Gain contribution and losses in Solar Radiation Collected by Realistic Solar Tower Plants

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1. Introduction

Solar Tower Plants (STPs) need an accurate solar resource assessment because of the large variation of atmospheric parameters. To consider such a variation requires high computation performance. We use the SMART-G code which simulates the radiative transfer in the atmosphere, from the top of the atmosphere to the heliostats and to the receiver, and which take also into account all the geometrical constraints as shadows, blocking, spillage... We focus on the gain contribution due to the consideration of the atmosphere and the environment at the receiver of a realistic STP.

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

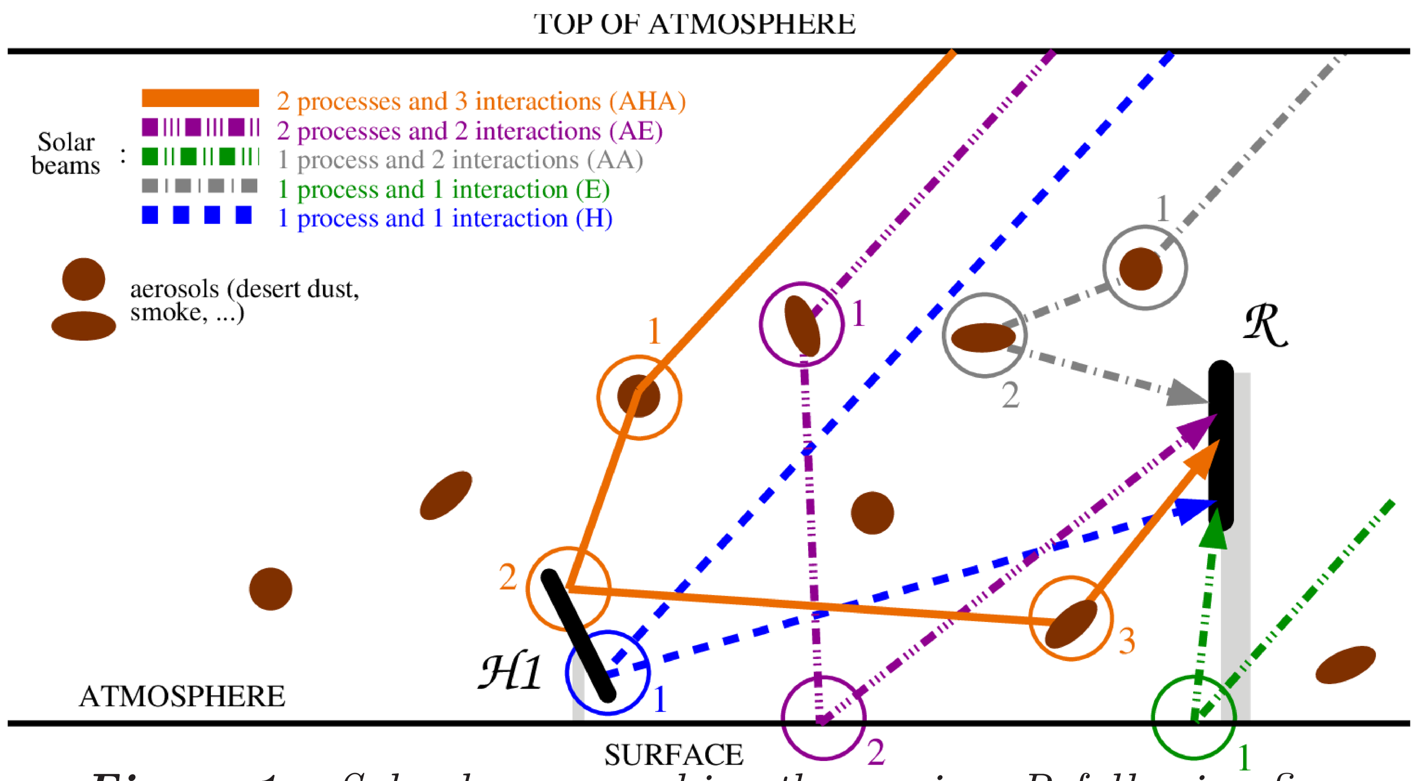

Figure 1 : Solar beams reaching the receiver R following five different paths in a STP with only one heliostat H1.

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.

Solar beams of Cat.2 provides the main contribution to the solar resource, all other categories generate gains which were never accounted for, according to our knowledge.

	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).

2. The SMART-G Tool

The Speed-Up Monte-Carlo Advanced Radiative Transfer code with GPU (SMART-G) [1] 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.

4. Simulation Description

Figure 2 : Planta Solar 10 (PS10), Spain

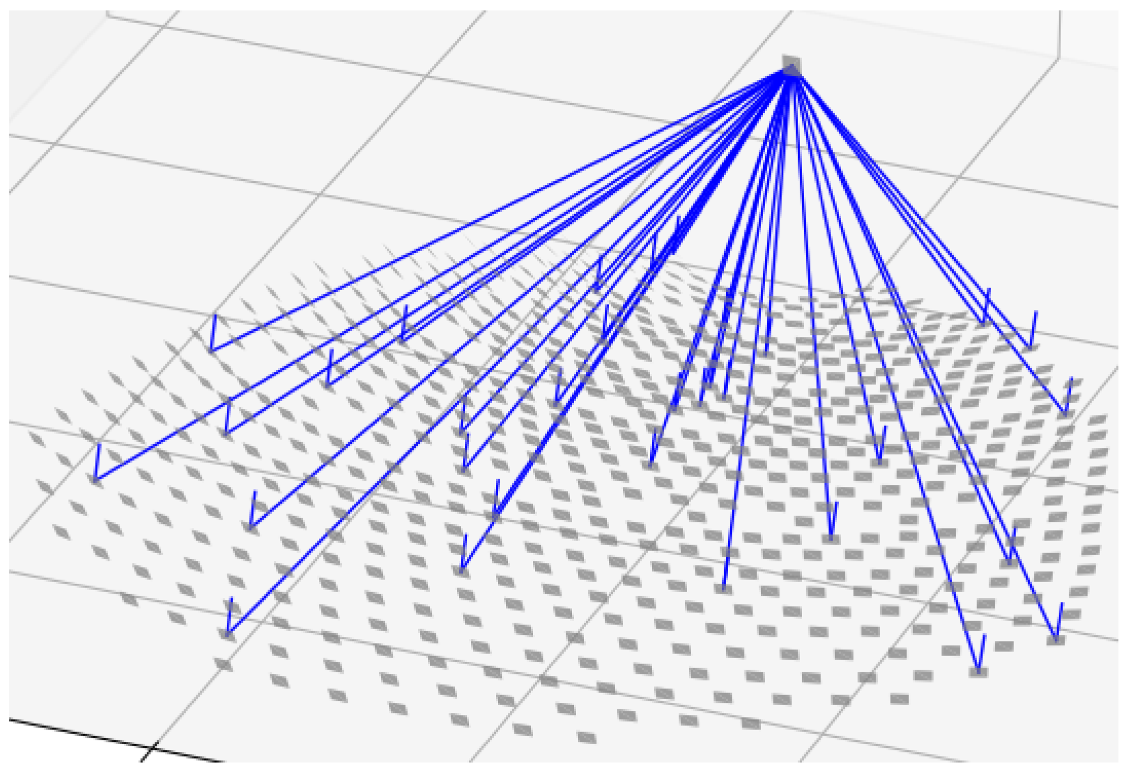

Figure 3 : PS10 modeling with the 624 well oriented heliostats and the receiver

Simulations setup are:

- Complete and realitic STP modeling where heliostats and the receiver positions and dimensions correspond to PS10 (Fig.2 and 3)
- Monochromatic simulations at 550 nm for 6 time periods, 2 type of aerosols (according to OPAC), 2 Aerosol Optical Thickness (AOT) and 6 roughness values (total of 144 simulations)
- Illumination condition of north Africa with a desert Stone ground albedo at an altitude of 1200 m
- Each simulation with 1 billion of beams launched in backward i.e. from the receiver to the sun (more than 100 times less beams for the same accuracy compared to forward simulations).

5. Gains due to the consideration of the atmosphere and the environment

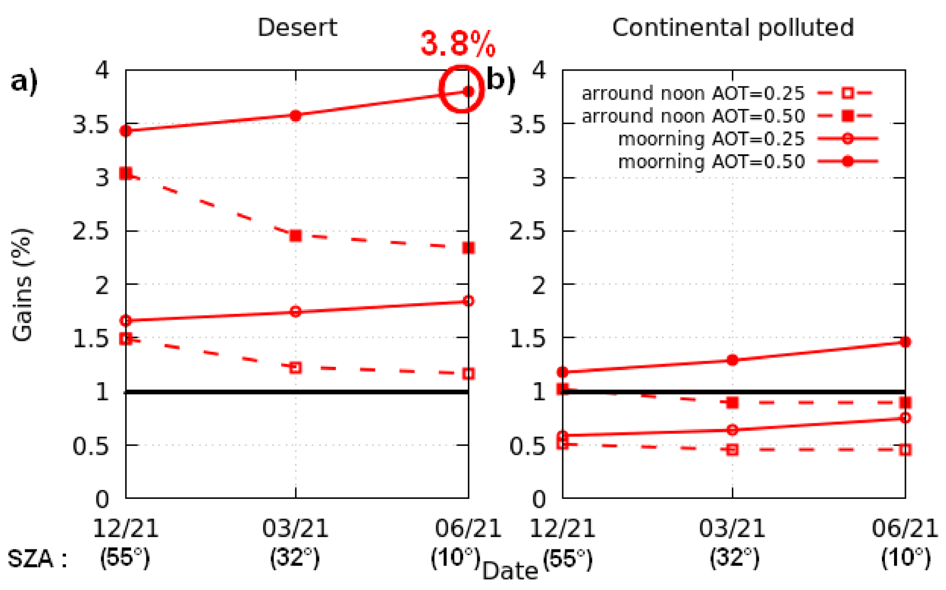

Figure 4 : Percentage of Cat.3, 4, 5 and 7 intensities relatively the Cat.2 intensity.

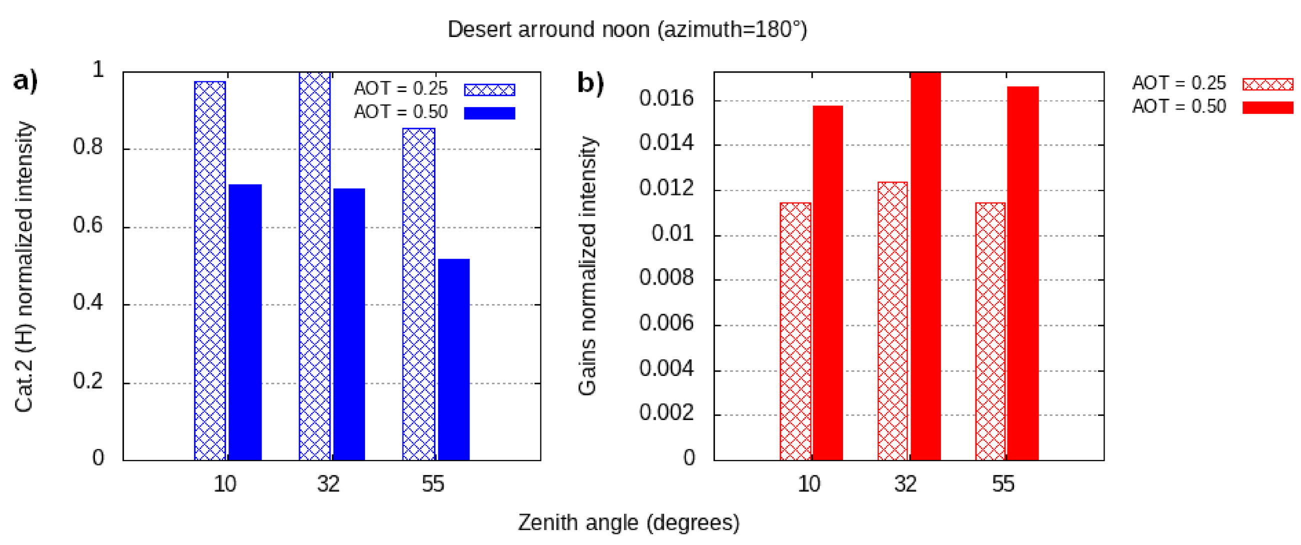

Figure 5 : Incident normalized intensity of solar beams from Cat.2 in image 5a. And from Cat.3, 4, 5 and 7 in the image 5b.

Figure 4 shows for desert aerosols that all gains exceed 1% of contribution and can reach **almost 4%**. For continental polluted the gain contribution exceed 1% only with AOT of 0.50 in the moorning, and at noon the 21 dec. The gain is multiplied by 2 for AOT increasing from 0.25 to 0.50, whatever the aerosol type and date. Figure 5 shows the sensitivity with the sun zenith angle (SZA), for SZA > 50°there is a significant decrease of Cat.2 intensity (Fig.5a). The large increase of the gain contribution from 0.25 to 0.5 (≈ x2) is explained by an important decrease of Cat.2 intensity and by the significant growth of the intensity of gains (Fig.5).

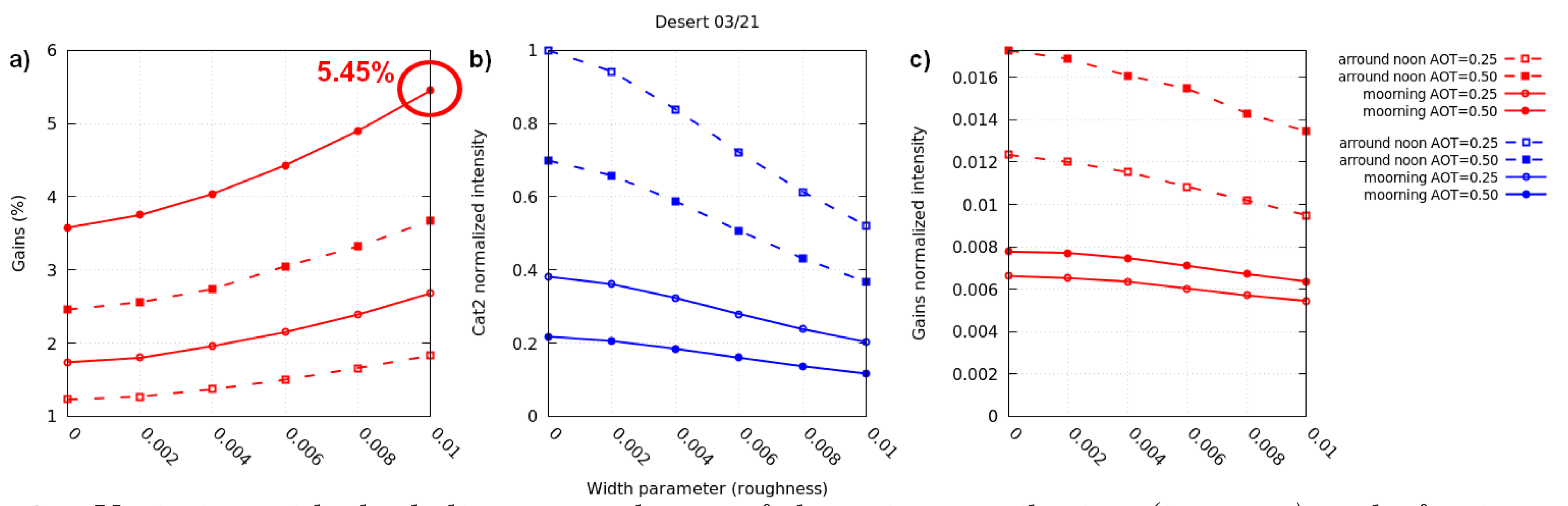

Figure 6 : Variation with the heliostat roughness of the gain contribution (image a) and of gain and Cat.2 normalized intensities respectively at image b and c.

If the surface roughness at heliostats is considered, the gain contribution increase and can go **beyong 5%** with a width parameter of 0.01 (Fig.6a). The contribution increase is due to a stronger decrease of Cat.2 intensity compared to the intensity of gains (Fig.6 b and c).

6. perspectives

- Consideration of the whole solar spectral range
- Consideration of the spectral albedo
- Simulation with a huge last generation STP of thousands of heliostats
- Annual estimations (gains, losses and the collected solar resource) following a realistic climatology for a particular location (satellite data base for several years or in-situ for short periods)

7. References

[1] Didier Ramon, François Steinmetz, Dominique Jolivet, Mathieu Compiègne, and Robert Frouin. Modeling polarized radiative transfer in the ocean-atmosphere system with the gpu-accelerated smart-g monte carlo code. *Journal of Quantitative Spectroscopy and Radiative Transfer*, 222:89–107, 2019.