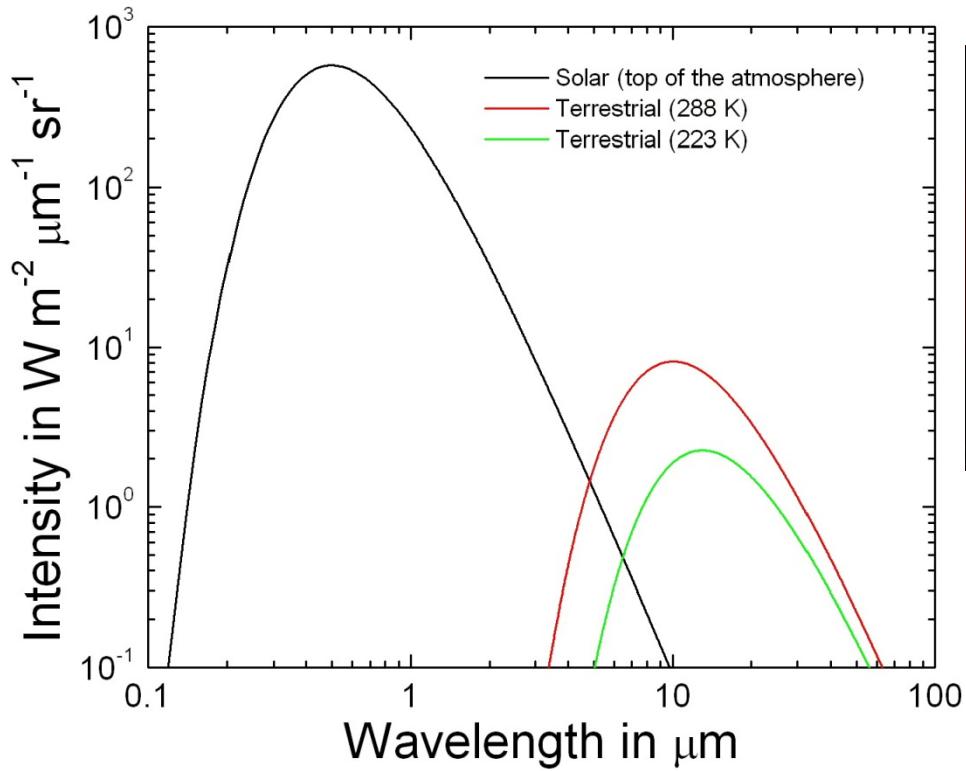


# Unit 12

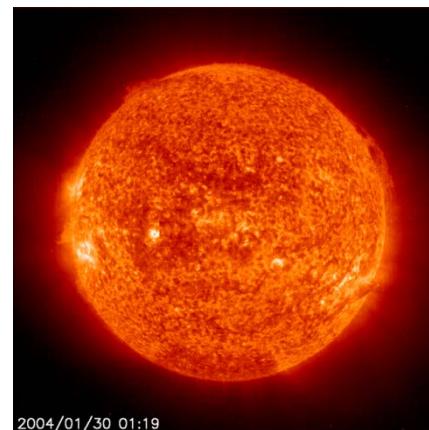
Shortwave and long-wave radiation  
Nicole Mölders

# Solar Spectrum vs. Terrestrial Spectrum

$$F = \pi \left( \frac{r_s}{r} \right)^2 \frac{F_s}{\pi} = \pi \left( \frac{r_s}{r} \right)^2 \int_0^{\infty} B_{\lambda}(T_{\text{Sun}}) d\lambda = \pi \int_0^{\infty} \left( \frac{r_s}{r} \right)^2 B_{\lambda}(T_{\text{Sun}}) d\lambda$$



Sun



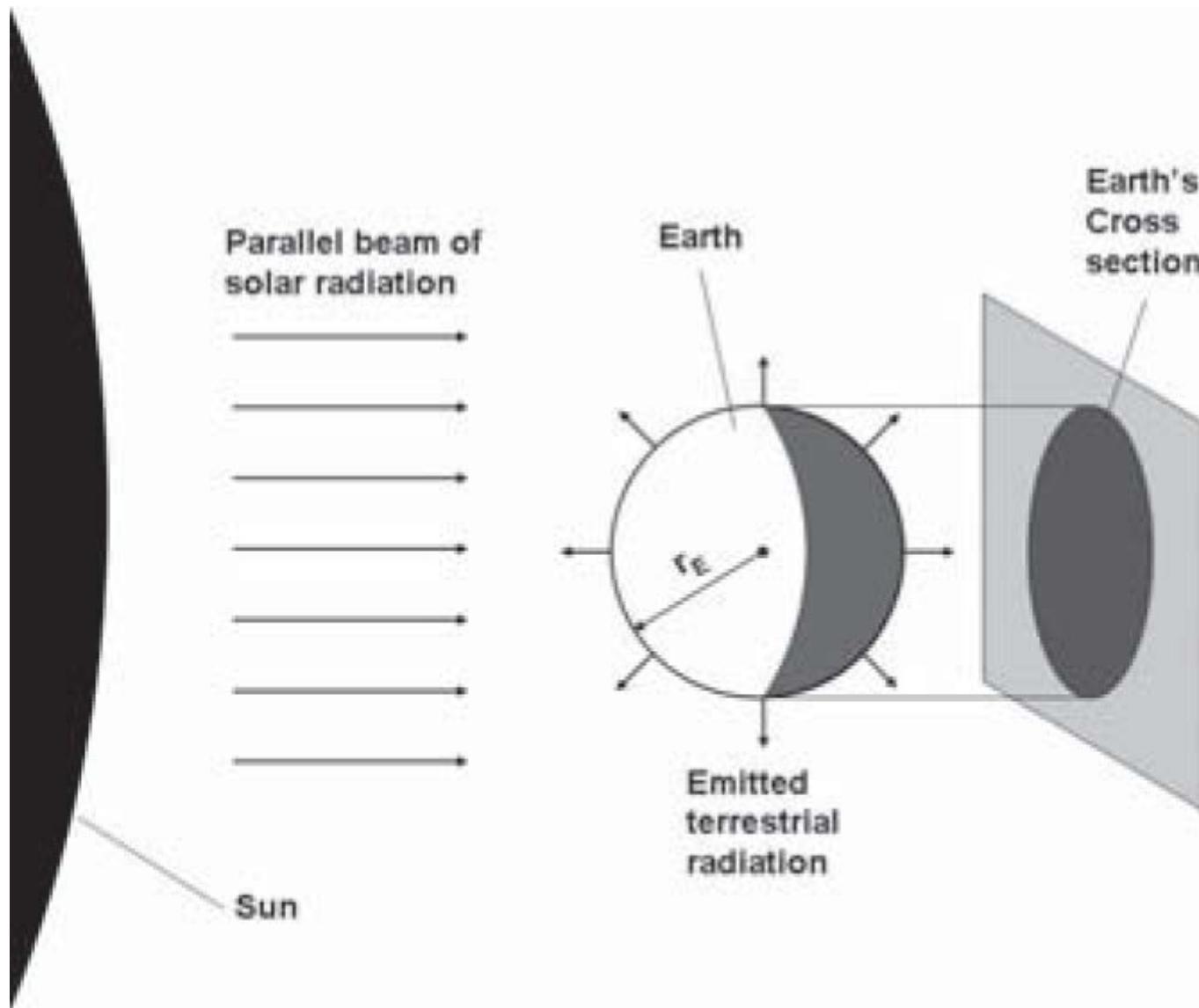
Earth



Images not to scale

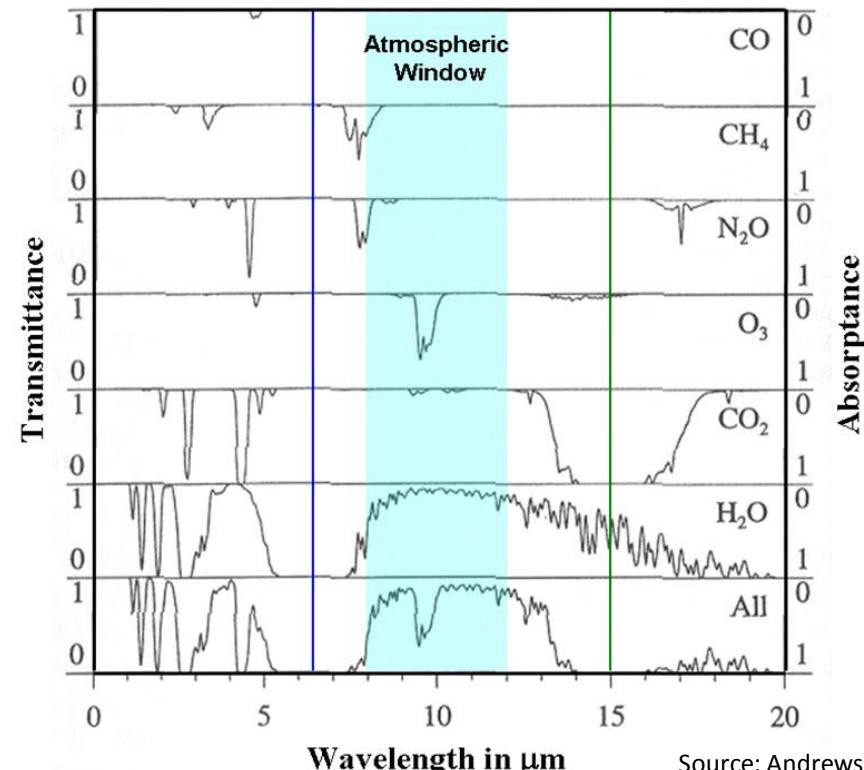
$$B_{\lambda, \text{TOA}} = \left( \frac{r_s}{r} \right)^2 B_{\lambda}(T_{\text{Sun}})$$

# Terrestrial vs. solar radiation



# Emission and absorption

The diagram illustrates molecular transitions between the ground state and excited state. It features two circular orbits representing atoms. The left circle has a dashed outer boundary and contains a positive nucleus ( $\oplus$ ) and a negative electron ( $\ominus$ ). The right circle has a solid outer boundary and also contains a positive nucleus ( $\oplus$ ) and a negative electron ( $\ominus$ ). A horizontal arrow labeled "Transition" points from the left circle to the right circle. In the bottom left, the left circle is labeled "Ground state" and "Excited state". In the bottom right, the right circle is labeled "Ground state" and "Excited state". A wavy arrow labeled "Photon" originates from the right side of the right circle and points towards the left side of the left circle.



- Water vapor ( $\text{H}_2\text{O}$ )
- Carbon dioxide ( $\text{CO}_2$ )
- Ozone ( $\text{O}_3$ )
- Methane ( $\text{CH}_4$ )
- Nitrous oxide ( $\text{N}_2\text{O}$ )
- Halocarbons (e.g.,  $\text{CFCl}_3$ ,  $\text{CF}_2\text{Cl}_2$ )

# Vertical structure of the atmosphere

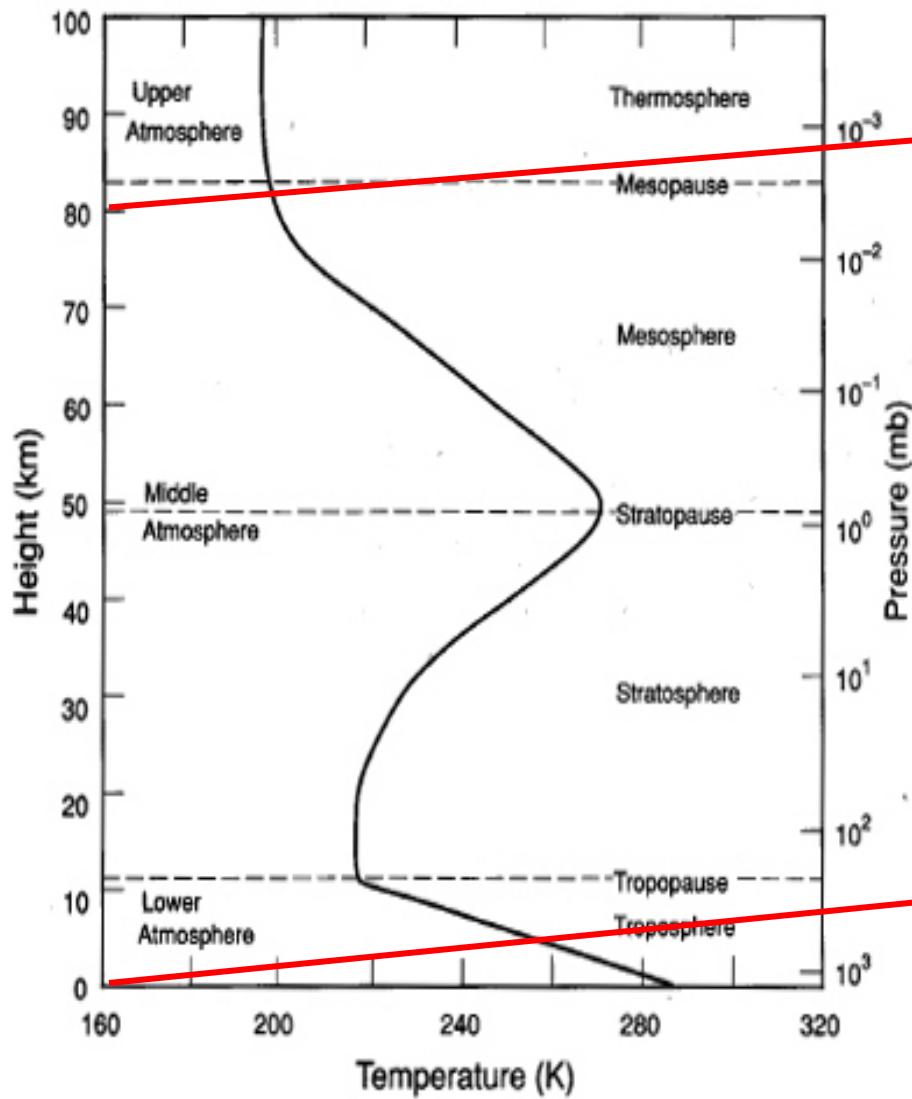


Figure 3.1 Vertical temperature profile after the U.S. Standard Atmosphere and definitions of atmospheric nomenclature.

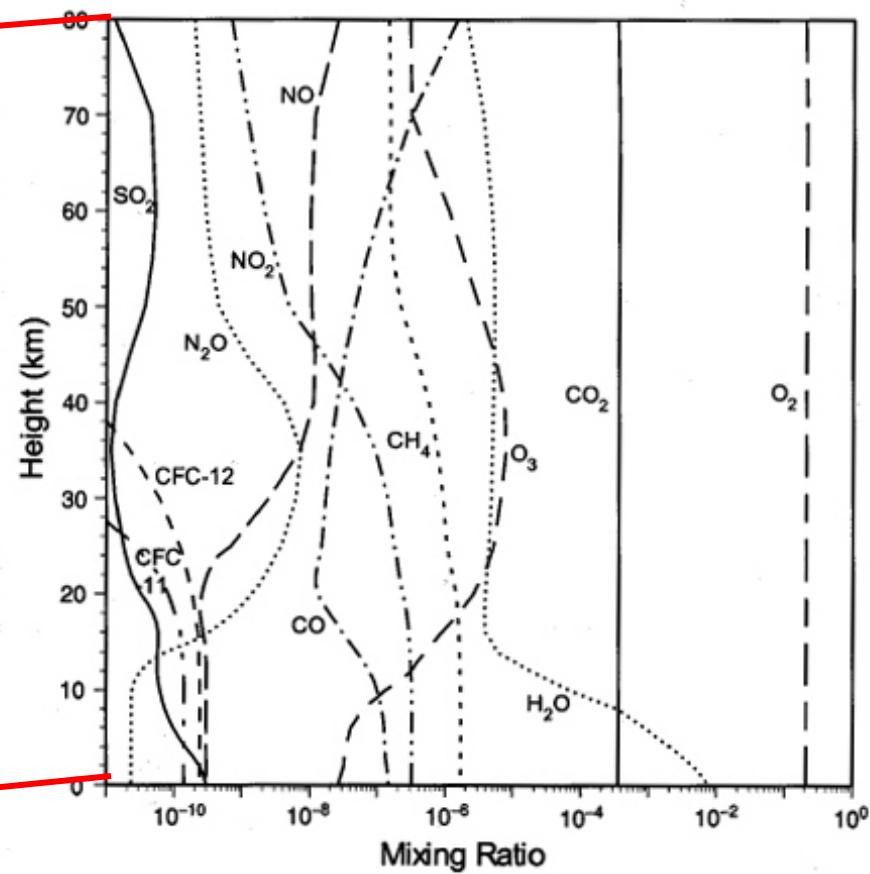
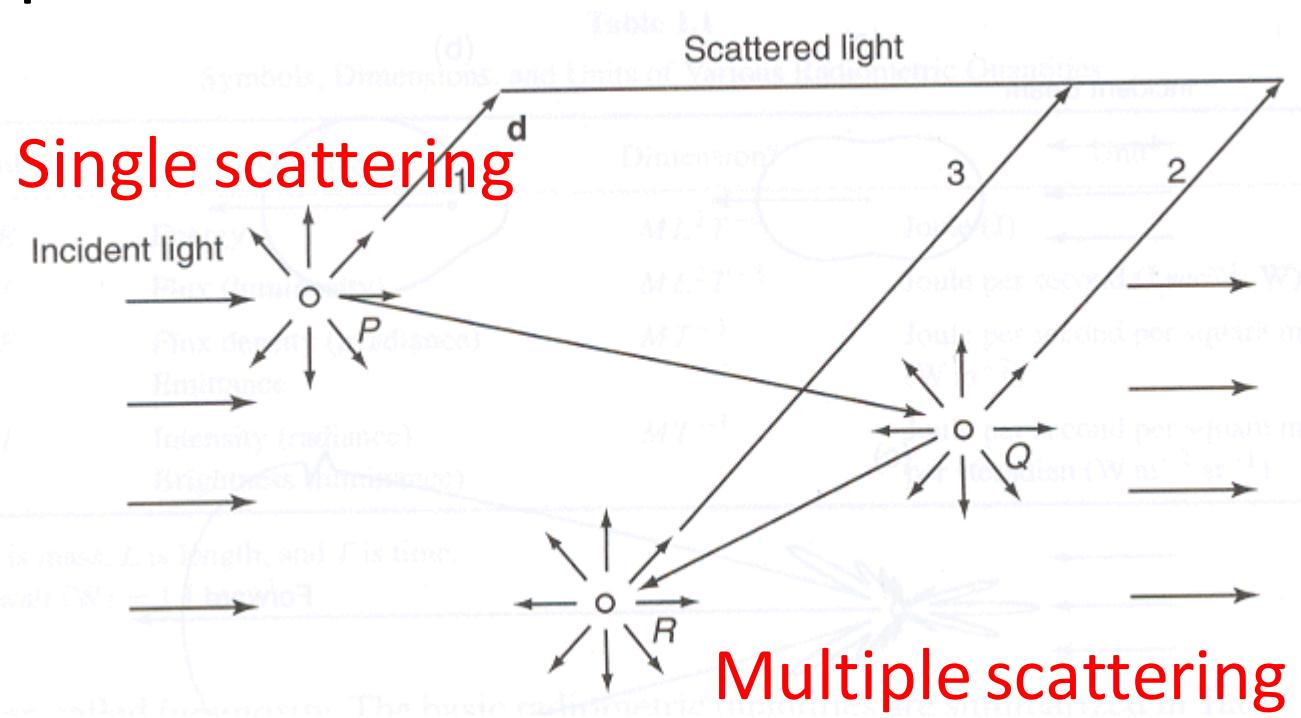


Figure 3.2 Representative vertical profiles of mixing ratios of selected species for midlatitude conditions.

From: Liou (2002)

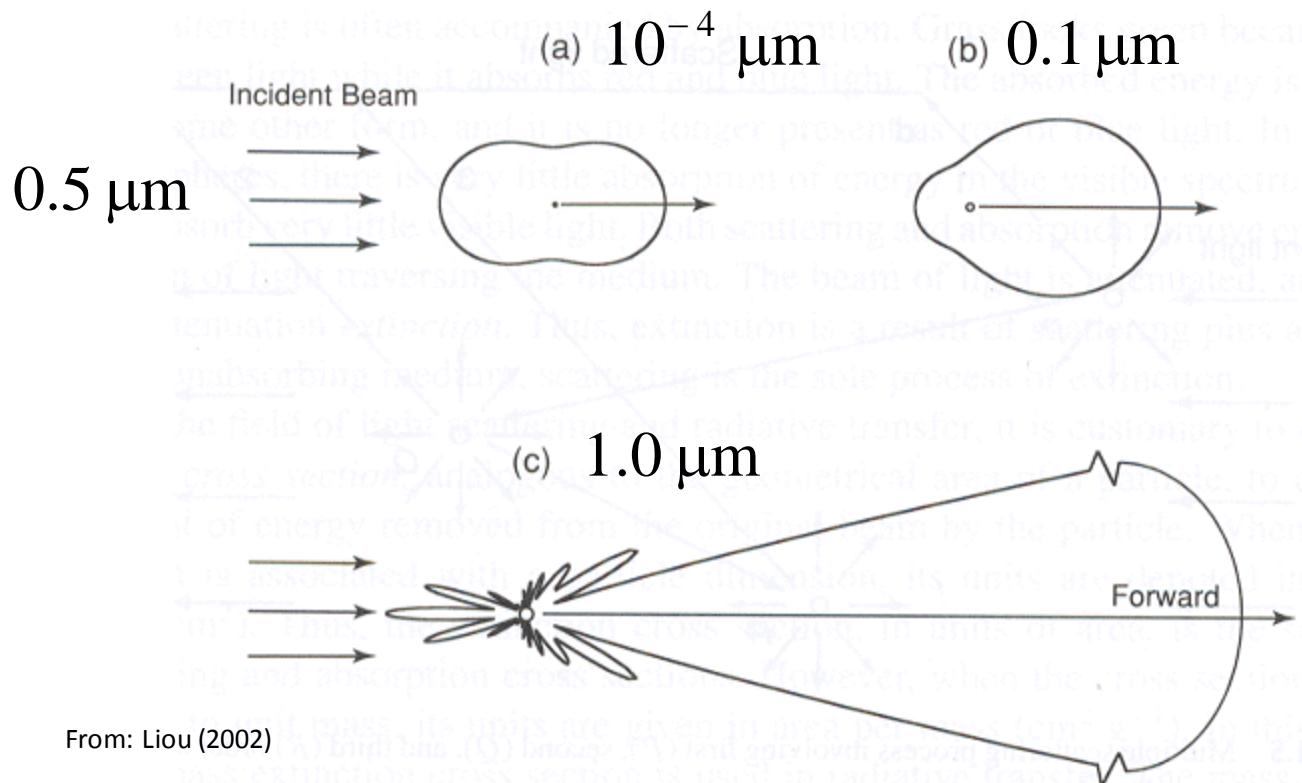
# Scattering

- Rayleigh scattering
- Mie scattering
- Geometrical optics



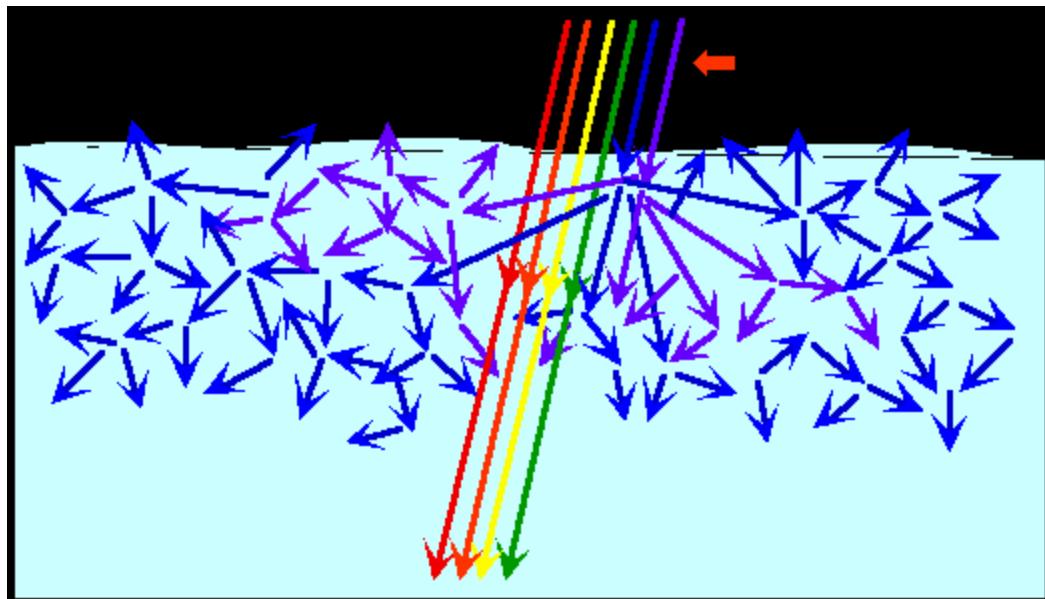
# Scattering

- Rayleigh scattering
- Mie scattering
- Geometrical optics



# Scattering

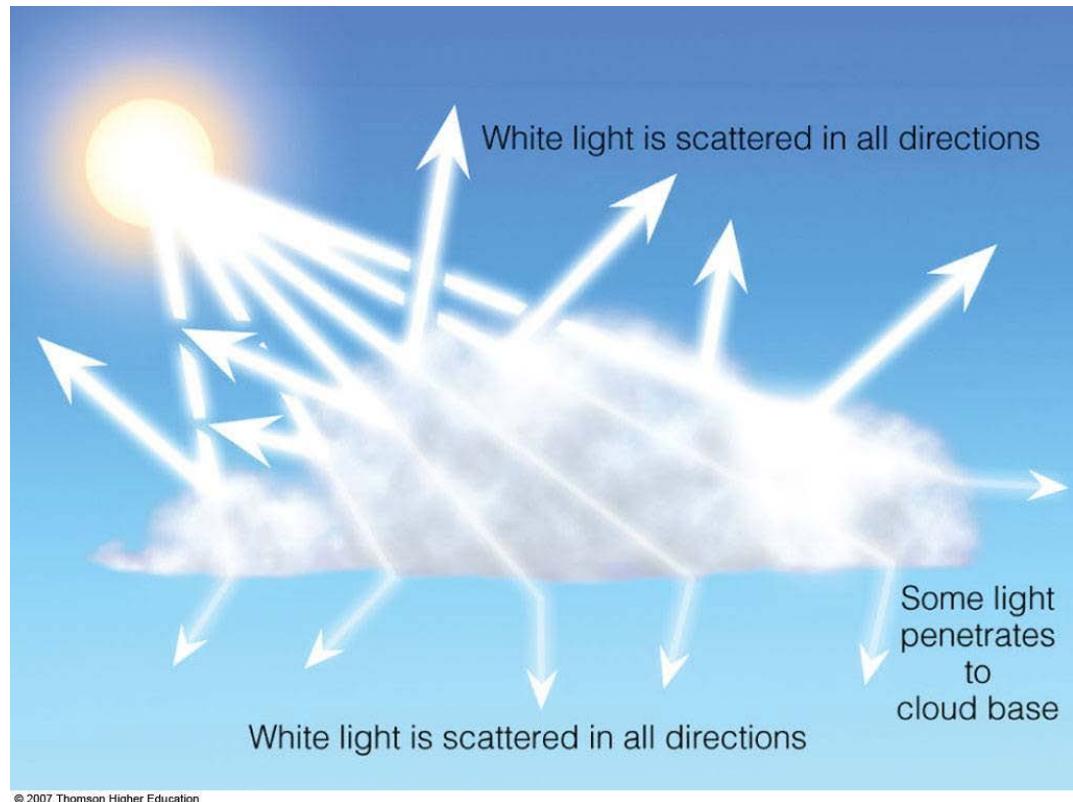
- Rayleigh scattering  
molecules  $d=10^{-4}\mu\text{m}$
- Mie scattering
- Geometrical optics



<http://home.comcast.net/~vinelandrobotics/bluesky.gif>

# Scattering

- Rayleigh scattering
- Mie scattering  
aerosols, droplets,  
ice crystals  $d \sim 1\text{-}10\mu\text{m}$
- Geometrical optics



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# Scattering

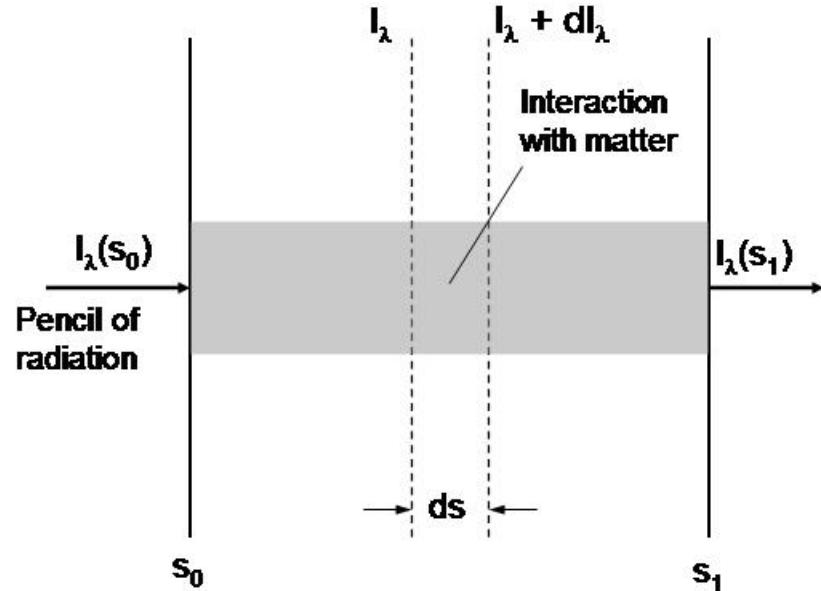
- Rayleigh scattering S
- Mie scattering
- Geometrical optics  
raindrops  
 $d \sim 100\mu\text{m}$



# Radiative Transfer

Four processes can modify the beam of radiation that travels a distance,  $ds$  through the volume

- radiation from the beam can be absorbed
- radiation can be scattered out of the volume into other directions
- radiation can be emitted
- radiation from other directions can be scattered into the beam



$$dI_\lambda = -\rho \beta_\lambda I_\lambda ds + \rho \beta_\lambda J_\lambda ds$$

$\rho$  = density of the material in  $\text{kg/m}^3$

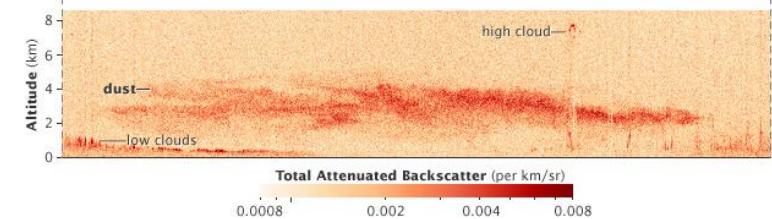
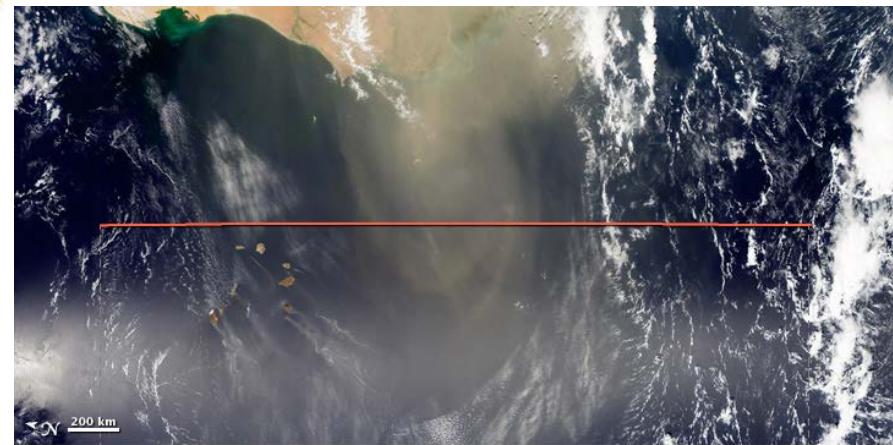
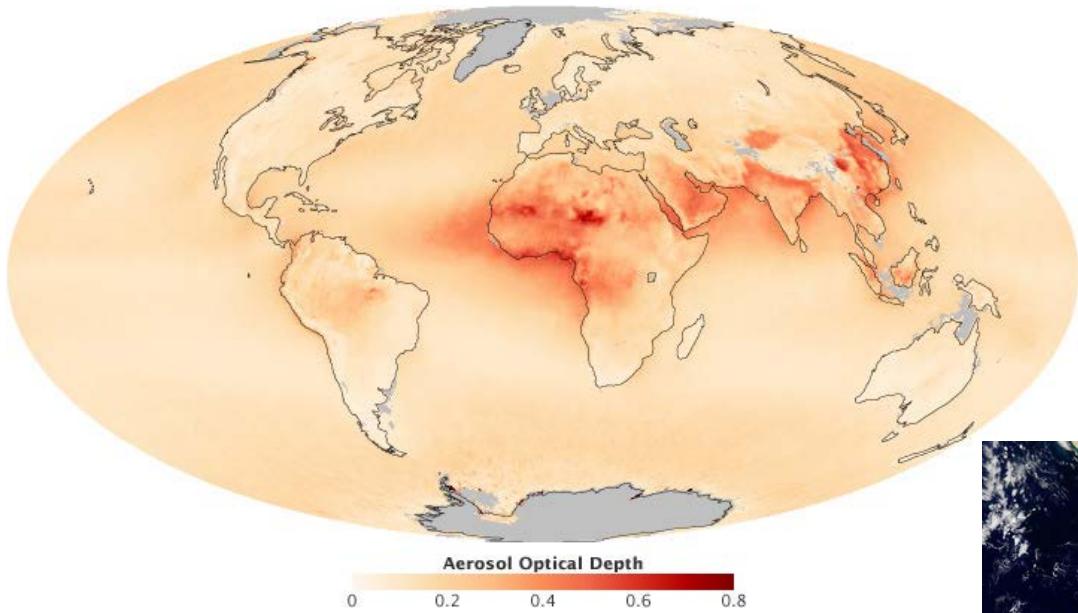
$\beta_\lambda$  = mass extinction cross section in  $\text{m}^2/\text{kg}$

$ds$  = thickness of the layer in m

$I_\lambda$  = monochromatic intensity  
in  $\text{W}/(\text{m}^3 \text{ sr})$

$J_\lambda$  = monochromatic source function (owing to emission and/or multiple scattering) in  $\text{W}/(\text{m}^3 \text{ sr})$

# Example of spatial optical depth variations



From: <http://earthobservatory.nasa.gov/Features/Aerosols/images/>

## EARTH'S RADIATION BUDGET

