University of Maryland Baltimore County - UMBC

Phys650 - Special Topics in Experimental Atmospheric Physics (Spring 2009)

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Class 5

- In Depth Discussion and Continuation of the Course Project
- Introduction to Radiative Transfer: Theory and Codes
- Introduction to radiometry
- Hands on Experiment: Calibration and Characterization of the Sunphotometer

In depth discussion and continuation of the course project:

- Introduction to Radiative Transfer and Radiative Transfer codes
- Introduction to Radiometric Analysis:
  - How many photos arrive at the surface of your detector?
  - What is the uncertainty of your measurement?
- Discussion on the FOV of the Photometer
  - What is the FOV of your system?
  - What is the FOV of the sun on the sky?
  - What is the associated error from the difference between the above FOVs?
- Discussion on the Calibration of the Photometer
  - What is the required accuracy for sunphotometry and what method can meet this requirement?
  - Calibration with Langley Plots
  - Calibration in Integrating Spheres

  After calibration, you can start measuring the aerosol optical depth at some location and compare it with Aeronet measurements, Lidar, or satellite retrievals. Notice that you cannot touch/modify your photometer after calibration.
- Discussion on measurements of sky radiance, moon photometry, etc.
  - How can you convert your sunphotometer to a sky radiometer?
  - How many photos do you get from the sky at the surface of your detector?
  - Can you convert your sunphotometer to a moon, or a star photometer?
  - How many photons do you need arriving at the surface of your detector in order to make an accurate measurement in each case?
  - How can you increase the number of photons arriving at the surface of your detector

Experiments

12:00-12:30 - Hands on Experiment:

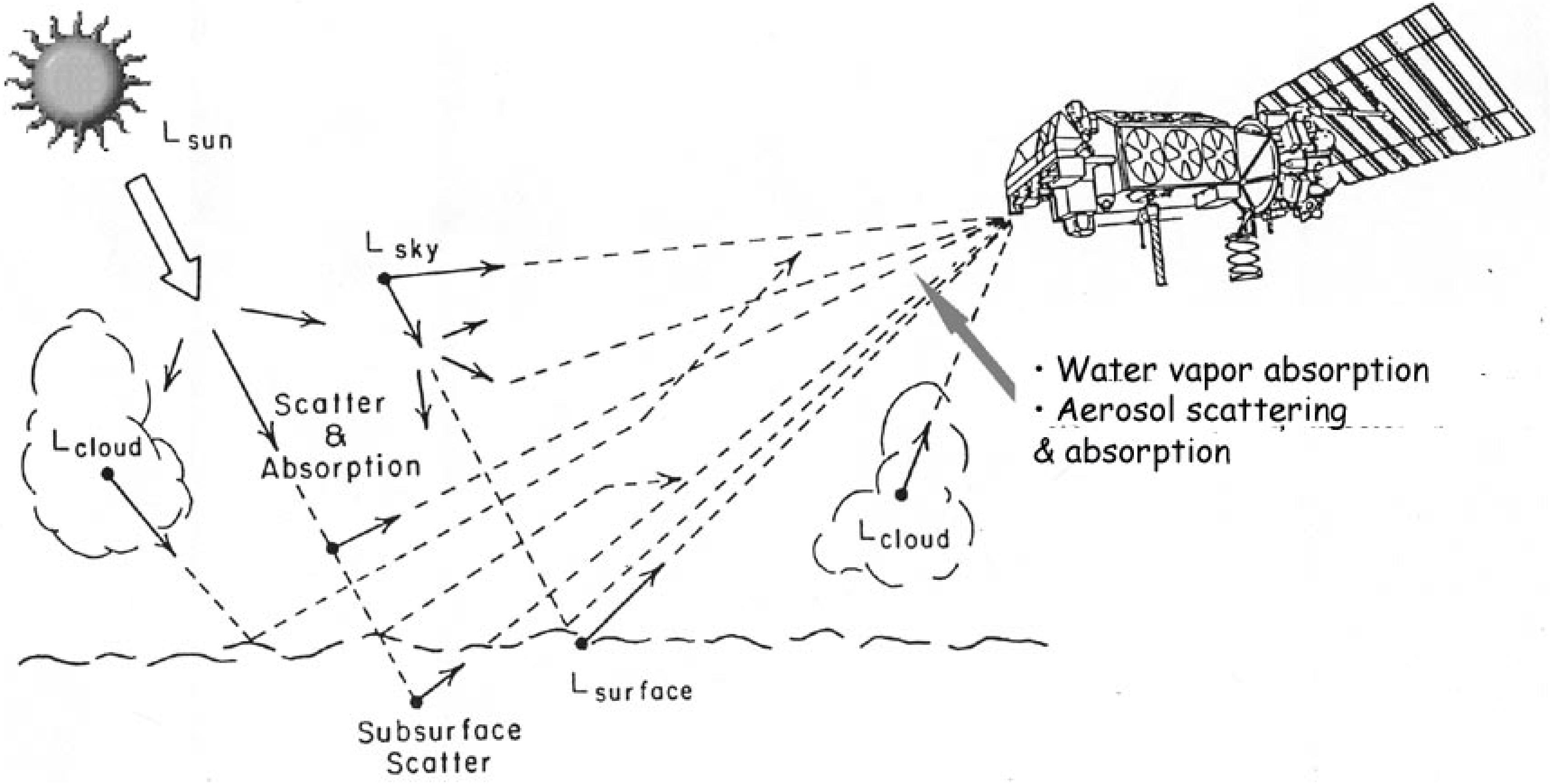
- Assemble a "Tiger team" to design your instrument and attack the questions above. Each team should address all the questions above theoretically and experimentally. Try to explore the expertise of the team. You should understand the whole experiment but, if you are better in theory or in computation, go for it and help the team to achieve its goals!!!
- Visit to the Integration sphere facility. Experiments with the sphere should be planned in advance. The sphere can only be used under supervision.

12:30- 3:00 PM - Open Lab:

Tiger Teams shall design and start their experimental setups to measure the properties of their photometers. Measurements will include:

- Measurements of the LED FOV (emission and detection)
- Alignment of the LED detection via emission
  - I have noticed a dark spot at the center of some LEDS!!! Double check if it have a negative effect on the detection!!!
- Radiometric calibration at the integrating sphere

Radiance sources and sinks affecting visible and IR wavebands



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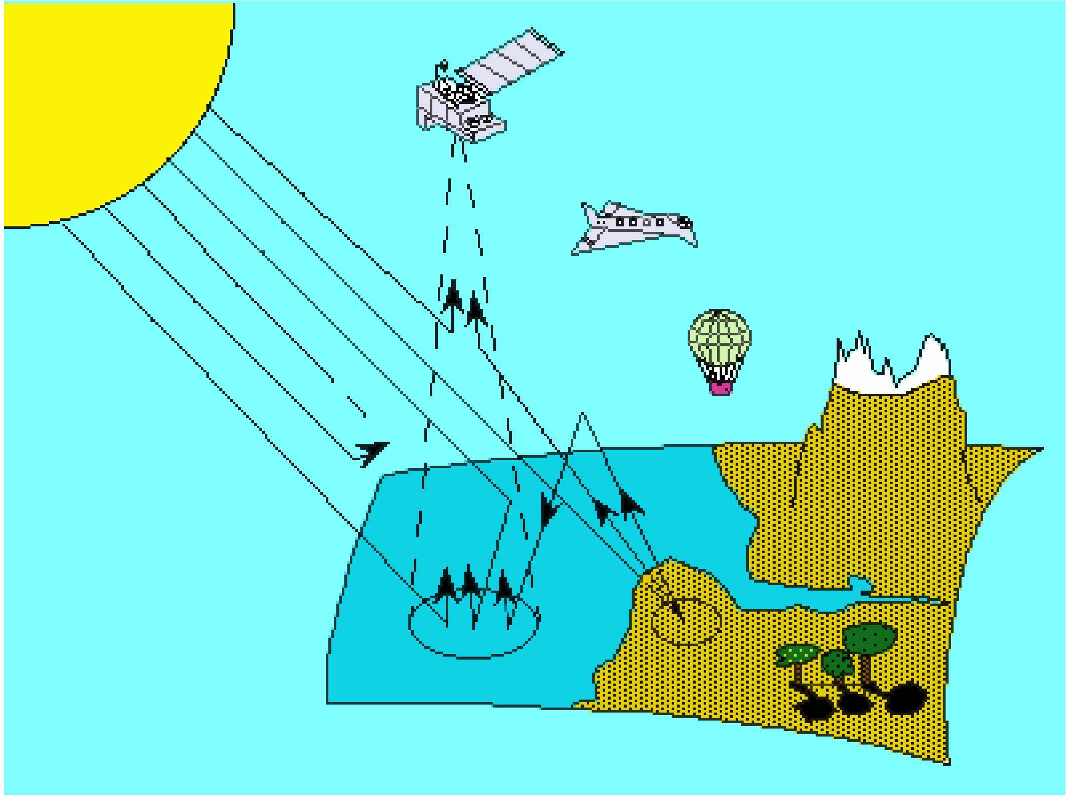
Solar Energy Paths



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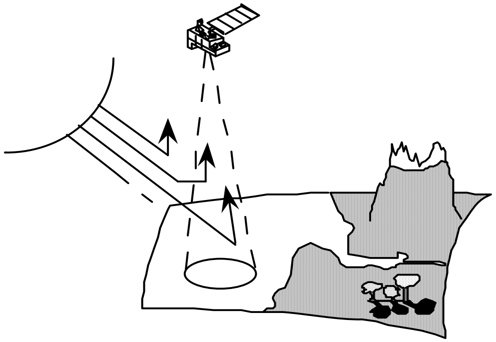
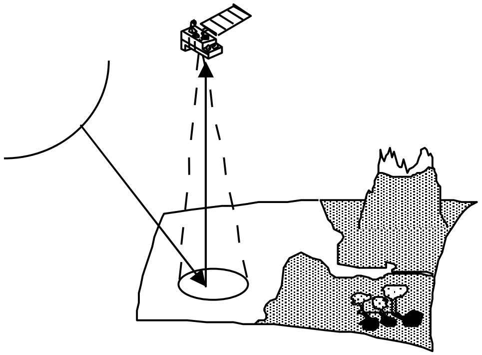
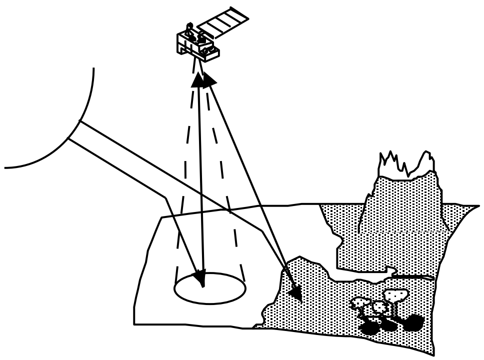


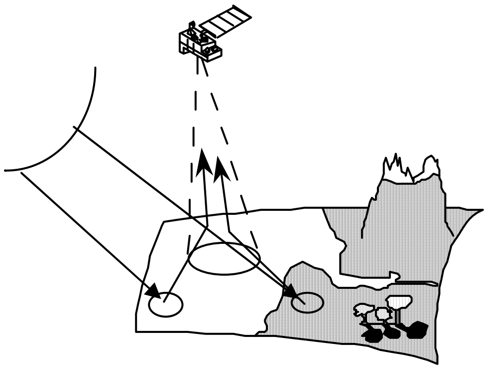
atmospheric contribution



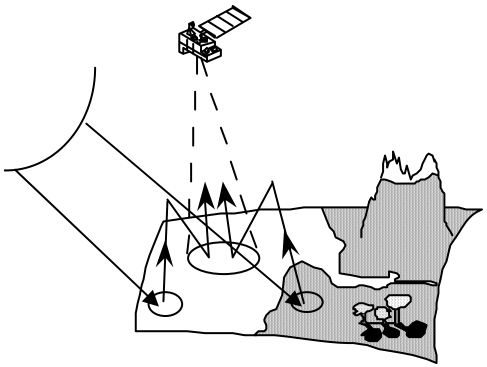
direct + direct



diffuse + direct



direct + diffuse



multiple scattering

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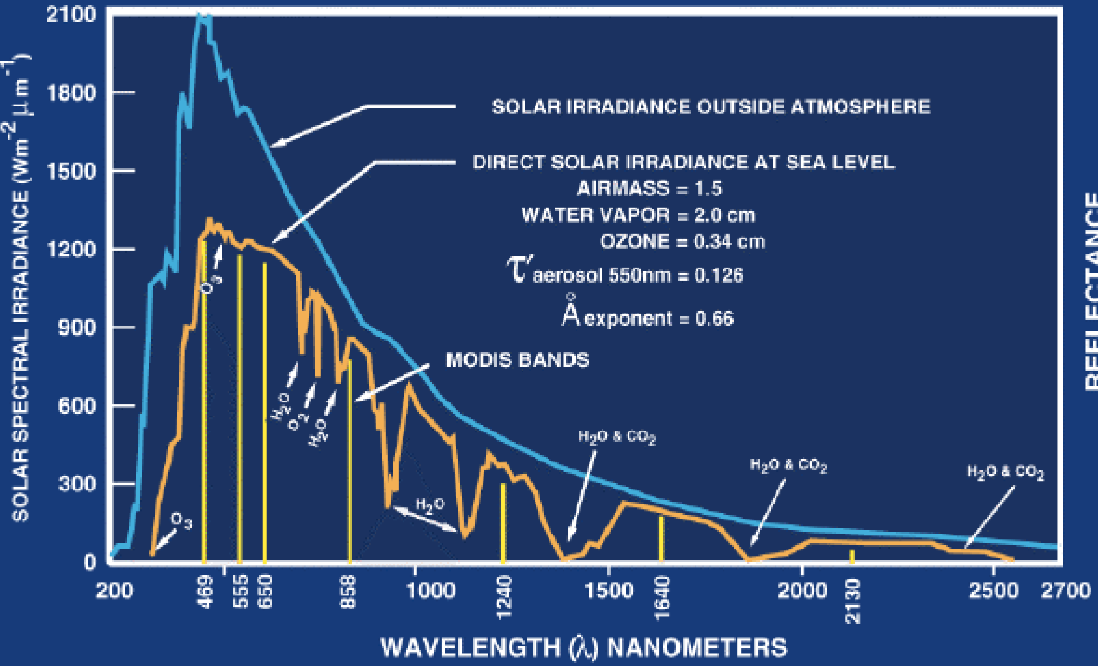
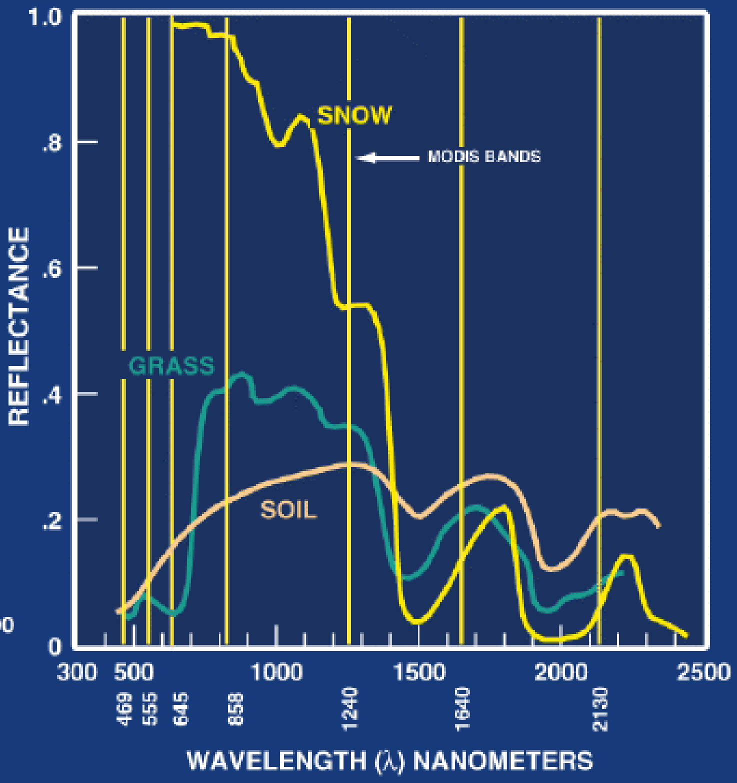
Solar (reflective) spectral domain





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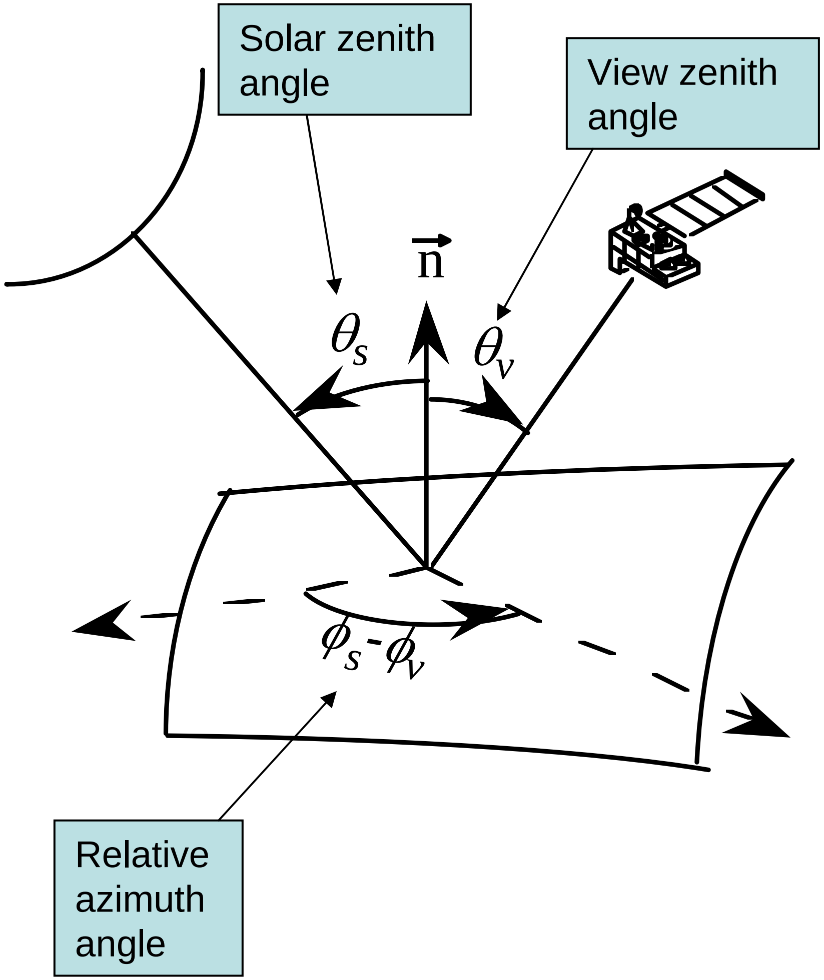
Observation Geometry



Solar zenith angle

View zenith angle

Relative azimuth angle

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Solution of the Radiative Transfer in the reflective domain for non absorbing atmosphere and lambertian ground

Atmospheric reflectance

Ground reflectance
(= albedo for lambertian)

$$\rho_{app}\left(\theta_s,\theta_v,\phi\right)=\rho_{atm}\left(\theta_s,\theta_v,\phi\right)+T_{atm}(\theta_s)T_{atm}(\theta_v)\frac{\rho_{ground}}{1-\rho_{ground}S_{atm}}$$

Atmospheric
Transmissions

Apparent reflectance at satellite level

Atmosphere
spherical albedo

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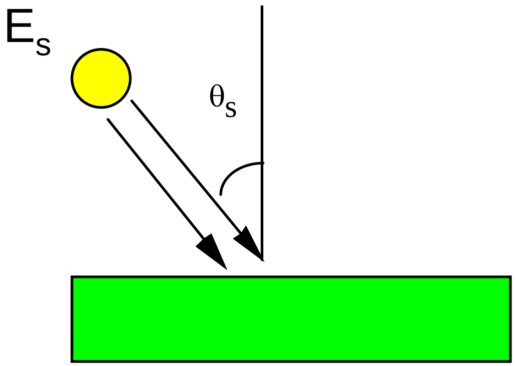
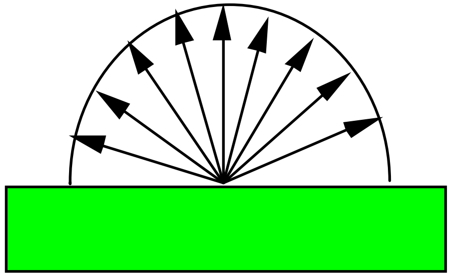
Perfect Lambertian Reflector

Radiance of the Perfect Lambertian Reflector

$$\int_0^{\pi}\int_0^{2\pi} RPLF(\theta_S,\theta,\phi)\cos(\theta)\sin(\theta)\,d\theta\,d\phi = E_s\cos(\theta_s)$$





Isotropic radiation

$$\rho_{Perfect\quad Lambertian\quad reflector}(\theta_S,\theta_V,\phi)=1$$

$$\rho_{Lambertian\quad reflector}(\theta_S,\theta_V,\phi)=\rho$$

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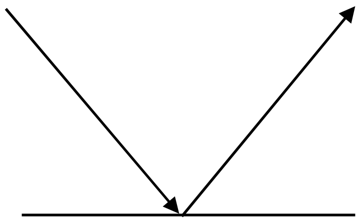
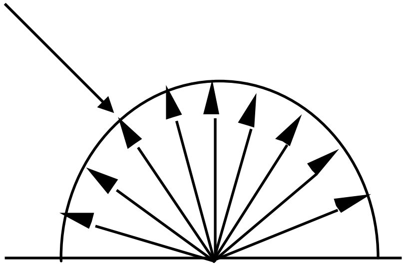
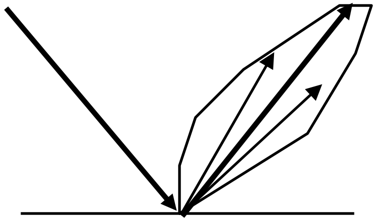
Different Types of Reflectors



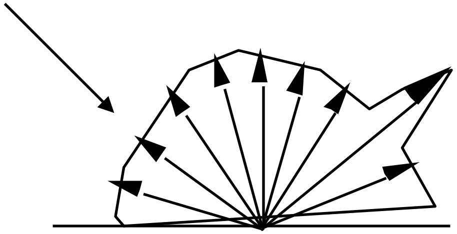
Specular reflector (mirror)



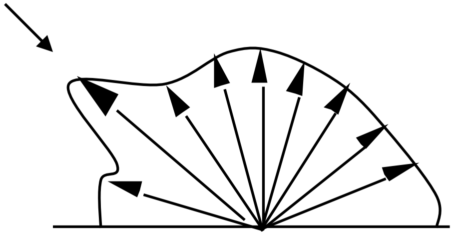
diffuse reflector (lambertian)



Nearly Specular reflector (water)



nearly diffuse reflector



Hot spot reflection

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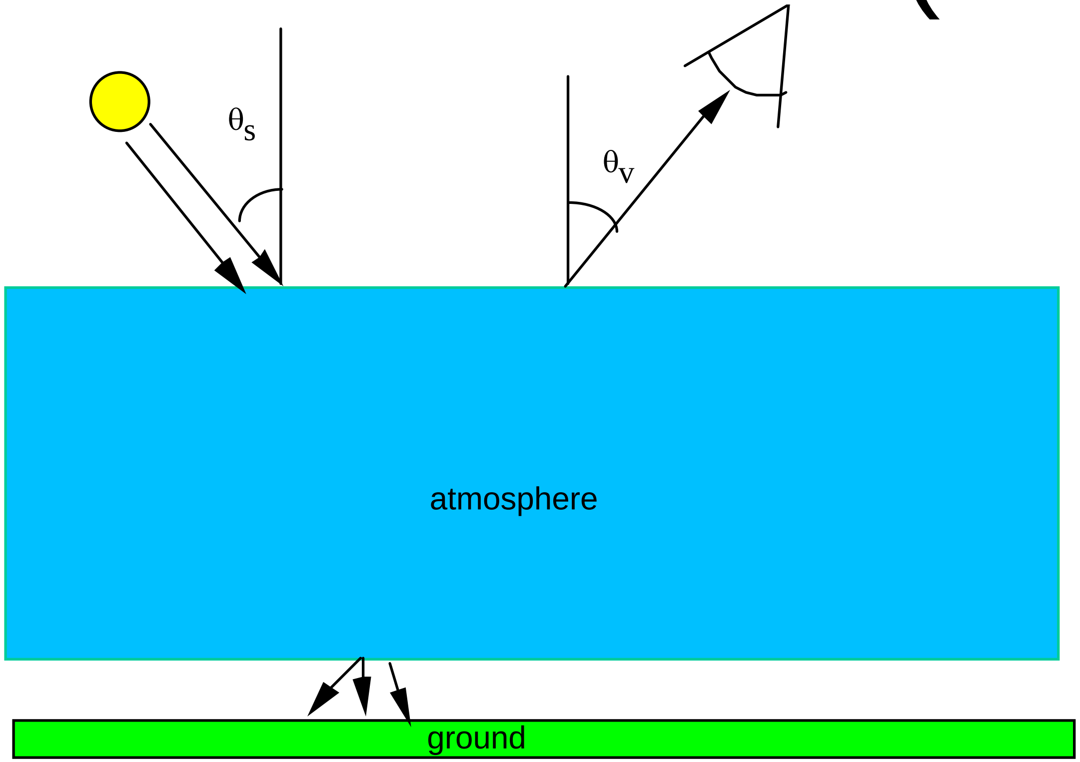
SRTE 1 interaction (cont.)



$$\rho_{app} = \rho_{atm} + \frac{E_o}{E_i}$$

$$\frac{E_o}{E_i} = \frac{T(\theta_v)E_r}{E_i} = \frac{T(\theta_v)\rho_{ground}E_t}{E_i} = T(\theta_v)\rho_{ground}T(\theta_s)$$

$$\rho_{app} = \rho_{atm} + T(\theta_v)\rho_{ground}T(\theta_s)$$

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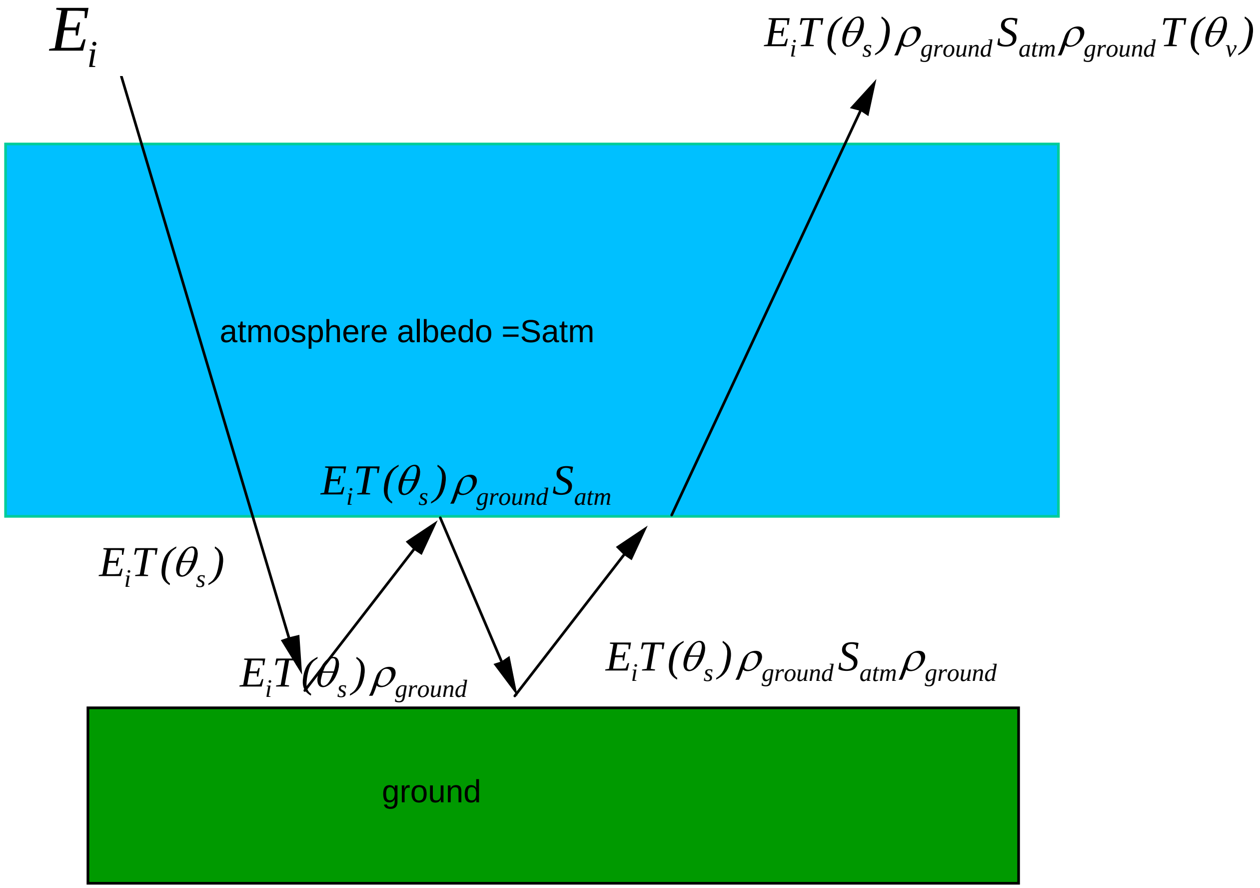
SRTE 2 interactions



E_i

$E_i T(\theta_s)\rho_{ground} S_{atm} \rho_{ground} T(\theta_v)$

atmosphere albedo =Satm

$E_i T(\theta_s)\rho_{ground} S_{atm}$

$E_i T(\theta_s)$

$E_i T(\theta_s)\rho_{ground}$

$E_i T(\theta_s)\rho_{ground} S_{atm} \rho_{ground}$

ground

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SRTE Multiple Interactions

$$\rho_{app} = \rho_{atm} + T(\theta_s)T(\theta_v)\rho_{ground}\left[1+\rho_{ground}S_{atm} + \left(\rho_{ground}S_{atm}\right)^2 + \left(\rho_{ground}S_{atm}\right)^3 \ldots\right]$$

$$1 + r + r^2 + r^3 + \ldots r^{n-1} = \frac{1-r^n}{1-r}$$

$\rho_{ground}S_{atm} < 1$ so when n->∞ then $(\rho_{ground}S_{atm})^n$ ->0

Therefore $$\left[1+\rho_{ground}S + \left(\rho_{ground}S\right)^2 + \left(\rho_{ground}S\right)^3 \ldots\right] = \frac{1}{1-\rho_{ground}S}$$

$$\rho_{app} = \rho_{atm} + T_{atm}(\theta_s)T_{atm}(\theta_v)\frac{\rho_{ground}}{1-\rho_{ground}S_{atm}}$$

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BRDF atmosphere coupling correction

Lambertian infinite target approximation

$$\rho_{app}(\theta_s,\theta_v,\phi)=\rho_{atm}(\theta_s,\theta_v,\phi)+T_{atm}(\theta_s)T_{atm}(\theta_v)\frac{\rho_{ground}}{1-\rho_{ground}S_{atm}}$$

BDRF atmosphere coupling approximation

$$\rho_{app}(\theta_s,\theta_v,\phi)=\rho_{atm}(\theta_s,\theta_v,\phi)+e^{-\tau/\mu_s}e^{-\tau/\mu_v}\rho_s(\theta_s,\theta_v,\phi)$$

$$+e^{-\tau/\mu_v}t_d(\theta_s)\bar{\rho}_s+e^{-\tau/\mu_s}t_d(\theta_v)\bar{\rho}'_s+t_d(\theta_v)t_d(\theta_s)\bar{\bar{\rho}}_s$$

$$+\frac{T_{atm}(\theta_s)T_{R+A}(\theta_v)S_{atm}\left(\bar{\bar{\rho}}_s\right)^2}{1-S_{atm}\bar{\bar{\rho}}_s}$$

$$\bar{\rho}_s(\mu_s,\mu_v,\phi)=\frac{\int_0^{2\pi}\int_0^1\mu L_{atm}^{\downarrow}(\mu_s,\mu,\phi')\rho_s(\mu,\mu_v,\phi'-\phi)d\mu d\phi'}{\int_0^{2\pi}\int_0^1\mu L_{atm}^{\downarrow}(\mu_s,\mu,\phi')d\mu d\phi'}$$

$$\bar{\bar{\rho}}_s(\mu_s,\mu_v,\phi)=\overline{\bar{\rho}'_s(\mu_s,\mu_v,\phi)}\qquad\bar{\rho}'_s(\mu_s,\mu_v,\phi)=\bar{\rho}_s(\mu_s,\mu_v,\phi)$$

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STRE for non absorbing atmosphere and lambertian ground

Atmospheric reflectance

Ground reflectance
(= albedo for lambertian)

$$\rho_{app}\left(\theta_s,\theta_v,\phi\right)=\rho_{atm}\left(\theta_s,\theta_v,\phi\right)+T_{atm}(\theta_s)T_{atm}(\theta_v)\frac{\rho_{ground}}{1-\rho_{ground}S_{atm}}$$

Atmospheric
Transmissions

Apparent reflectance at satellite level

Atmosphere
spherical albedo

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The composition of the atmosphere

Permanent Constituents		Variable constituents	
Constituent	% by volume	Constituent	% by volume
Nitrogen (N_2)	78.084	Water Vapor (H_2O)	0.04
Oxygen (O_2)	20.948	Ozone (O_3)	12 x 10^{-4}
Argon (Ar)	0.934	Sulfur dioxide (SO_2)[b]	0.001 x 10^{-4}
Carbon dioxide (CO_2)	0.033	Nitrogen dioxide (NO_2)	0.001 x 10^{-4}
Neon (Ne)	18.18 x 10^{-4}	Ammonia (NH_3)	0.001 x 10^{-4}
Helium (He)	5.24 x 10^{-4}	Nitric oxide (NO)	0.0005 x 10^{-4}
Krypton (Kr)	1.14 x 10^{-4}	Hydrogen sulfide (H_2S)	0.00005 x 10^{-4}
Xenon (Xe)	0.089 x 10^{-4}	Nitric acid vapor	trace
Hydrogen (H_2)	0.5 x 10^{-4}		
Methane (CH_4)	1.5 x 10^{-4}		
Nitrous Oxide (N_2O)	0.27 x 10^{-4}		
Carbon Monoxide (CO)	0.19 x 10^{-4}		

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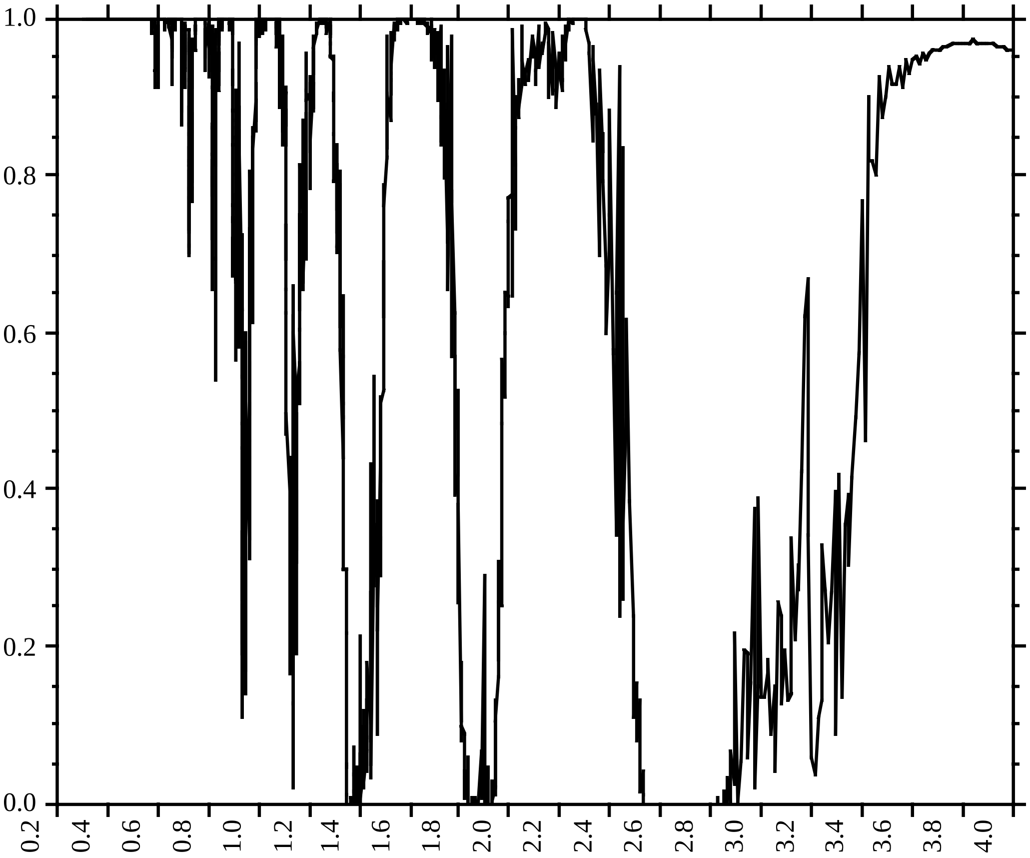
Gaseous Absorption (H_2O)



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Modified SRTE to account for absorption

In case of a pure molecular atmosphere (no aerosol) we can write:

$$\rho_{app}(\theta_s,\theta_v,\phi) = Tg^{other\ gases}(m,U_{gaz})\left[\rho_{atm}(\theta_s,\theta_v,\phi) + Tg^{H_2O}(m,U_{H_2O})T_{atm}(\theta_s)T_{atm}(\theta_v)\frac{\rho_{ground}}{1-S_{atm}\rho_{ground}}\right]$$

m is the air mass = $1/\cos(\theta_s)+1/\cos(\theta_v)$
U_{gaz} is the gaz concentration

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Phase function

- The phase function, P(Θ), describe the distribution of scattered radiation for one or an set of particles. It is normalized such as:

$$\int_0^{2\pi}\int_0^{\pi} P(\Theta)d\omega = 4\pi$$

since $$\int_0^{2\pi}\int_0^{\pi} P(\Theta)\sin(\theta)d\theta d\phi = 2\pi\int_0^{\pi} P(\theta)\sin(\theta)d\theta$$

we have $$\int_0^{\pi} P(\theta)\sin(\theta)d\theta = 2$$

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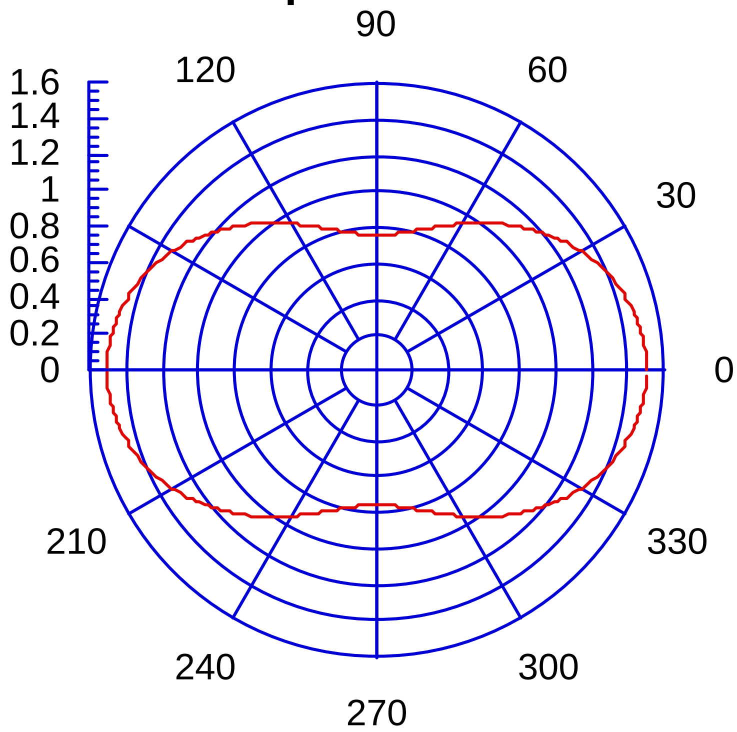
Rayleigh/molecular scattering 1/4

- Rayleigh or molecular scattering refers to scattering by atmospheric gases, in that case:

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



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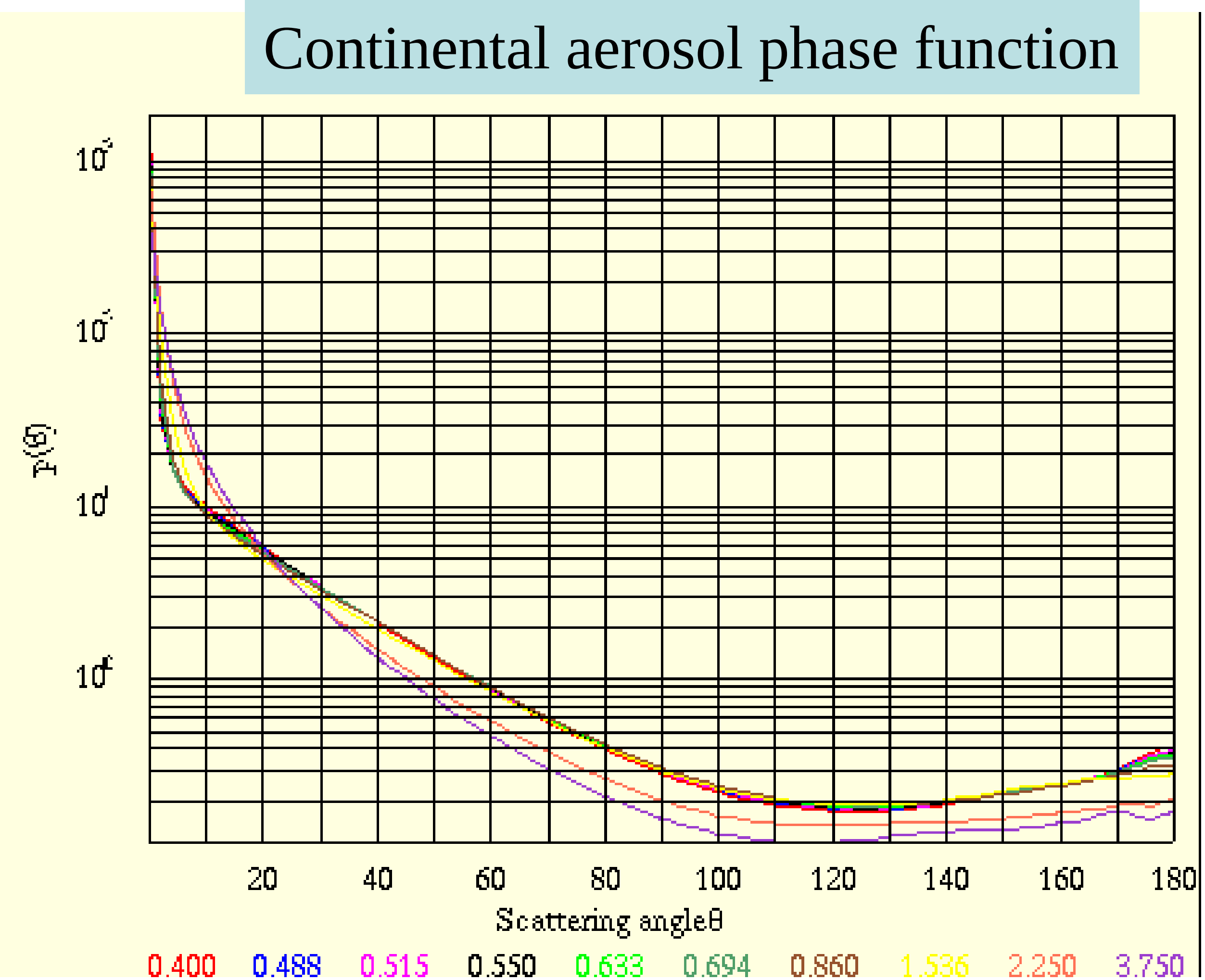
Aerosol scattering 2/5


Continental aerosol phase function

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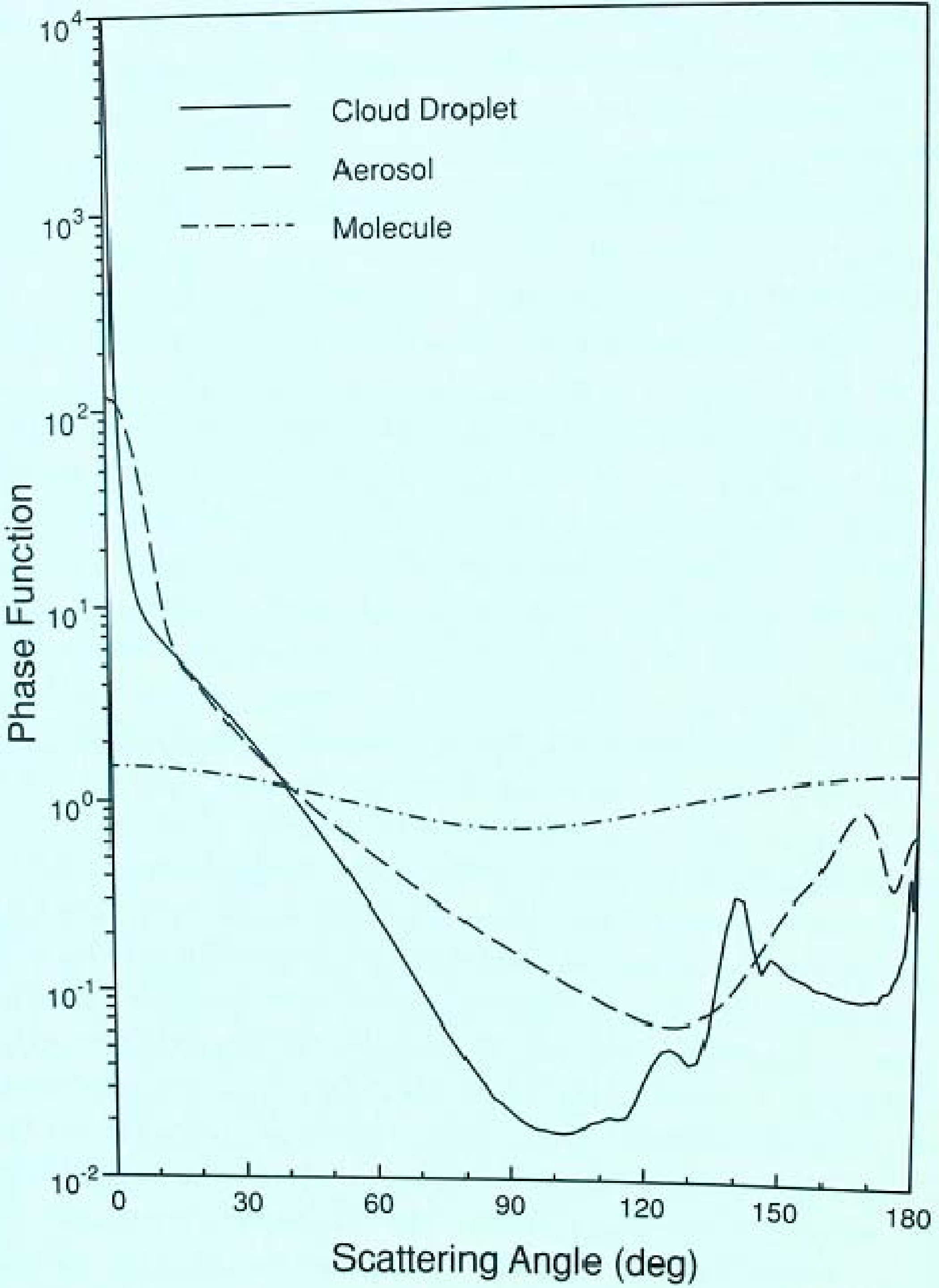

Cloud Droplet
Aerosol
Molecule
Phase Function
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
0
30
60
90
120
150
180
Scattering Angle (deg)

Some Useful Radiative Transfer codes:

Mie codes:

Homogeneous Sphere:
ftp://climate1.gsfc.nasa.gov/wiscombe/Single_Scatt/Homogen_Sphere/Exact_Mie
Layered Sphere:
ftp://climate1.gsfc.nasa.gov/wiscombe/Single_Scatt/Coated_Sphere

Disort:

For Fortran 77:
ftp://climate1.gsfc.nasa.gov/wiscombe/Multiple_Scatt/DISORT1.2

For Fortran 90:
ftp://climate1.gsfc.nasa.gov/wiscombe/Multiple_Scatt/DISORT1.3

Other Multiple Scattering Codes:
ftp://climate1.gsfc.nasa.gov/wiscombe/Multiple_Scatt

SBDART:

http://www.paulschou.com/tools/sbdart/