A 3D polarized Monte Carlo LIDAR system simulator for studying cirrus inhomogeneities effects on Caliop/Calipso measurements

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Scientific context :

LIDAR is a powerful tool for deriving the cirrus properties, but the main difficulty to overcome is the significant extinction of the Lidar beam in its path through the cloud, and one must take into account multiple scattering (Hogan, 2008, Hu et al., 2001). In reality, the "apparent" backscatter estimated by the LIDAR system from the "basic Lidar equation" is not equal to the "true" backscatter of the cirrus as multiple scattering is omitted. The cirrus properties are also assumed to be horizontally homogeneous at each level into and around the Lidar system "footprint".
Our objective is to quantify the effects of cirrus inhomogeneities represented by 3D spatial fluctuations of extinction on the apparent backscatter and the apparent depolarization ratio measured by Caliop/Calipso.

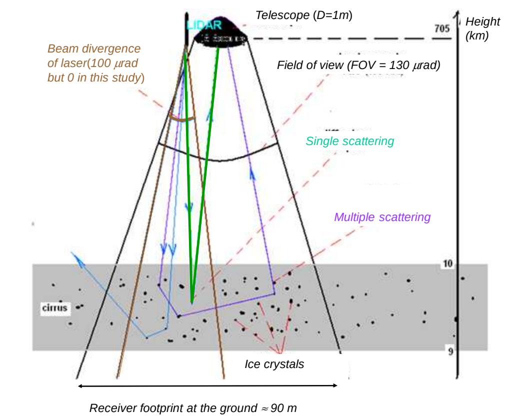
Methodology :

We developed a 3D polarized LIDAR simulator based on 3DMCPol (Cornet et al., 2010), a forward Monte Carlo radiative transfer model using the local estimate method which allows the computation of the Stokes vectors $S=(I,Q,U,V)$.

Our LIDAR simulator calculates the apparent total backscatter $\tilde{\beta}_{3D}(z)$ and the apparent depolarization ratio $\tilde{\delta}_{3D}(z)$, where *z* is the height above ground, as "seen" by Caliop/Calipso.

We estimated differences between $\tilde{\beta}_{3D}(z)$ and $\tilde{\beta}_{PP}(z)$,and between $\tilde{\delta}_{3D}(z)$ and $\tilde{\delta}_{PP}(z)$, where $\tilde{\beta}_{PP}(z)$ and $\tilde{\delta}_{PP}(z)$ are the apparent backscatter and depolarization ratio as "seen" by Caliop/Calipso if, at each vertical discretization level, the cloud is assumed homogeneous plane-parallel with the extinction equal the mean horizontal extinction of inhomogeneous cloud.

Lidar system scheme



Conditions of simulation

- Lidar system parameters
- Laser beam divergence = 0
- Linearly polarized laser
- λ_{laser} = 352 nm
- FOV = 130 µrad
- $D_{telescope}$ = 1 m
- Height : 705 km
- Laser entrance pixels : middle of cloud domain

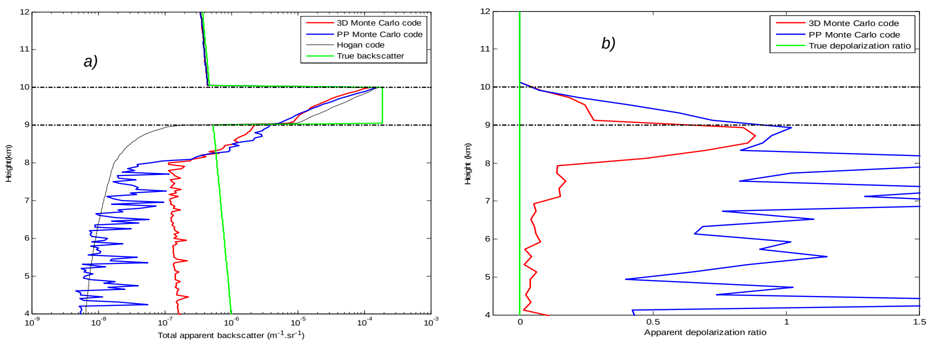
- Atmospheric parameters
- No sun
- No ground albedo
- Gaz optical depth from Hansen and Travis (1974)
- Gaz depolarization factor (90°) = 0.0275
- Gaz phase function : Rayleigh theory

- Numerical parameters
- Horizontal extension domain = 1 km
- Vertical extension domain = 20 km
- Horizontal resolution = 20 m
- Vertical resolution = 25 m
- Pixels number : *Nx* = *Ny* = 50, *Nz* = 400
- Each simulation : 70 independent batches of 10 millions of photons; at each batch, inhomogeneous cloud is reinitialized.

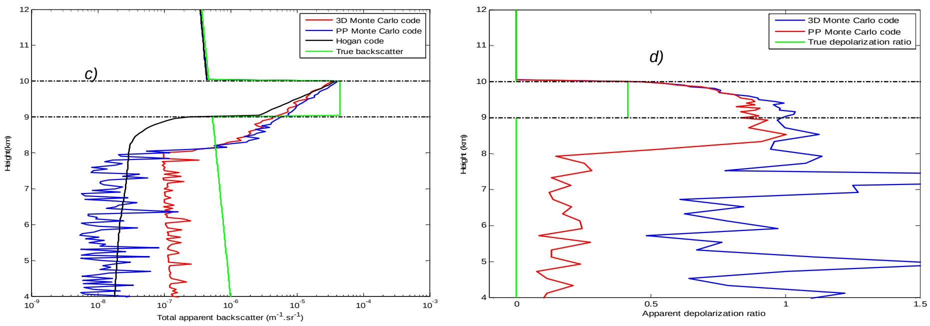
- Cloud parameters
- Mean optical depth = 3
- Base and top height = 9 and 10 km

- Inhomogeneous cloud model :
-random horizontal fluctuation of extinction but vertically homogeneous extinction.
- Mean optical depth is constrained to be equal to 3 every 100×100 m2 (size of footprint).

Case 1 : Spherical ice crystals, R_{eff} = 10 µm, Lognormal distribution, Mie Theory



Case 2 : Rough plate ice crystals, R_{eff} = 25 µm , Aspect ratio = 0.5, Gamma distribution ,IGOM, Yang and Liou (1996)



Total apparent backscatter and apparent depolarization ratio as a function of height for homogeneous plane parallel cloud (PP, blue line), for the random inhomogeneous cloud (3D, red line). The true backscatter and the true depolarization ratio are shown (green line). Simulations done with the fast Hogan's LIDAR simulator (Hogan et al. ,2008) are plotted for comparisons (black line). Figures a) and b) are case 1. Figures c) and d) are case 2

Early results

- Significant differences exist between our LIDAR simulator and Hogan's lidar simulator, especially 1 km beneath the cloud base.
- Our lidar simulation shows lot of spikes (due to the locate estimate method).
- Effects of 3D spatial fluctuations of cloud extinction on the apparent backscatter seem to be negligible.
- Effects of 3D spatial fluctuations of cloud extinction on the apparent depolarization ratio seem not to be negligible : $\tilde{\delta}_{3D}(z)<\tilde{\delta}_{PP}(z)$
  - This bias between $\tilde{\delta}_{3D}(z)$ and $\tilde{\delta}_{PP}(z)$ increases with distance from the top of the cloud,
  - This bias is larger for spherical ice crystals than for rough plate ice crystals.

Perspectives

- In order to smooth out the spikes, truncation or delta scaling methods shouldn't be used, because they introduce bias with polarized phase function (not shown in this poster). Variance reduction methods presented in Buras and Mayer (2010) should be implemented in our LIDAR simulator.
- In order to generalize these early results, sensitivity tests must be carried out with more realistic fluctuations of cirrus extinction and with other ice crystals shapes.

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Acknowledgements : This work is supported by the Programme National de Télédétection Spatiale (PNTS) of the Institut National des Sciences de l'Univers (INSU).

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