Monte Carlo Calculation of Cloud Layer Reflectance for Isotropic, Rayleigh & Forward Scattering

A. Gambhir & W. A. van Wijngaarden
Physics Dept., York University, Toronto, Canada

Abstract

Scattering occurs when cloud particles interact with incoming radiation. Rayleigh & isotropic scattering applies for small particles. Mie scattering which is predominantly in the forward direction occurs for larger particles. Photons scatter numerous times in the cloud before exiting from top or bottom. The reflectance was found for different incident angles for the case of zero cloud absorption. Photons incident at near horizontal trajectory are less likely to be transmitted through the cloud than those incident perpendicularly. Reflectance is lower for forward scattering than for isotropic or Raleigh scattering.

Phase Function

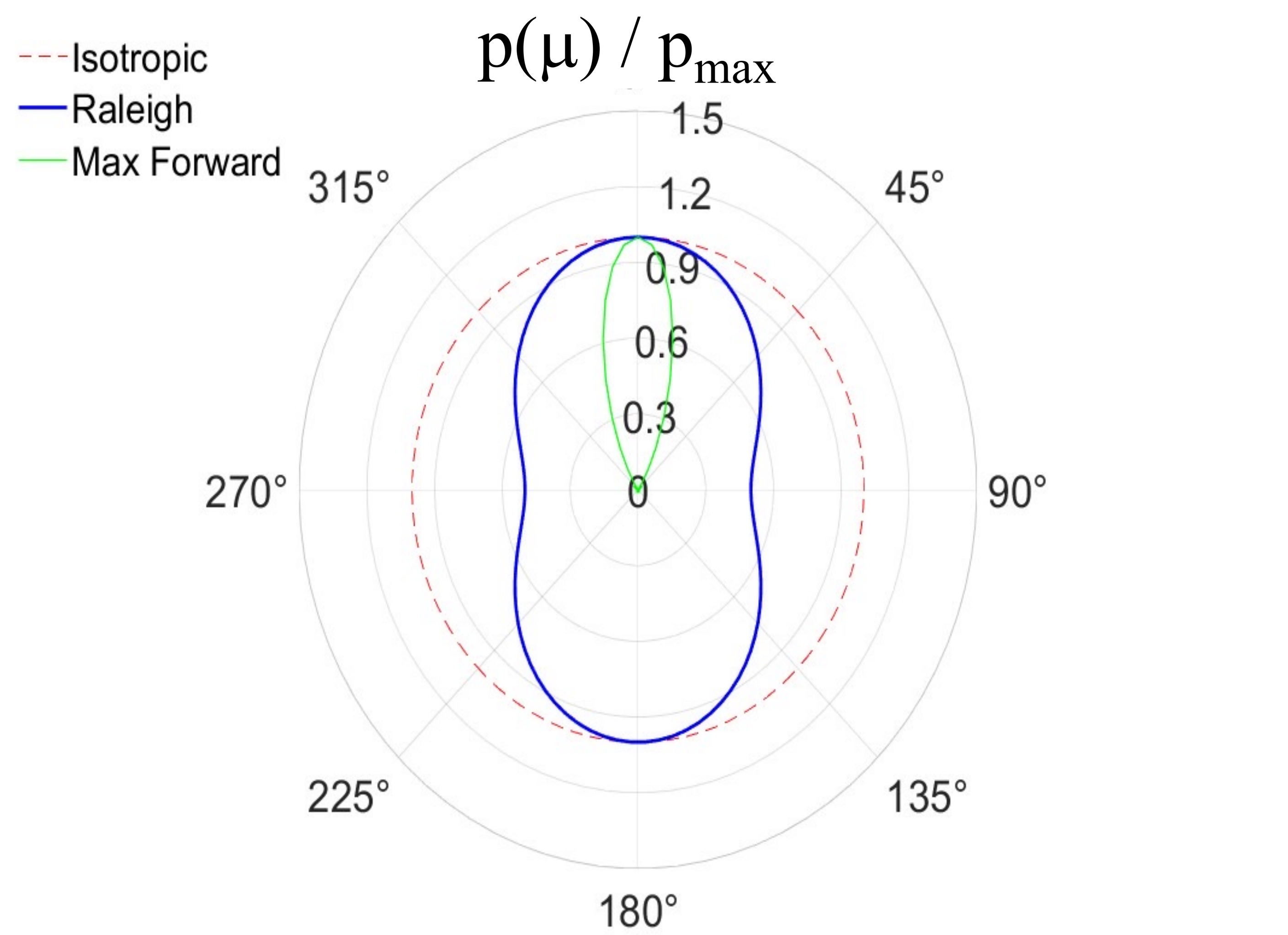
The phase function p(μ) is the probability that an incident photon is scattered by angle $\theta = \cos^{-1} \mu$.

a) Isotropic Scattering $P(\mu) = 1$

b) Raleigh Scattering $P(\mu) = \frac{3}{4}(1 + \mu^2)$

c) Forward Scattering $P(\mu) = \sum_l P_l(\mu)(2l + 1)w_l^{(p)}$

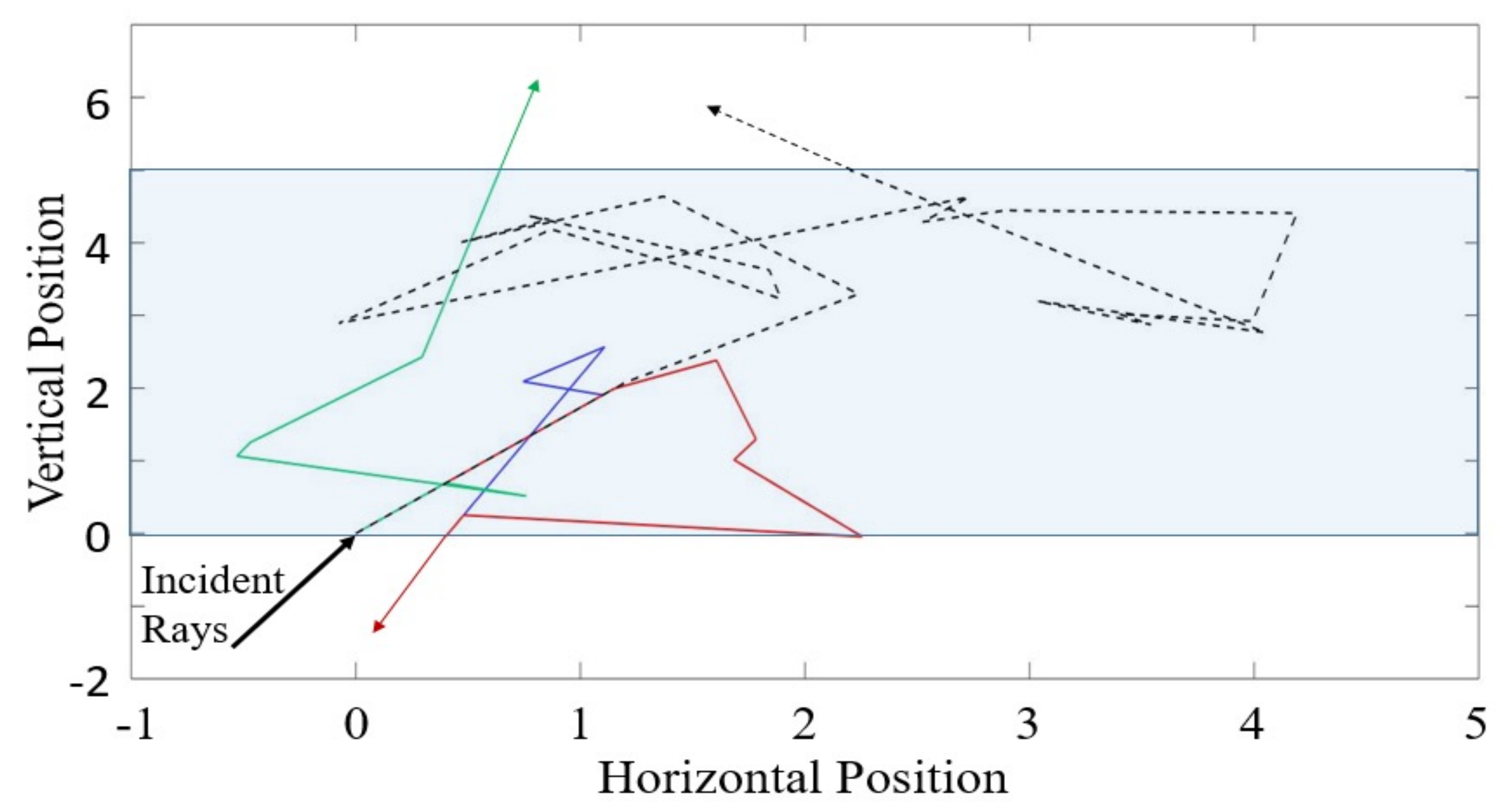
where $P_l(\mu)$ is Legendre polynomial of degree l and $w_l^{(p)}$ are from W. A. van Wijngaarden & W. Happer, **2022**, *Atmos. & Oceanic Physics* arXiv: 2205.09713.



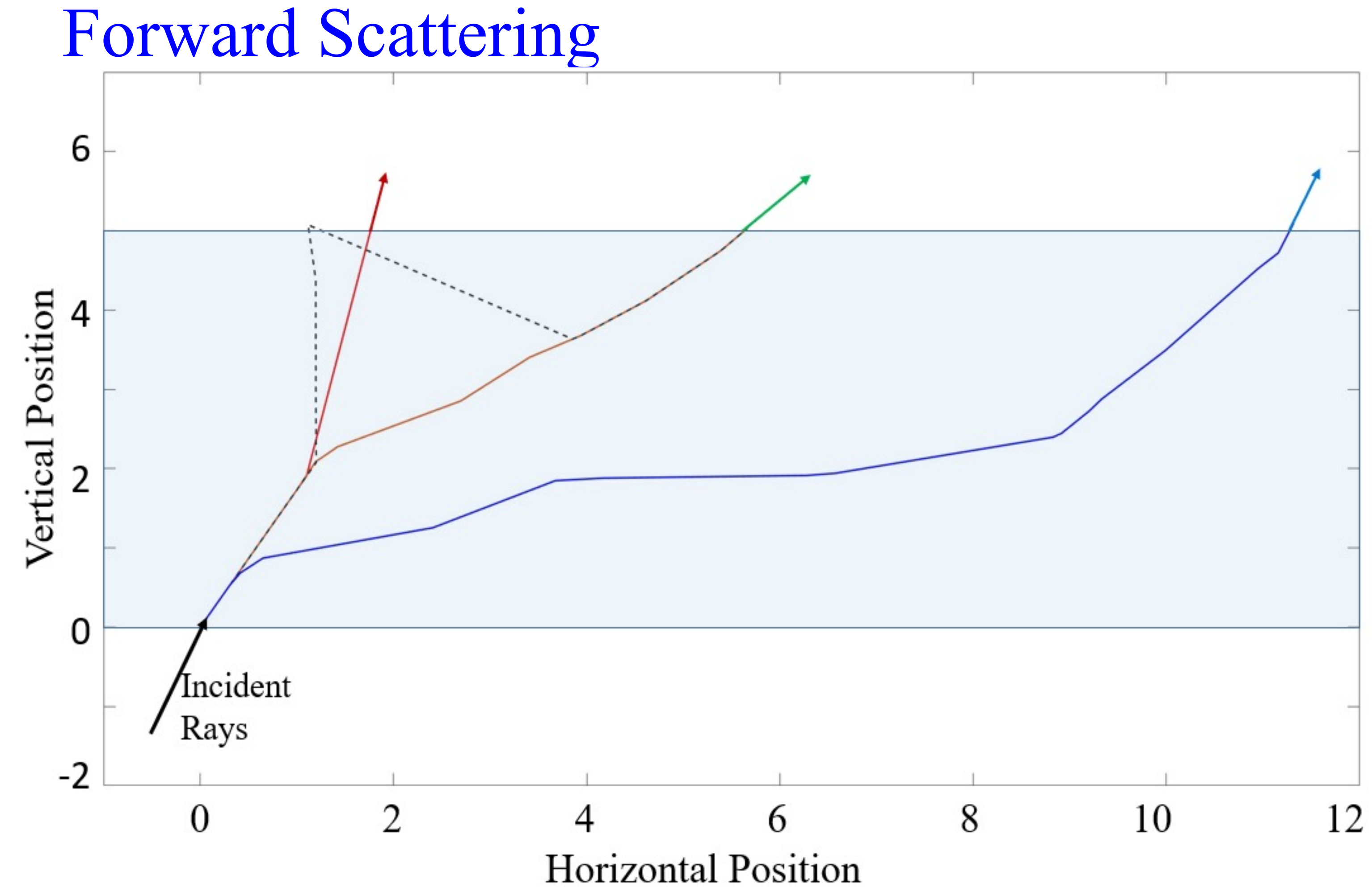
Procedure

The Monte Carlo method considers an incoming photon moving through a cloud layer. The probability photon is scattered is $(1 - e^{-x})$ where x was set to 0.1, the incremental distance the photon moves. A random number generator was used to find whether a scatter event occurred and if so a second random number generator was used to find the scattered angle using the phase function. This was repeated until the scattered photon emerges from either the cloud top or bottom. For isotropic & Raleigh (forward) scattering, the trajectories of 100,000 (10,000) photons were considered to find the cloud reflectance. The figures below show the random walks for 4 different photons.

Raleigh Scattering

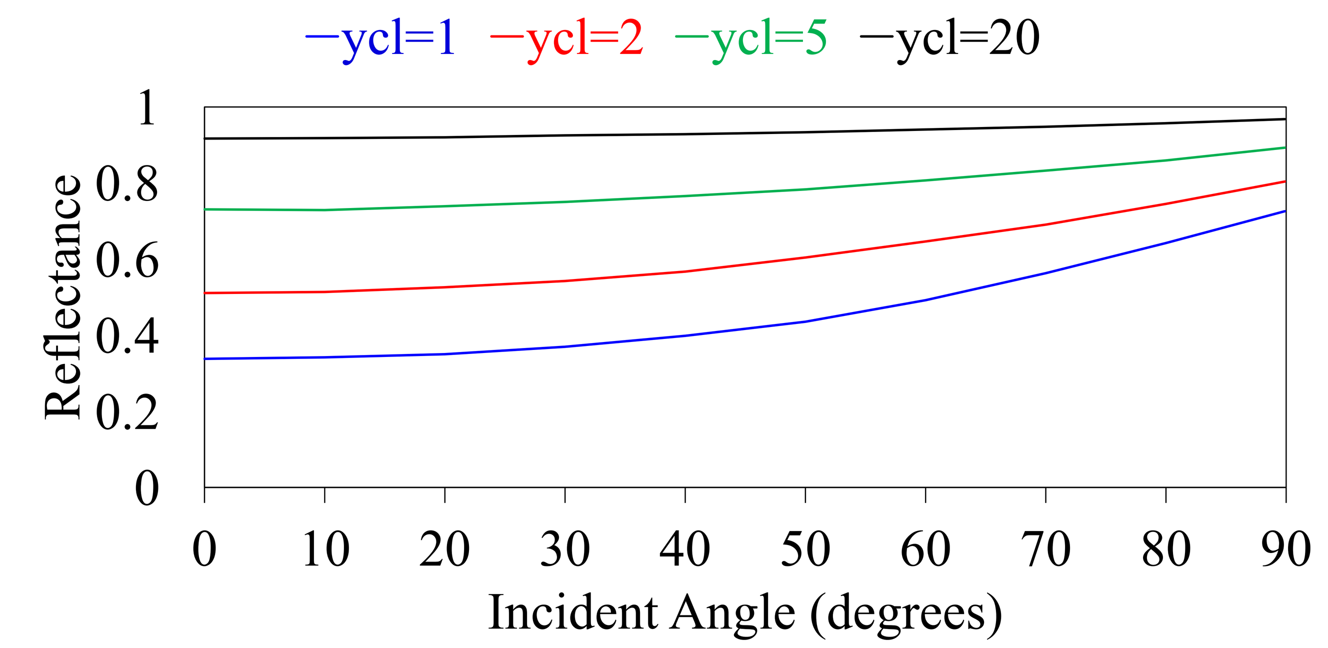


Forward Scattering

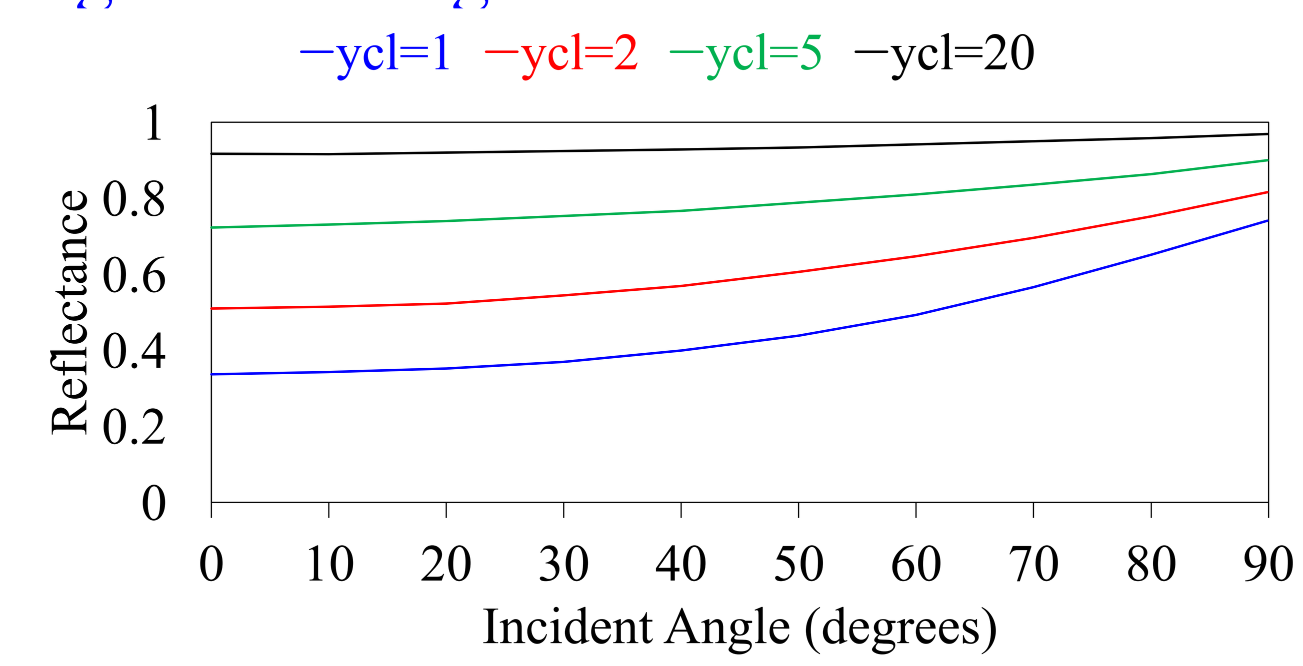


Reflectance Dependence on Incident Angle for cloud of optical thickness y_{cl}

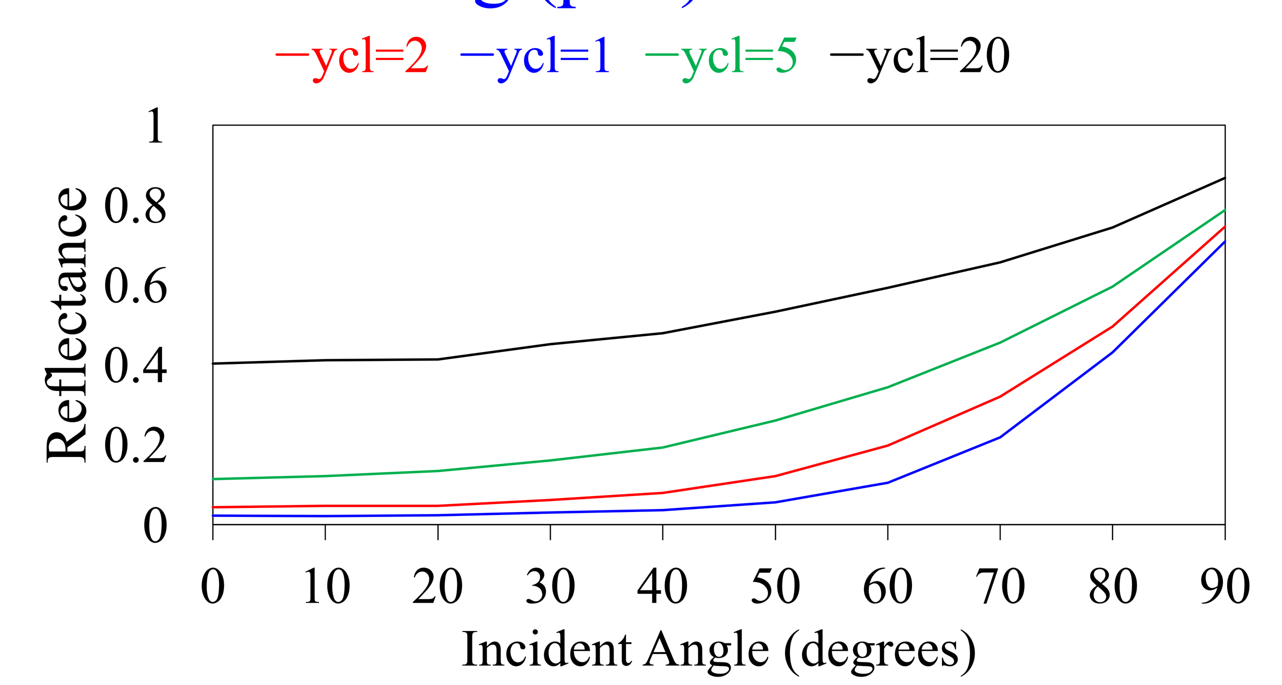
Isotropic



Raleigh Scattering



Forward Scattering (p=5)



Conclusions

The dependence of cloud reflectance on incident angle was found for isotropic, Raleigh and forward scattering. Cloud absorption was not considered. Reflectance increased for thicker clouds and for nearly horizontal photons having incident angle θ ~ 90°. The Matlab programs ran on a desktop computer. The eventual goal is to investigate cloud scattering effect on radiative forcing to examine possible climate change.