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REMOTE SENSING - RADIATIVE TRANSFER IN THE ATMOSPHERE

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ITC FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

INTRODUCTION

- Main topic: Radiative transfer
- At the end of this lesson, you can:
  - Describe the main modes of remote sensing: active and passive
  - Perform calculations of the transmission and attenuation of electromagnetic radiation
  - Explain what the concepts reflection, absorption, emission, and scattering are and where they are found in the atmosphere
  - Extract spectral information from (Earthshine) spectra
  - Perform comparative analyses of satellite reflectance vs. lab reflectance curves

OUTLINE

- Introduction
- Recap: EMR, Blackbodies & Resolution
- Radiative transfer
  - Attenuation, transmission, reflection
  - Absorption
  - Scattering
- Types of remote sensing for EO
- Exercise

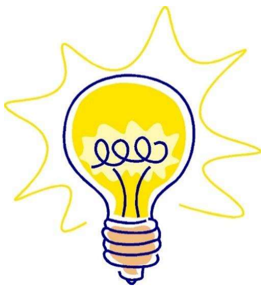
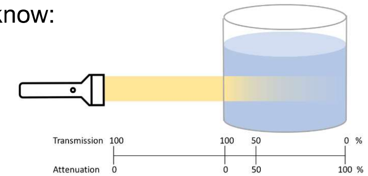
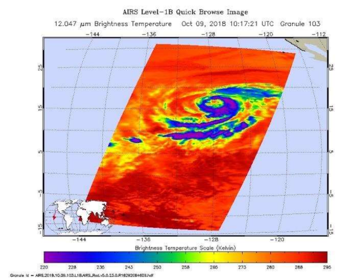


Image from ClipArtBest.com

APPLICATIONS OF RADIATIVE TRANSFER

- You need to understand RT when you want to know:
  - how far your signal will travel
  - how strong your source needs to be
  - what you're looking at (remote sensing)
  - what your radiation might do...





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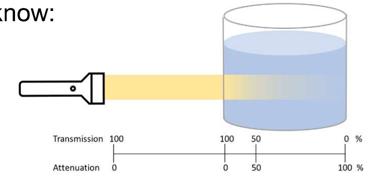

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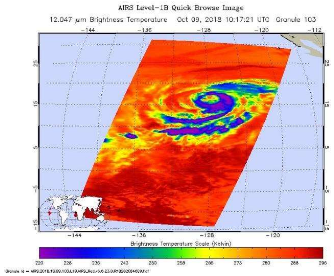
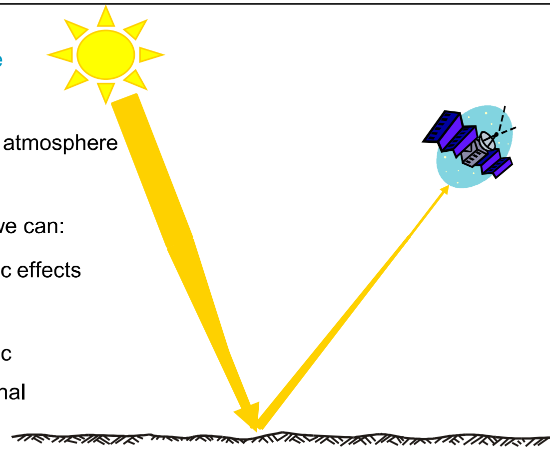


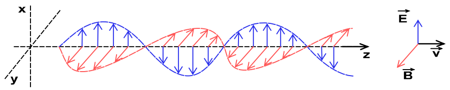
WHY DO WE NEED TO UNDERSTAND RT?

- Interpretation of satellite observations
- Radiation is affected by atmosphere and surface
- If we understand how, we can:
  - Remove atmospheric effects from signal
  - Retrieve atmospheric information from signal



RECAP: ELECTROMAGNETIC RADIATION

- Electromagnetic radiation consists of coupled electric and magnetic fields travelling through space at ...?



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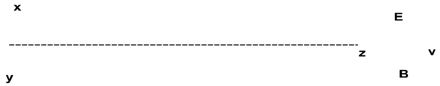
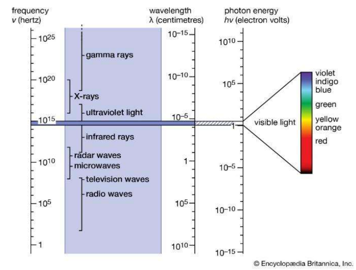
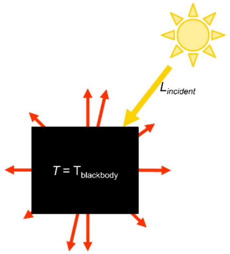


- EMR can be described as wave or particle
- $c = \lambda \nu$, therefore if λ is large, ν is...?
- $Q = h\nu = \frac{hc}{\lambda}$, therefore if λ is large, Q is...?



RECAP: BLACKBODY RADIATION

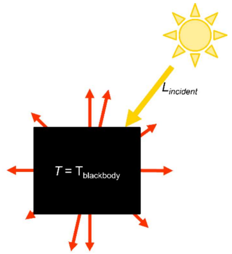
- Every object with T>0 K emits radiation
- Blackbody:
  - Absorbs all incident radiation
  - Emitted radiation depends only on its temperature

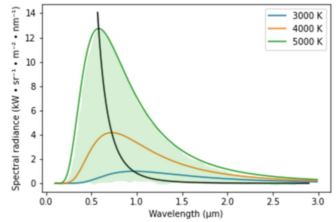


RECAP: BLACKBODY RADIATION

- Every object with T>0 K emits radiation
- Blackbody:
  - Absorbs all incident radiation
  - Emitted radiation depends only on its temperature
- Planck's law: $L_{BB} = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}$
- In thermal equilibrium (no change in *T*):

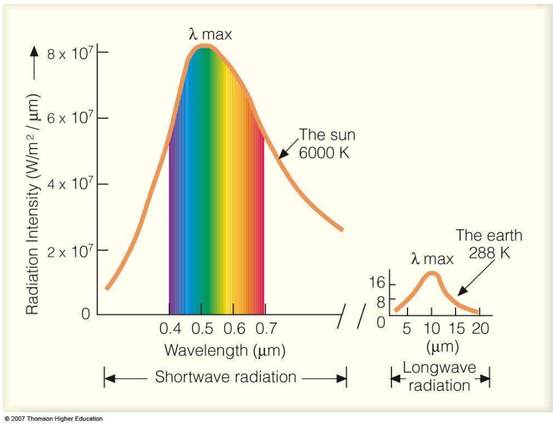
  $L_{BB} = L_{incident}$
- Wien's law: $\lambda_{max} = \frac{b}{T}$
- Stefan-Boltzmann equation: $M = \sigma T^4$





EMISSION BY SUN AND EARTH

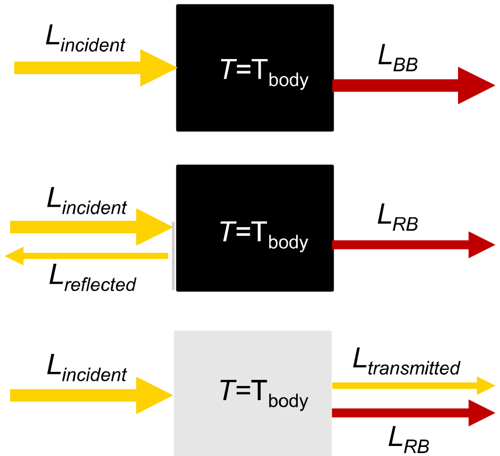
- Sun is much hotter than Earth -> λ_{max} shorter and M much greater
- Emission curves of Sun and Earth barely overlap



REAL OBJECTS

- Real objects are not blackbodies, they
  - reflect and/or
  - transmit
- In thermal equilibrium (T constant):

  $L_{in} = L_E + L_T + L_R$
- Emissivity $\varepsilon_{RB} = \frac{L_{RB}}{L_{BB}}$



QUIZ ON BLACKBODY RADIATION

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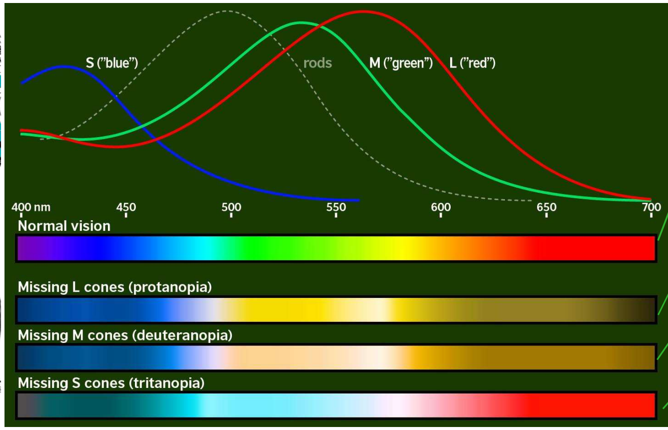
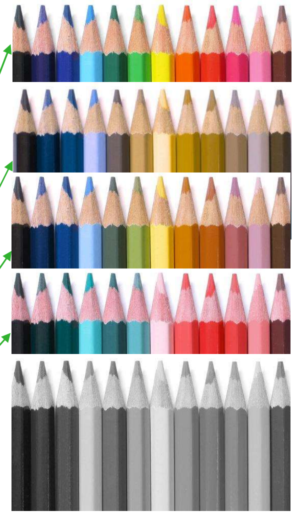
RECAP: SPECTRAL RESOLUTION





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https://factsverse.com/color-blind-people-see-world/
http://www.scifun.ed.ac.uk/pages/about_us/shows/cb/cb-spectra-bars.jpg

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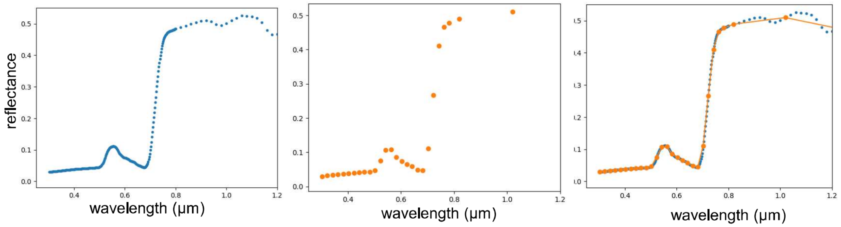

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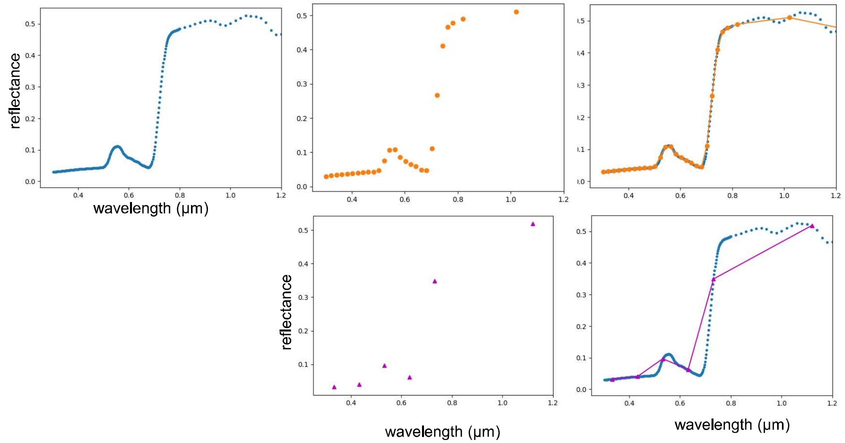

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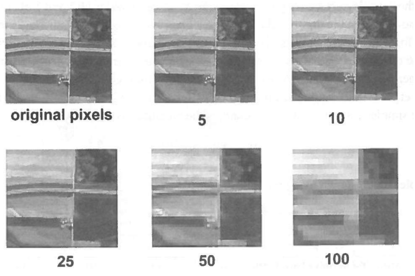
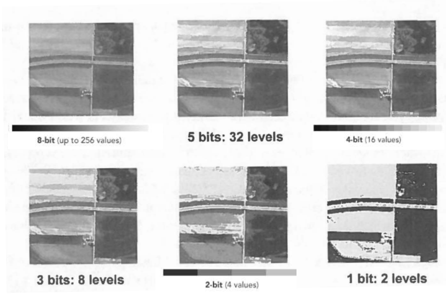
RECAP: SPATIAL VS. RADIOMETRIC RESOLUTION

- Spatial



Radiometric



RADIATIVE TRANSFER IN THE ATMOSPHERE

WHAT DOES THE ATMOSPHERE DO TO RADIATION?

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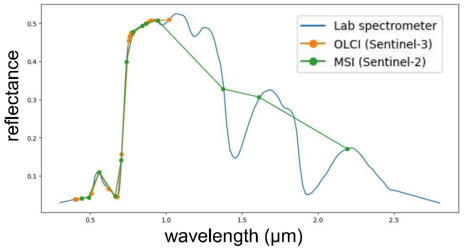
LET ME MAKE THIS CLEAR...

- Satellites do not measure cloud cover or soil moisture content or even temperature
- Satellite instruments detect upwelling (reflected, scattered, emitted) radiation



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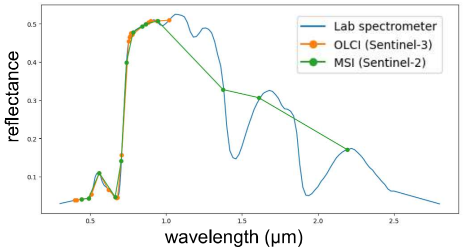
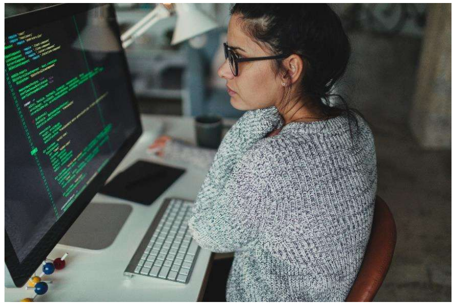
- Satellite instruments detect upwelling (reflected, scattered, emitted) radiation
- It's up to the scientist to interpret the radiation patterns



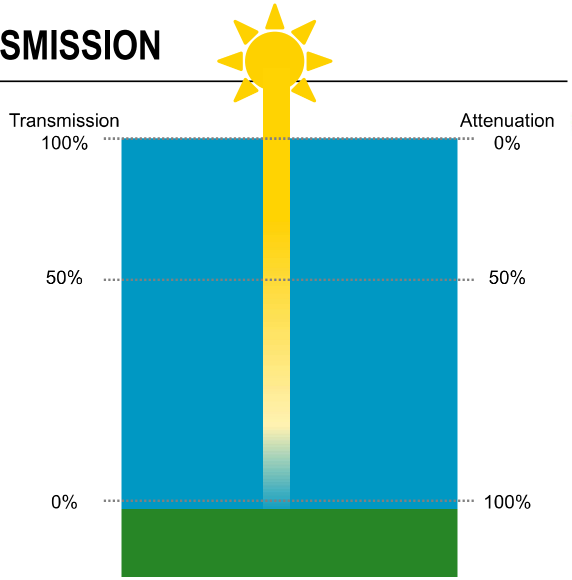


RADIATIVE TRANSFER

ATTENUATION AND TRANSMISSION

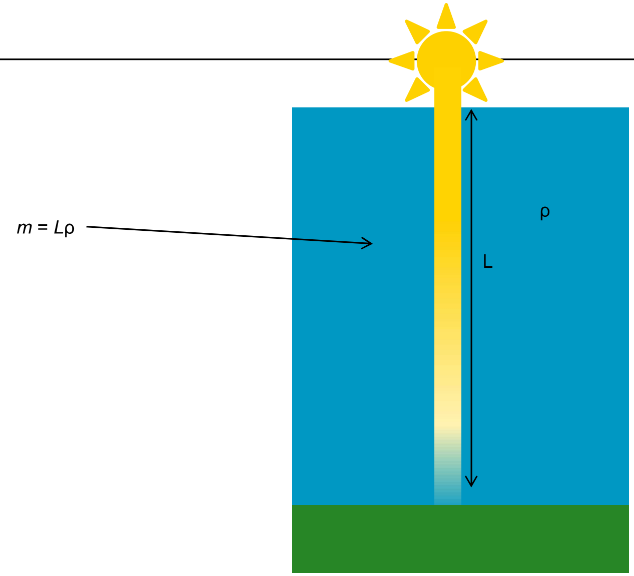
ATTENUATION AND TRANSMISSION

- Radiation is either attenuated or transmitted by the atmosphere
- Radiation can be attenuated by scattering or absorption



ATTENUATION

- Degree of attenuation (optical air mass *m*) depends on:
  - path length through medium (*L*) and density of medium (ρ)
- But the atmosphere is layered…



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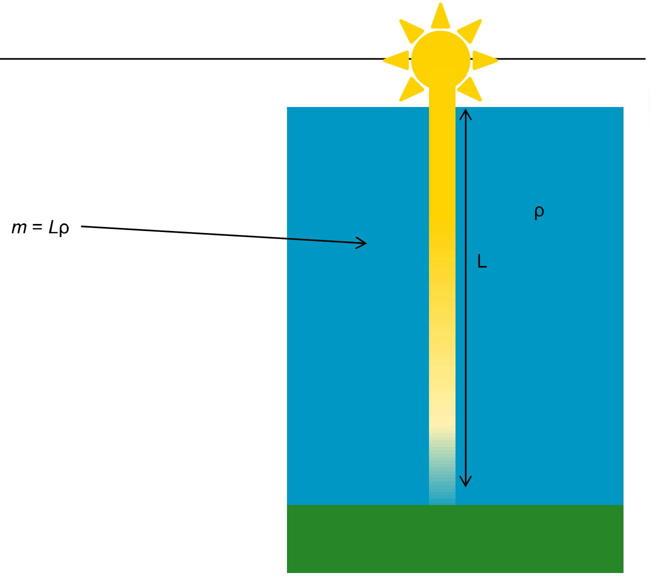

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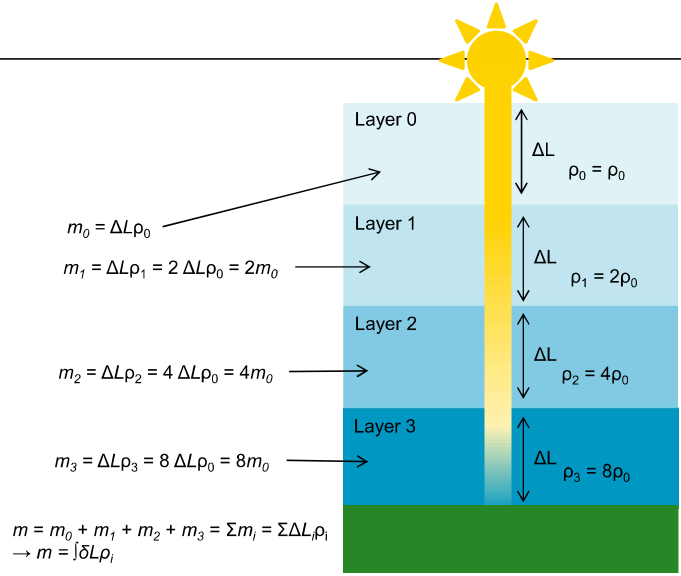

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SO HOW TO CALCULATE TRANSMISSION?

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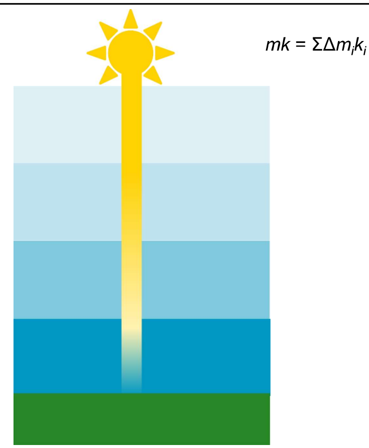

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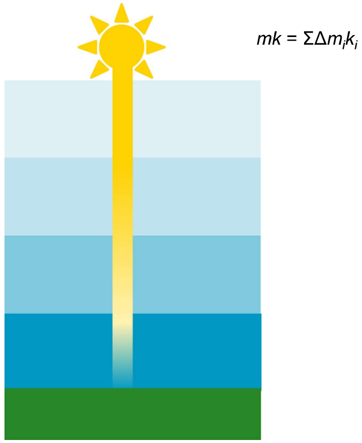
- So transmissions are multiplicative!



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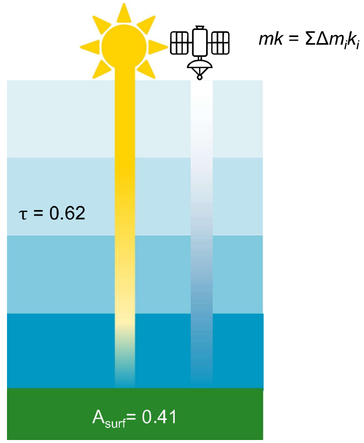
$$\tau_{\uparrow} = e^{-\int_{z=BOA}^{z=TOA} m(z)k(z)dz}$$



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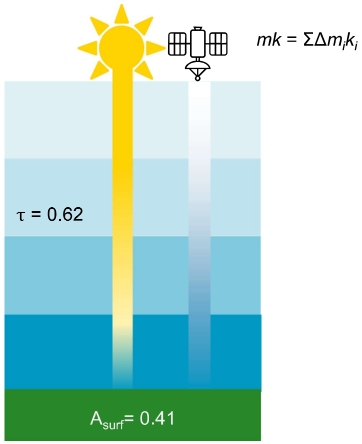
$$\tau_{\uparrow} = e^{-\int_{z=BOA}^{z=TOA} m(z)k(z)dz}$$

$$\tau_{\downarrow} = e^{-\int_{z=TOA}^{z=BOA} m(z)k(z)dz}$$

$$\tau = \tau_{\uparrow} \cdot \tau_{\downarrow} = 0.62 \cdot 0.62 = 0.38$$

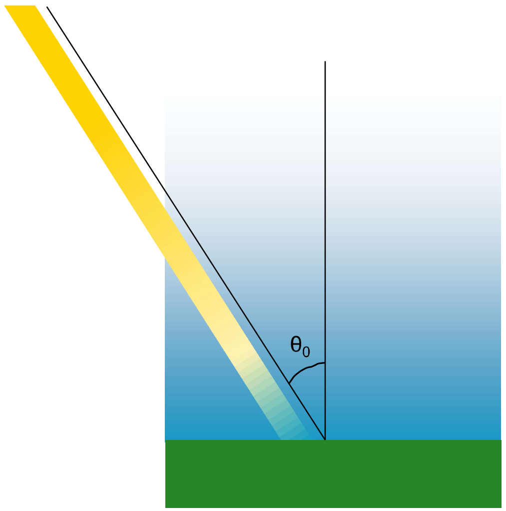
$$\mathrm{R} = A_{surf}\tau_{\downarrow}\tau_{\uparrow} = 0.41 \cdot 0.62 \cdot 0.62 = 0.16$$



RELATIVE AIR MASS

- Slant paths are longer -> larger optical air mass
- Normalization using relative air mass, m_r

$$m_r = \frac{L_s \cdot \rho}{L \cdot \rho} = \frac{m_s}{m}$$



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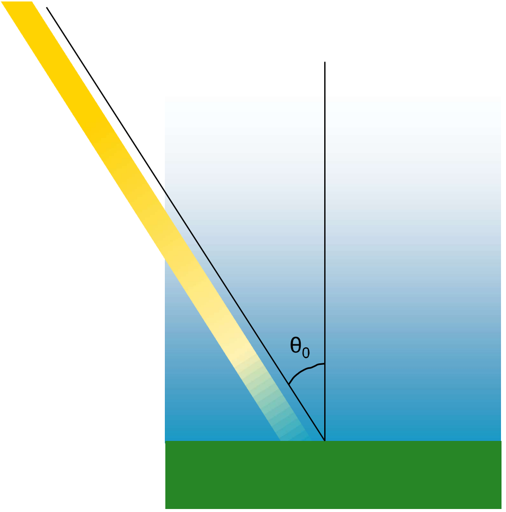
- Radiation from Sun to Target: $m_r = \cos\theta_0$
- So: $m = m_r \Sigma \Delta L \rho_i$



QUIZ ON ATTENUATION AND TRANSMISSION

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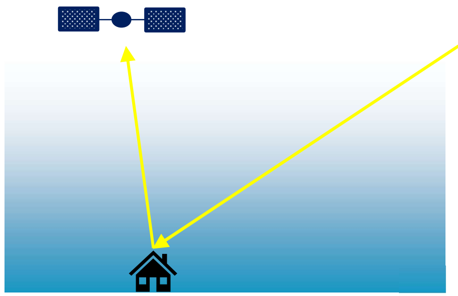
CALCULATE TRANSMISSIONS (1)

A medium has four constituents with optical transmissivities:

$\tau_1 = 0.99$, $\tau_2 = 0.98$, $\tau_3 = 0.97$, $\tau_4 = 0.96$

What is the total transmission of the medium?



CALCULATE TRANSMISSIONS (2)

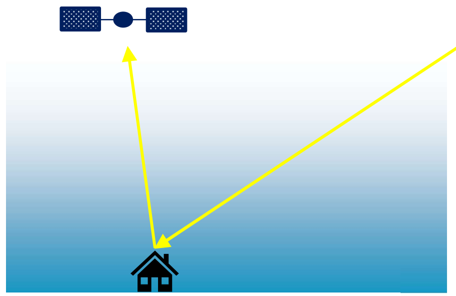
A medium has four constituents with optical transmissivities:

$\tau_1 = 0.99$, $\tau_2 = 0.98$, $\tau_3 = 0.97$, $\tau_4 = 0.96$

What is the total transmission of the medium?

Bouguer's law: transmission $\tau = e^{-mk}$

With increasing solar zenith angle, the relative air mass increases, hence the transmission...



THAT WAS IT FOR THE EQUATIONS!

- Well, almost…

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RADIATIVE TRANSFER

SCATTERING

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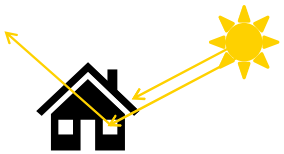
SCATTERING

- Interaction of radiation with large objects (>> wavelength)
  - Reflection
  - Absorption



SCATTERING

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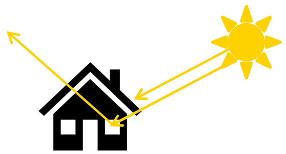
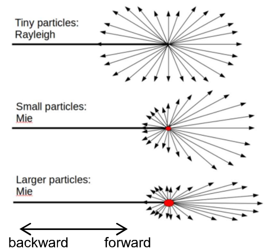


- Interaction of radiation with small objects (≤ wavelength)
- Absorption + (partial) re-emission
- Re-emission in all directions: scattering



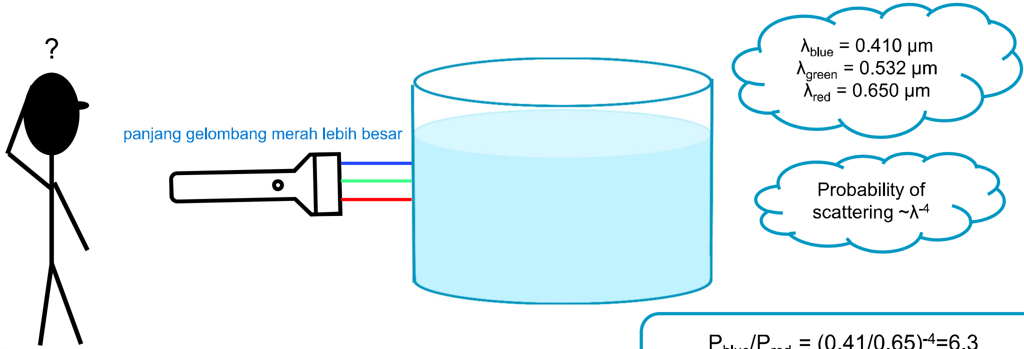
RAYLEIGH SCATTERING

- Scattering is continuous, but depends on wavelength:
  - Size parameter $\alpha = \pi D/\lambda$
- Rayleigh scatter: $\alpha \ll 1$
- Probability of Rayleigh scatter $\sim\lambda^{-4}$
- Rayleigh scatter explains why we perceive the sky as blue and sunsets as red

Photograph by Gabriel Parodi, ITC

LET'S DO AN EXPERIMENT!

- What happens if we shine a blue, green or red laser into a container of milk?



$P_{blue}/P_{red} = (0.41/0.65)^{-4}$=6.3
$P_{blue}/P_{green} = (0.41/0.532)^{-4}$=2.8
P_{green}/P_{red} = 5 $(0.532/0.65)^{-4}$= 2.2

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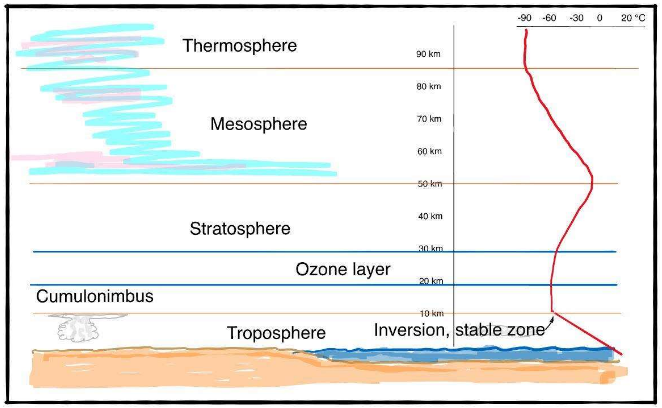
RADIATION IN THE ATMOSPHERE

ABSORPTION

ATTENUATION IN THE ATMOSPHERE

- Atmosphere is layered:
- Layers separated by temperature profile
- Density decreases exponentially with altitude
- Most gases located in lowest layer



ATMOSPHERIC COMPOSITION

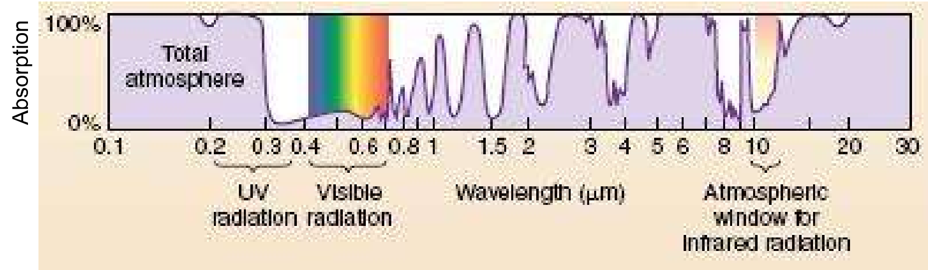
- Nitrogen, oxygen, and argon make up 99.96% of the dry atmosphere
- Carbon dioxide (CO_2) adds 0.04%
- Water vapour is variable, mostly in troposphere

- ppm = parts per million (10^6)
- ppb = parts per billion (10^9)

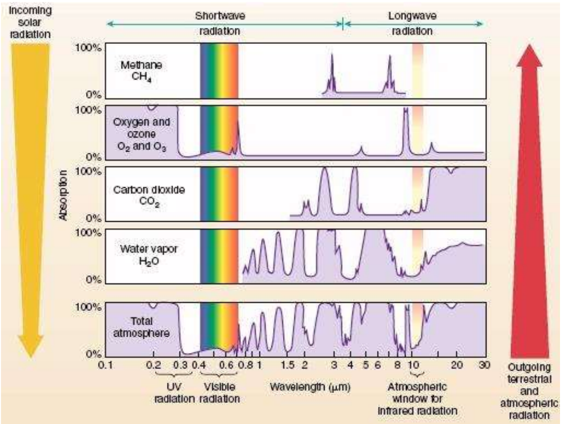
Constituent gas	Content % Volume or ppmv	
Nitrogen (N_2)	78.084 %	Permanent gases
Oxygen (O_2)	20.946 %	
Argon (Ar)	0.934 %	
Carbon Dioxide (CO_2)	0.0416 % or 416 ppm	
Other noble gases (Ne, He, Kr, Xe)	0.0024 % or 24 ppm	Variable gases
Hydrogen (H_2)	0.00006 % or 6 ppm	
Methane (CH_4)	1.8 ppm	
Nitrous oxide (NO_3)	0.27 ppm	
Ozone (O_3)	0 to 0.04 ppm	
Sulfur dioxide (SO_2)	0.01 ppm	
Nitrogen dioxide NO_2	0.001 ppm	
Ammonia (NH_4)	0.02 ppm	
Carbon Monoxide (CO)	0.09 ppm	
Nitric Oxide (NO)	0.005 ppm	
Hydrogen sulfide (H_2S)	0.002 ppm	
Nitric acid vapor	traces	

ABSORPTION IN THE ATMOSPHERE

- Question: In which wavelength regions is the atmosphere (mostly) transparent to radiation?



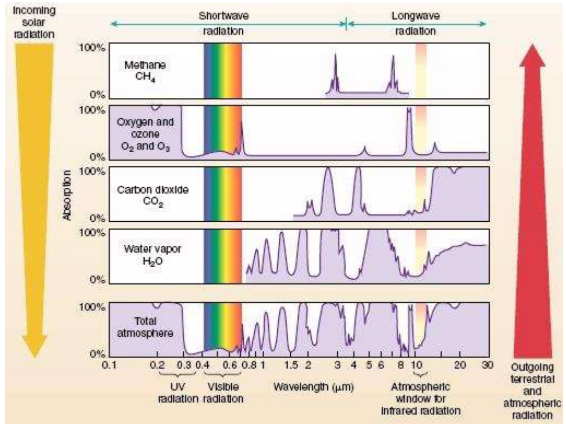
ABSORPTION IN THE ATMOSPHERE



https://cimss.ssec.wisc.edu/sage/meteorology/lesson1/AtmAbsorbtion.htm

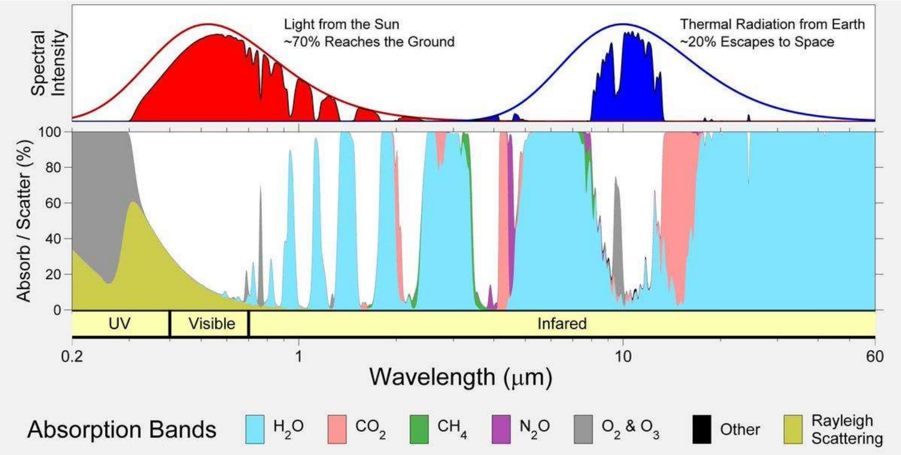
ABSORPTION IN THE ATMOSPHERE

- Main absorbers in the atmosphere: O_3, H_2O, CO_2
- Most of the radiation emitted by Earth is absorbed
- In thermal equilibrium: energy received = energy emitted
- Atmospheric windows allow Earth to cool down!



https://cimss.ssec.wisc.edu/sage/meteorology/lesson1/AtmAbsorbtion.htm

GREENHOUSE EFFECT



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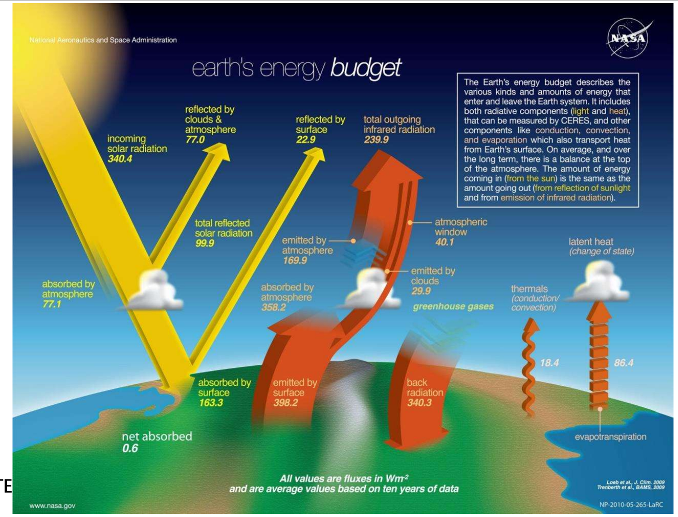
https://twitter.com/rarohde/status/1196761516051238912

EXCURSION: EARTH'S ENERGY BUDGET



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WHAT DOES THE ATMOSPHERE DO TO RADIATION?

How to participate?

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1. Go to **wooclap.com**
2. Enter the event code in the top banner

Event code
CINZCA

1. Send @CINZCA to 0970 1420 2908
2. You can participate

Copy participation link

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SUMMARY

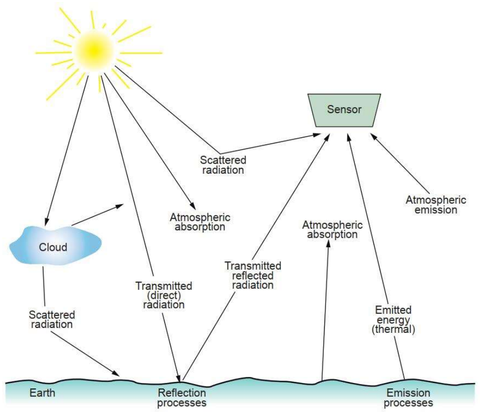

Figure 2.6
Interactions of EM radiation with the atmosphere and the Earth's surface.

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Core book

TODAY'S EXERCISE

- Supervised exercise:
  - Farzaneh Dadrass Javan
  - Srinidhi Gadde
- 10:45 - 15:30
- Rooms 2405 and 2409
- At the end of this exercise, you will be able to:
  1. Interpret reflectance spectra
  2. Find and analyse lab-based reflectance data, including metadata
  3. Extract reflectance spectra from a satellite data set using QGIS
  4. Compare spectra obtained from the lab and from satellites