Massively Parallel Monte-Carlo Radiative Transfer Code on a Desktop PC

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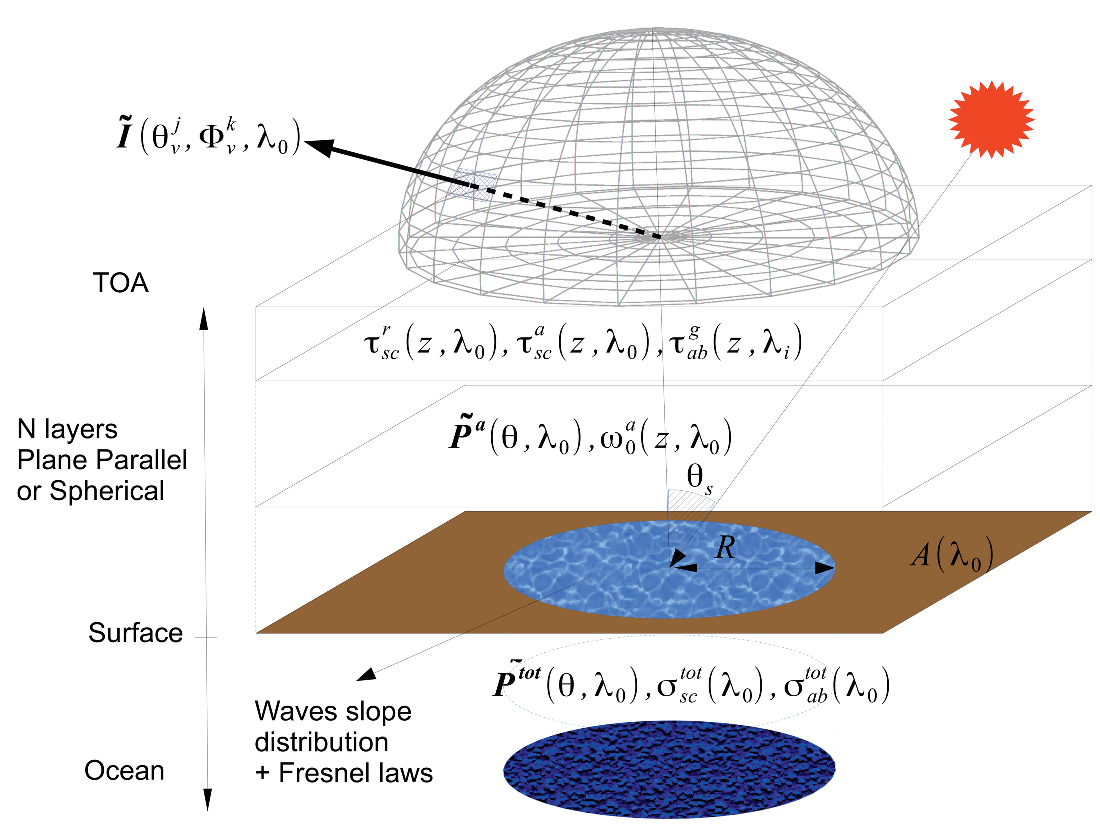
Introduction

Monte Carlo (MC) Radiative Transfer Codes (RTC) have been considered for long to be slow. The emergence of easily programmable Graphical Processing Unit (GPU) has enabled to massively parallelize, and thus dramatically speed up MC RTC, using only a desktop PC equipped with an additional standard graphics card. We present here the code SMART-G (Speed-up Monte-carlo Advanced Radiative Transfer code using GPU), that calculates **spectral polarized radiances** in the coupled **ocean-atmosphere** system. We give some examples where the performance and capabilities of MC RTC codes rank first when looking for a simulation and/or inversion tool: spherical geometry, horizontal inhomogeneities of surface albedo (adjacency effects), and potentially Line by Line in narrow bands using the ALIS method (Emde et al. 2011)

Principle



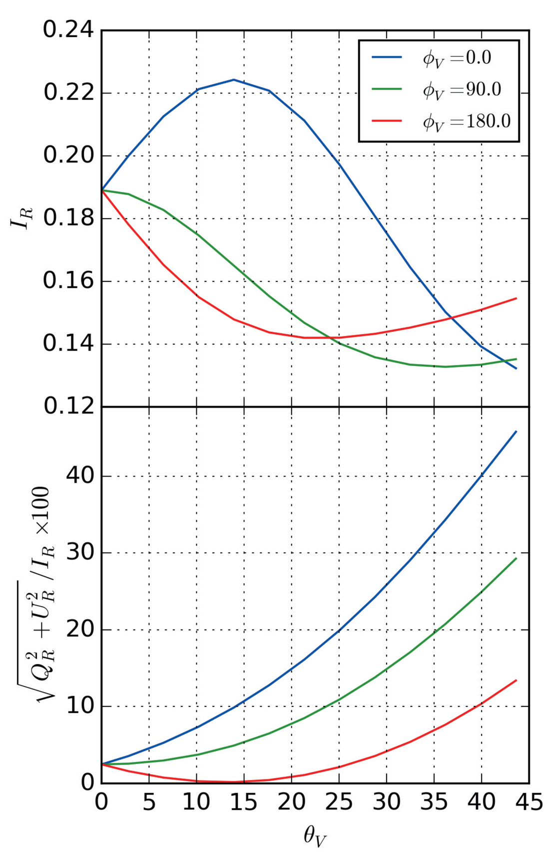
◄ *Fig. 1 - Backward Monte-Carlo code SMART-G.*

Photons are injected in the atmosphere from the detector and traced until they leave the atmosphere. They are counted in angular boxes, one for each possible solar geometry.
Each elementary processor of the GPU implements **the same code** that is the computation of the state of individual "photons" characterized by 3 Stokes parameters, a propagation direction and a weight. These photons are experiencing sequences of the following physical processes:

* *Initialization*
* *Propagation*
* *Scattering*
* *Reflection and or Transmission at interfaces*
* *Exit and counting.*

Absorption is treated with the Beer law and is affecting the weight only

Accurate computation with the local estimate : MERIS Rayleigh LUT



The local estimate (LE) variance reduction technique (see Marchuk, 1980) was implemented in SMART-G. Using the LE capability, SMART-G was evaluated with other RTE solvers in the framework of MERIS working group for the generation of Rayleigh Look-Up Tables with sun glint. For a single geometry with 10^8 photons, a computation lasts typically 3s (speed-up of ~200 regarding single CPU MC models) for a resulting variance of 0.01% for total intensity and 0.05% for polarized intensity.

◄ *Fig. 3 - Part of the MERIS LUT for 412.5 nm channel. The glitter is set for 5 m/s. The sun zenith angle is 13.93 deg. We only show a subset of relative azimuth angle for clarity.*

Simulations in spherical shell atmosphere

GEO-OCULUS ESA project: Atmospheric corrections at high airmass

TORMS ESA project: Retrieval of total column ozone from multipspectral imagers operating in the visible range (MERIS - OLCI)

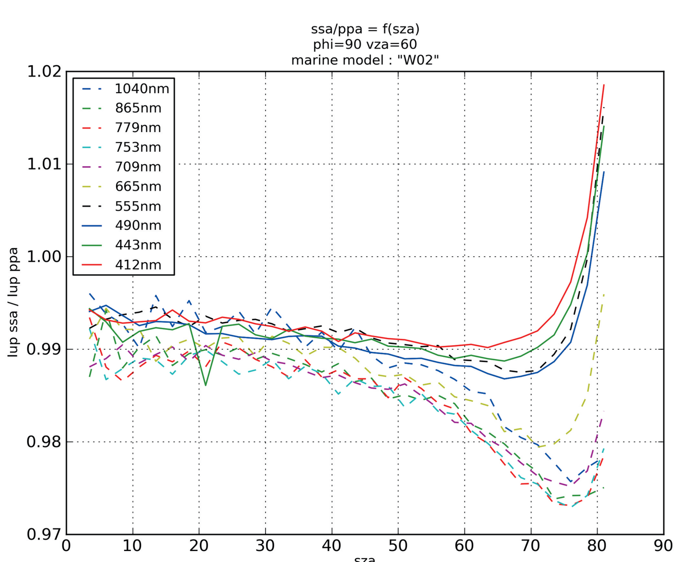
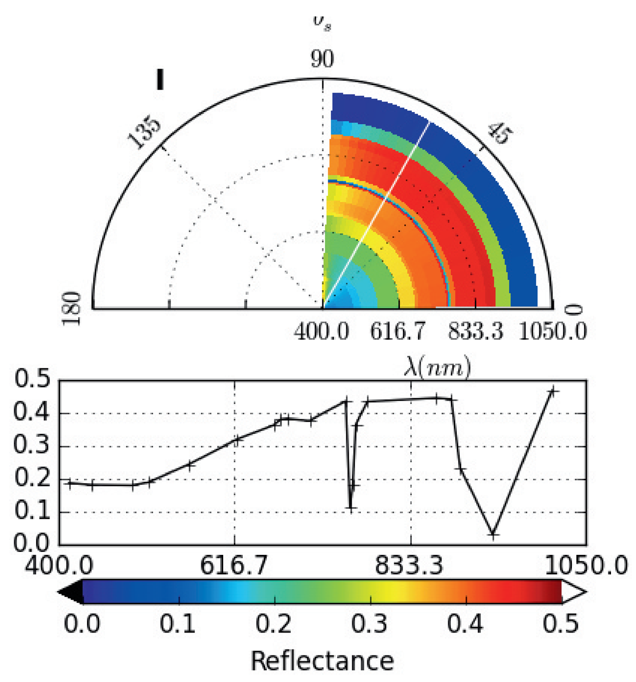


Figure: ratio of the TOA reflectance calculated in SSA over the reflectance calculated in PPA as a function of the solar zenith angle for the MERIS bands. The viewing angle is 60° and the relative azimut angle is 90°. A maritime aerosols model is used with an AOT (defined at 550 nm) of 0.1. Surface model is a rough sea surface (Cox and Munk with a windspeed of 5 m/s) and the chlorophyll concentration is 1 mg/m3 (case-1 water)



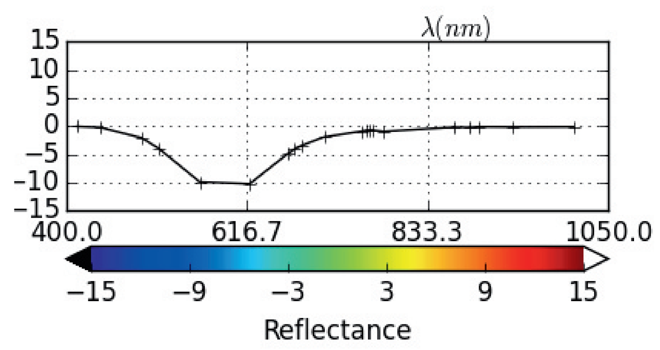


Figure: OLCI TOA reflectances (left) and ozone transmittances for 300 Dobson Units (bottom right). The parameters of the simulation are the following: SZA=60°, VZA=30°, RAA 87°, mid-latitude summer profile, desertic aerosols (AOT=0.2), desert surface (aridisol).
Calculations are made in SSA

Adjacency effects in ocean colour remote sensing

In ocean colour application, the hypothesis of horizontal homogeneity of the surface in the computation of reflectances may lead to substantial errors near the coasts or for inland waters where the reflectivity contrast between the water body and its surroundings is important. We made a simple sensitivity study of the adjacency effects with SMART-G in few minutes in the case of a circular lake

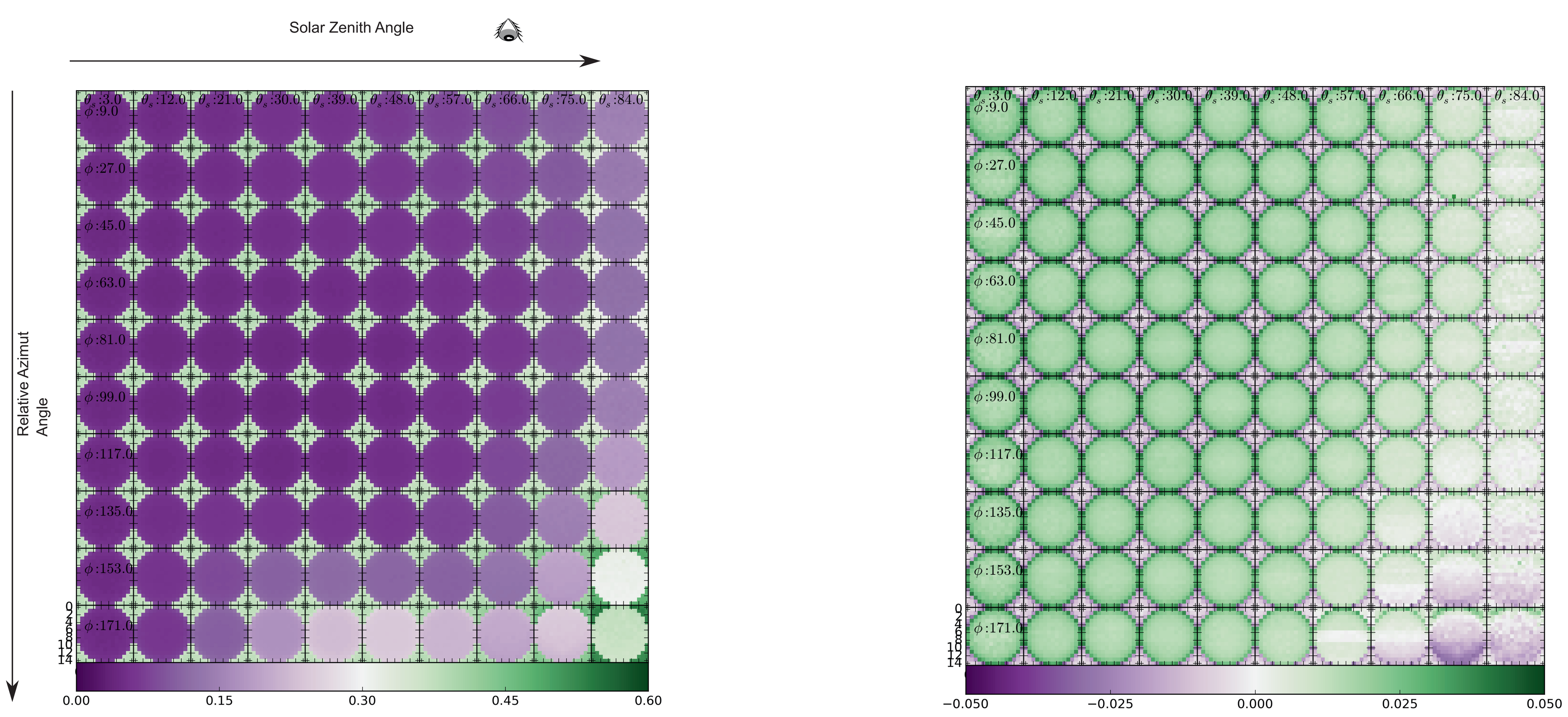
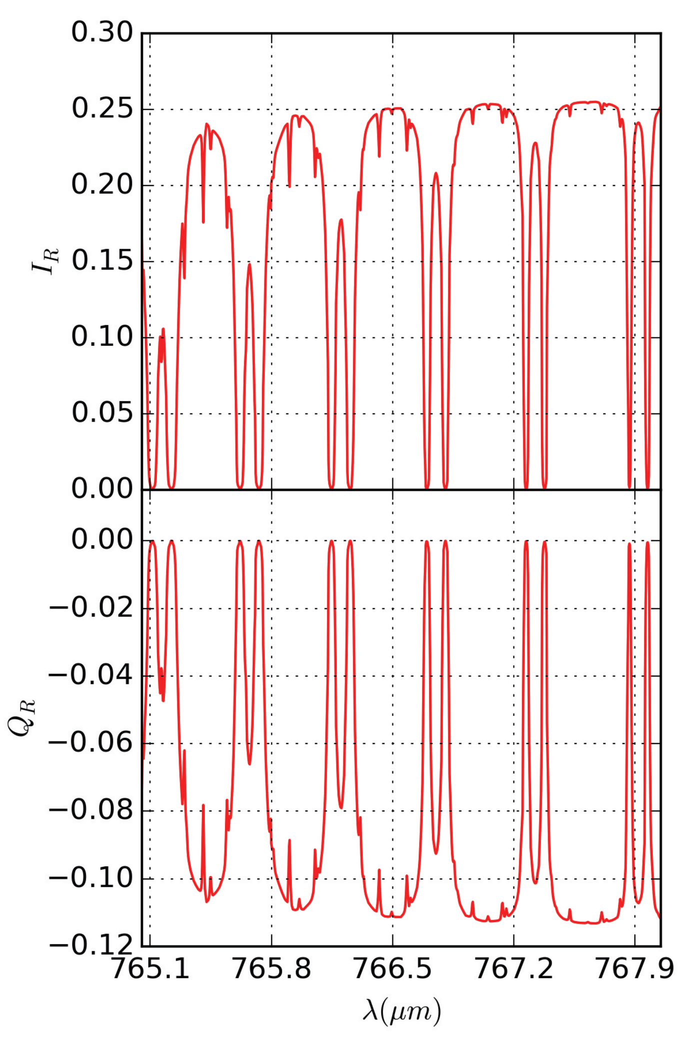


Fig. 4 - Simulation of images of 15x15 pixels centred on a lake of 10 km radius surrounded by a lambertian reflector of albedo 0.4 typical of vegetation. The wavelength is 775 nm and windspeed is 5 m/s. The atmosphere model is the AFGL mid latitude summer with maritime clean aerosols with an AOT at 550nm of 0.3. The images are calculated for a viewing angle of 40° and ***all solar azimut and view angles****. (Left) TOA reflectances, (Right) Differences in TOA reflectances between actual values and calculations without including adjacency effects. A relative azimut angle of 180° means a sun in front of the observer which is located here in the north side of the lake*

Gaseous absorption



In order to handle line by line (**LBL**) gas absorption, the ALIS method (Emde et al., 2011) is currently being implemented in SMART-G. It allows for the calculation of spectra by tracing the photon paths once for all wavelengths (by absorption/scattering decoupling) and thus save computation time. ALIS method allowed CPU based MYSTIC Monte-Carlo code to become as fast as the classical RTE solver DISORT for LBL purpose. Our preliminary implementation already shows **speed-up of ~50** compared to MYSTIC.

We also foresee the use of a parametrized method like the correlated *K-distribution*. Those methods are based on the use of absorption repartition function, making it natural to implement in Monte-Carlo context.

◄ *Fig: 765 to 768 nm spectral window of the TANSO-FTS band 1. This polarized spectrum is computed for the TOA with a clear sky over the sun glint (wind speed 5m/s). The sun zenith angle is 30 deg. The observation geometry is that of the glitter's maximum reflectance. For the 961 wavelengths, the computing time is 13s for 10^6 photons. NB: the Monte-Carlo noise (0.14%) plays on the absolute level of the spectrum, not on its shape.*

Conclusions

Monte-Carlo method allows one to account for complex effects such as complex bondaries, spherical or 3D geometries, in computing radiative transfer. Compare to classical RTE solver, it also is more accurate in accounting for the scattering of particles with strong forward peak in their phase function since no Legendre polynomial expansion or truncation is required. Although generally being slower than classical solver, it became equally efficient for line by line computation thanks to the ALIS method.

As illustrated with our code SMART-G, the implementation of MC code on GPU leads to **speed up factors of typically 2 orders of magnitude** compare to CPU based code for a use on a single desktop PC. On the other hand, High Performance Computing and especially machines from the Top500 list now systematically integrate GPU. This opens new pespectives for Monte-Carlo methods to be run either on a single PC for sensitivity test or prototyping purpose and at a larger scale in operationnal context.

References

- 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

- Marchuk, G. I.; Mikhailov, G. A. & Nazaraliev, M. A. The Monte Carlo methods in atmospheric optics Springer Series in Optical Sciences, Berlin: Springer, 1980, 1980