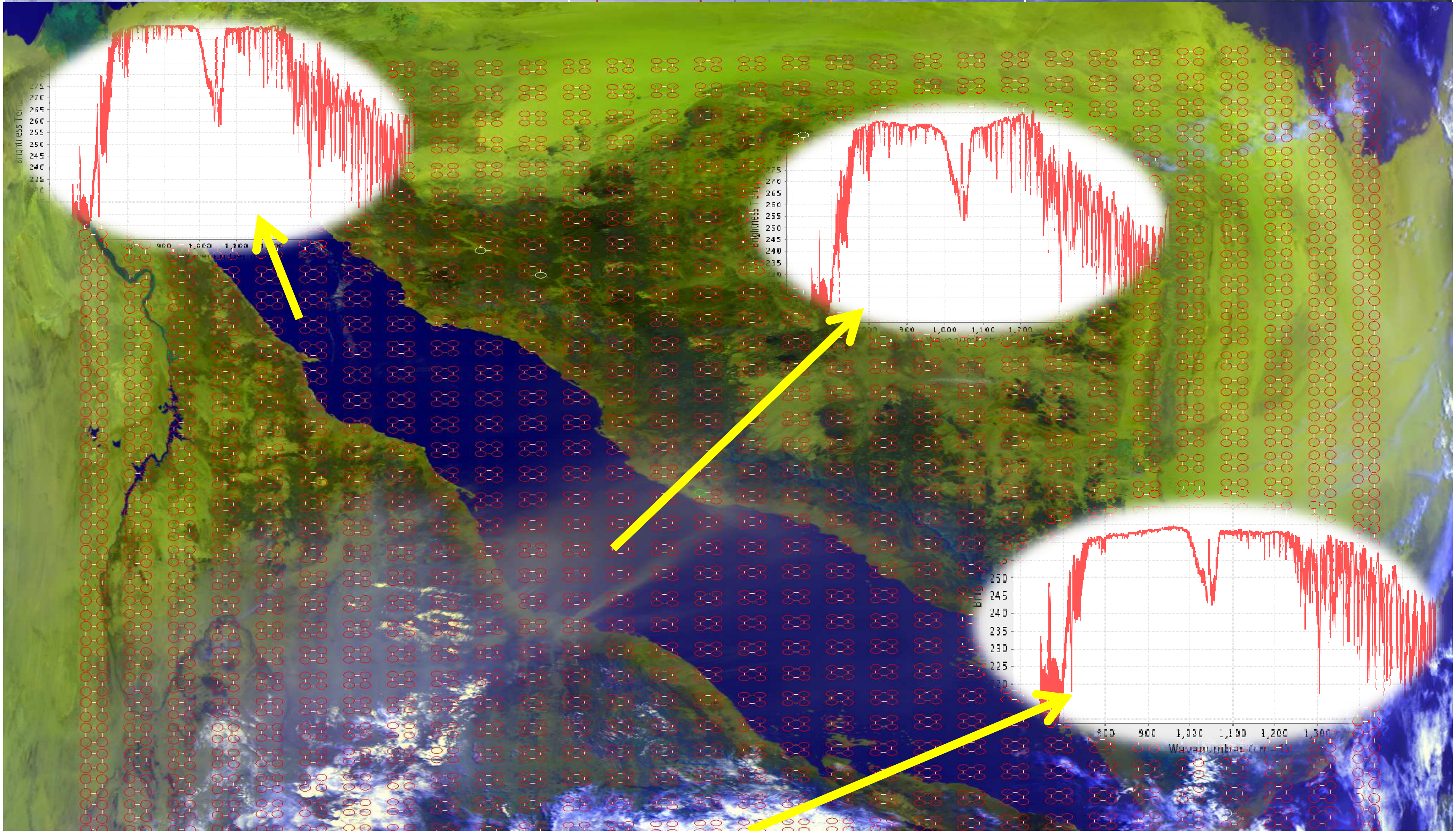
IASI Example



The End

Thank you for your attention!

Consider yourself "remote sensing experts" now!