Fast high spectral resolution polarized radiative transfer with GPU based Monte-Carlo

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Summary

In accounting for multiple scattering, Monte-Carlo methods are traditionally known to be significantly slower than classic radiative transfer equation (RTE) solvers based on discrete ordinate or doubling-adding. However, Emde et al. (2011) showed that using the importance sampling technic, Monte-Carlo methods could become competitive in terms of computing time regarding classic solvers in the context of high spectral resolution radiance modelling. Their method is called ALIS for Absorption Lines Importance Sampling.

SMART-G (Speed-up Monte carlo Advanced Radiative Transfer on GPU) is a Monte-Carlo solver implemented on Graphic Processor Unit device (GPU). This allows a massive parallelisation of the computation on a single desktop computers by means of a GPU device costing a couple of hundred euros. The acceleration regarding a Monte-Carlo code running on a single CPU is generally around two orders of magnitude.

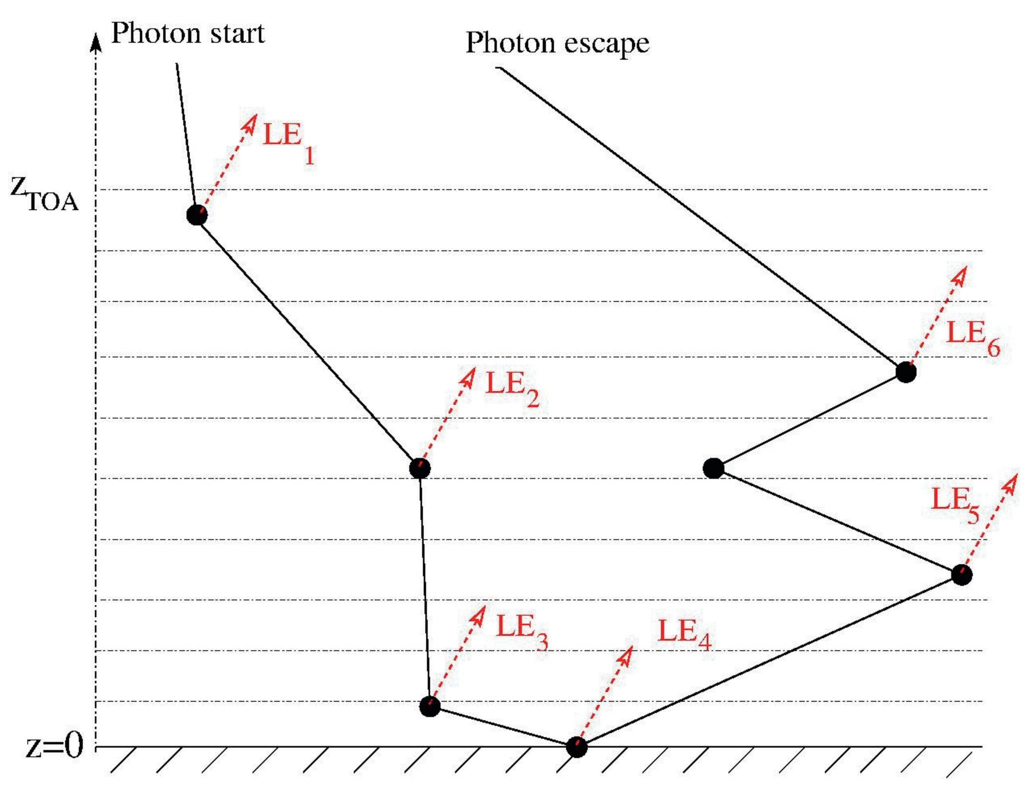
We implemented ALIS on our SMART-G solver. The acceleration is two orders of magnitude regarding CPU implementation presented in Emde et al. (2011). Results obtained with SMART-G are compared to benchmark obtained with ARTDECO (see poster of Dubuisson et al.). Compare to an adding-doubling code with 16 streams running on a single CPU, SMART-G with 10^6 photons is two orders of magnitude faster.

I - Speed-up Monte carlo Advanced Radiative Transfer on GPU: SMART-G

SMART-G (Speed-up Monte carlo Advanced Radiative Transfer on GPU) is a **Monte-Carlo** solver implemented on **Graphic Processor Unit device (GPU)**. It is written with CUDA (Compute Unified Device Architecture). SMART-G accounts for polarisation. The ocean-atmopshere coupling as well as spherical geometry can be handled (Ramon et al, in prep.).

For the present work, we consider a **vertically inhomogeneous atmosphere treated as plan-parallel layers** defined by their optical properties (extinction cross-section, single scattering albedo, scattering phase matrix). **Gas and aerosols** enter atmosphere composition. We do not include the ocean coupling. **Line-by-line absorption coefficients are an input.**

Top of Atmopshere radiance is sampled using the **local estimate (LE) technic**: At each photon interaction, we compute the probability that it directly reaches the detector.



Scattering / absorption decoupling

Scattering properties used to:
- get photon path (free path length, direction change)
- get LE (probability to scatter in detector's direction, probability not to interact before reaching the detector)

Absorption properties used to:
- apply absorption on photon path
- apply absorption on the way to detector for LE

II - The Absorption Lines Importance Sampling (ALIS, Emde et al., 2010)

The photon path is computed for a single wavelength and re-used for all wavelengths (**photon path recycling**). Additionnaly to the line-by-line absorption coefficients, a correction factor is applied to account for the wavelength dependence of the photon path through scattering properties (**Importance Sampling**).

As a result of this technic, **no Monte-Carlo noise** is present **between wavelengths**. Only the absolute level of the spectrum is affected by random noise.

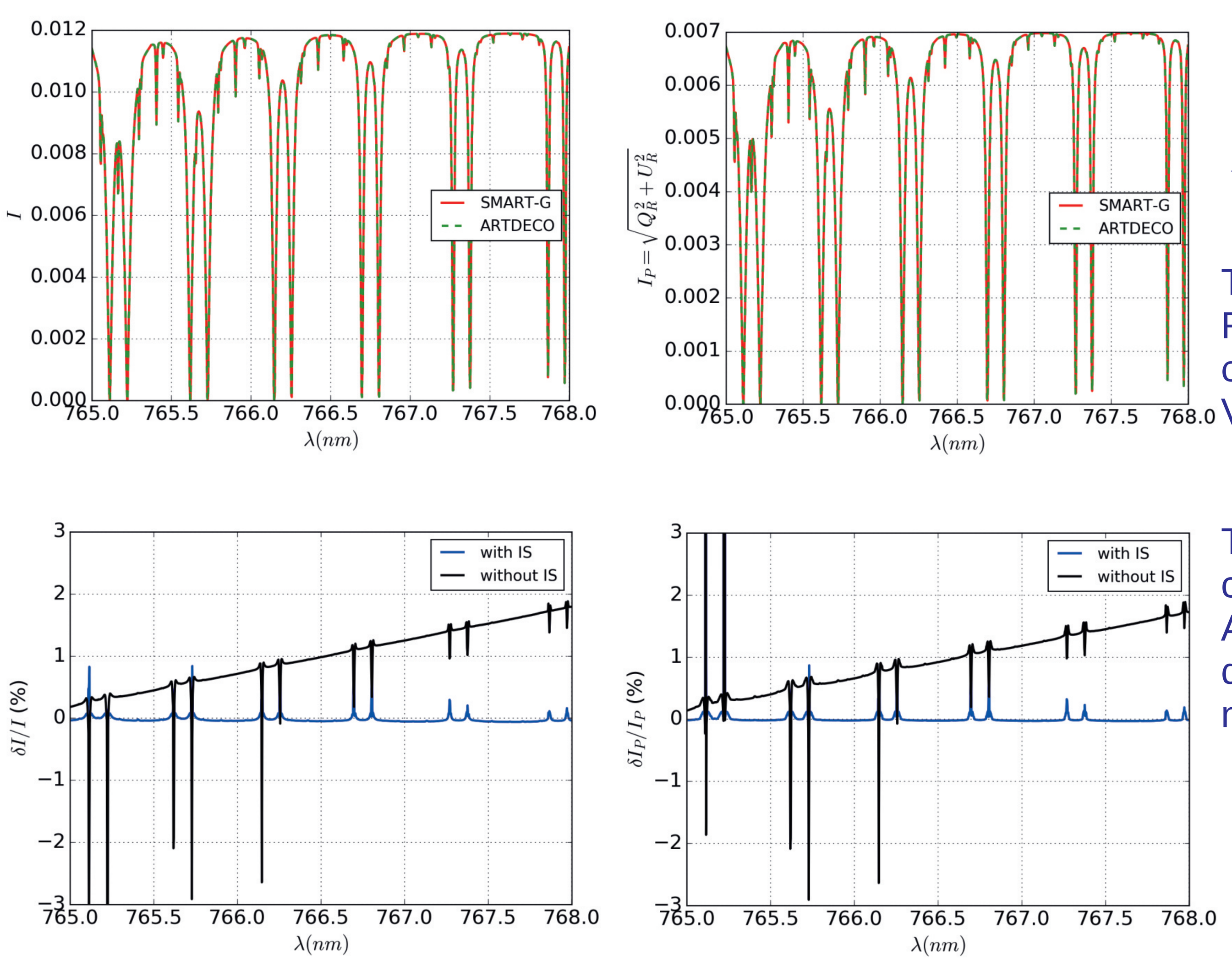


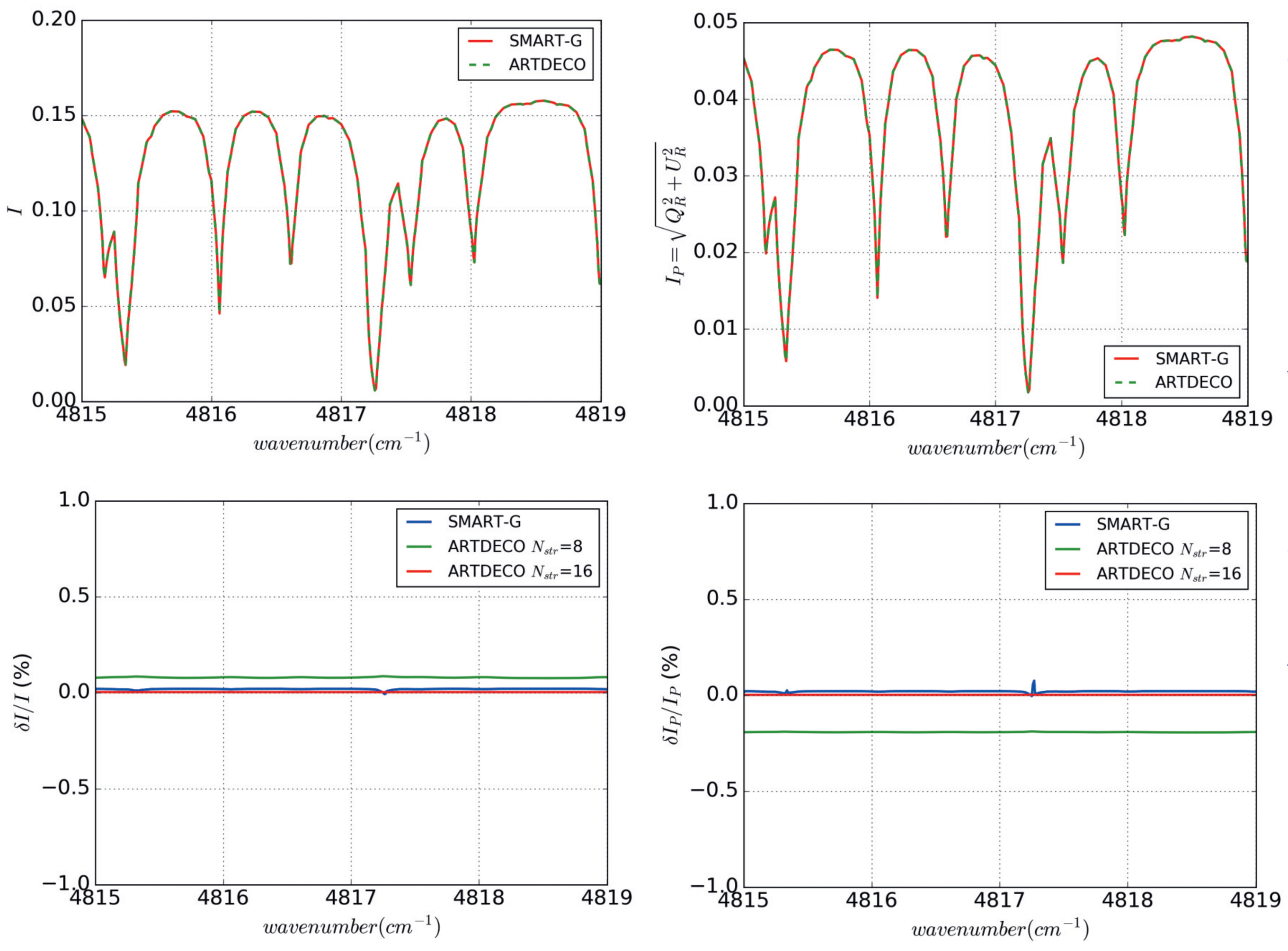
Illustration of Importance sampling (IS) effect

TOA reflectance for Rayleigh atmosphere only (SZA=60^o, VZA=0^o, RAA=0^o).

The reference computation is ARTDECO : Adding-doubling with $n_{streams}$=32.

III - SMART-G/ALIS performance & validation

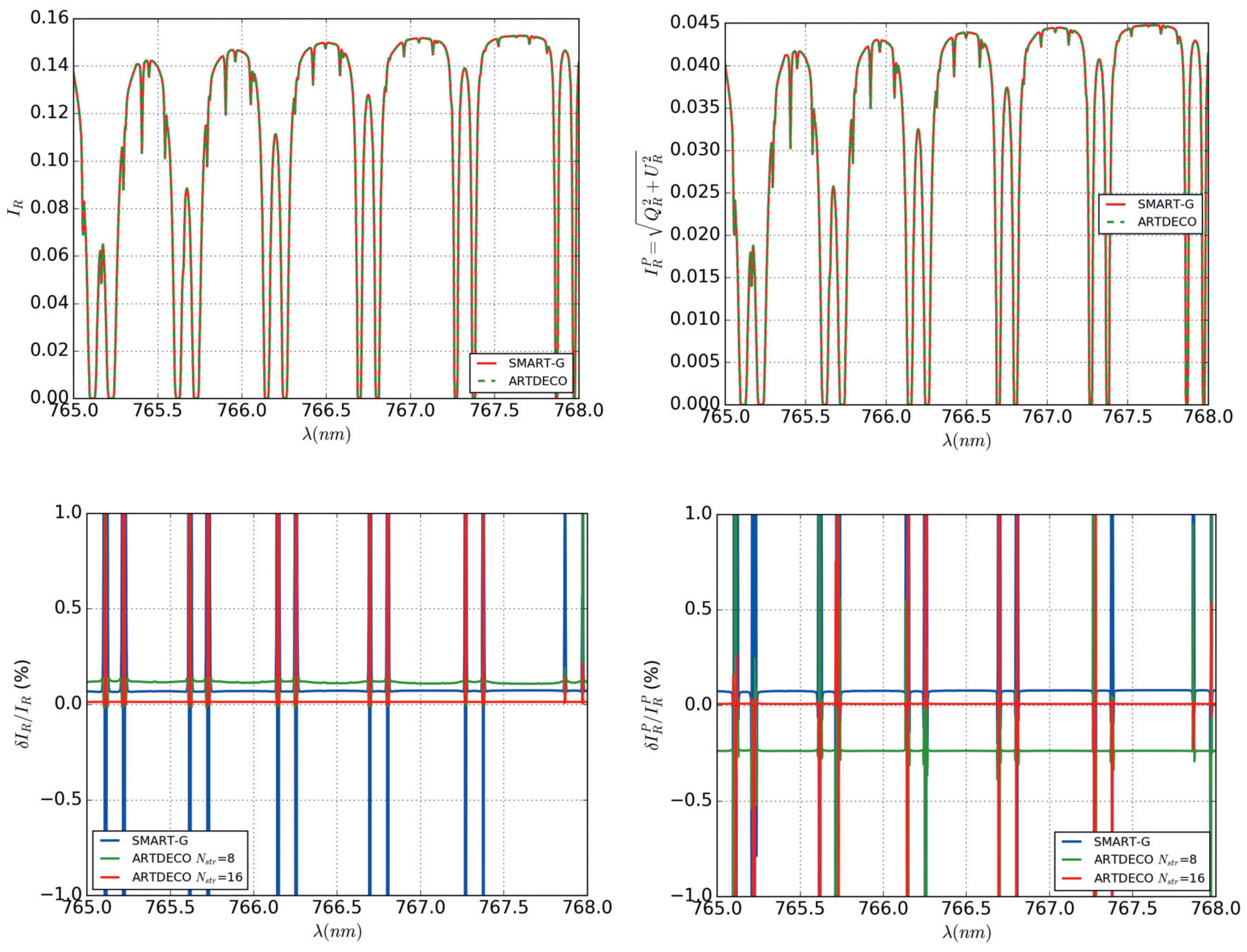
Computations are performed on a nVidia GeForce GTX 970 graphic card.



TOA reflectance for an atmosphere with maritime aerosols (OD=0.05 at 2 microns) over glitter in TANSO-FTS 3 band (SZA=30^o, VZA=20^o, RAA=0^o, N_{WVL}=449).

The reference computation is ARTDECO : Adding-doubling with $n_{streams}$=32.

SMART-G results have a relative error < 0.1%. SMART-G computing time is ~1.2s for 10^6 photons. ARTDECO computing time is ~210s with $n_{streams}$=16 on a single CPU. Same computation with MYSTIC/ALIS on a single CPU is ~145s (Emde et al., 2011).

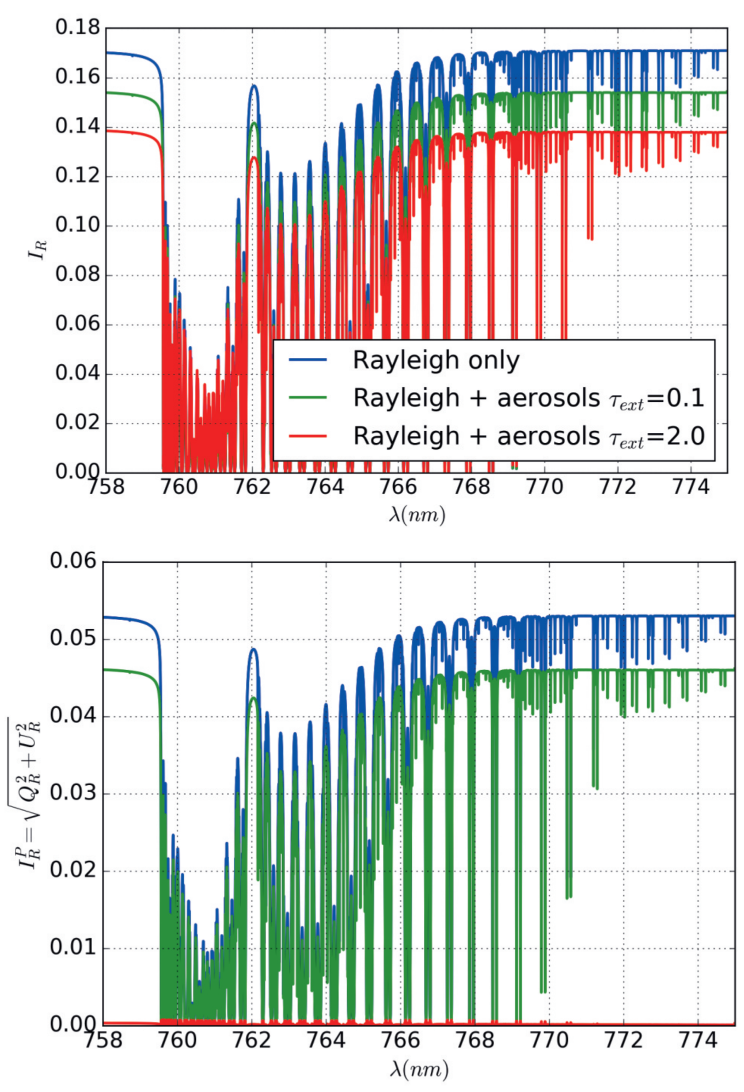


TOA reflectance for an atmosphere with desert aerosols (OD=0.1 at 766.5 nm) over glitter in TANSO-FTS 1 band (SZA=30^o, VZA=20^o, RAA=0^o, N_{WVL}=1089).

The reference computation is ARTDECO : Adding-doubling with $n_{streams}$=32.

SMART-G results have a relative error < 0.1%. SMART-G computing time is ~2.70s for 10^6 photons. ARTDECO computing time is ~620s with $n_{streams}$=16 on a single CPU.

IV - Test case : GOSAT TANSO FTS-1 modelling



TOA reflectance for an atmosphere with desert aerosols over glitter for the full TANSO-FTS1 range with a resolution of 10^{-2} cm^{-1} (SZA=30^o, VZA=20^o, RAA=0^o, N_{WVL}=27137).

	Rayleigh	Rayleigh+ aerosols (OD = 0.1)	Rayleigh+ aerosols (OD = 2.0)
SMART-G 10^6 phot.	60 s	81 s	640 s

As in any Monte-Carlo code, the computing time increases with increasing the scattering opacity of the atmosphere.

For our implementation, the computing time increases almost linearly as a function of the number of wavelengths (up to ~27000 wavelengths, the maximum number tested).

References

- ARTDECO (Atmospheric Radiative Transfer Database for Earth Climate Observation) : Publicly available raditive transfer suite at http://www.icare.univ-lille1.fr/projects/artdeco

- Emde, C.; Buras, R. & Mayer, B. ALIS: An efficient method to compute high spectral resolution polarized solar radiances using the Monte Carlo approach, JQSRT, 2011, 112, 1622-1631

-Ramon et al., in preparation, Ocean-Atmosphere Monte-Carlo Polarized Radiative Transfer on GPU with SMART-G

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