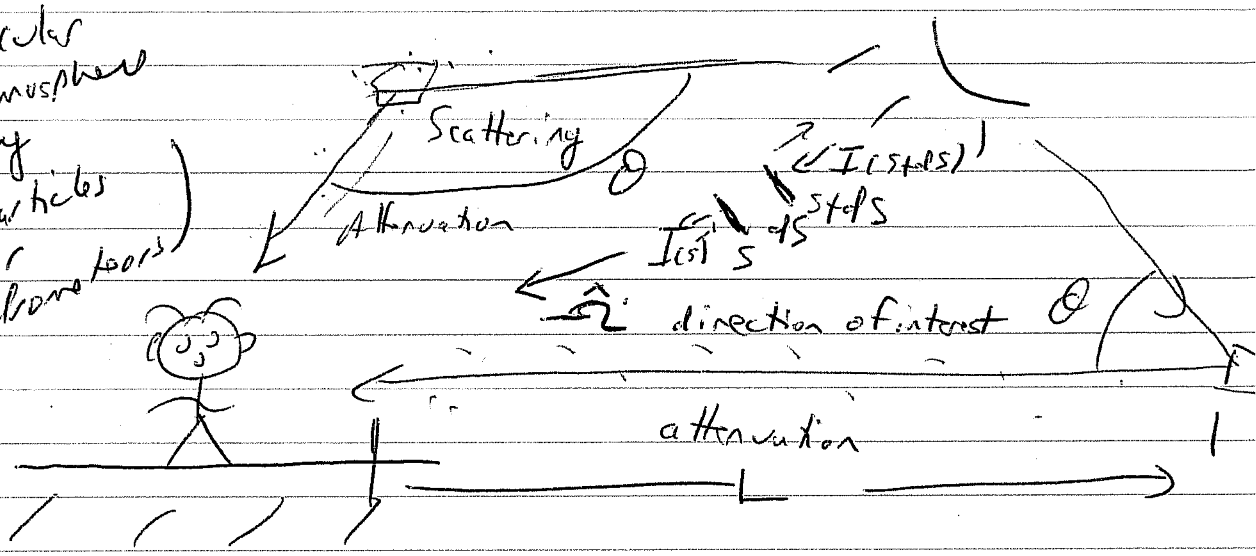
Overview of Scattering in the Atmosphere

Molecular atmosphere only (no particles or hydrometeors)

or also from those



1) Direct beam attenuation, $t = e^{-\beta_{ext} L}$

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

2) Need to know about angular scattering by {Molecules, Particles, hydrometeors}

Generally

$$dI = I(s+ds) - I(s)$$

(1) $$dI = dI_{ext} + dI_{emit} + dI_{scat}$$

lder ideas

$dI_{ext} = -\beta_{ext} I ds = -\beta_{ext} ds\, I$ $\qquad \beta_{ext} = \beta_{abs} + \beta_{sca}$

$dI_{emit} = \beta_{abs} ds\, B[T(s)]$ $\qquad \beta_{abs} = \beta_{ext}(1 - \bar{\omega})$ $\quad \bar{\omega} = \frac{\beta_{sca}}{\beta_{ext}}$

Single Scatter Albedo

$dI_{scat} = \beta_{sca}\, ds \frac{1}{4\pi} \int_{4\pi} P(\hat{\Omega}', \hat{\Omega}) I(\hat{\Omega}') d\omega'$

solid angle

Radiance as a function of direction at s

$\beta_{sca} = \bar{\omega} \beta_{ext}$

Scattering Phase function that describes the probability that incoming light of direction $\hat{\Omega}'$ is scattered ...

Summary: Generally

(2) $dI(s) = -\beta_{ext}\,ds\,I(s) + \beta_{abs}\,ds\,B[T(s)] + \beta_{sca}\,ds \dfrac{\int_{4\pi} P(\hat{\Omega}', \hat{\Omega}) I(\hat{\Omega}')\,d\omega}{4\pi}$

or

Extinction Emission Scattering

(3) $\dfrac{dI(s)}{\beta_{ext}\,ds} = -I(s) + (1-\bar{\omega})B[T(s)] + \bar{\omega}\int_{4\pi} \dfrac{P(\hat{\Omega}', \hat{\Omega})\, I(\hat{\Omega}', s)\,d\omega}{4\pi}$

$\bar{\omega}$ = Single Scattering Albedo = $\dfrac{\beta_{sca}}{\beta_{ext}} = \dfrac{\beta_{ext} - \beta_{abs}}{\beta_{ext}}$

(2) and (3) are the general forms of Equations that describe radiation transfer.

Parameters to Study:

$\beta_{abs} = \sum_i \sigma_{abs,i} N_i$

$\left(\dfrac{1}{\text{distance}}\right)$ Distance^2 $\dfrac{\text{\# Things that \{emit\} absorb of type } i}{\text{Distance}^3}$

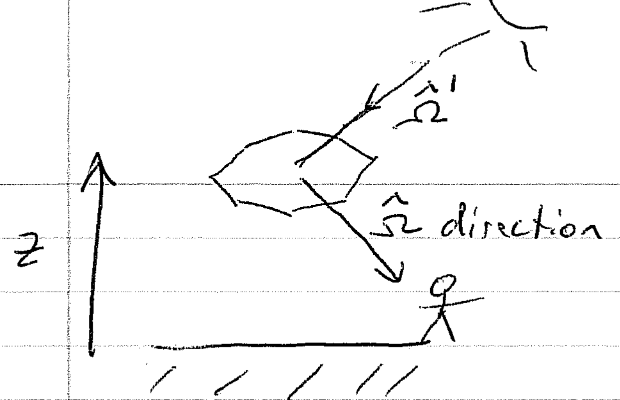
$\beta_{sca} = \sum \sigma_{sca,i} N_i$

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

$\bar{\omega} = \dfrac{\beta_{sca}}{\beta_{ext}}$ Probability that the extinction event results in Scattering

$P(\hat{\Omega}', \hat{\Omega}) \sim$ Probability that light $\hat{\Omega}'$ Scattered by things goes in direction $\hat{\Omega}$.

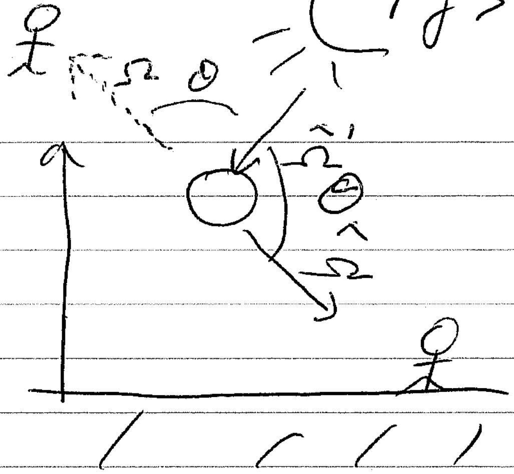
Some thoughts on the Phase function follow.



"Large" oriented ice crystals:
Z direction important,
Use $P(\hat{\Omega}', \hat{\Omega}, \hat{z})$

(Won't consider)

(Hydrodynamics
determines
orientation)



Spherical Particle or
randomly oriented
Non spherical Particle
"Small" ice crystals, aerosol
Generally only need Θ,

$\cos\Theta \equiv \hat{\Omega}' \cdot \hat{\Omega}$

$P(\hat{\Omega}', \hat{\Omega}) = P(\cos\Theta)$

Normalization of the Phase function for spheres or
randomly oriented nonspherical particles:

$$\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} P(\cos\Theta)\sin\Theta\, d\Theta\, d\phi = 1 \qquad \text{or}$$

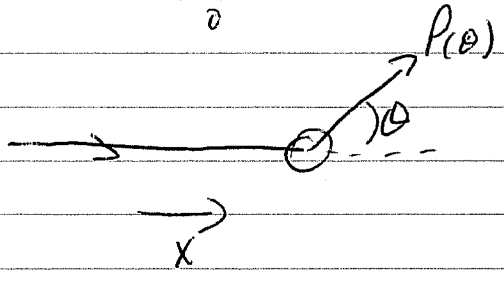
Do ϕ, $\mu \equiv \cos\Theta$ $\quad d\mu = -\sin\Theta\, d\Theta$

$$\frac{1}{2}\int_0^{\pi} P(\cos\Theta)\sin\Theta\, d\Theta = \frac{1}{2}\int_{-1}^{1} P(\mu)\, d\mu = 1$$

<u>Asymmetry Parameter</u>: g $\qquad -1 \leq g \leq 1$

Used for 1-D Models

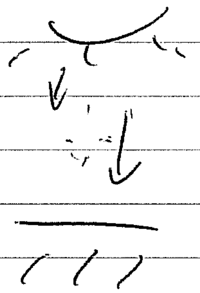
$$g \equiv \frac{1}{2}\int_0^{\pi} P(\cos\Theta)\cos\Theta\sin\Theta\, d\Theta = \frac{1}{2}\int_{-1}^{1} P(\mu)\,\mu\, d\mu$$



$\cos\Theta$ brings out the
Part of $P(\Theta)$ that
goes in the original direction
($+x$ in this case)

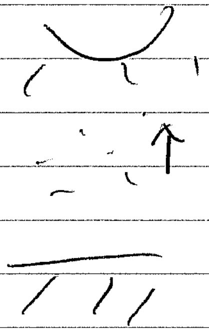
Cases of asymmetry Parameter

$g = 1$



All scattered light in the forward direction

$g = -1$



All Scattered light in backward Direction.

In 1-D, Probability forward Scatter $= \frac{1+g}{2}$

$-1 \leq g \leq 1$

Backward Scatter $= \frac{1-g}{2}$

Generally $P(\Theta)$ and g must be calculated from Mie theory or appropriate theory. Simple model Phase function is

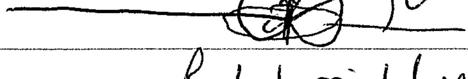
Henyey - Greenstein Phase function:

$$P_{HG}(\cos\Theta) = \frac{1-g^2}{(1+g^2-2g\cos\Theta)^{3/2}}$$

Rayleigh Phase function for air molecules in Vis:

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

will study in depth



[illegible]