First Results to Evaluate Losses and Gains in Solar Radiation Collected by Solar Tower Plants

Mustapha Moulana[1, 2, a)], Thierry Elias[1], Céline Cornet[2], Didier Ramon[1]

[1]Hygeos, Euratechnologies, 165 Avenue de Bretagne, 59000 Lille, France.

[2]Univ. Lille, CNRS, UMR 8518 – LOA – Laboratoire d'optique atmosphérique, F-59000, France.

[a)]mm@hygeos.com

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1. Introduction

Solar Tower Plants (STPs) need an accurate solar resource assessment because of the large variation of atmospheric parameters. Such a variation requires high computation performance to be considered. Thus, solar resource estimates study is generally separated in two steps. The first step is the estimation of the solar radiation in the atmospheric column incoming at heliostats, using ground-based observation or Radiative Transfer (RT) codes to obtain the Direct Normal Irradiance (DNI). In the second step, the DNI is an input parameter to simulate the solar radiation in the slant path between heliostats and the receiver using optical simulation codes (DELSOL3, STRAL, etc.). We study the interest of simulating the solar radiation with RT codes in both the atmospheric column and the slant path. The main limitation is the computational time, but with the exponential increase of Graphic Power Unit (GPU) performance, such an ambition is now possible. The RT code used parallelized by GPU is SMART-G, where the atmospheric, the reflection and the cosine losses [1] are automatically considered. We focus on the gain contributions at the receiver. The simplified system used (STP of maximum 8 heliostats) enables to have an order of magnitude for gain contributions from small SPT to larger SPTs, with an average horizontal heliostat-receiver distance D_{hr} from 200 to 900 meters.

2. The SMART-G Tool

The Speed-Up Monte-Carlo Advanced Radiative Transfer code with GPU (SMART-G) [2] enables to simulate the propagation of the light in both the atmosphere and the ocean. The solar beams can be absorbed and scattered by the atmosphere components such as molecules, aerosols and droplets, and also reflected by the ground. It was improved to allow the interactions of solar beams with objects as heliostats, receiver, etc.

3. The Incident Solar Beams at the Receiver Separated in Several Categories

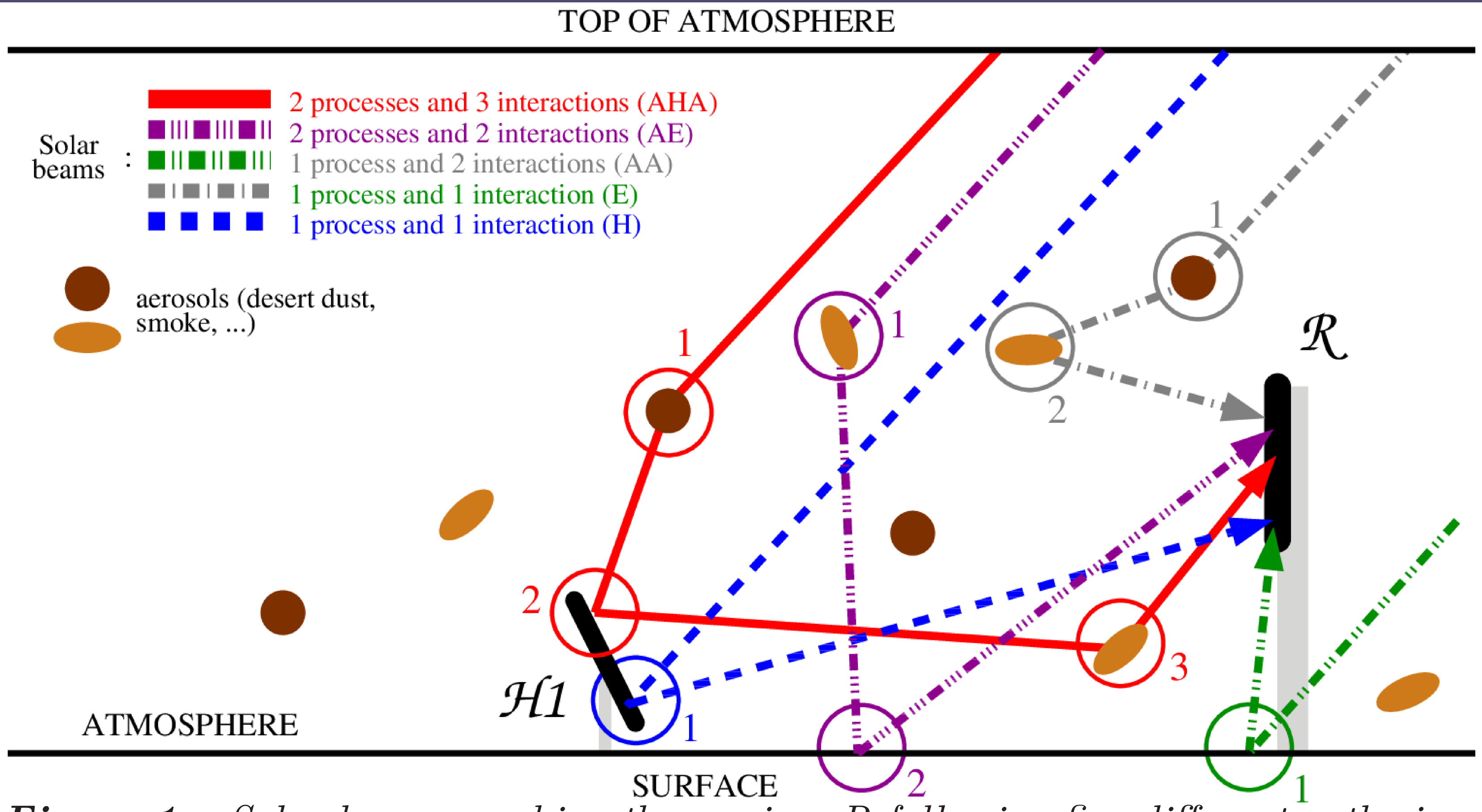

***Figure 1 :** Solar beams reaching the receiver R following five different paths in a STP with only one heliostat H1.*

The solar beams incident at the receiver R are divided in 8 categories following 3 radiative processes responsible to a trajectory modification: the Atmospheric scattering (A), the reflection by a Heliostat (H) and the reflection by an Environment element (E) as the ground.

The reference for gains is the intensity of solar beams from Cat.2, the intensities from all the other categories are considered as gains.

	Number of Processes	Which Process(es)	Possible Paths from 1 to 3 Interactions
Cat.1	0	without any processes	D
Cat.2	1	Heliostat reflection (H)	H, HH, HHH
Cat.3	1	Environment reflection (E)	E, EE, EEE
Cat.4	1	Atmosphere scattering (A)	A, AA, AAA
Cat.5	2	H and A	HA, AH, AAH, AHA, AHH, HHA, HAH, HAA
Cat.6	2	H and E	HE, EH, HHE, HEH, HEE, EEH, EHE, EHH
Cat.7	2	E and A	EA, AE, AAE, AEA, AEE, EEA, EAE, EAA
Cat.8	3	H and E and A	AHE, AEH, HAE, HEA, EAH, EHA

***Table 1 :** Solar beams from all the possible optical paths classified with three radiative processes in eight categories. Abbreviation AA, for instance, means two interactions with only the process of atmospheric scattering as shown in Fig.1 (grey dot-dashed line).*

4. Simulation Description

- Atmospheric properties corresponding to the Noor III location (via observation measurements).
- 200 billion of beams distributed at Top Of Atmosphere (TOA) with a solar zenith angle of 14.3°.
- Monochromatic simulation at 550nm with maximum 8 heliostats (total of 16 simulations).
- Inspired by the PS10 STP.
- The D_{hr} is equal to the sum of all the horizontal heliostat-receiver distance divided by the number of heliostats.

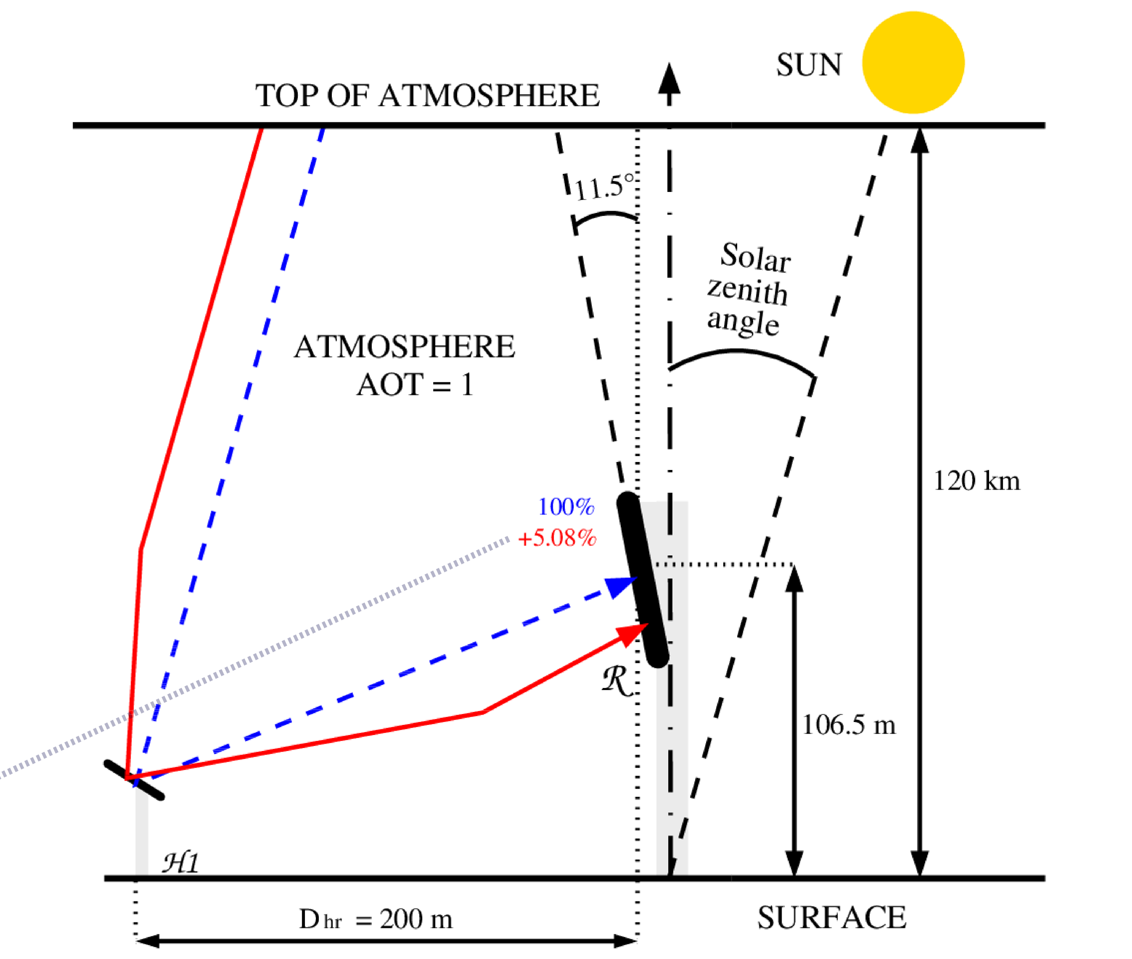

***Figure 2 :** Setting for simulation with one heliostat.*

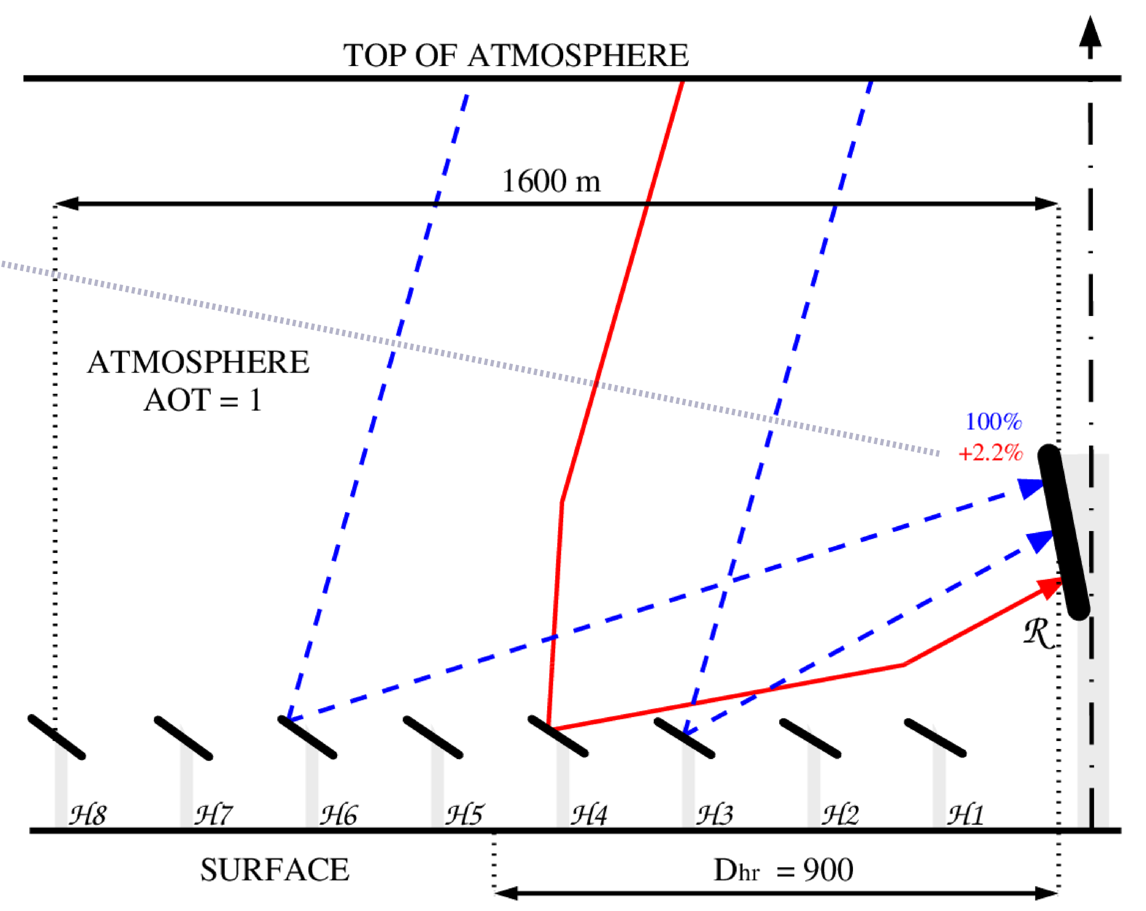

***Figure 3 :** Simulation with 8 heliostats spaced by 200 meters.*

5. Results

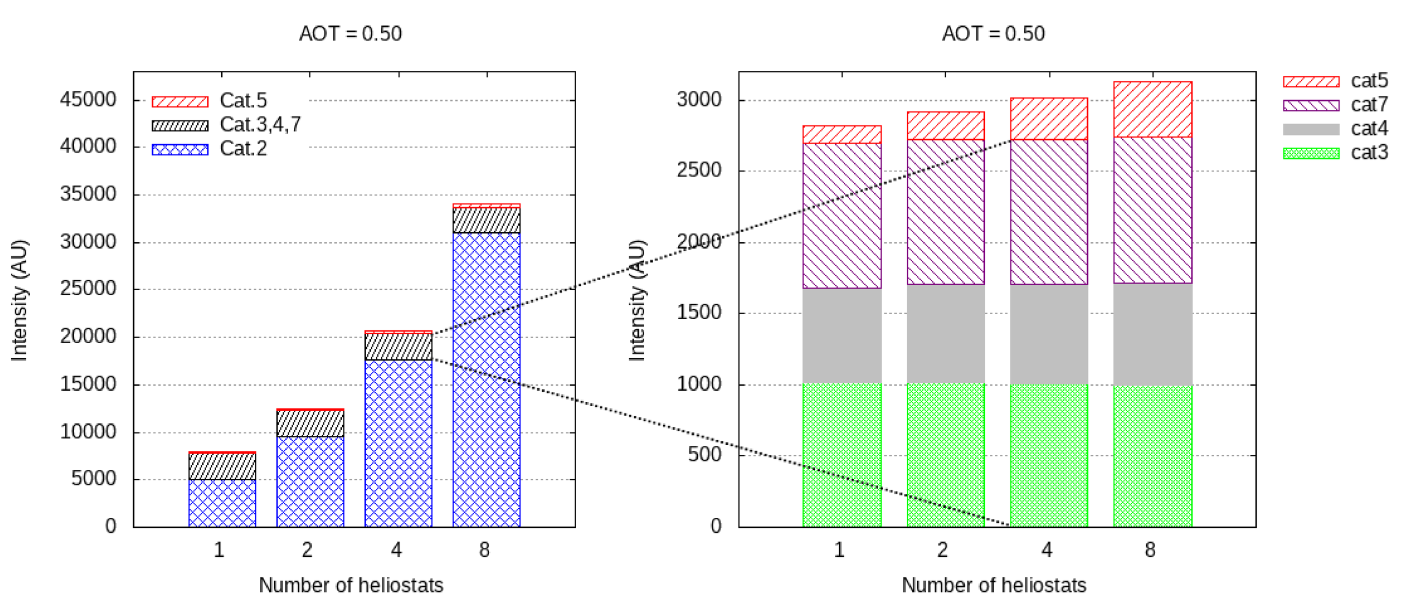

***Figure 4 :** Receiver incident intensities (Arbitrary Unit proportional to power unit) of solar beams from Cat.2, 3, 4, 5 and 7 in the left image. And the same intensities without Cat.2 in the right image.*

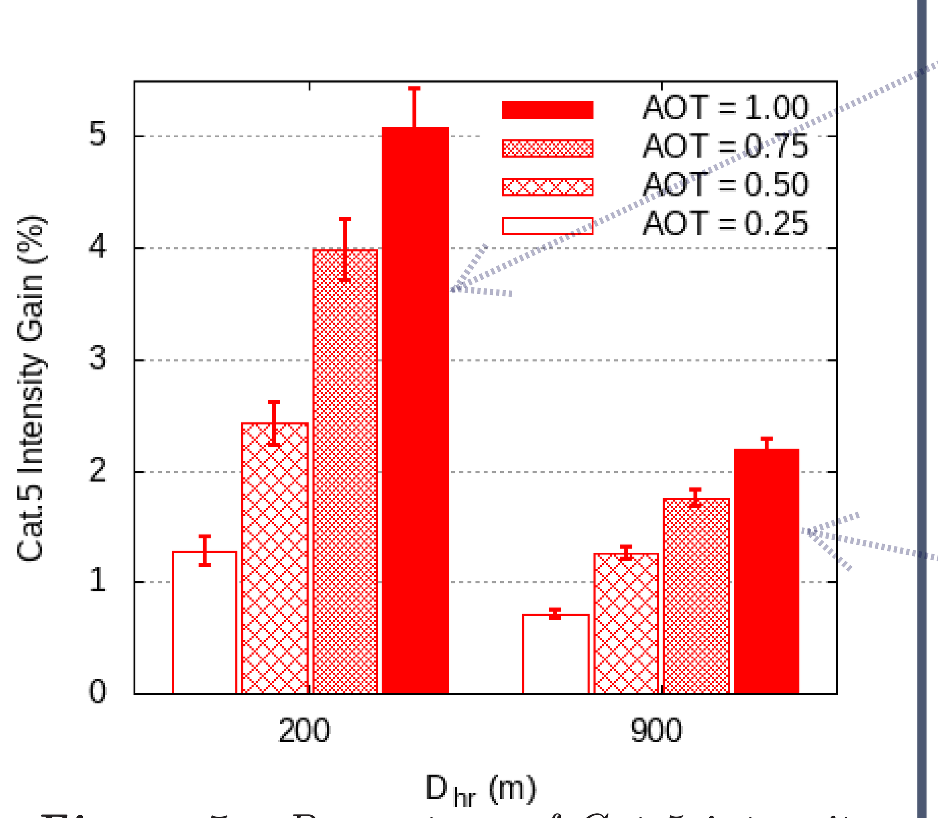

***Figure 5 :** Percentage of Cat.5 intensity relatively the Cat.2 intensity (reference for gains).*

- The intensities of solar beams from Cat.3, 4 and 7 are independent on the number of heliostats, the contribution becomes then negligible for real STP (with a higher total heliostat area).
- The intensity from Cat.8 is very close to 0 then not represented.
- The intensities from Cat.0 and 6 are equal to zero due to the simulation conditions: (Cat.0) the sun is behind the receiver and (Cat.6) a plane ground is used + absence of surface roughness in heliostats.
- The only gain contribution increasing with the number of heliostats is from Cat.5 solar beams.

For large STP with a D_{hr} of 900m, the gain contribution (from Cat.5) equals to 0.71% for an AOT of 0.25 and can reach 2.2% for an AOT of 1. For a small STP with a D_{hr} of 200m, this contribution is equal to 1.28% for an AOT of 0.25 and can reach 5.08% for an AOT of 1. The results give the same order of magnitude at the receiver level in gain contribution than Blanc *et al* [3] for DNI (at heliostats level).

6. perspectives

- Disk Sun source implementation with consideration of the sun solid angle as Reinhardt et al [4].
- Backward mode for improving the accuracy and computational performance.
- Consider a complete STP (to consider shadow and blocking losses) with the whole solar spectral range
- Consider the surface roughness (spillage loss) and quantify all the six optical losses

7. References

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