Analysis of the direct and diffuse partitions of solar irradiance measured in the North of France, and comparison with their estimates from satellite (one product)

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Laboratoire d’Optique Atmosphérique (LOA, Université de Lille/CNRS):

**Interested by:**
- description of atmospheric components (aerosols, clouds and their precursors), and the retrieval of their properties (microphysical, chemical, radiative).
- and their impacts, on the radiation field in particular.

**Exploit and develop:**
- **satellite measurements** from polar passive sensors (e.g., PARASOL, 3MI) and active sensors (lidar CALIOP and radar CloudSat), and also geostationnary satellite.
- **in situ measurements**: photometers, radiometers (UV, VIS, IR), spectrometer, lidar, sky imager, airborne instruments.
Motivation of this research activity toward solar energy:

Help to better describe the characteristics of the solar irradiance at the surface as a function of the atmospheric content (link between meteorology and solar resource) Ultimately: to help to improve the efficiency of solar systems, to help to forecast the solar resource

Particular motivation for the current study:

The direct/diffuse partition of the surface solar irradiance is very important for the performance of solar systems:
- plants and photosynthesis (Gu et al (JGR, 2002))
- amorphous vs mono/poly-cristallin vs dye sensitized solar cells
- CSP technology exploit direct solar component
- optimized orientation of PV panels?
- it is a challenge for solar satellite-based estimates

Objective of the current study:

- Study the climatology of the solar resource in Lille from in situ measurements (with the analysis of the partition between direct and diffuse radiations)
- Study the capability of solar satellite-based inference to get correct evaluation of the surface solar irradiance in clear or cloudy conditions, and understand the differences
Climatology of solar irradiance at LOA’s site

1/ Measurement system

Kipp & Zonen pyrheliometer CH1 and pyranometer CMP22 + sun tracker + shadower

\[ \mu_0 = \cos(\theta_0) \]

\[ \text{Total}_{\text{horiz}} = \text{DIR} \cdot \mu_0 + \text{DIFF} \]

every minute
Climatology of solar irradiance at LOA’s site

2/ Climatology in 2016: daily energy (kWh/m²)

- Seasonal variation.
- Strong temporal variation and wide range of values for direct and total.
- Smoother variation for diffuse.
Climatology of solar irradiance at LOA’s site

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Climatology of solar irradiance at LOA’s site

3/ Atmospheric transmittance: monthly variation 2009-2016

\[ T = \frac{\mu_0 \cdot DIR + DIFF}{\mu_0 \cdot I_0} \]

- **Seasonal variation.**
- **Strong temporal variation and wide range of values for direct and total**
- **Smoother variation for diffuse**
- **Maximum in April**
Climatology of solar irradiance at LOA’s site

3/ Atmospheric transmittance: monthly variation 2009-2016

\[ T = \frac{\mu_0 \cdot DIR + DIFF}{\mu_0 \cdot I_0} \]

- Seasonal variation.
- Strong temporal variation and wide range of values for direct and total.
- Smoother variation for diffuse.
- Maximum in April.
Climatology of solar irradiance at LOA’s site

4/ Instantaneous atmospheric transmittance: can be very high and exceed unity!

Explanation:
- Fractional cloud cover can cause efficient 3D radiative transfer cases
- Clouds act as additional radiative sources
- Direct is (still) high while diffuse is high
Climatology of solar irradiance at LOA’s site

4/ Instantaneous atmospheric transmittance: can be very high and exceed unity!

Explanation:
- Fractional cloud cover can cause efficient 3D radiative transfer cases
- Clouds act as additional radiative sources
- Direct is (still) high while diffuse is high

Ex: 29 February 2016
Climatology of solar irradiance at LOA’s site

4/ Instantaneous atmospheric transmittance: can be very high and exceed unity!

Explanation:

- Fractional cloud cover can cause efficient 3D radiative transfer cases
- Clouds act as additional radiative sources
- Direct is (still) high while diffuse is high

Ex: 31 July 2018
Climatology of solar irradiance at LOA’s site

4/ Instantaneous atmospheric transmittance: can be very high and exceed unity!

Explanation:
- Fractional cloud cover can cause efficient 3D radiative transfer cases
- Clouds act as additional radiative sources
- Direct is (still) high while diffuse is high

Count of 3D “minutes”:

when $T \geq 0.80$

Not rare events!

Important: this is not an artifact of the measurement process!
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

1/ Satellite-based solar product

- **PVGIS (Photovoltaic Geographical Information System).**
  + Developed by European Commission Joint Research Center.
  + Aim to provide solar radiation assessment, PV performance studies
  + Available at http://re.jrc.ec.europa.eu/

- **PVGIS-CMSAF:**
  + Europe, Africa and a part of South America
  + Period 2007-2016
  + Hourly time resolution
  + Spatial resolution: ~ 2.5 km
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

2/ Strategy of comparison

- Case study

- Statistically per type of nebulosity:
  - Sunny/clear days: \((\text{direct} / \text{total}) > 0.6\)
  - Cloudy days: \((\text{direct} / \text{total}) < 0.3\)
  - Partly cloudy day: \(0.3 < (\text{direct} / \text{total}) < 0.6\)

- Sensitivity to 3D minutes
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

2/ Case study#1: perfectly clear day

Strong evidence of a bias with compensation

Origin: definition of “direct” is not the same; effect of circumsolar radiation

Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

2/ Case study#1_1: clear day with some cirrus

Strong evidence of a bias with compensation

Origin: definition of “direct” is not the same; effect of circumsolar radiation

Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

2/ Case study#2: very cloudy day

Strong evidence of a bias with compensation; Direct is overestimated

Origin: Effect of cloud heterogeneity and satellite pixel resolution
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

3/ Statistical difference

Strong evidence of a bias with compensation, with changing sign
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

3/ Statistical difference

Strong evidence of a bias with compensation, with changing sign
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

3/ Sensitivity to 3D minutes

Strong evidence of a bias with compensation, with changing sign 3D minutes: increase the bias for cloudy cases
Conclusion

- Climatology of surface solar irradiance in Lille shows a balanced partition between direct and diffuse radiation:
  - Annual direct (resp. diffuse) irradiance $= 45\%_{-2}^{+3}$ (resp. $55\%_{-3}^{+2}$) of total irradiance
  - Mean annual transmittance: $46\% \pm 2\%$
  - Mean monthly transmittance: $24\% \rightarrow 60\%$
- Many efficient 3D radiative transfer cases with instantaneous high transmittivity
- Comparison with PVGIS product shows an overall good agreement for total irradiance
- Estimate of direct and diffuse radiations includes (limited) biases (hourly, daily, monthly scales) that tend to compensate
- 3D minutes don’t change the bias but increase it for cloudy days

Perspectives

- Analyse further the climatology of the solar irradiance
- Obtain atmospheric transmittance per cloud type thanks to the synergy with lidar and other instruments
- Compare with other solar satellite-based products
- Analyse further 3D effects on solar irradiance
Thanks for your attention!

And thanks to

and JRC for their nice website
Effects of cloud heterogeneity

Underestimate of the true mean optical thickness
Effects of cloud heterogeneity

**Diffuse radiation**

- True value
- Underestimated value

**Direct radiation**

- True value
- Overestimated value

\[ \tau_{\text{estimated}} \]
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

3/ Sensitivity to 3D minutes

Partly cloudy days

Cloudy days

Strong evidence of a bias with compensation, with changing sign
3D minutes: an issue for cloudy cases
Comparison pyrheliometer + CMP22

vs

CMP11 without shadower

Total energy – days in 2018

Number of 3D minutes – days in 2018
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

1) Monthly data: over 8 years

- Total radiation from LOA and PVGIS are in relatively good agreement.

![Comparison of total radiation from 2009-2016](image)
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

1) Monthly data: over 8 years

The diffuse radiation is underestimated

The direct radiation is overestimated

The bias seems to compensate
EXEMPLE

Cirrostratus

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20 mai 2014