# Advanced Irradiance Modelling for Solar Assessment

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## INTRODUCTION AND MOTIVATION

Solar resource assessment is a main issue for developing solar technologies. When ground data availability is scarce, models are used to retrieve radiative data (such as DNI) to be used in other technology models. Here we will describe a method based on Monte-Carlo to estimate a directional intensity in order to obtain, if needed, DNI, GHI or even solar spectrum. This methodology can be used coupled with other ray tracing models to estimate power plant efficiency or to perform location selection for ground data campaigns.

## Monte-Carlo method to estimate directional intensity

A Monte-Carlo method can be used to solve the Radiative Transfer Equation (RTE) in order to estimate the directional intensity $L_\lambda(\underline{x},\underline{\omega})$ at the wavelength $\lambda$, the position $\underline{x}$ and in the direction $\underline{\omega}$. This calculation is based on a ray tracing between sun and ground level (that can represent a receptor, photovoltaic panels or heliostat) taking into account the heterogeneities of the atmosphere. To perform the computation, aerosols optical depth, local atmospherics compounds (like water, ozone, CO2 …) are used to calculate in each point the absorption and scattering coefficient of the atmosphere. Usual quantities can be derived from the directional intensity such as:

The Direct Normal Irradiance: $\mathrm{DNI}_{t,} = \int_{\omega\in\Omega_s}\int_{\lambda_{min}}^{\lambda_{max}} L_\lambda(\underline{x},\underline{\omega})\mathrm{d}\omega\mathrm{d}\lambda$ , by a geometrical integration over the solid angle $\Omega_s$ and whole spectrum

A spectral component of the global horizontal irradiance: $\mathrm{GHI}_{t,\lambda} = \int_{\omega\in\Omega_H} L_\lambda(\underline{x},\underline{\omega}).\underline{\omega}\cdot\underline{n}\mathrm{d}\omega$, by a geometrical integration over the whole hemisspere concidering a horizontal plane of normal $\underline{n}$

## Spectral validation

Measurement of solar spectrum is not common and typical spectrums are mostly used in concentrated solar modelling. With our model, such spectrums can be derived from satellites data. The MACC (Monitoring atmospheric composition & climate) data has been used for the aerosols optical depth above the Atacama desert (Chile) to compare GHI spectrum (DNI measurement was not available) with in-situ measurements. Those spectrum have been measured almost every hours between 10 am and 6 pm during several days. For validation, spectrums (both simulated and measured) have been integrated considering an heliostats reflectivity and results are presented in the Table 1.

| | Number of spectrums | MBE | RMSE |
|---|---|---|---|
| | [#] | [%] | [%] |
| Antofogasta | 24 | -1 | 4 |
| Calama | 15 | -1 | 2 |
| Caldera | 11 | -5 | 6 |
| Chajnantor | 20 | -2 | 4 |
| D. Almagro | 13 | -1 | 2 |
| El Salvador | 22 | 0 | 2 |
| **All stations** | **136** | **-2** | **3** |

Table 1: MBE and RMSE for GHI spectral validation in 6 different stations

## Solar ressource validation

Satellites data can be combined with in-situ measurement to be used as input of the model. We have been using the Aeronet database for aerosols properties, and satellites data for all other atmospherics inputs. Results of simulations have been compared with 9 BSRN stations. Figure 1 shows result for DNI estimation (scatter plot and distribution) at Cabauw (Netherlands) station.

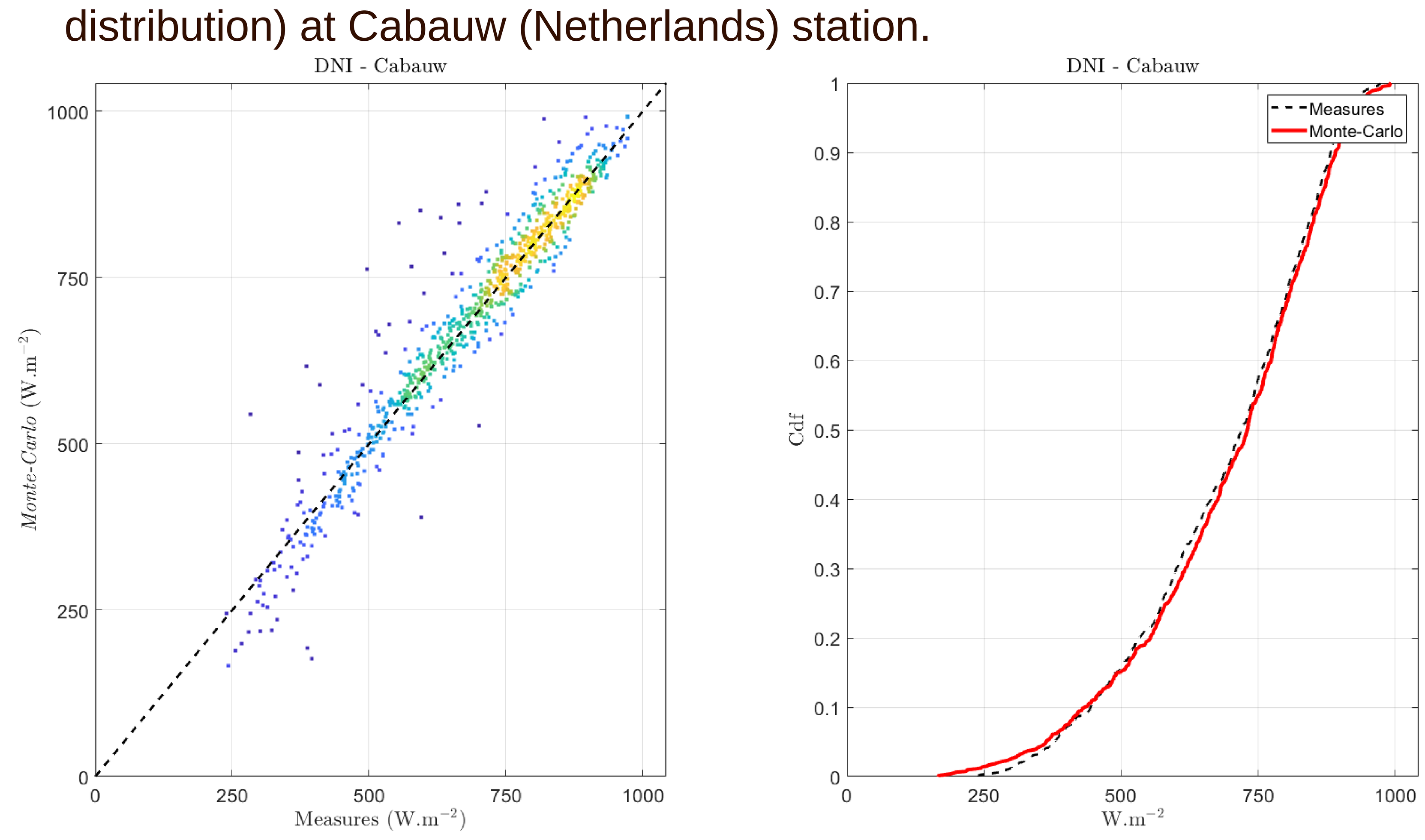


Figure 1: DNI Scatter plot and distribution for Simulation and Measurement at Cabauw BSRN station

## Application in tower power plants

Attenuation between heliostat and tower can highly reduce available power from heliostat field depending on power plant location. Based on our model, the attenuation at ground level can be computed based on satellite data. This attenuation has been calculated for Tamanrasset (Algeria), XiangHe (China), Plataforma Solar de Almeria (PSA, Spain), Diego de Almagro (Chile) and Ourzazate (Morocco) (figure 2). This estimation was based on a one-year integration received energy at the solar tower receiver, taking into account heliostat reflectivity and atmospheric attenuation. Some locations (Tamanrasset and XiangHe) have high attenuation values (above 12% of incoming flux) at 2000 meters from the tower. In comparison, at the same distance, attenuation for PSA and Ouzazate is around 7% and around 5% for Diego de Almagro. This could provide a significant techno-economic advantage for central receiver plants.

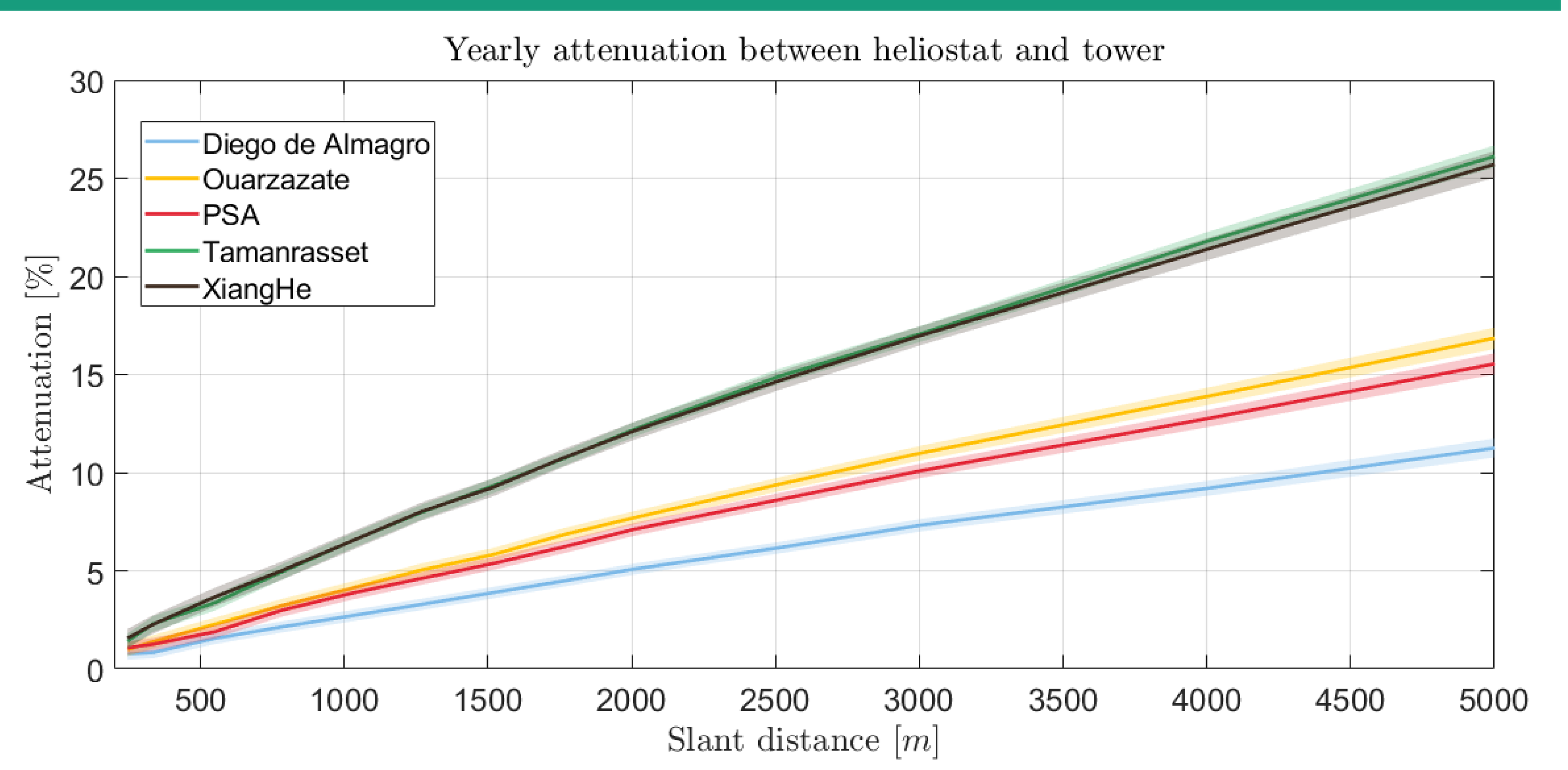


Figure 2: Yearly attenuation between heliostat and a tower receiver at 225m above ground

## Conclusions

The accurate estimations provided by the Monte-Carlo model can be used to calculate a complete production, including the non-linear efficiency and the time dependency of any solar technology power plant. This model can be coupled with any other models used in concentrated power modelling to estimate other quantities. In our case, we used this model to estimate energy losses in a heliostat field to estimate a yearly efficiency including ground attenuation, reflectivity, shadowing and blocking.

## Acknowlegments

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