# Transmission: radiative transfer, albedo, attenuation (scattering, absorption) by molecules, aerosols and clouds.

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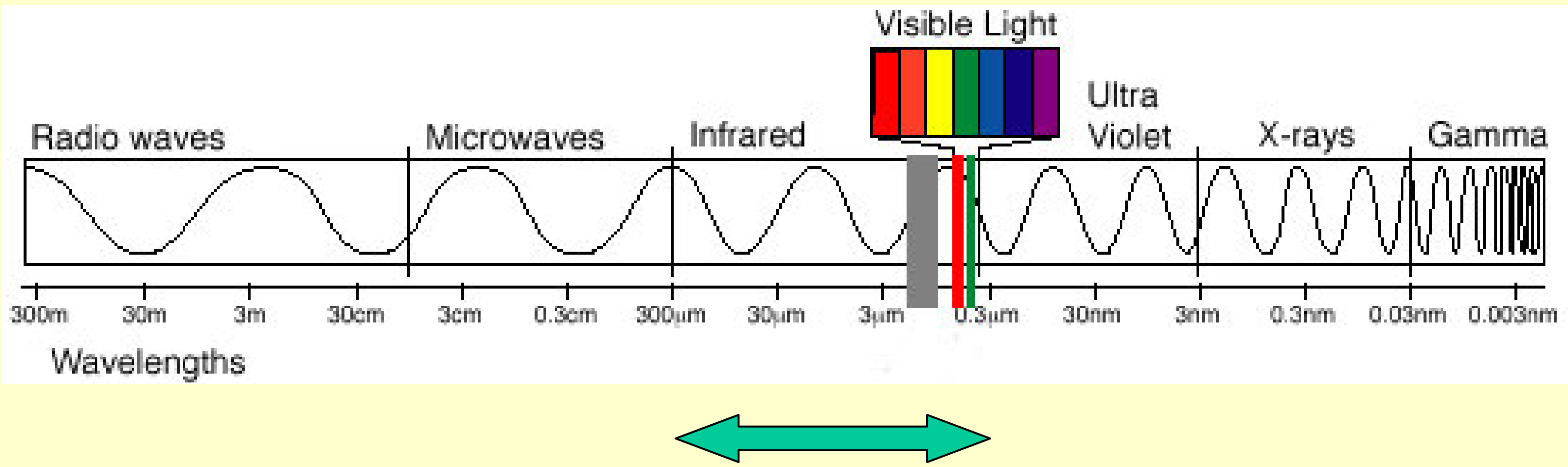
# Content

- Electromagnetic spectrum
- Physical processes
- General definitions
- Atmospheric components
  - Molecules/Gases
  - Aerosols
  - Clouds
- Radiative transfer equation
  - Single and multiple scattering

# Electromagnetic Spectrum

# The Electromagnetic Spectrum




- We are concerned by the “visible light” and the Infrared portions of the EM spectrum

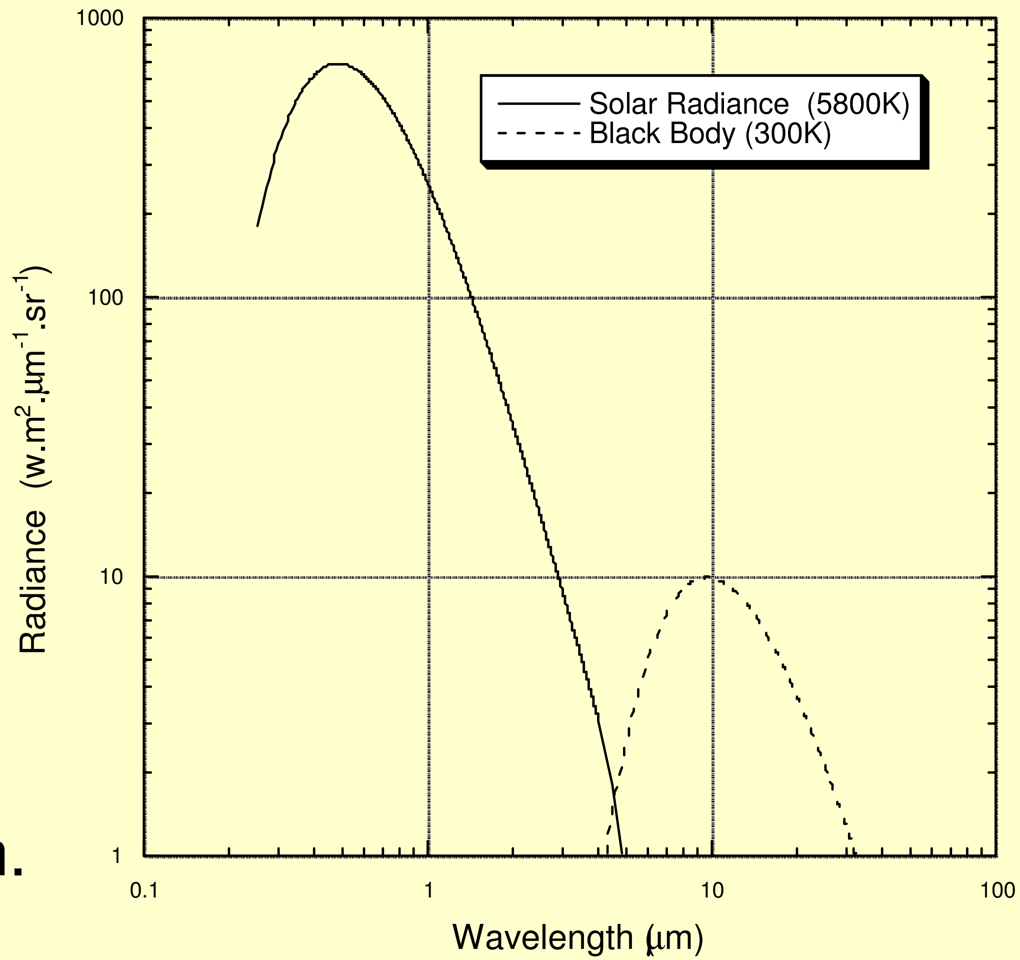
# Sources: Solar spectrum & Earth Emission

Black Body radiation:

- Sun: 5800K
- Earth: 300K

Two regions:

- Up to 3µm, no contribution from IR
- From 5µm, solar contribution can be neglected
- Contributions are equivalent around 4µm.



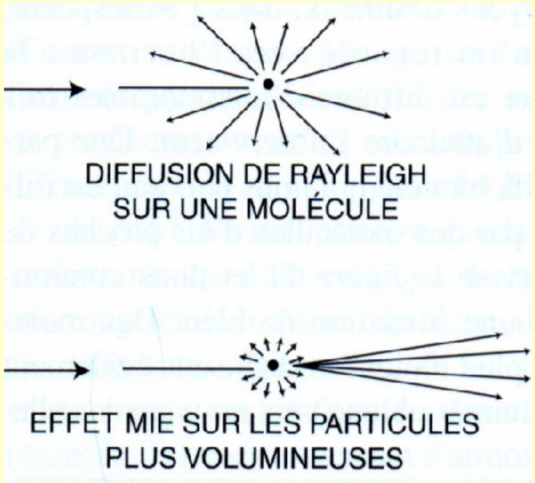
# Three Physical Processes

Scattering

Absorption

Emission

**Scattering:** **it is a fundamental process associated with light and its interaction with matter, particles are the point source of the scattered ennergy**

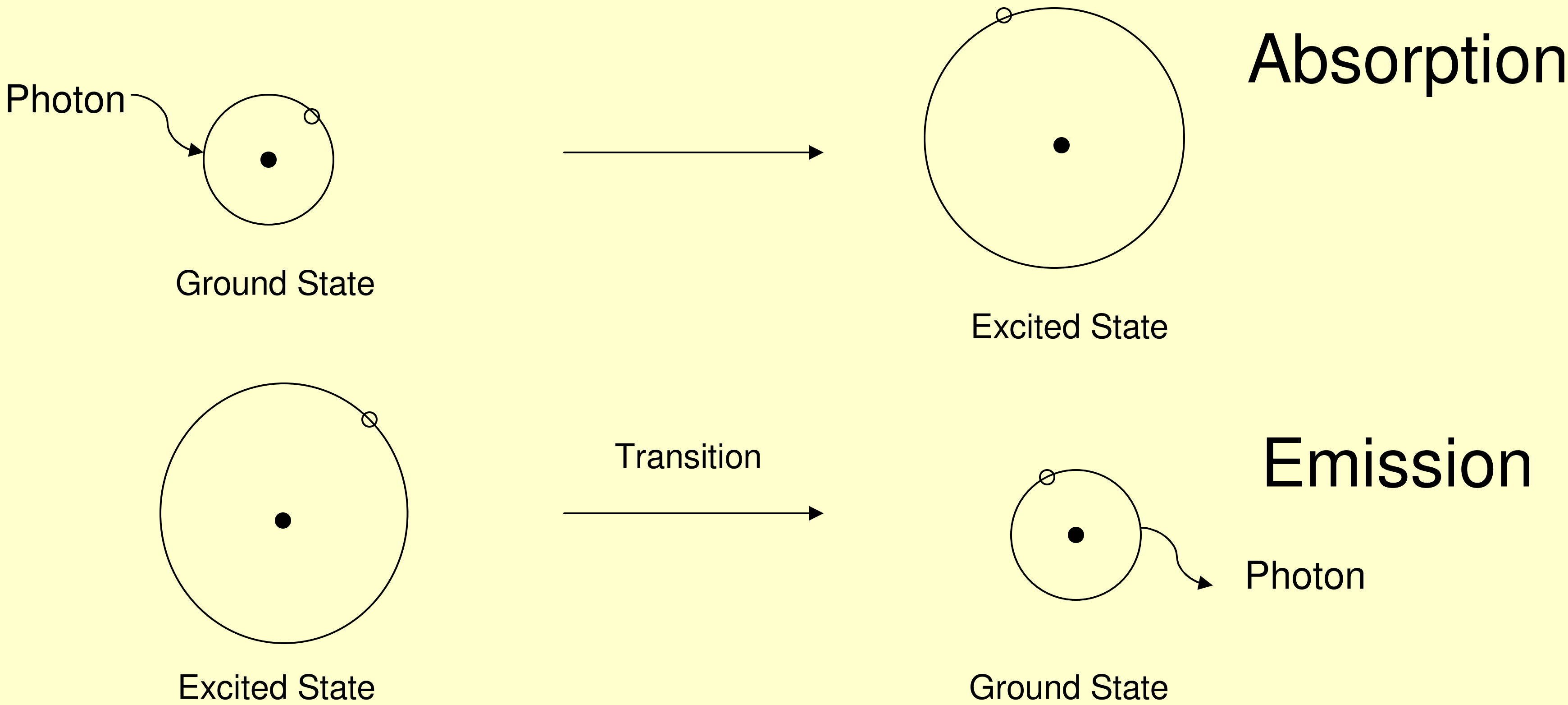



- Rayleigh: electric dipole
- Follows the Maxwell equations

# Absorption & Emission:

**Absorbed energy is converted into some other form and is no longer present at the same wavelength.**

**This absorption leads to emission.**

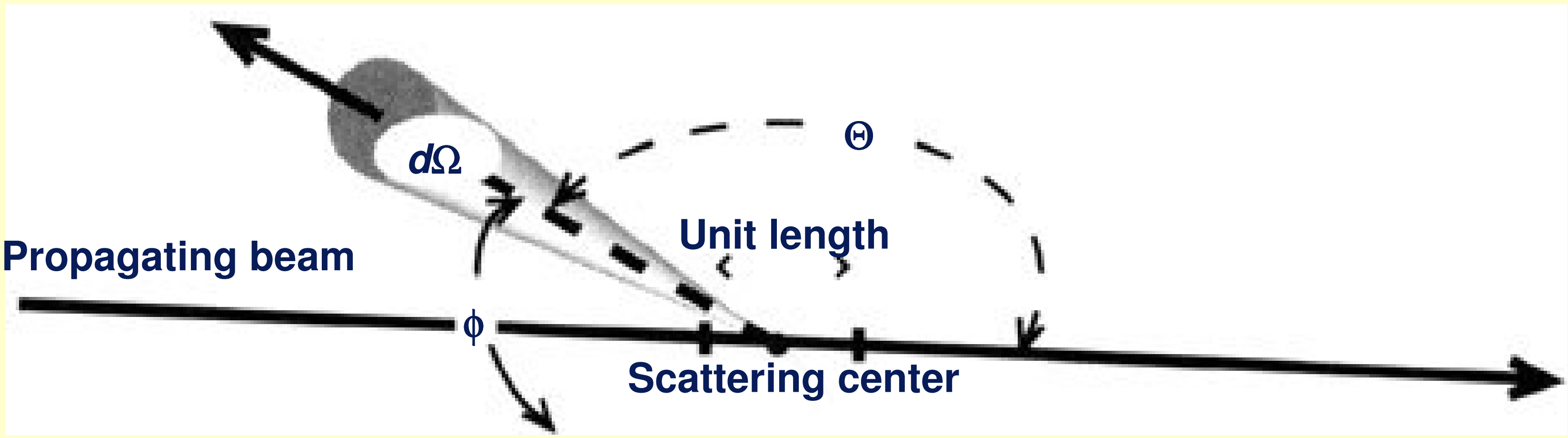


# General Definitions

(solar spectrum)

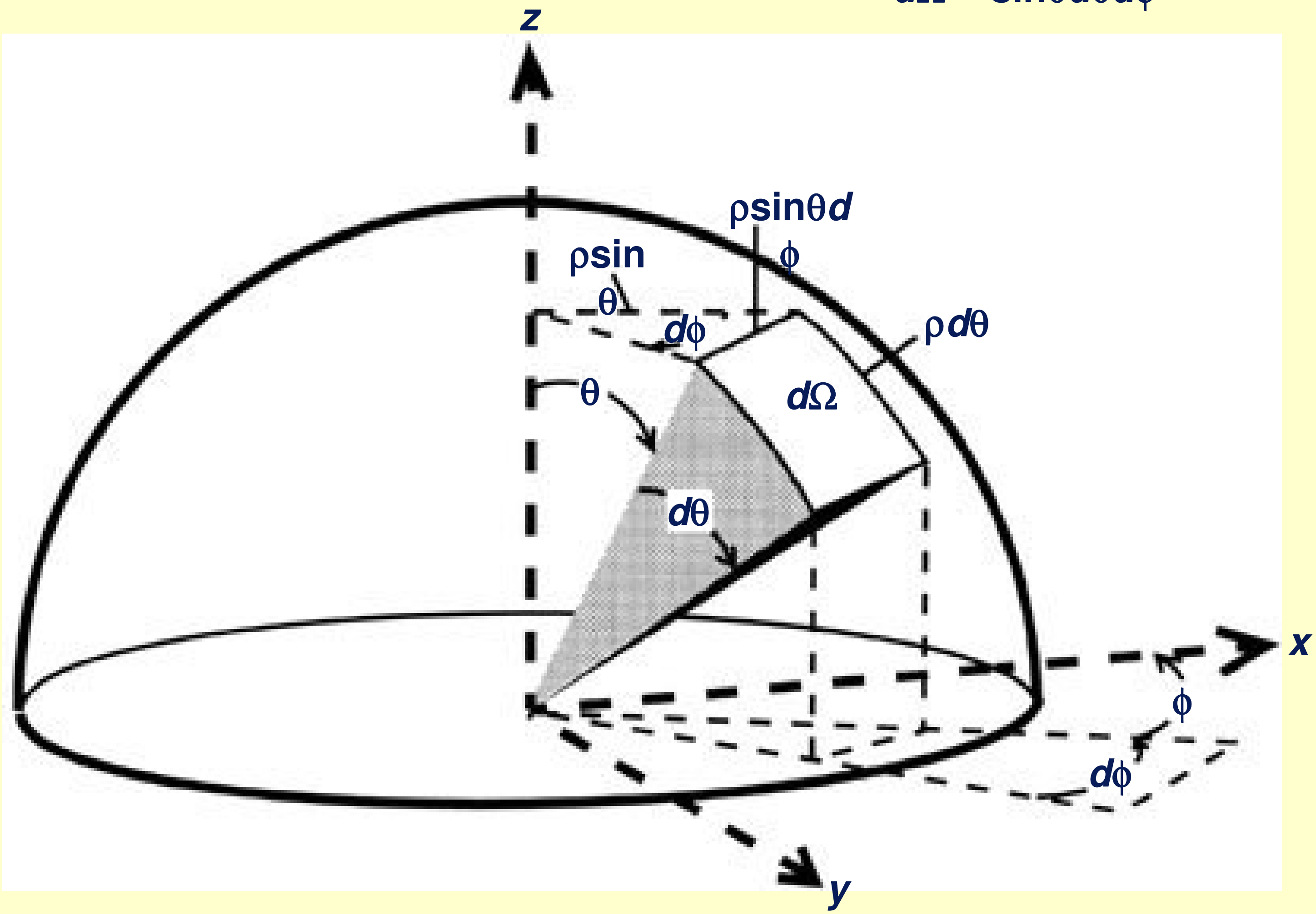
# Angular Scattering Coefficient

- Angular scattering coefficient [β(Θ)]:
  - Fractional amount of energy scattered into the direction Θ per unit solid angle per unit length of transit [$m^{-1}$ $sr^{-1}$]



# Angular Scattering Coefficient

$d\Omega = \sin\theta \, d\theta \, d\phi$



# Volume Scattering and Extinction Coefficient

- Volume scattering coefficient [$\sigma_{sca}$]
  - Fractional amount of energy scattered in all directions per unit length of transit [$m^{-1}$]

$$\sigma_{sca} = \int \beta(\Theta) d\Omega$$

$$= \int_0^{2\pi} \int_0^{\pi} \beta(\Theta) \sin\Theta \, d\Theta \, d\phi$$

- Volume absorption coefficient [$\sigma_{abs}$]
  - Fractional amount of energy absorbed per unit length of transit [$m^{-1}$]

# Volume Scattering and Extinction Coefficient

- Volume extinction coefficient [$\sigma_{ext}$]
  - Fractional amount of energy attenuated per unit length of transit [$m^{-1}$]

$$\sigma_{ext} = \sigma_{sca} + \sigma_{abs}$$

- Single scattering albedo [$\omega_0$]
  - Fraction of energy scattered to that attenuated

$$\omega_0 = \sigma_{sca}/(\sigma_{sca} + \sigma_{abs})$$

# Optical Thickness

- Optical depth [$\tau$]
  - Total attenuation along a path length, generally a function of wavelength [dimensionless]

$$\tau(\lambda) = \int_0^X \sigma_{ext}\, dx$$

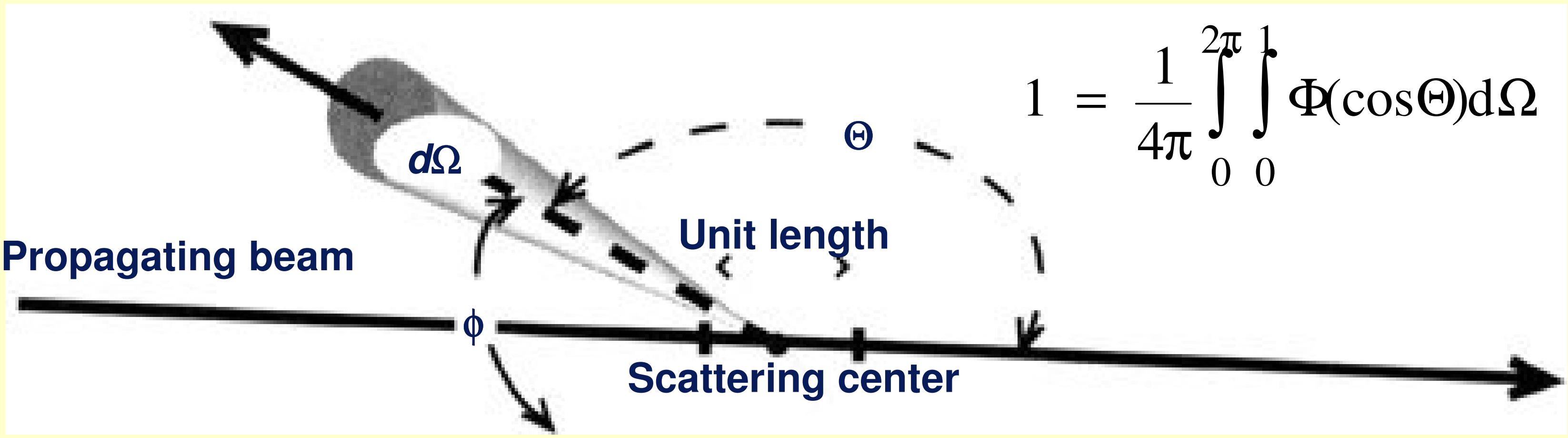
- Total optical thickness of the atmosphere [$\tau_t$]
  - Total attenuation in a vertical path from the top of the atmosphere down to the surface

$$\tau_t(\lambda) = \int_0^\infty \sigma_{ext}\, dz$$

# Scattering Phase Function

- Scattering phase function is defined as the ratio of the energy scattering per unit solid angle into a particular direction to the average energy scattered per unit solid angle into all directions

$$\Phi(\cos\Theta) = \frac{\beta(\Theta)}{\dfrac{\int \beta(\Theta)\,d\Omega}{4\pi}} = \frac{4\pi\beta(\Theta)}{\sigma_{sca}}$$




$$1 = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{1} \Phi(\cos\Theta)\,d\Omega$$

# Atmospheric components: (Solar spectrum)

Molecules:

Aerosols

Clouds (C. Stubenrauch)

# Atmospheric components: Molecules

- The main atmospheric gases are:
  - oxygen ($O_2$);
  - ozone ($O_3$);
  - water vapor ($H_2O$);
  - carbon dioxide ($CO_2$);
  - methane ($CH_4$);
  - nitrous oxide ($N_2O$).

# Atmospheric components: gazeous absorption

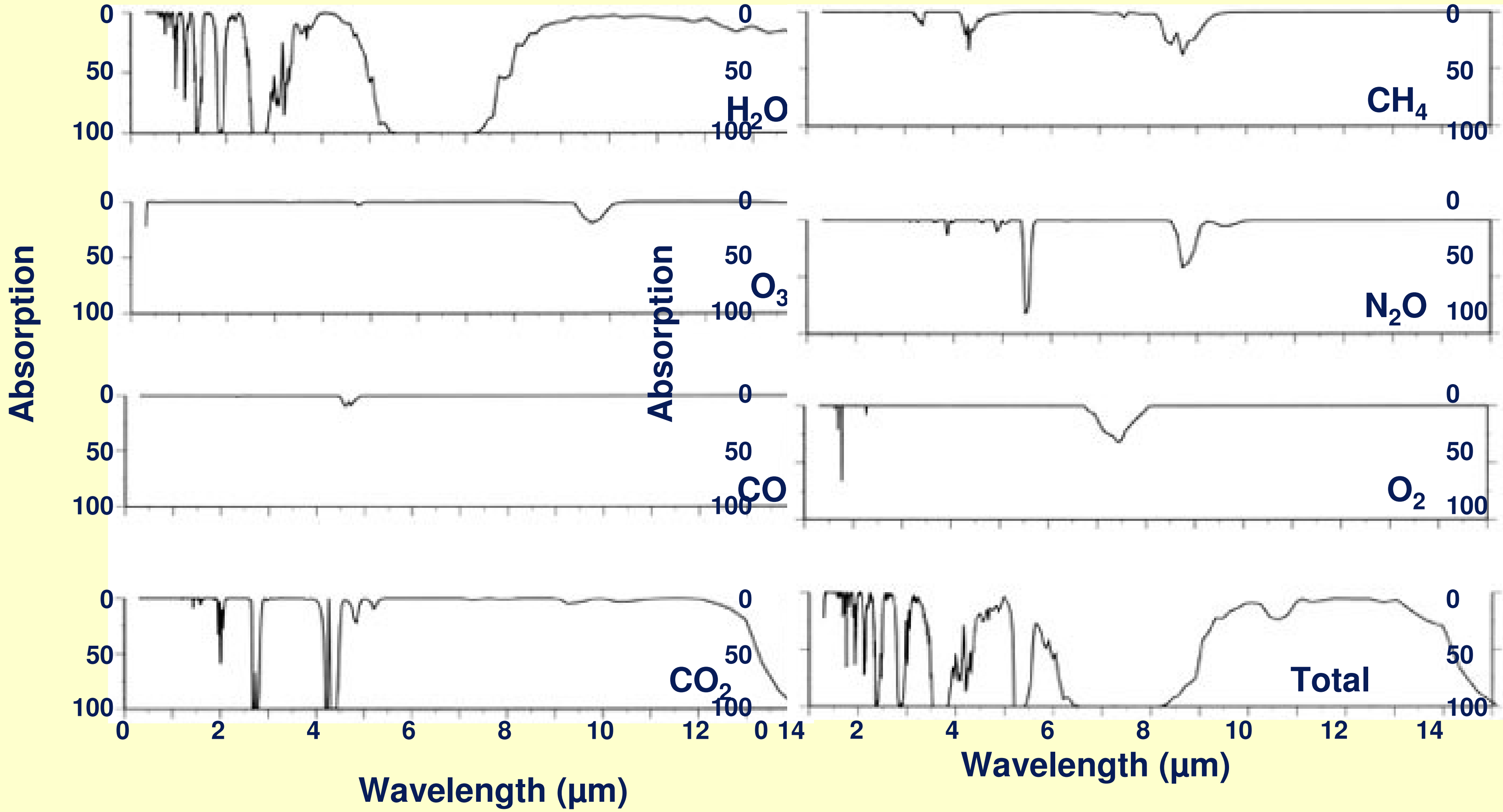
- Gases absorb the radiation by changes of rotational, vibrational or electronic states.

  - rotational energy are weak and correspond to the emission or to the absorption located in microwave or far-infrared range.
  - vibrational transitions correspond to greater energy which open to absorption spectrum in the near infrared.
  - electronic transitions correspond to more important energy and give rise to absorption or emission bands in the visible and the ultra-violet range.

# Atmospheric components: gazeous absorption

- These transitions occur at discrete values, the absorption coefficients vary very quickly with the frequency and present a very complex structure

# Absorption Properties of the Earth's Atmosphere



# Atmospheric components: gazeous absorption

- $O_2$, $CO_2$, $CH_4$, and $N_2O$ are assumed constant and uniformly mixed in the atmosphere, $H_2O$ and $O_3$ concentrations depend on the time and the location.

# Atmospheric components: Molecular scattering

$\tau(\lambda) =$ f ($\lambda^{-4}$,

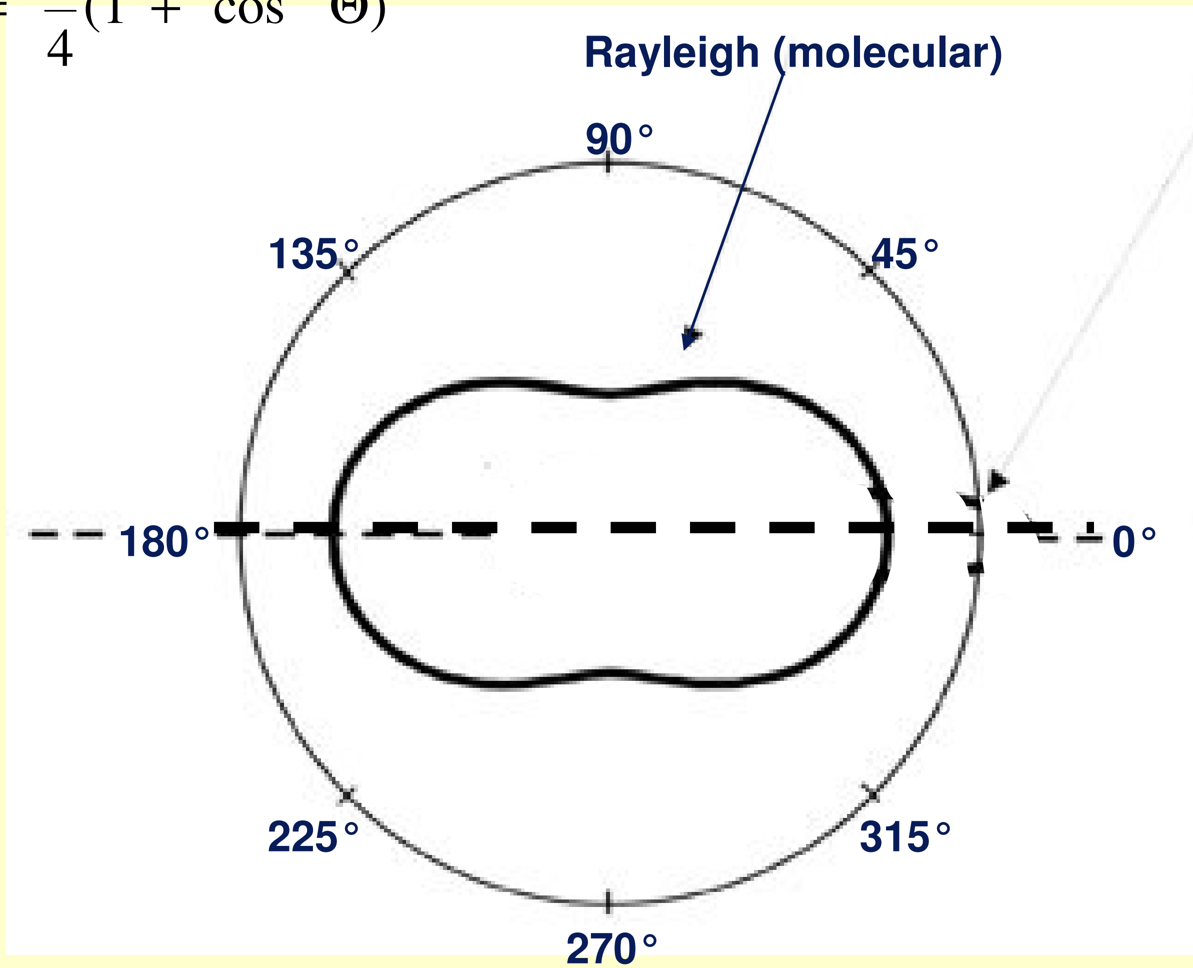
molecules number/$cm^3$ (P, T, Ps)

and cst= refractive index, molecular density);

$\tau$ (550) = 0.10

# Shapes of Scattering Molecular Phase Function

$$\Phi(\cos\Theta) = \frac{3}{4}(1 + \cos^2\Theta)$$



# Atmospheric components: Aerosols


- Aerosol particles larger than about 1 µm in size are produced by windblown dust and sea salt from sea spray and bursting bubbles (coarse mode)
- Aerosols smaller than 1 µm are mostly formed by condensation processes such as conversion of sulfur dioxide ($SO_2$) gas (released from volcanic eruptions) to sulfate particles and by formation of soot and smoke during burning processes (accumulation mode).
- After formation, the aerosols are mixed and transported by atmospheric motions and are primarily removed by cloud and precipitation processes.

# Scattering Coefficient:

Scattering efficiency depends on the size, refractive index and wavelength,

$$\frac{2 \times \pi \times r}{\lambda}(m-1) = \alpha(m-1)$$

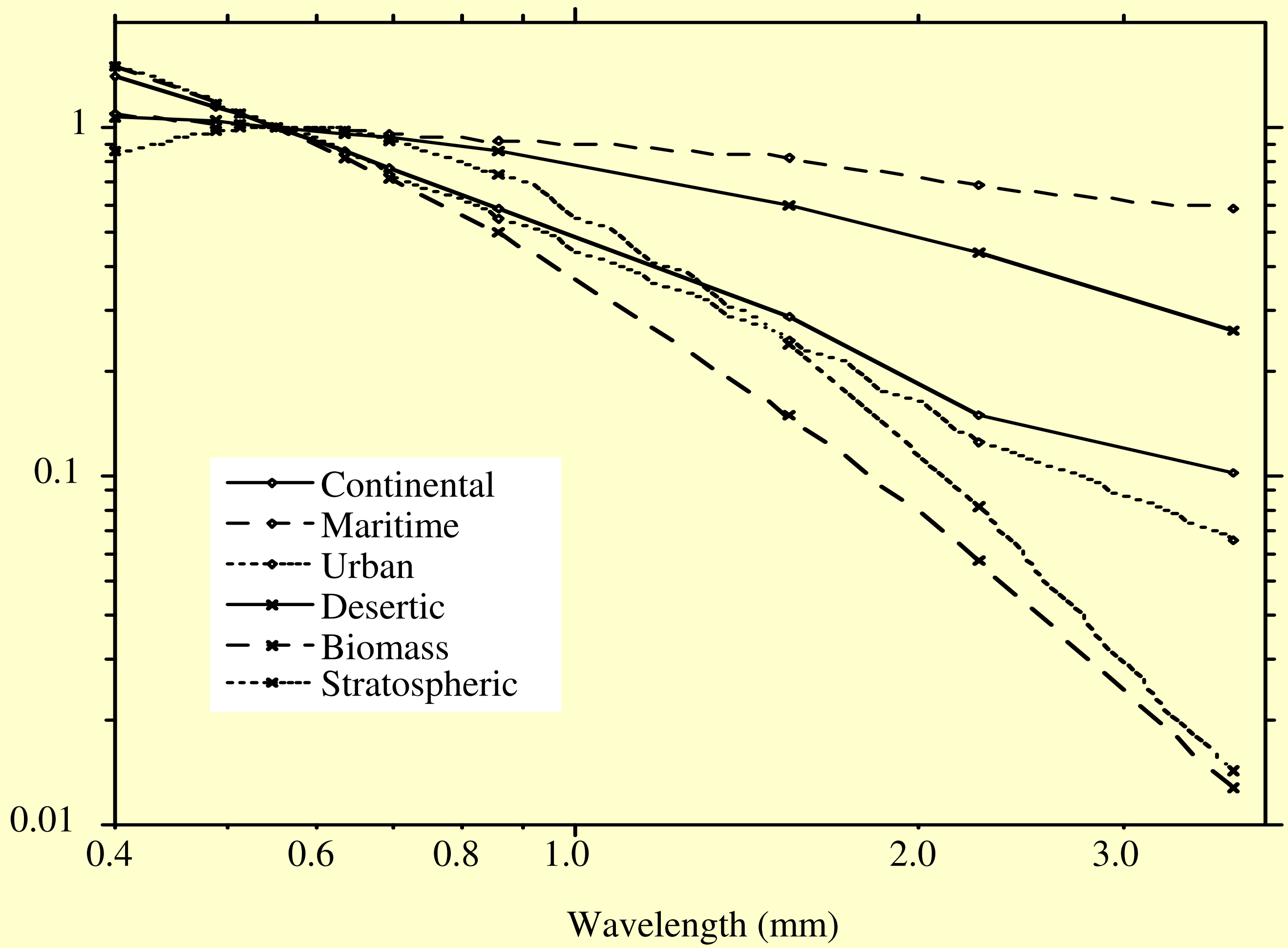
Efficiency is maximum for aerosol sizes similar to wavelength. In the visible solar spectrum, it corresponds to aerosols that are in the accumulation mode; In the infrared solar spectrum, it corresponds to aerosols that are in the coarse mode;

# Optical thickness:

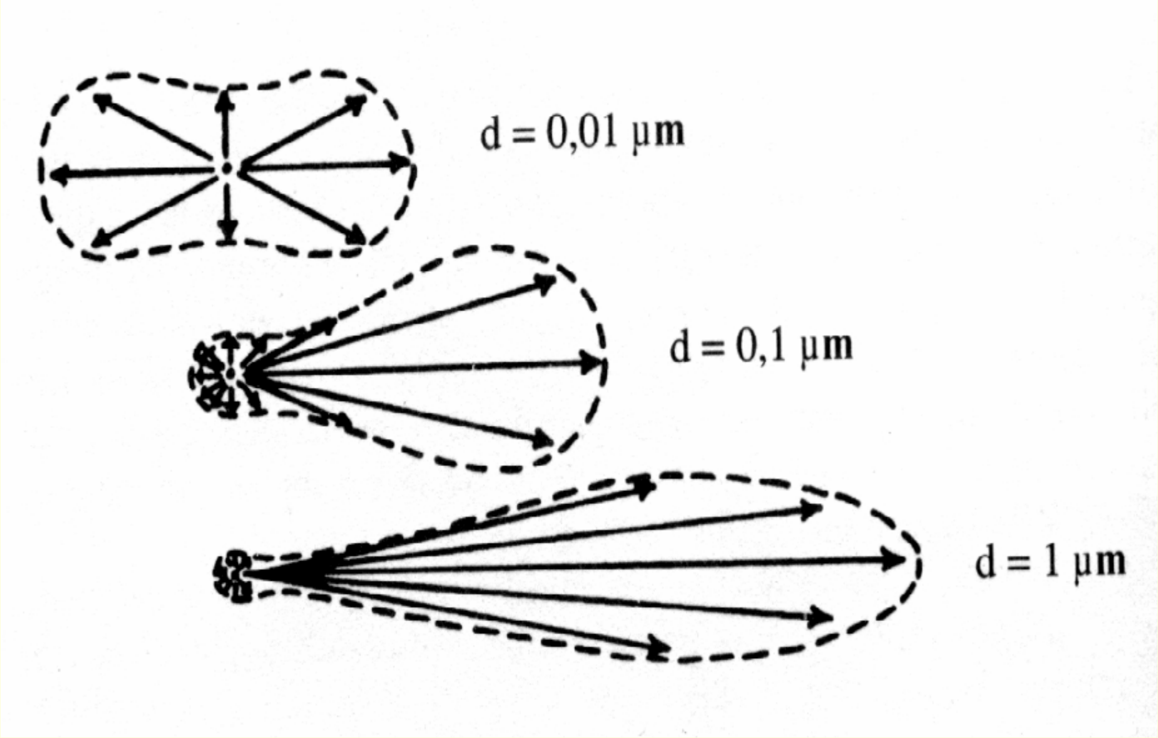
$\tau_a(\lambda) \sim C.\,\lambda^{-\alpha}$ (C is proportional to the number of particles)

- $\alpha$ is the Angstrom exponent
    - If $\alpha$ is around 1 ~ 2 => small particles
    - If $\alpha$ is around 0 => large particles

# Spectral dependence of aerosol Optical thickness:



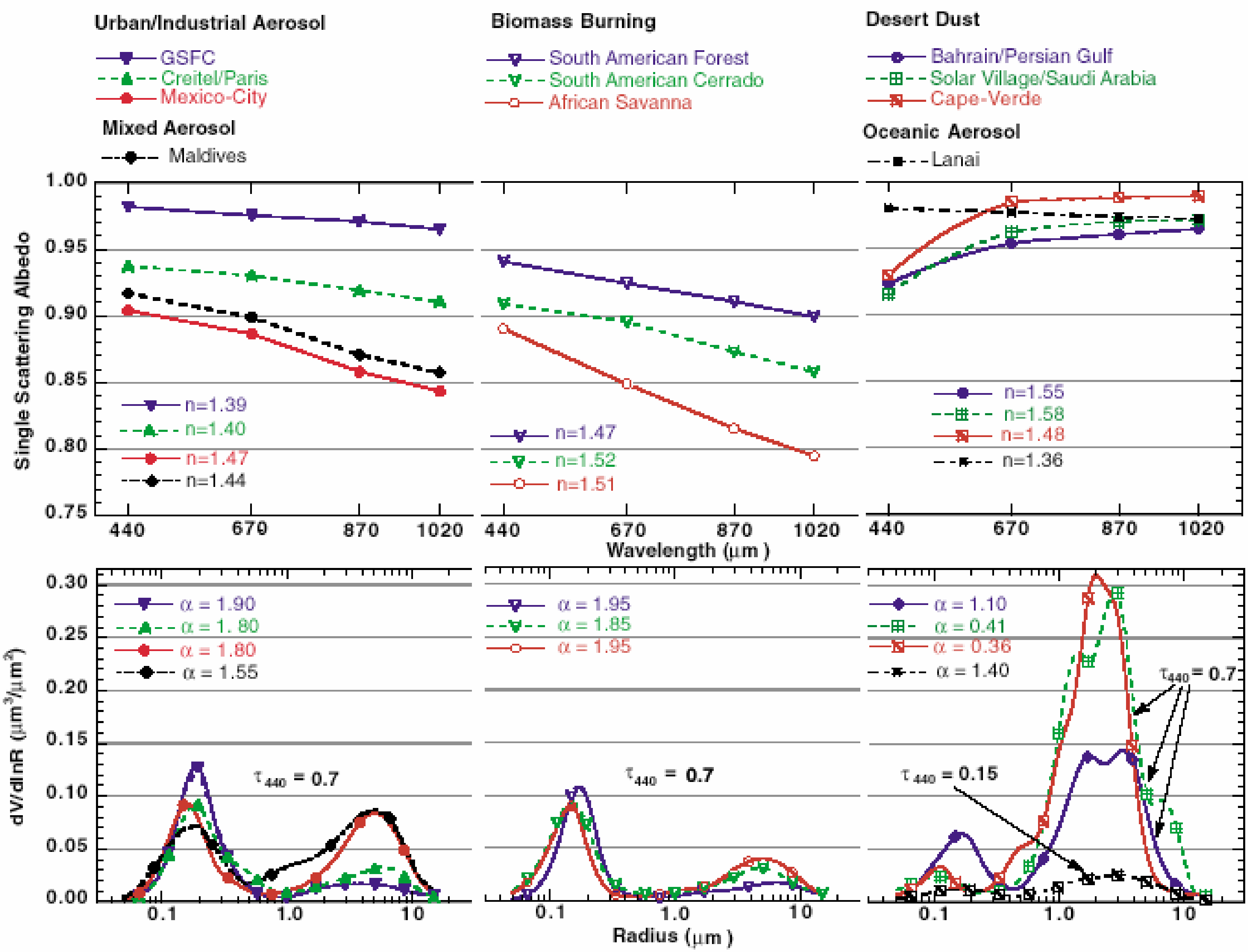
# Scattering Aerosol Phase Function



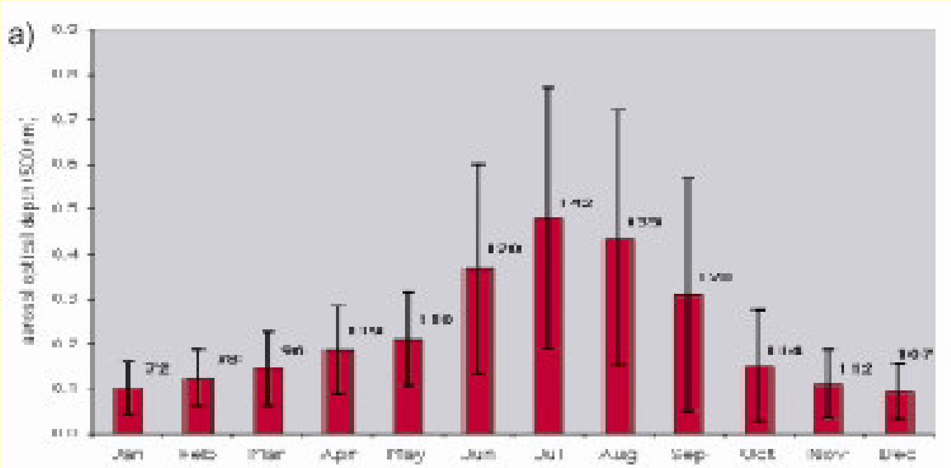
# Single scattering albedo:

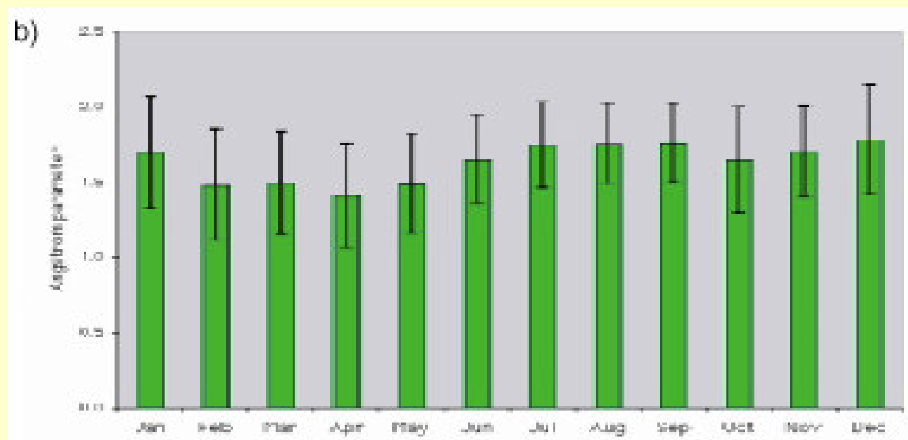
Aerosols are generally slightly absorbing $\omega_0 > 0.80$

- Dust ($1.0 > \omega_0 > 0.9$)
- Biomass burning($0.95 > \omega_0 > 0.80$)
  depends on the ratio of BC/OC
- Sulfate( $1.0 > \omega_0 > 0.95$)

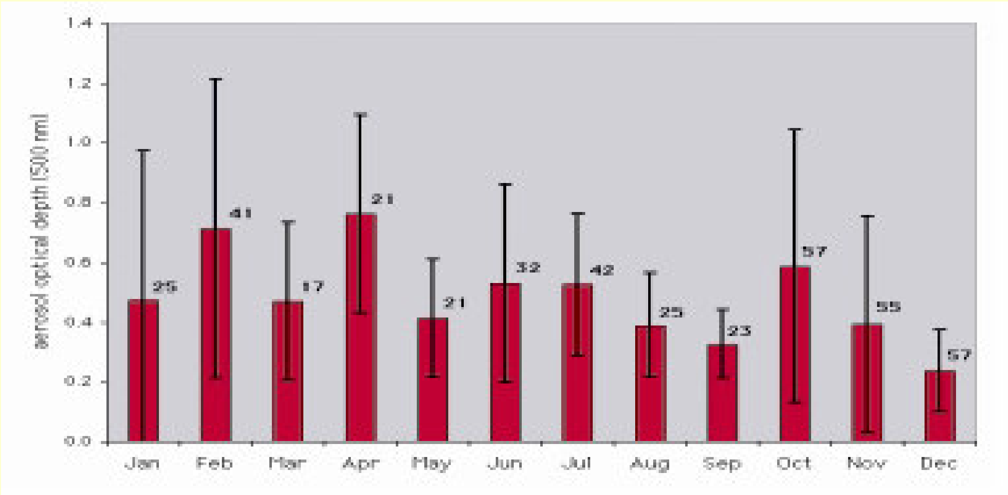


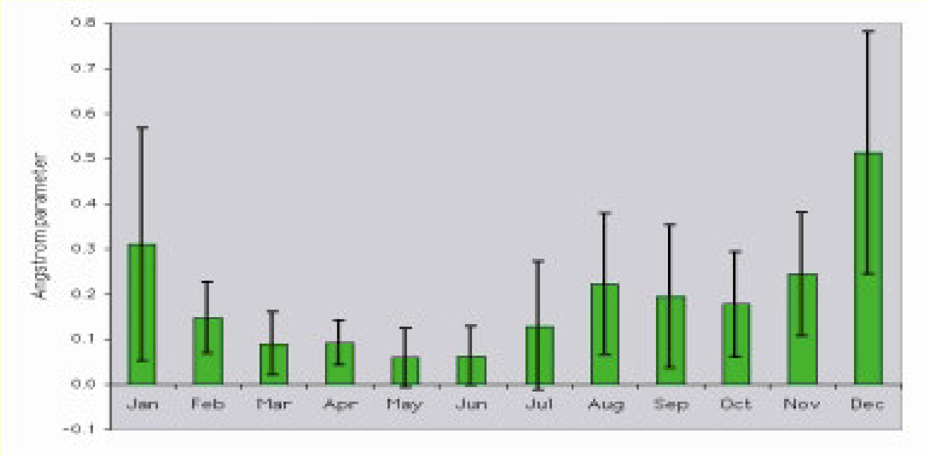
Urban/Industrial Aerosol
GSFC
Creitel/Paris
Mexico-City
Mixed Aerosol
Maldives
Biomass Burning
South American Forest
South American Cerrado
African Savanna
Desert Dust
Bahrain/Persian Gulf
Solar Village/Saudi Arabia
Cape-Verde
Oceanic Aerosol
Lanai
Single Scattering Albedo
n=1.39
n=1.40
n=1.47
n=1.44
n=1.47
n=1.52
n=1.51
n=1.55
n=1.58
n=1.48
n=1.36
Wavelength (μm )
dV/dlnR (μm³/μm²)
α = 1.90
α = 1. 80
α = 1.80
α = 1.55
α = 1.95
α = 1.85
α = 1.95
α = 1.10
α = 0.41
α = 0.36
α = 1.40
τ440 = 0.7
τ440 = 0.7
τ440 = 0.7
τ440 = 0.15
Radius (μm )



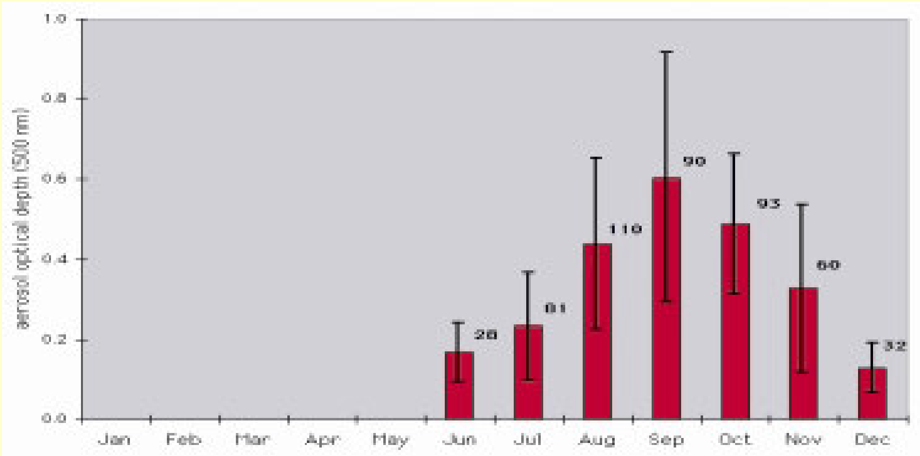



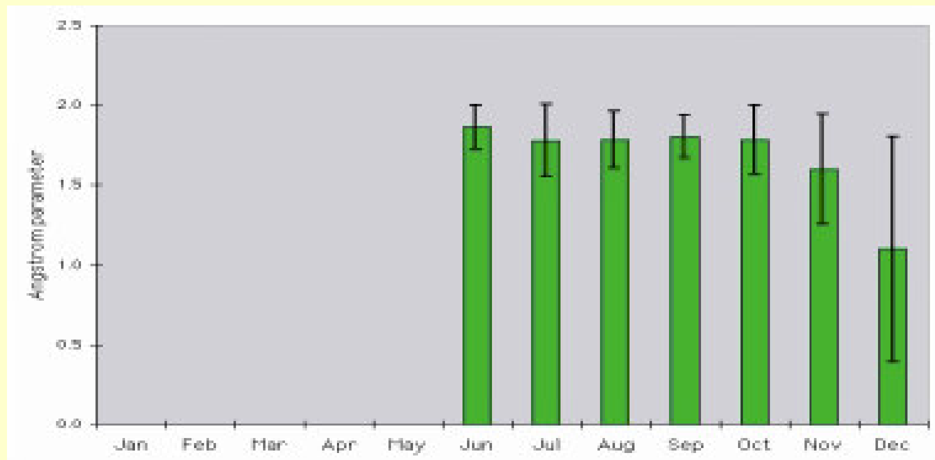

GSFC site/USA



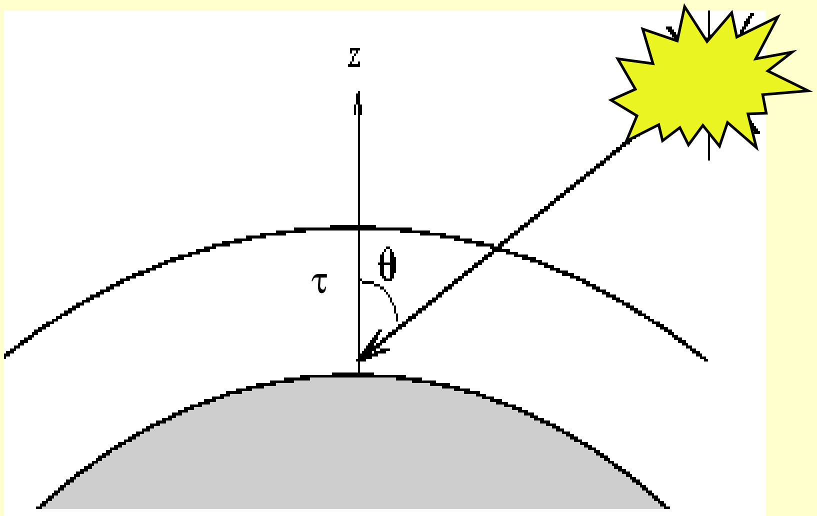

Banizoumbou site/Niger




Mongu site/Zambia

# Direct solar flux attenuated by the atmosphere

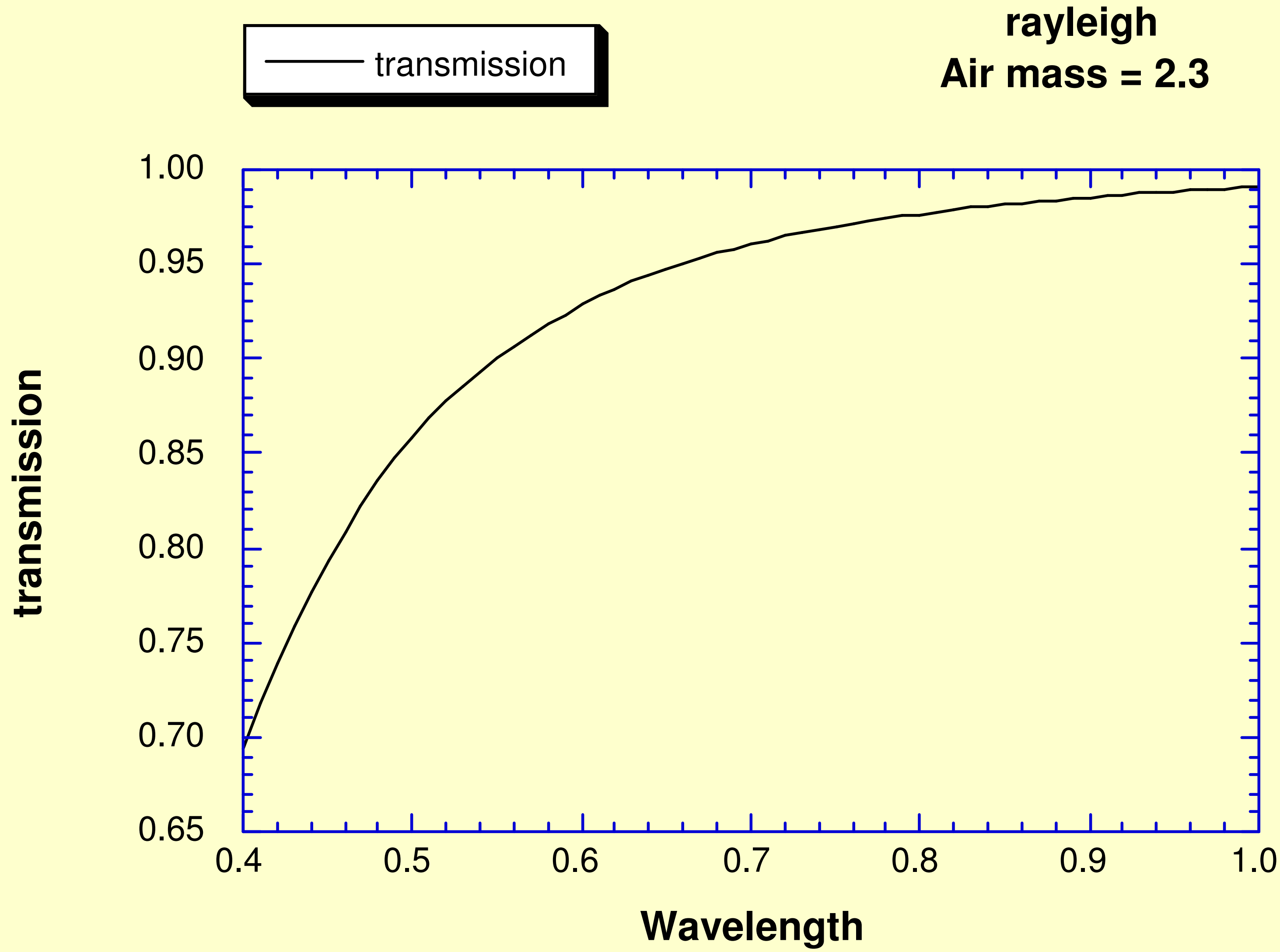



$E(\lambda)=E_o(\lambda) \times Tg(\lambda) \times \exp(-\tau(\lambda)/\cos(\theta_o))$

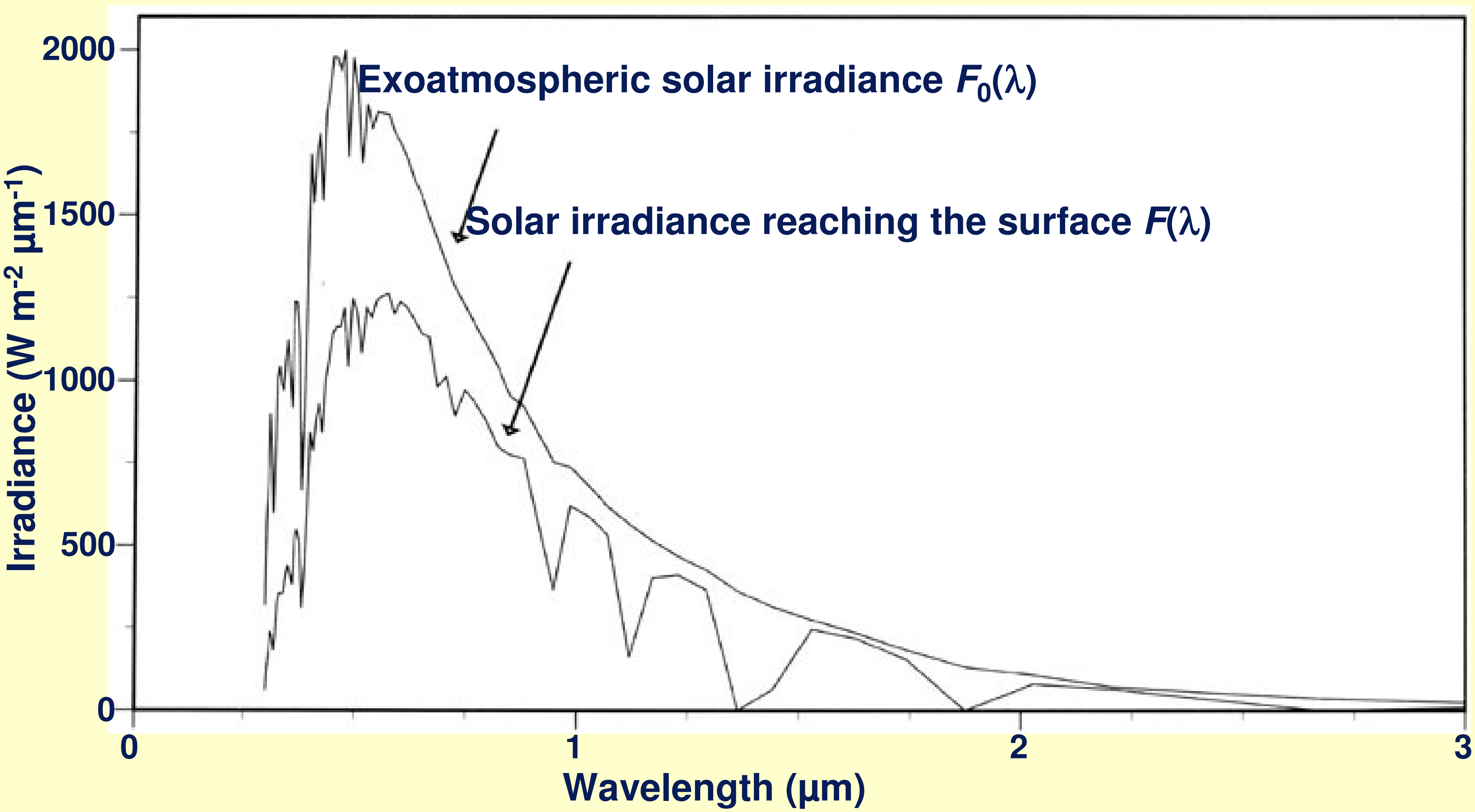
$\tau(\lambda)= \tau_m(\lambda) + \tau_a(\lambda)$

$Tg(\lambda)$ is the gaseous transmission , complex structure,

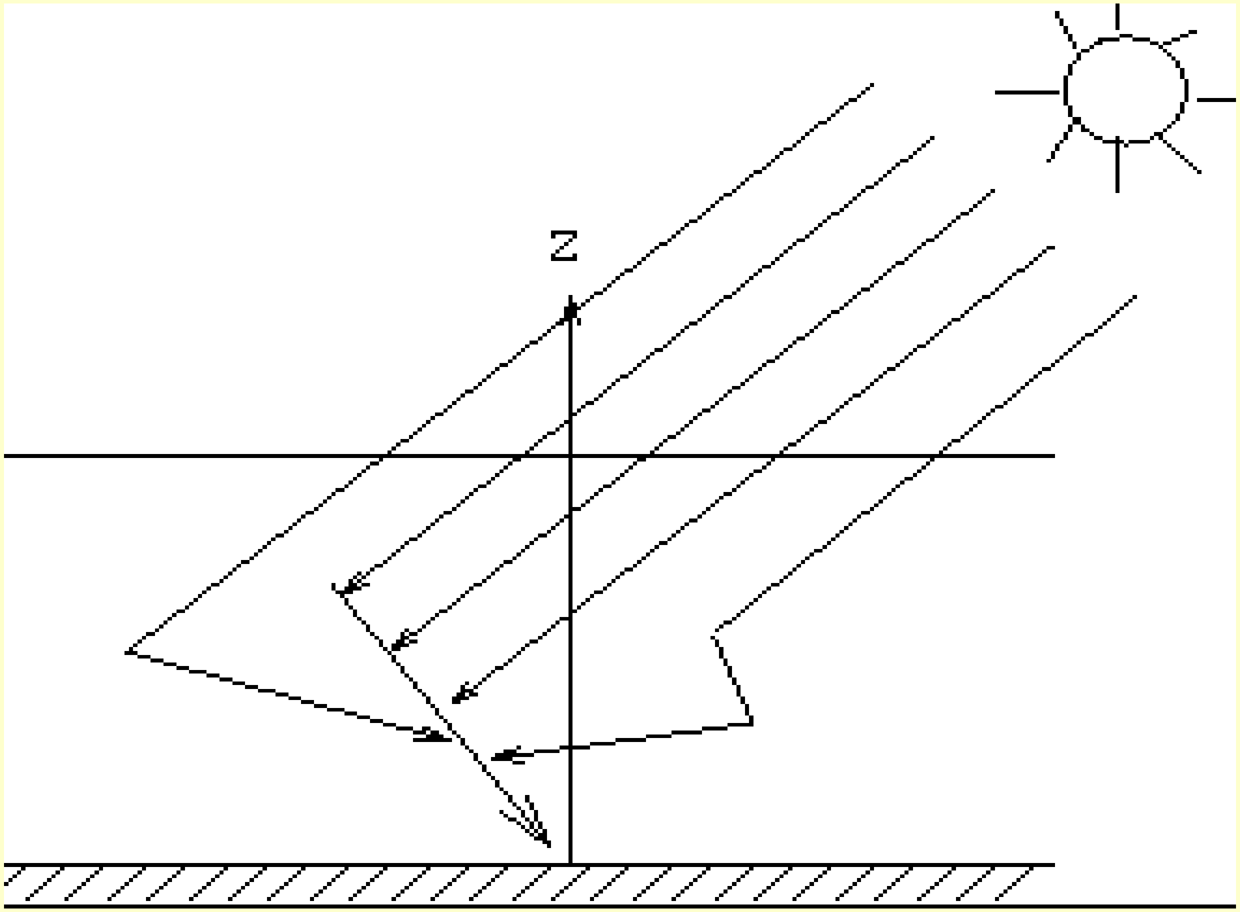
$\tau(\lambda)$ total optical thickness, smooth function,


transmission
rayleigh
Air mass = 2.3
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
transmission
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Wavelength

# Direct solar flux attenuated by the atmosphere



# Scattering/Ground-Based Measurements



# Radiative Transfer Equation

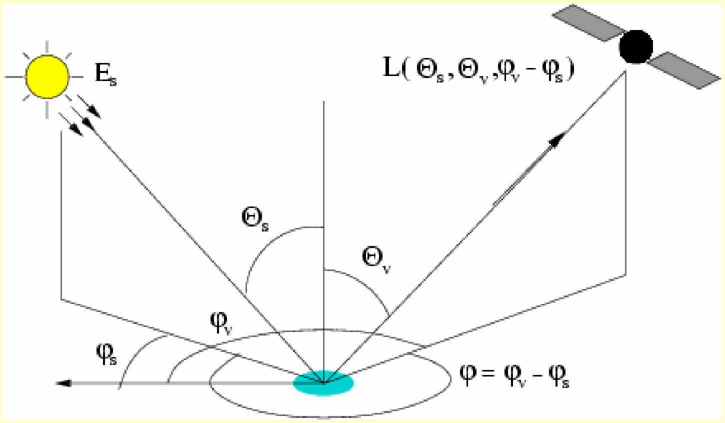
# Radiative transfer equation

Plane-parallel atmosphere:

Radiance L at altitude z

Sun direction ($\mu_s$=cos ($\Theta_s$), $\phi_s$)

View direction ($\mu_v$=cos ($\Theta_v$), $\phi_v$)




$$\mu \frac{dL_\lambda(z;u,\phi)}{dz} = -\sigma_{e,\lambda}[L_\lambda(z;u,\phi) - J_\lambda(z;u,\phi)]$$

$J_\lambda$ Source function

It is a 4x4 pb if polarization is considered

# Radiative transfer equation

$J_\lambda$ Source function $J = J_{sc} + J_{em}$

$$J_\lambda^{sc} = \frac{\omega_\lambda(z)}{4\pi}\int_0^{2\pi}\int_{-1}^{+1} P_\lambda(z;\mu,\phi;\mu',\phi')\,L_\lambda(z;\mu',\phi')\,d\mu'\,d\phi'$$

$$J_\lambda^{em} = [1-\omega_\lambda(z)]\,L_\lambda^B[T(z)]$$

# Radiative transfer equation

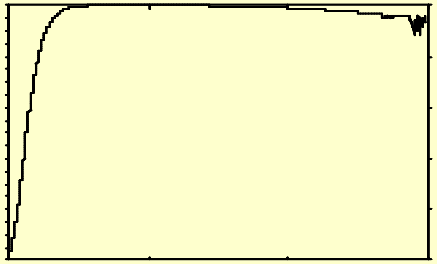
First scattering approximation, with no surface contribution :

TOA $$L_\lambda[0;\mu>0,\phi]=\frac{\varpi_0\tau_\lambda P_\lambda(\mu;\mu_0;\phi-\phi_0)}{4\mu}$$

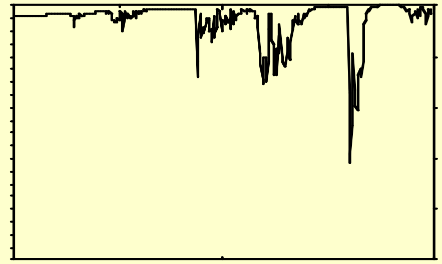
BOA $$L_\lambda[\tau;\mu<0,\phi]=\frac{\varpi_0\tau_\lambda P_\lambda(\mu;\mu_0;\phi-\phi_0)}{4\mu}$$

# Conclusion:

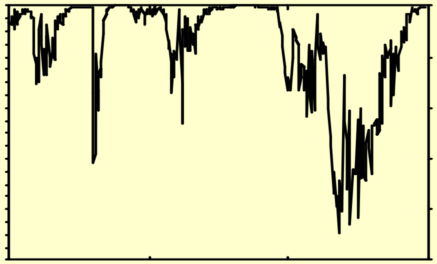
- Atmospheric Windows:
  - Visible (.35µm -.75µm)
  - Solar infrared (0.86µm; 1.02 µm; 1.2µm,; 1.6µm; 2. 1µm, 3.7µm)
- Aerosols
  - Transmission function is « smoother » $\tau_a(\lambda)$ ~[0-2]
  - Transmission can be very small
- The scattered light contributes to surface illumination
  - For instrument with small FOV (1.5°), it can be neglected except for very high optical thickness (>1.0)



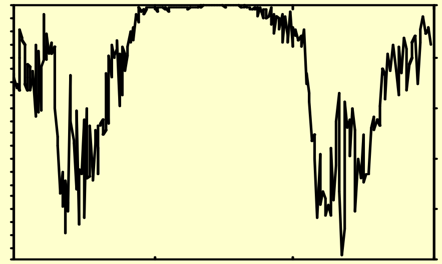
Visible Atmospheric window (1/2)



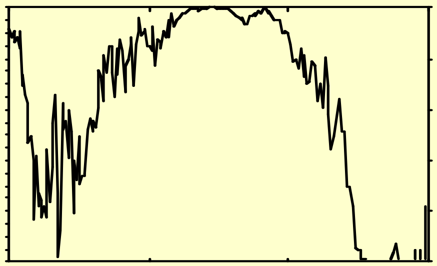
Visible Atmospheric window (2/2)



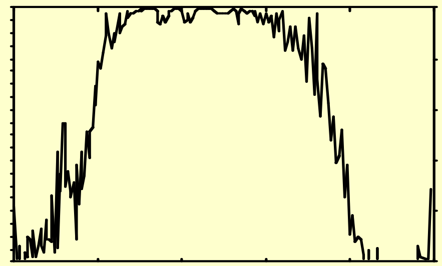
Atmospheric window at 0.85 $\mu m$



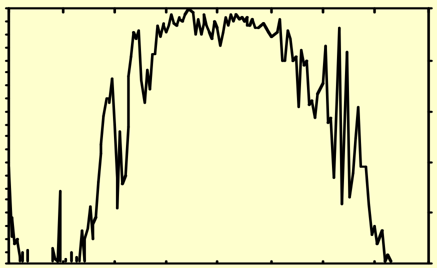
Atmospheric window at 1.06 $\mu m$



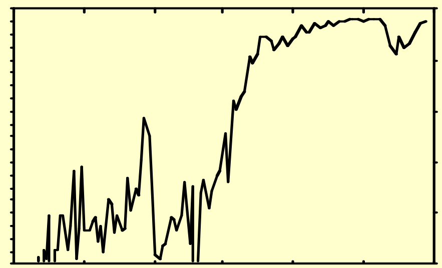
Atmospheric window at 1.22 $\mu m$



Atmospheric window at 1.60 $\mu m$



Atmospheric window at 2.20 $\mu m$



Atmospheric window at 3.70 $\mu m$

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