Fast physical radiative transfer code to compute solar radiation effectively collected by a photovoltaic panel

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1. Introduction

To gain high precision and accuracy on solar resource for photovoltaic (PV) solar plants, the angular distribution as well as the spectral dependence of the downwelling radiation are required at high time resolution to take into account the variable atmospheric conditions.

Most PV panels[2] are significantly tilted in order to increase the collected solar radiation, which is computed by summing the direct and diffuse components, projected on the tilted plane. It is different to GHI, commonly provided by ground-based instruments and operational products.

Nowadays, the only way to obtain such details and precision in the radiation field is to run a physical radiative transfer code for the location of the solar plant. The computer time being a constraint, we propose to use the fast radiative transfer code SMART-G[3] and the ARTDECO toolbox[4].

This poster shows that both direct and diffuse components are validated at Lille, France.

3. Spectral and atmospheric dependence of the direct and diffuse components of the annual yield

The annual yield is computed by summing 1-hour data for direct/diffuse/global irradiance in sunny/cloudy/all-sky conditions, based on ground-based observation data at Lille in 2011. ***Fig. 4*** shows that the sunny contributions contributed by a large proportion of 36% to the all-sky GHI. The direct/diffuse ratio was 3 in clear-sky, while it was 0.5 in cloudy conditions.

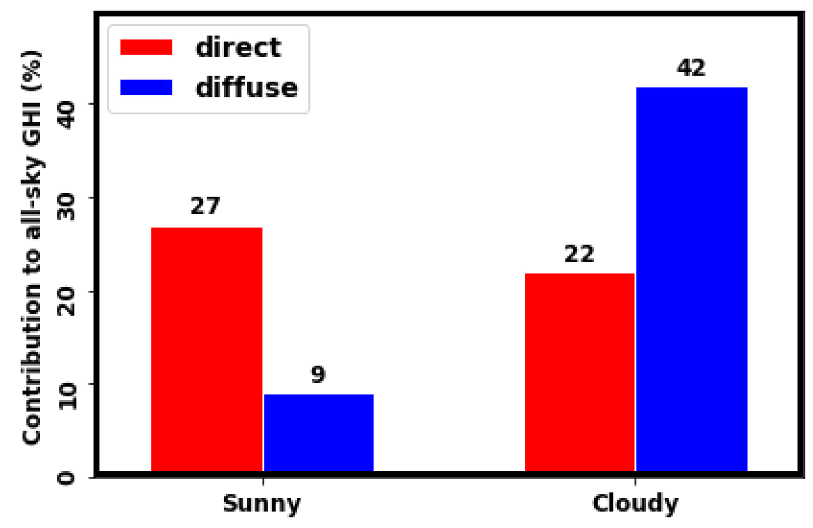

Figure 4. *Contribution of direct and diffuse components to all-sky GHI, in sunny and other (cloudy) conditions. The sum makes 100% of all-sky GHI. Computations are made with measurements made at Lille in 2011.*

Usually the panels are tilted to increase the solar resource by increasing the direct component. The direct/diffuse ratio of ~1 in all-sky could be larger than 2 in tilted.

The direct/diffuse ratio can also change with the PV panel technology, as the spectral absorption of the solar radiation depends on the PV cell composition. The panels absorb either mostly in the visible domain (a-Si, GaAsAl), either in the near infra red (c-Si, GaAs). The spectral influence is studied by computing collected solar radiation in both the 400-700 nm and 700-1000 nm domains. The visible domain (400-700 nm) contributes by 41% to the direct component in sunny conditions, and by 57% to the diffuse component (***Fig. 5***). Oppositely, the NIR domain contributes by 20% to the direct component but 30% to the diffuse component. Consistently, the cloudy conditions is a mixture of both spectral dependences, with 25% NIR and 52% visible, consistently to the white color of clouds. Consequently, the direct/diffuse ratio in all-sky changes from 0.8 in visible to 1.2 in NIR domains.

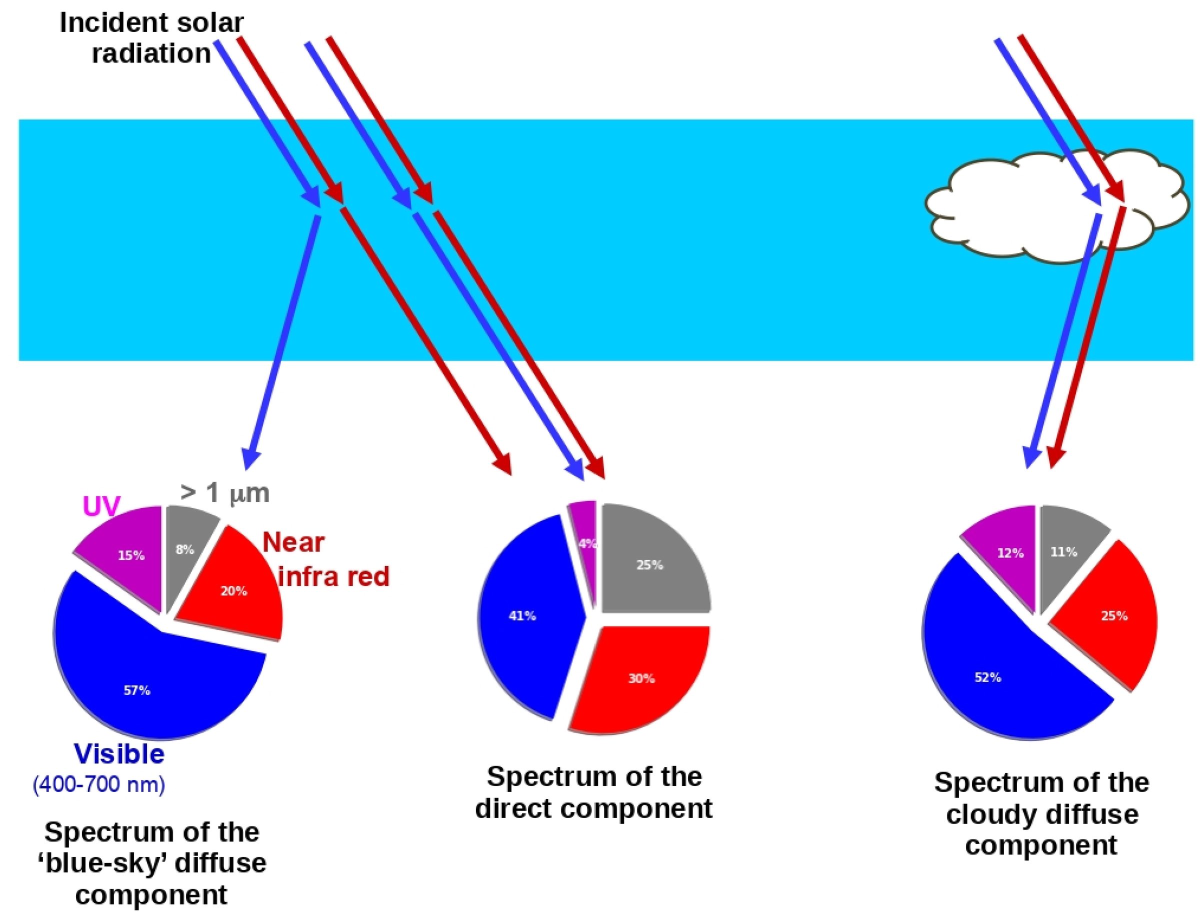

Figure 5. *Spectra of the solar radiation reaching the surface, at Lille in 2011. Computations made for the direct and diffuse components, in clear-sky and cloudy conditions, by the ARTDECO toolbox with MERRA-2 input data.*

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We also acknowledge McClear and the SODA service to deliver the irradiance data, as well as Jörg Trentmann et Uwe Pfeifroth (DWD, SAF) for SARAH-2 data.

2. Validation

Data used for validation were observed at Lille, France, in 2011, at the platform of LOA [Ferlay *et al.*, poster 5CV.3.9, EUPVSEC2019]. Both the direct normal irradiance (DNI) and the global horizontal irradiance (GHI) were measured at 1-minute resolution. Moreover, these measurements were performed nearby an instrument from the AErosol RObotic NETwork (AERONET)[5]. All measurements were averaged over 1 hour.

A cloud-screening scheme in the solar direction is defined with the DNI data, and combined with the AERONET cloud-screening. Measurements were performed during 3741 hours in 2011, and 756 hours were declared 'Sunny'.

The environment of SMART-G is used to compute DNI (strict[6]), with input data provided by AERONET (clear-sky) and by MERRA-2 (all-sky). The ARTDECO toolbox is used to compute both DNI and the diffuse component with input data provided by MERRA-2 (all-sky). MERRA-2 is a reanalysis global data set[7]. Computations are made at 10-minute resolution and also averaged over 1 hour. GHI is computed as the sum of the direct and diffuse horizontal (DifHI) components (sza is the solar zenith angle).

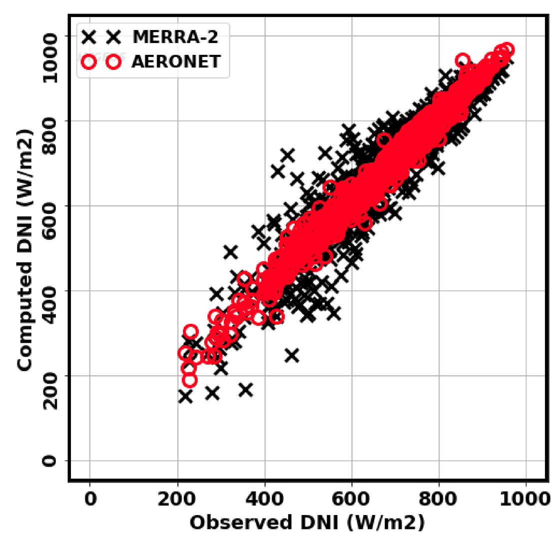

Figure 1. *Comparison between computation and observation of 1-hour DNI in clear-sky conditions at Lille in 2011. Computations by SMART-G with AERONET and ARTDECO with MERRA-2 input data.*

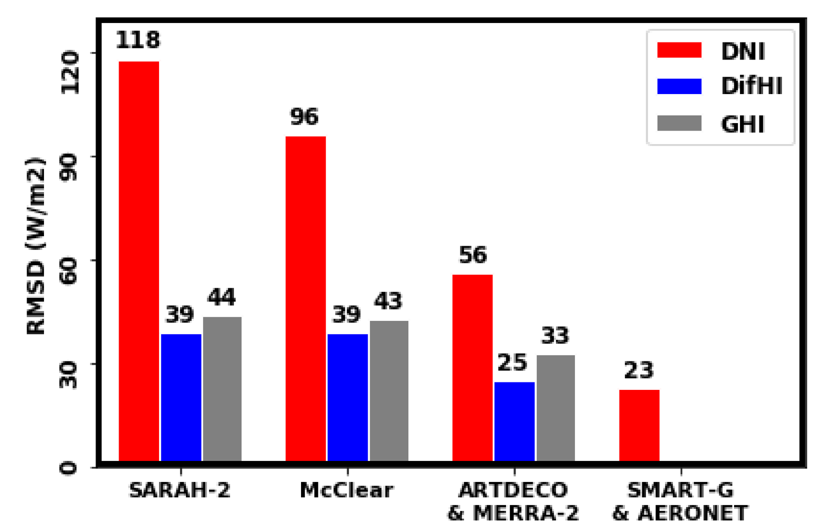

Figure 2. *RMSD between computations and observation of DNI, DifHI and GHI in clear-sky conditions at Lille in 2011. Computations are made by HYGEOS-LOA (SMART-G, ARTDECO) and also provided by operational products (SARAH-2, McClear).*

The methodology is validated as observed DNI was reproduced with a root mean square difference (RMSD) of only 24 W/m² during the 756 Sunny hours, even if the aerosol optical thickness (AOT) is moderate and variable with a mean value of 0.17±0.12, as is the water vapor content (WVC) of 1.3±0.5 g/cm². The mean annual DNI was 672±150 W/m², and the RMSD was smaller than 4%.

Computations strongly depend on the input data as RMSD in DNI was multiplied by ~2 by using MERRA-2 (***Fig. 1***). It remained anyhow smaller than with the operational products as provided by McClear[8] and SARAH-2[9] (***Fig. 2***). Even the RMSD in GHI was smaller with our approach than with the operational products.

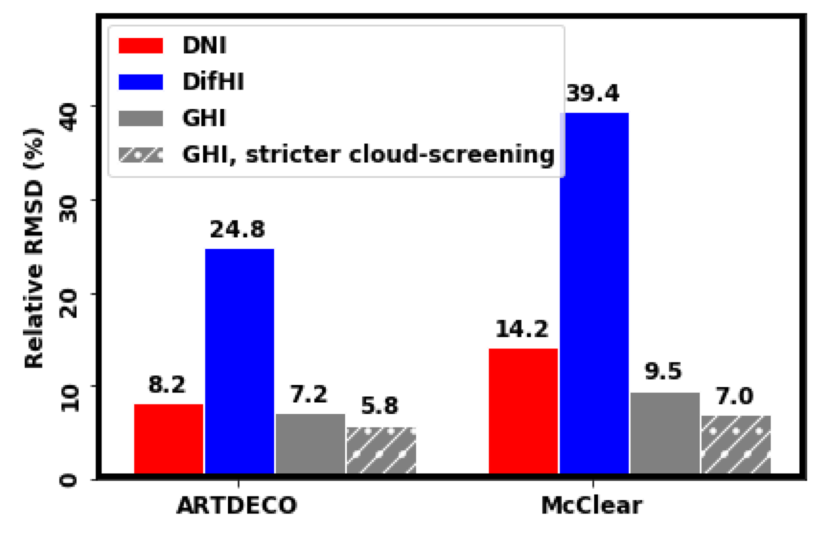

Figure 3. *Comparison between computation and observation of 1-hour DNI in clear-sky conditions at Lille in 2011. Computations with SMART-G with AERONET and MERRA-2 input data.*

The relative value of the RMSD in GHI could decrease thanks to a stricter cloud-screening keeping only 267 'blue sky' hours. Indeed mean annual observed GHI significantly increased from 448±224 to 557±164 W/m², and the relative RMSD significantly decreased from 7.2 to 5.8% (***Fig. 3***). See also the computations by Ferlay *et al.* [poster 5CV.3.9, EUPVSEC2019].

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