Radiative Transfer accurate tool for Ocean Colour

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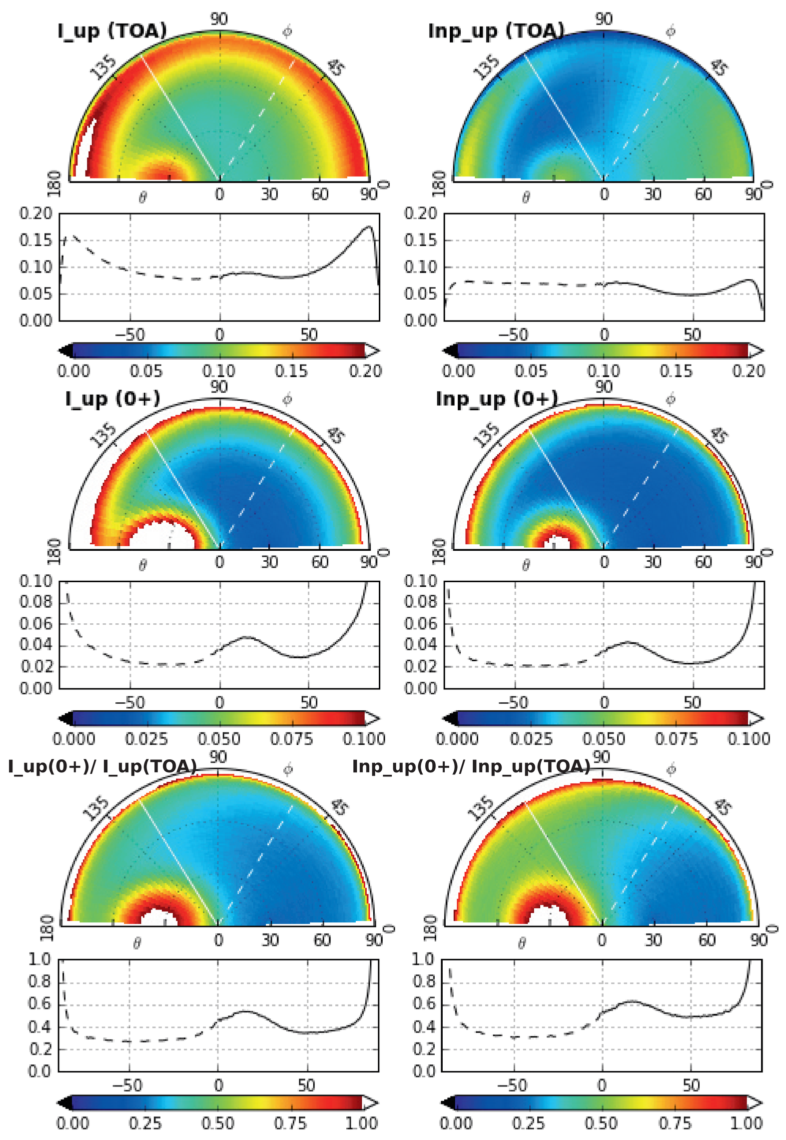
Abstract

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, PAR estimation, horizontal inhomogeneities of surface albedo (adjacency effects), and potentially Line by Line in narrow bands.

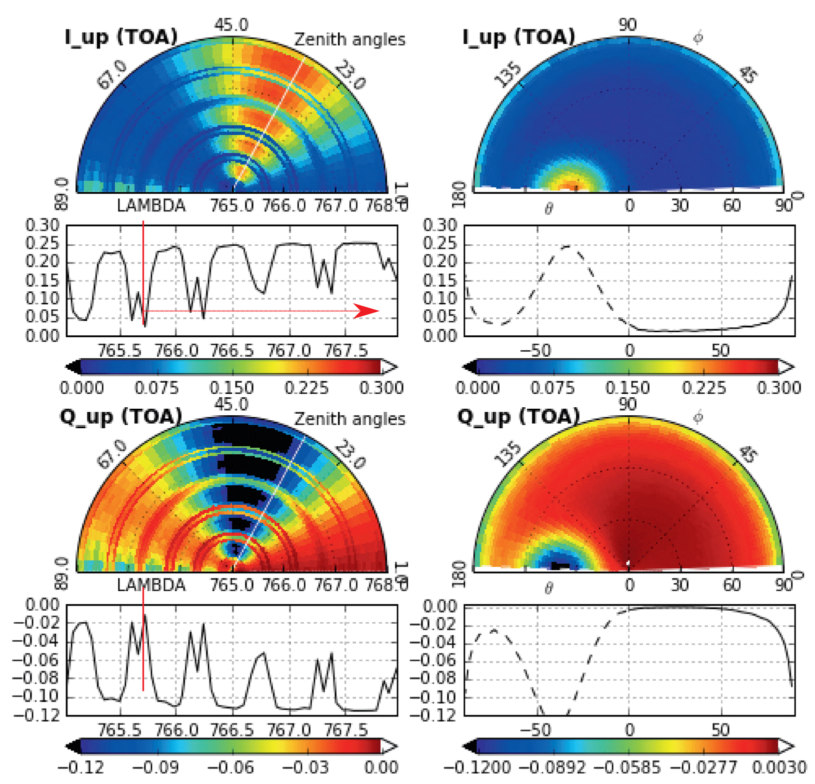
Application: atmospheric corrections

TOA and surface reflectances for a polarized sensor at 550 nm. The windspeed is 5 m/s. The atmosphere model is the AFGL mid latitude summer with urban aerosols with an AOT at 550nm of 0.3 and SPM dominated waters with SPM = 1. mg/l. The viewing angle is 30°. On the left is the total intensity and on the right is the non polarized one. The bottom row shows the ratio of surface reflectance over TOA reflectance. Atmospheric corrections should be slightly more efficient over non polarized intensity.

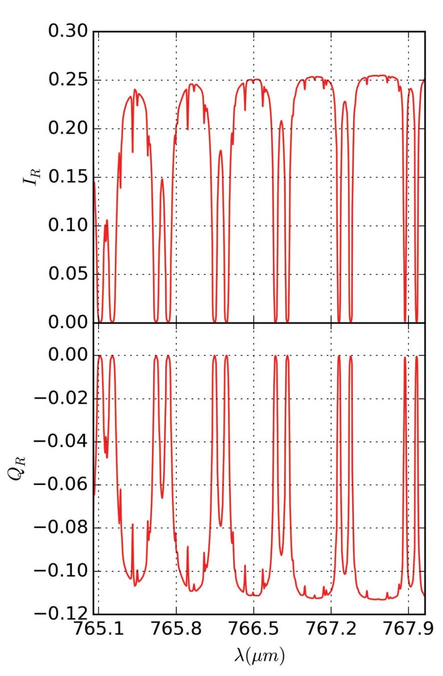


Gaseous Absorption

Multi-Spectral (k distribution or equivalent)
Each "photon" is assigned a wavelength. All optical properties (excepting High Resolution Spectral Absorption) of the medium are precalculated for these wavelengths



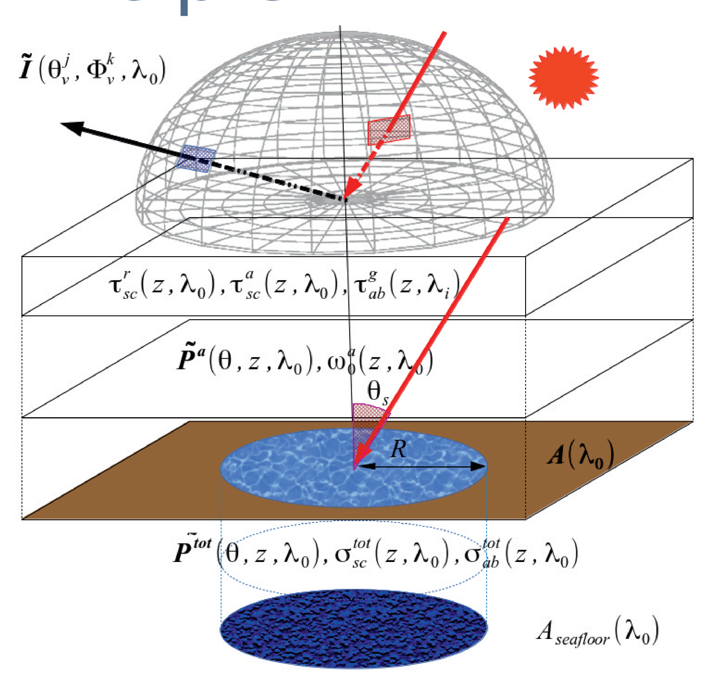
◄ *Part of O_2 A bands. I and Q spectra are computed at TOA with a clear sky over the sun glint (wind speed 5 m/s). The sun zenith angle is 30 deg. The observation geometry is that of the glitter's maximum reflectance. The absorption coefficient are obtained from the REPTRAN parametrization (Gasteiger et al. 2014) with channels of 1 cm-1 width*



High Spectral Resolution
(under development)
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**). 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.

◄ *For the 961 wavelengths between 765 and 768 nm, 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*

Principle



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. Another version implements the Local Estimate variance reduction technique (Marchuk et al., 1980)
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.

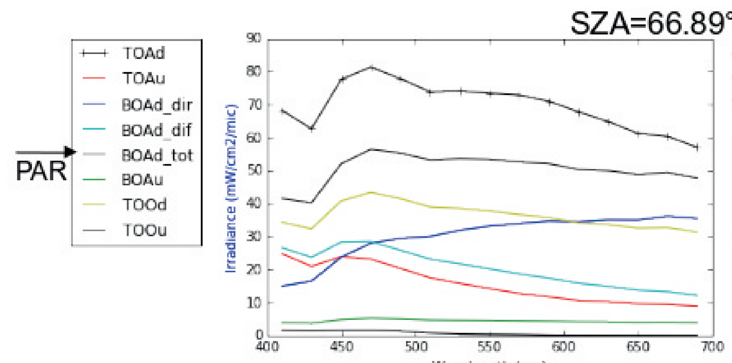
These photons are experiencing sequences of the following physical processes:

- Initialization
- Propagation
- Scattering (elastic or inelastic)
  - Rayleigh, aerosols, clouds, pure water, water particulate matter
  - Raman scattering, fluorescence (under development)
- Reflection and or Transmission at interfaces
  - Environment, Seafloor (lambertian)
  - Sea surface (Cox and Munk slope distribution or wave height realization from Fourier spectrum of El Fouhaily (1997), under development)
- Exit and counting.

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

Application: PAR simulation

Within the ESA SEOM program (http://seom.esa.int/), we plan to deliver a daily PAR product for MERIS and S3/OLCI and also secondary experimental products such as under-water PAR, spherical PAR, UV flux, absorbed fraction of PAR by live algae, diurnal variation of PAR and spectrally resolved PAR. Here we build a daily PAR simulator and applied it to typical NPP/VIIRS observations.

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*****************************
* 400.00 - 700.00 nm
******* SZA : 66.89  ********
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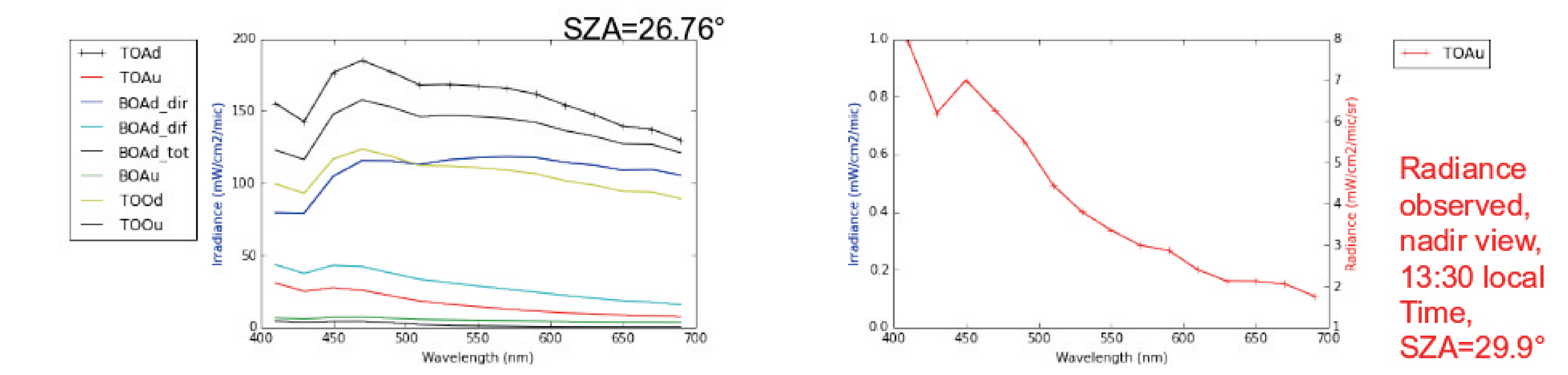
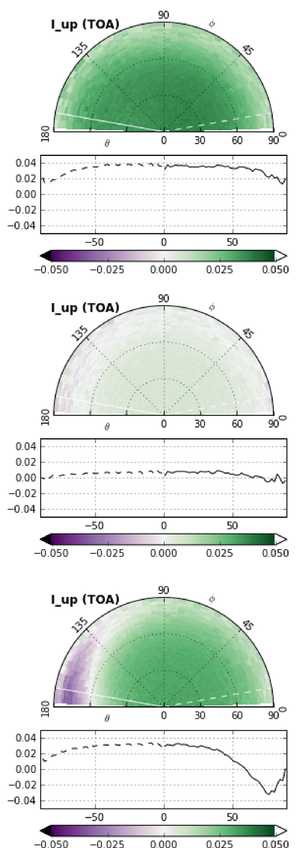
Level	PAR(Ein./m2/day)	R/T	Irr.(mW/cm2/mic)	R/T
(1) TOA incident	82.093	1.000	69.621	1.000
(2) TOA up	17.590	0.214	15.617	0.224
(3) BOA (0+) down (dir)	36.988	0.451	30.158	0.433
(4) BOA (0+) down (dif)	23.179	0.282	20.282	0.291
(5) BOA (0+) down (tot)	60.167	0.733	50.440	0.724
(6) BOA (0+) up	5.208	0.087	4.398	0.087
(7) BOA (0-) down	42.849	0.712	36.301	0.720
(8) BOA (0-) up	0.681	0.016	0.666	0.018

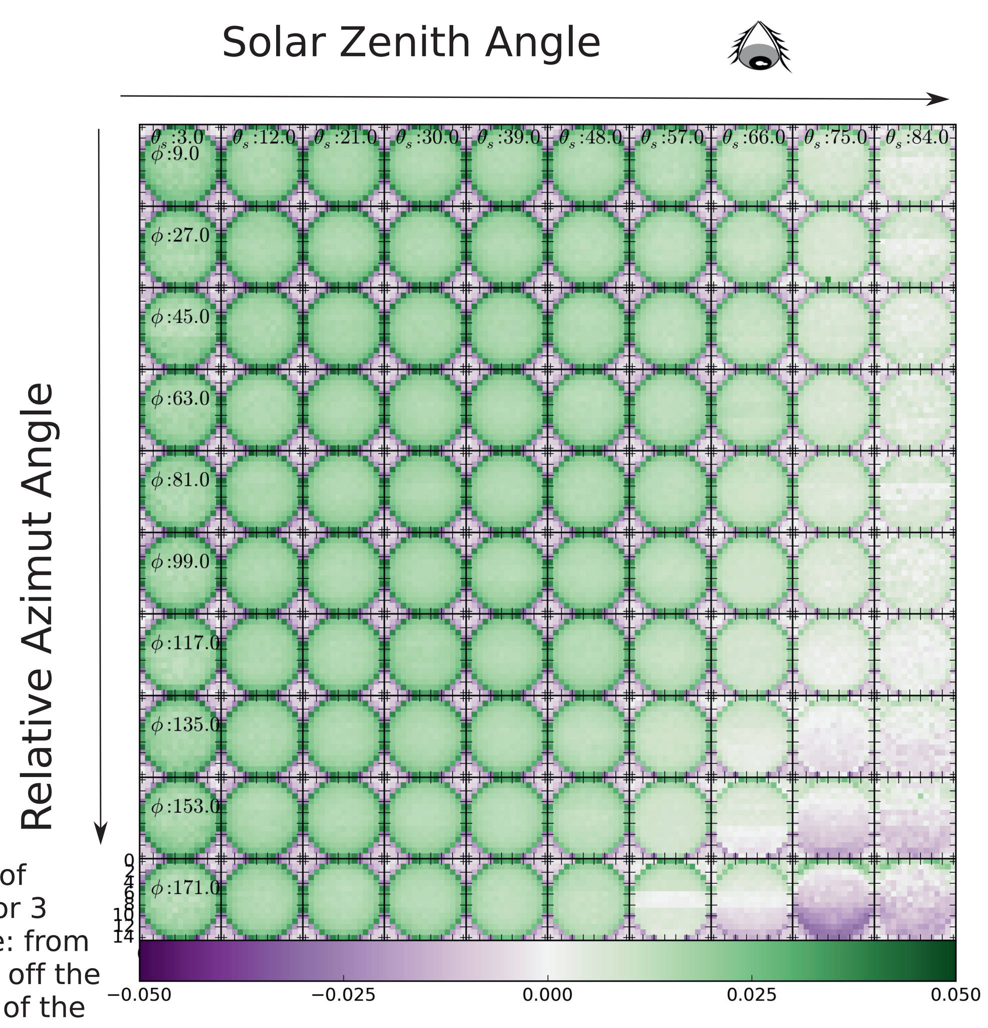


Spectral fluxes and PAR for 2 SZA for the 15 July at various levels above and within water and spectral radiances that would VVIRS measure at 13:30 local time. Clear sky conditions with contineltal aerosols in the North Atlantice (45°N, -40 W) (TOO ~ 0- : Top Of Ocean)

Application : Adjacency effects



Directional pattern of adjacency effects for 3 points over the lake: from top to bottom, 1km off the north coast, center of the lake, 1km off the south coast



Difference between actual radiance and the one computed with the horizontal homogeneity hypothesis. Simulation of images of 15x15 pixels centred on a black 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. 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

Conclusions

Monte-Carlo method allows one to account for complex effects such as complex boundaries, spherical shell geometry, wavelength redistribution in computing the polarized radiative transfer in the fully coupled ocean atmospeher system. Even for LBL calculation, the ALIS method, the Monte Carlo approach is very competitive compared to Discrete Ordinates codes.
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. This allows Monte-Carlo methods to be run either on a single PC for fast sensitivity tests or prototyping purposes.

References

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