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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(*) Cimel Electronique, Paris

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 ressource)

Ultimately: to help to improve the efficiency of solar systems, to help to forecast the solar ressource

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

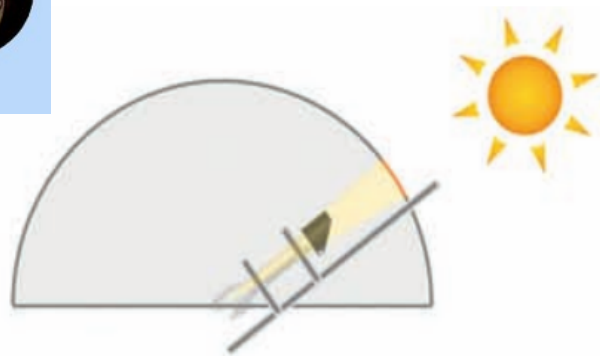
Objective of the current study:

- Study the **climatology of the solar ressource 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

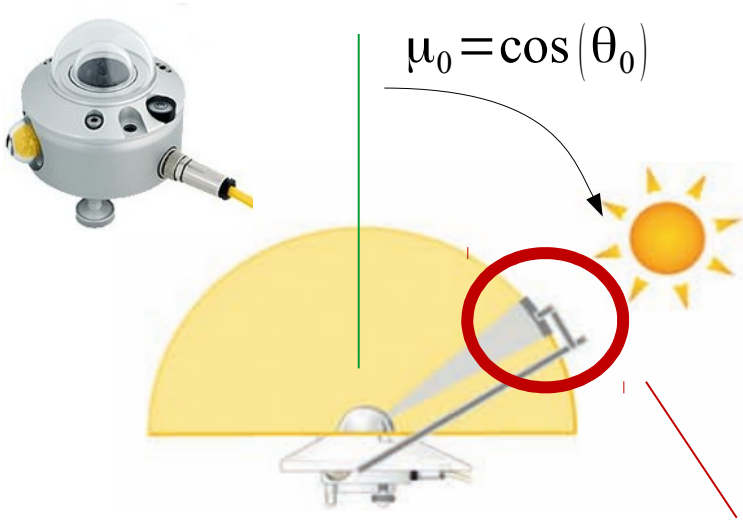
Climatology of solar irradiance at LOA's site

1/ Measurement system

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



Measures direct radiation DIR



Measures diffuse radiation DIFF

Shadower

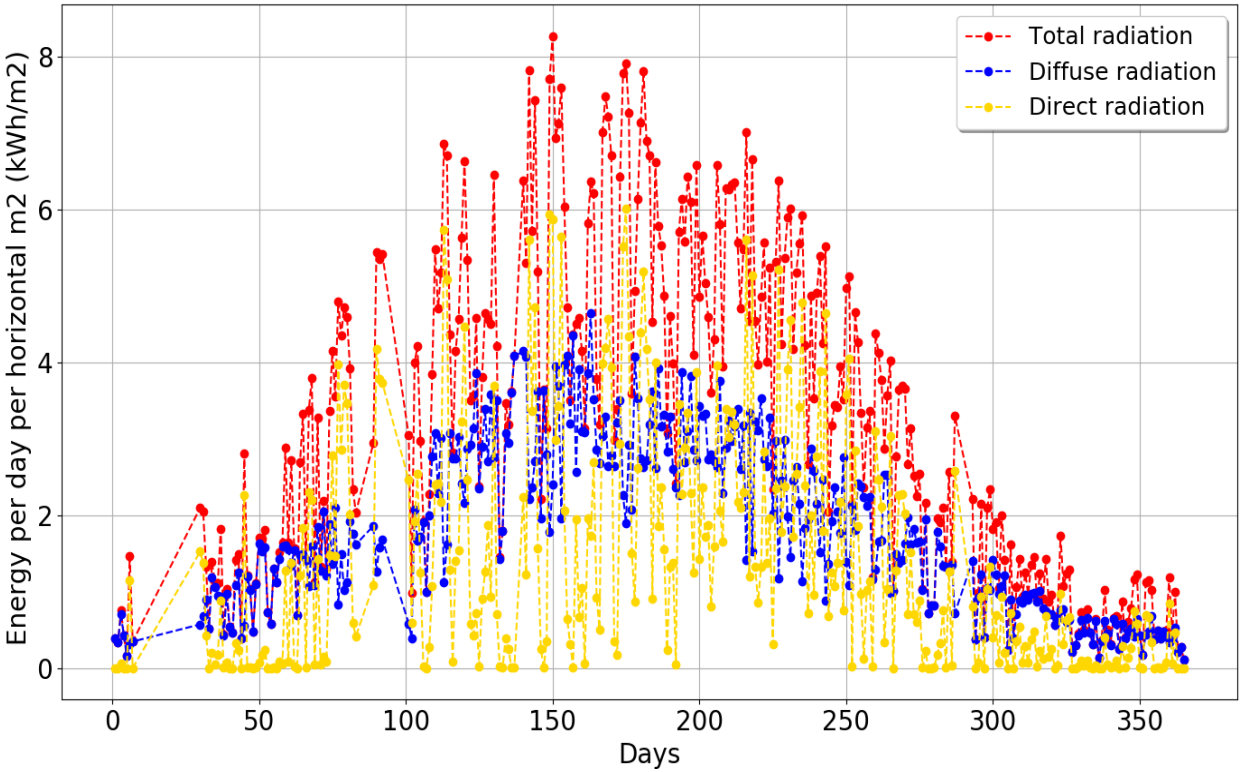
$$\mathrm{Total}_{\mathrm{horiz}} = \mathrm{DIR} \cdot \mu_0 + \mathrm{DIFF}$$

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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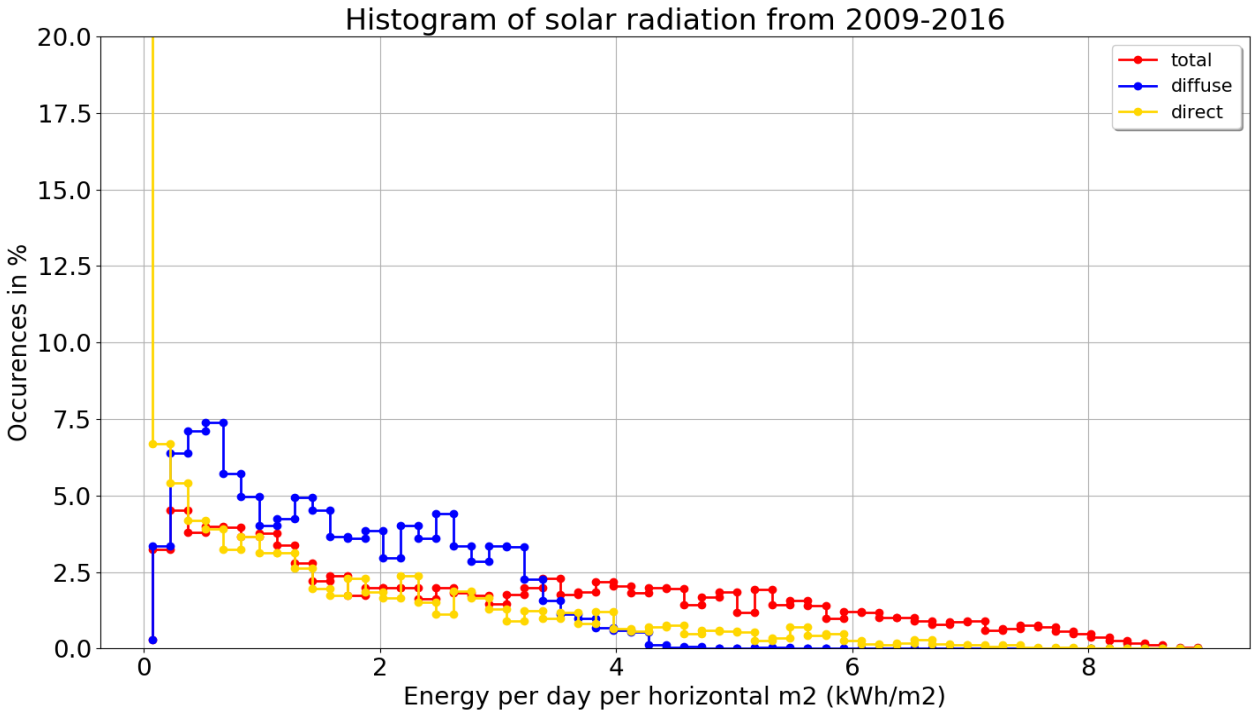
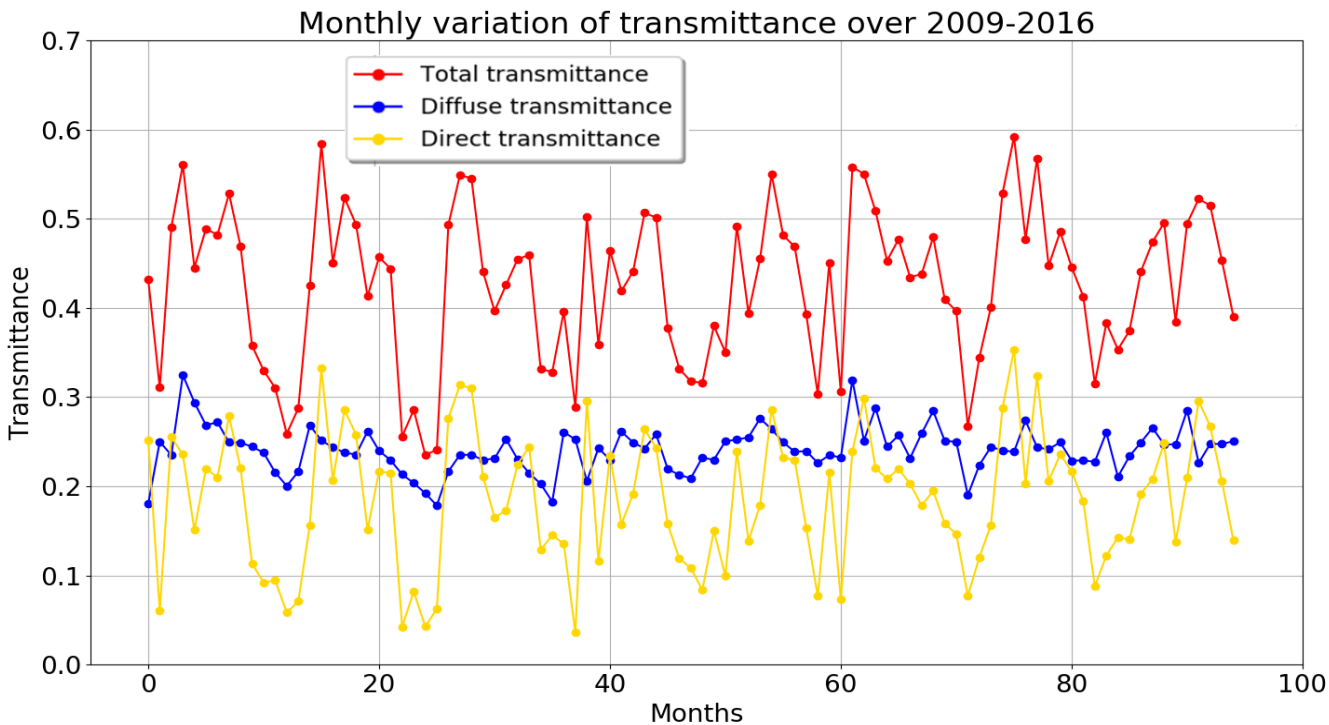


Climatology of solar irradiance at LOA's site

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

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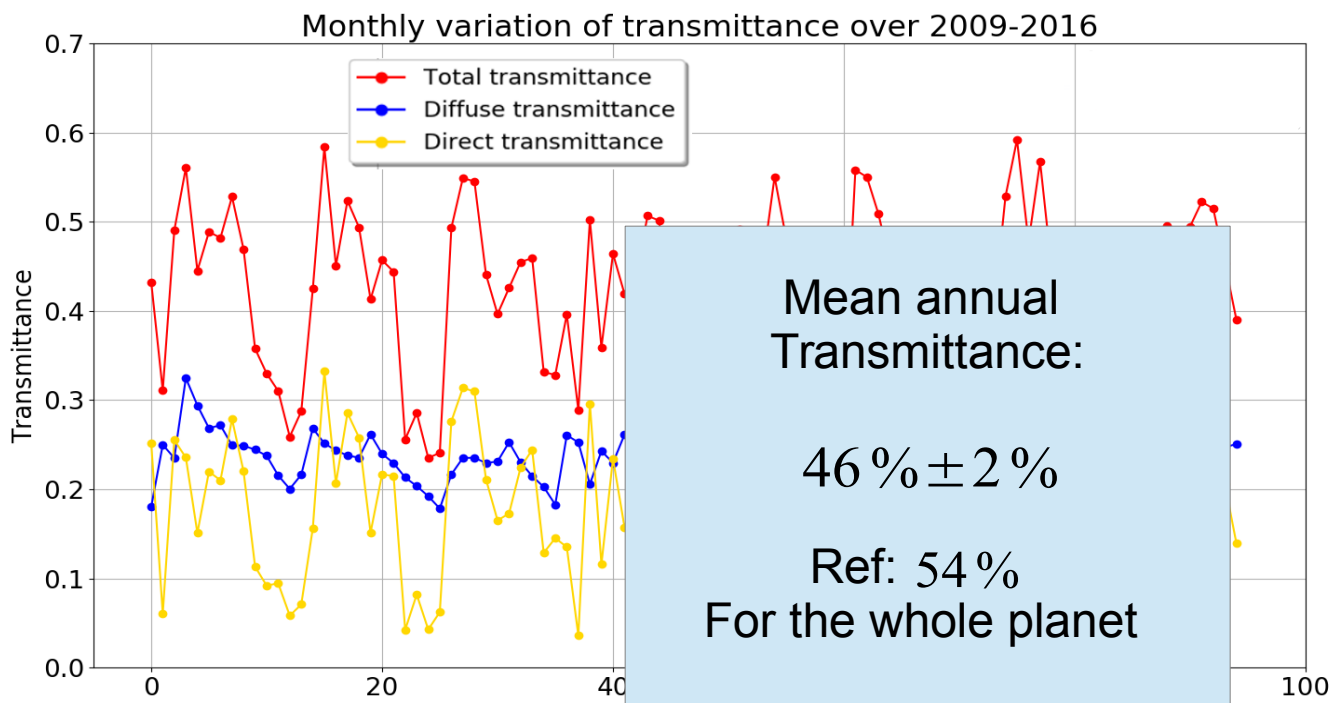


Mean annual Transmittance:

$46\,\% \pm 2\,\%$

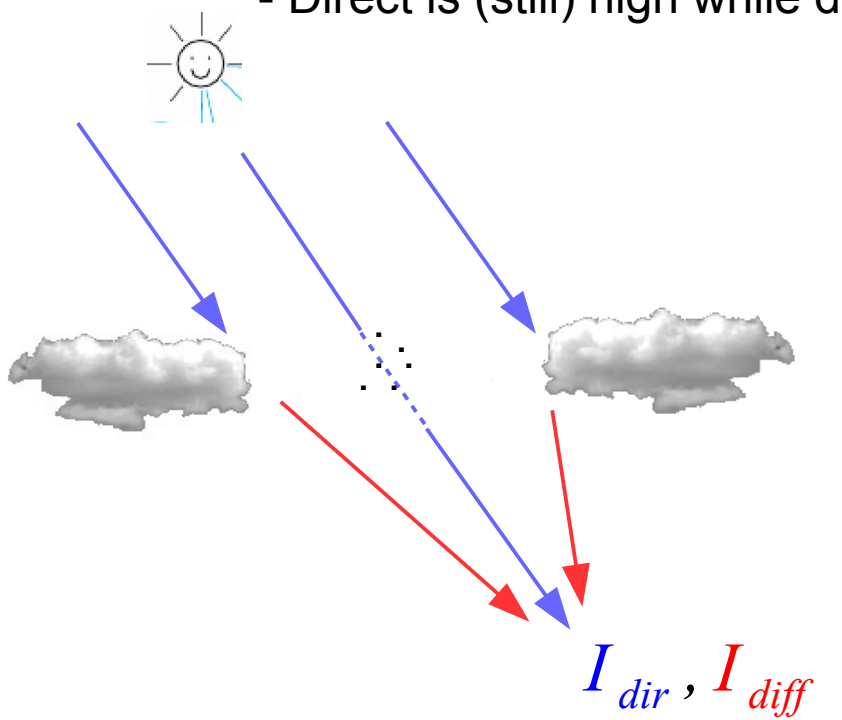
Ref: $54\,\%$
For the whole planet

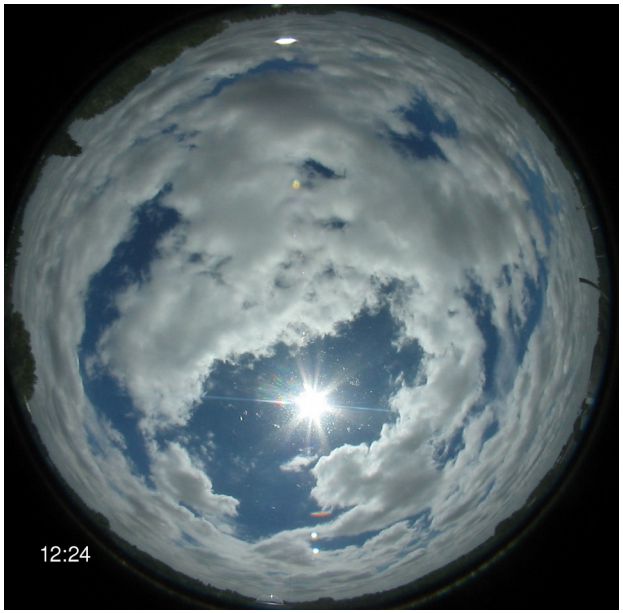
Part of direct (diffuse):
$45\,\%^{+3}_{-2}\left(55\,\%^{+2}_{-3}\right)$

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 additionnal radiative sources
- Direct is (still) high while diffuse is high





Climatology of solar irradiance at LOA's site

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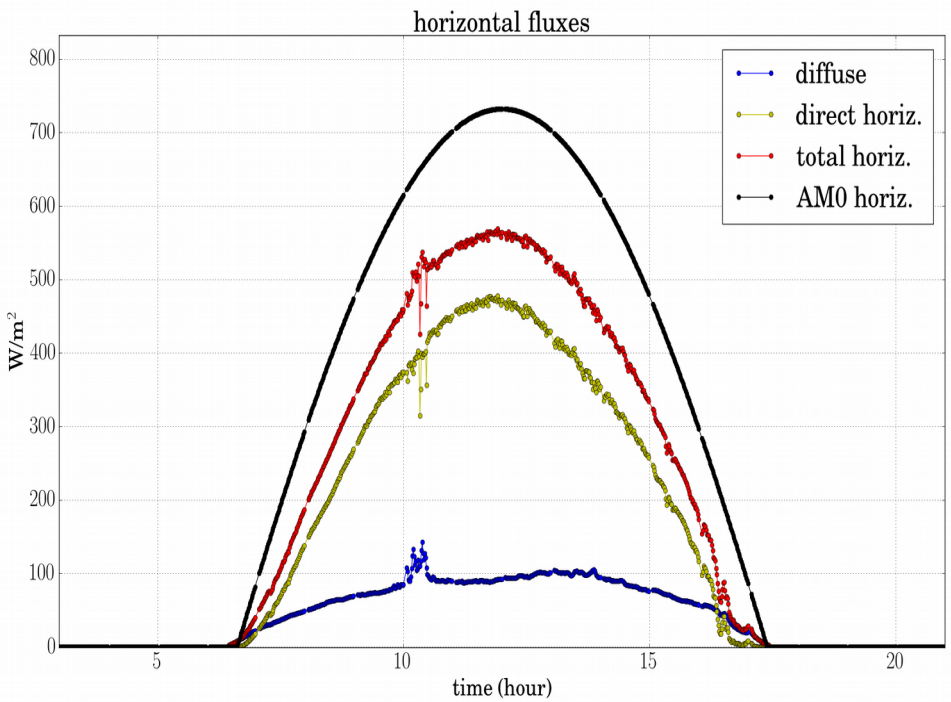
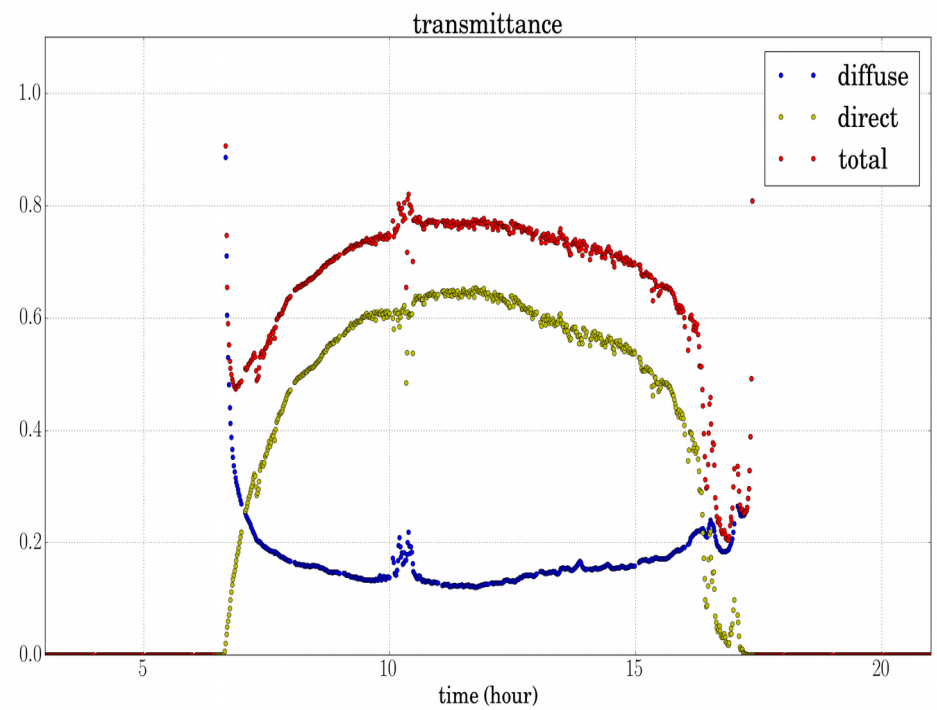
Ex: 29 February 2016





Climatology of solar irradiance at LOA's site

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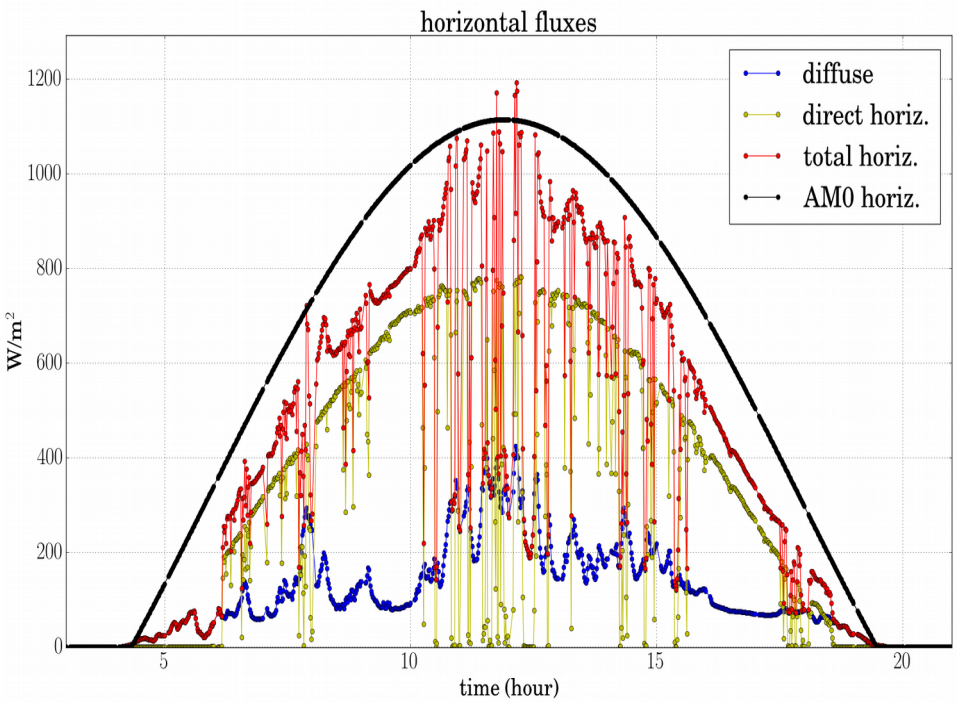
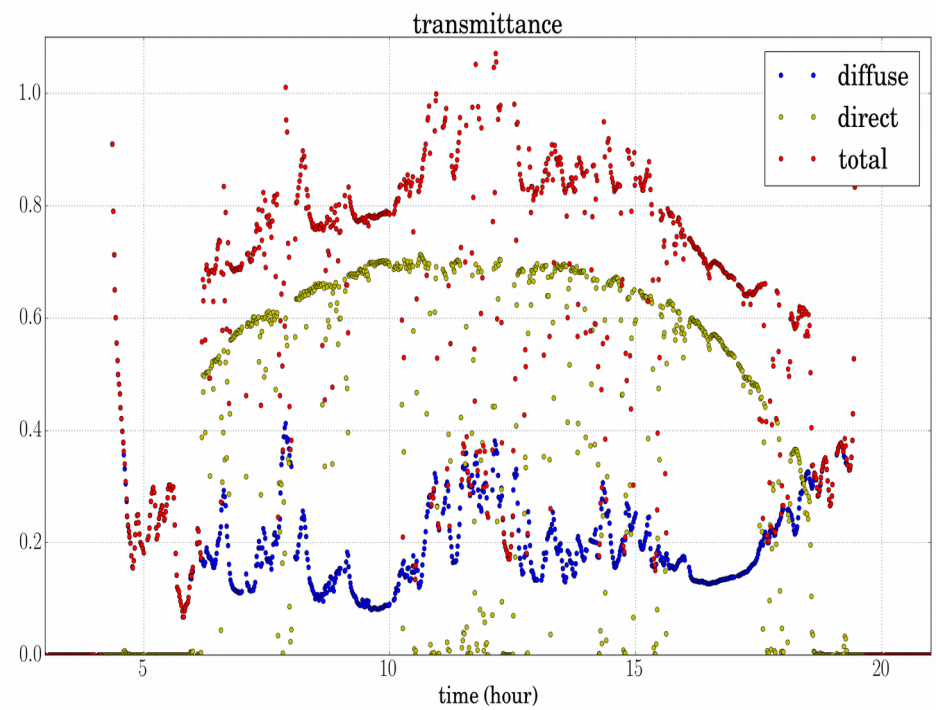
Ex: 31 July 2018





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
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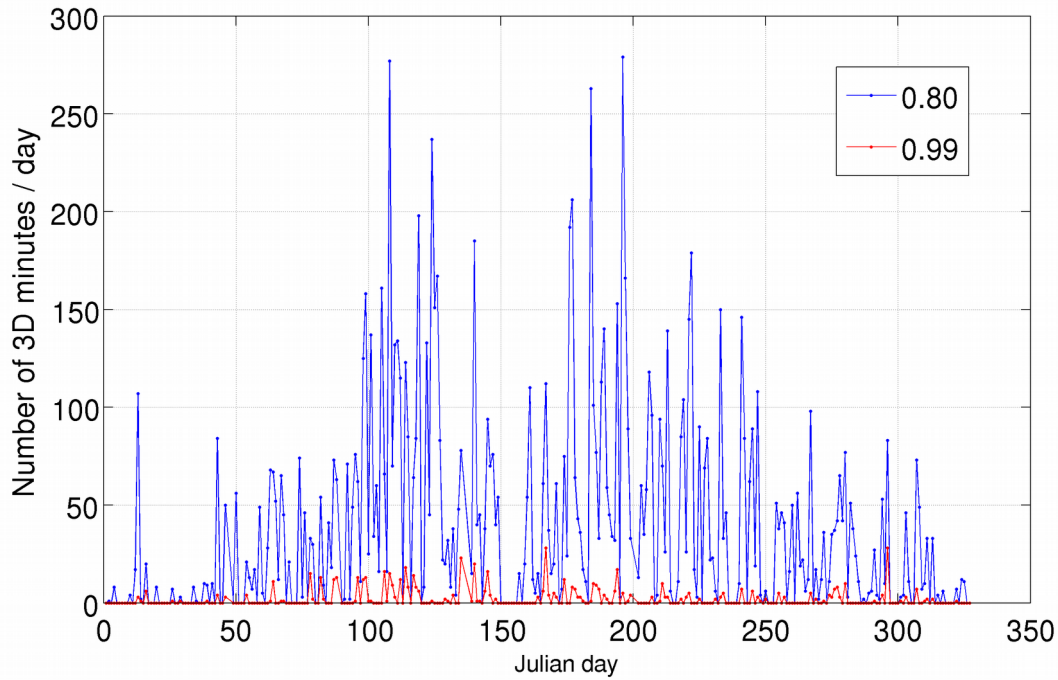
- Direct is (still) high while diffuse is high

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

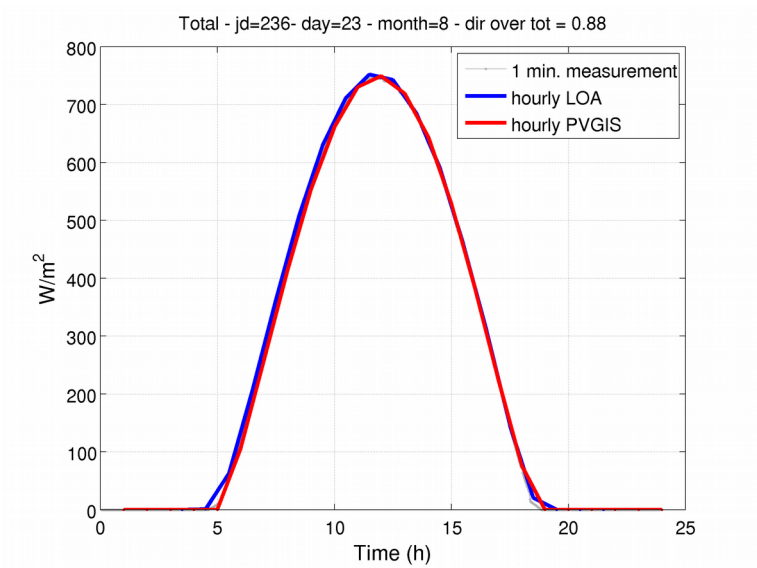
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

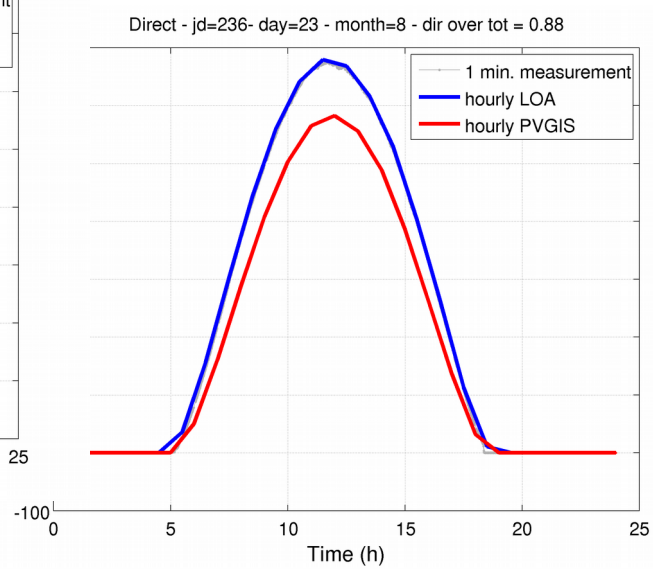
2/ Strategy of comparison

- **Case study**
- **Statistically per type of nebulosity:**
  - **Sunny/clear days :** **(direct / total) > 0.6**
  - **Cloudy days:** **(direct / total) < 0.3**
  - **Partly cloudy day:** **0.3 < (direct / total) < 0.6**
- **Sensitivity to 3D minutes**

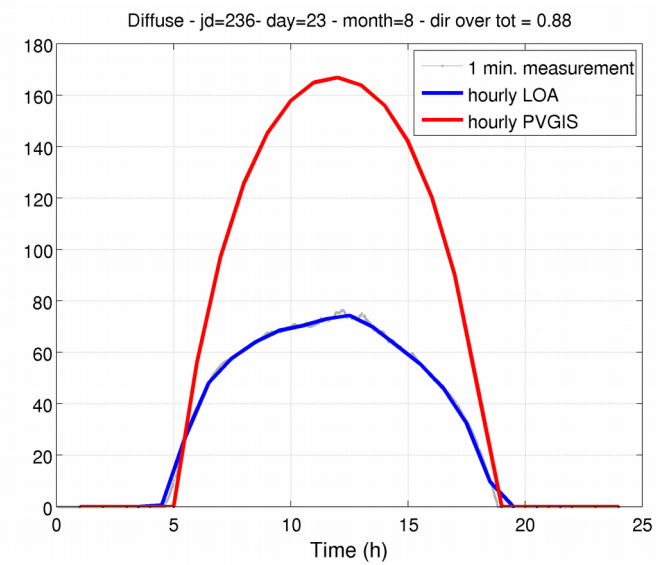
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

2/ Case study#1: perfectly clear day





Negative bias for direct
Positive bias for diffuse



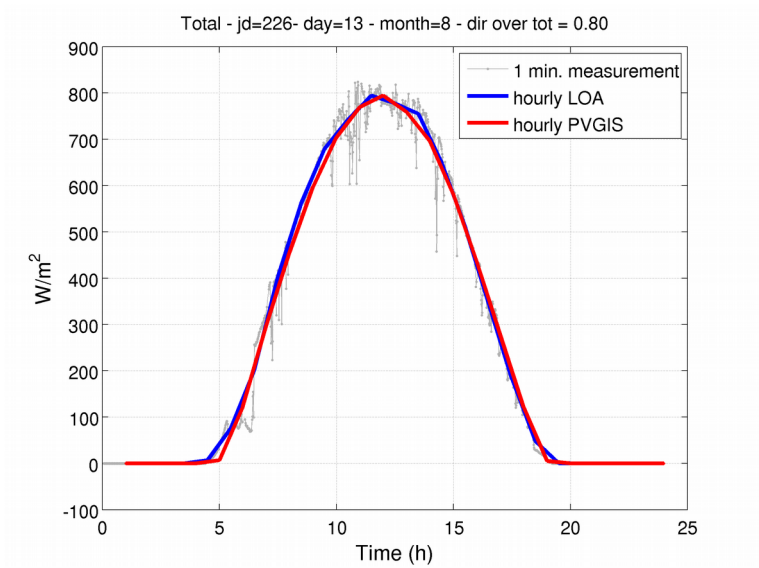
Strong evidence of a bias with compensation

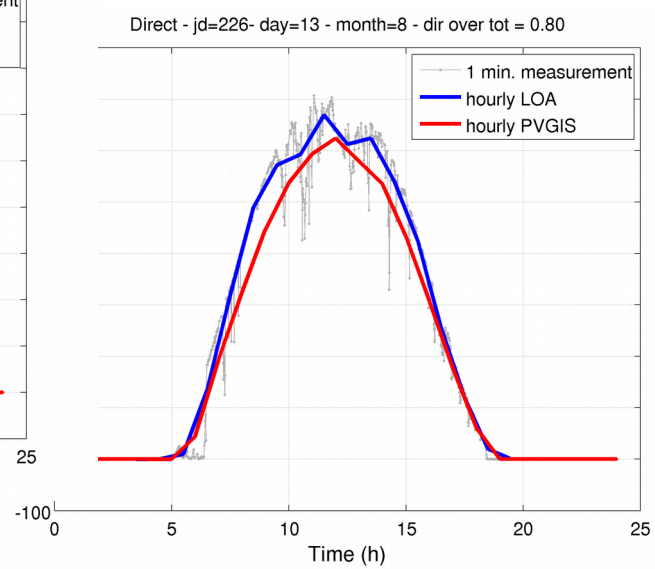
Origin: definition of “direct” is not the same; effect of circumsolar radiation

Gueymard (2001), Blanc et al (2014)

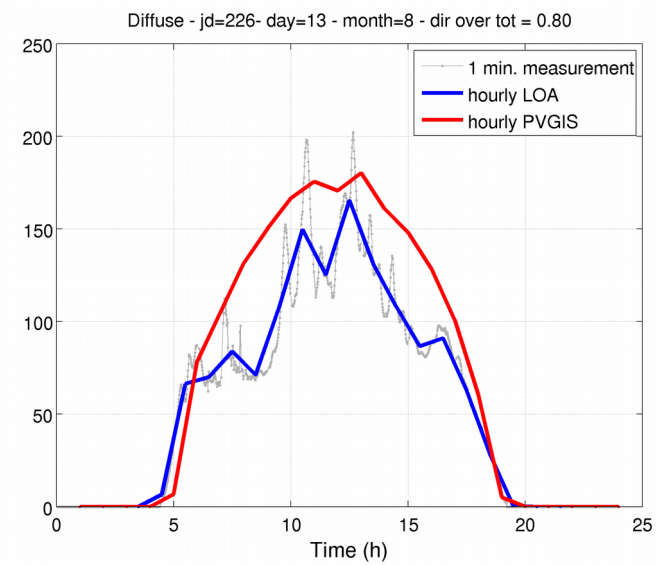
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

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





Negative bias for direct
Positive bias for diffuse



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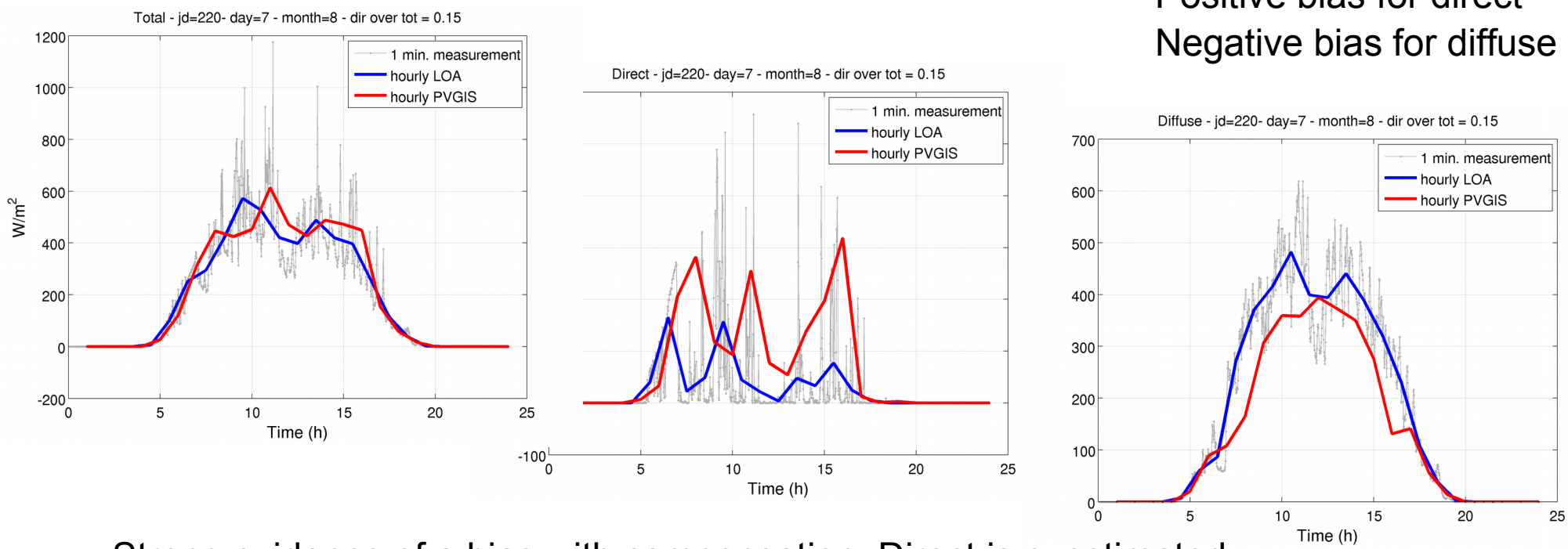
Gueymard (2001), Blanc et al (2014)

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

2/ Case study#2: very cloudy day

Positive bias for direct
Negative bias for diffuse

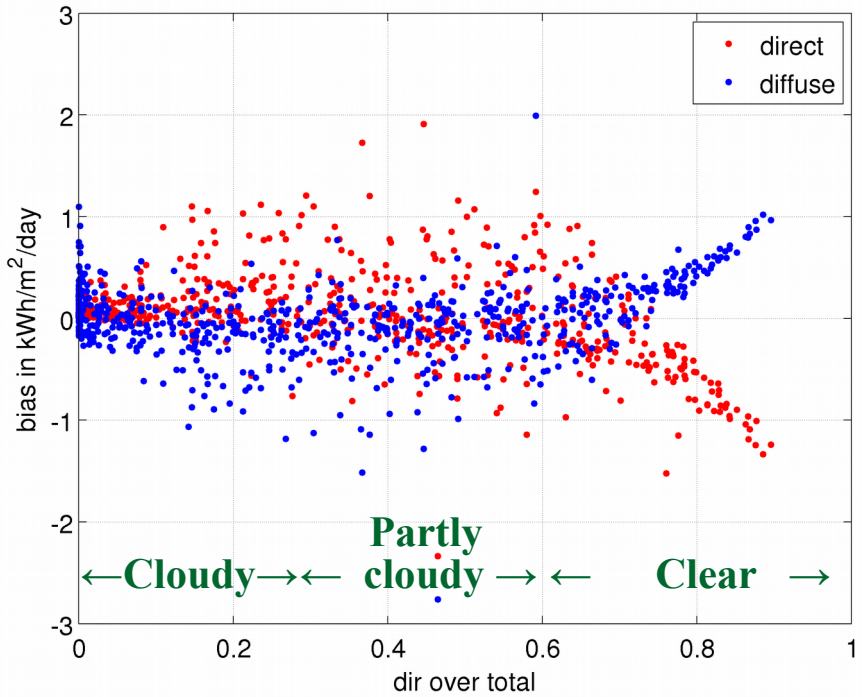


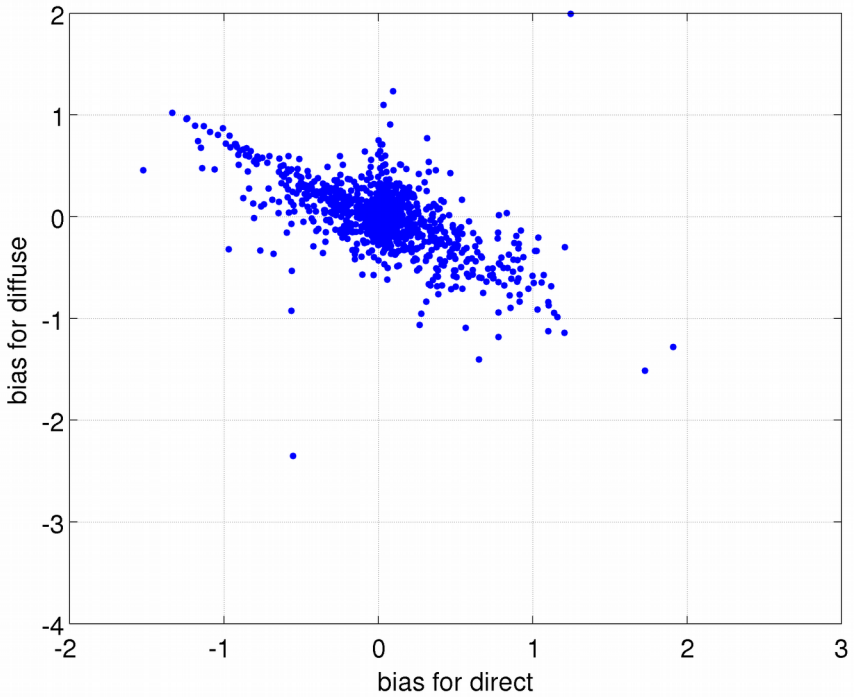
Strong evidence of a bias with compensation; Direct is ovestimated

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

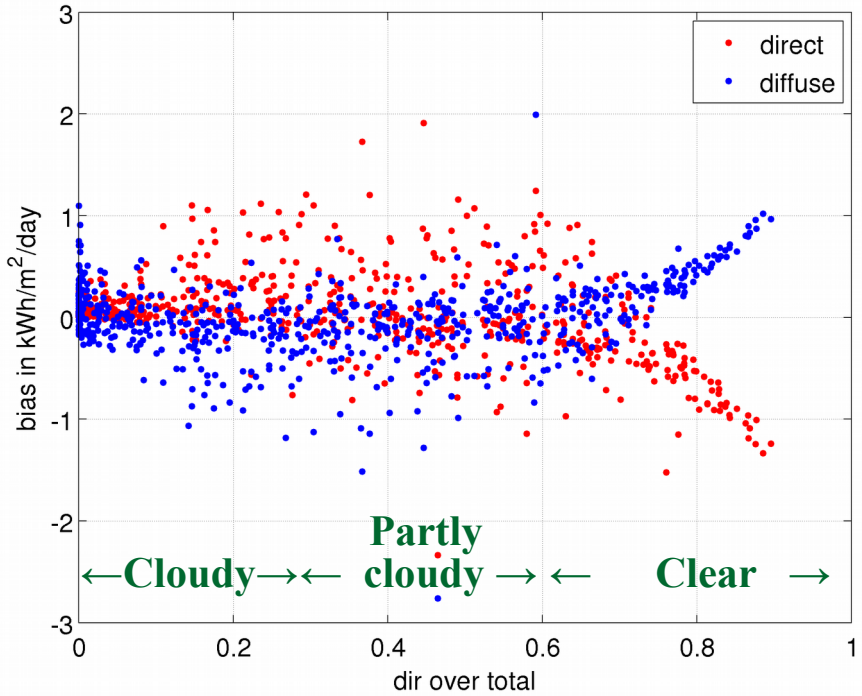


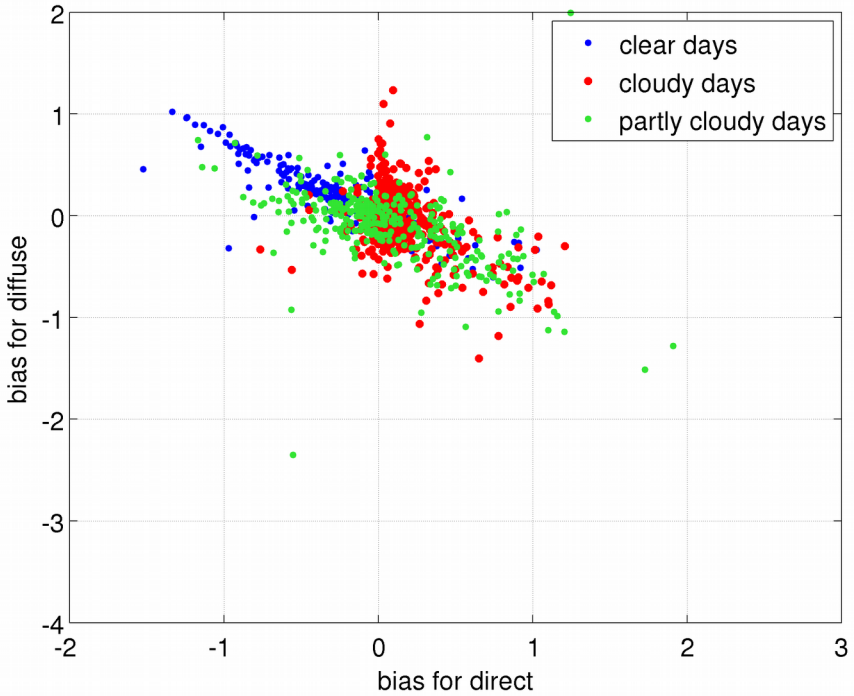


Strong evidence of a bias with compensation, with changing sign

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

3/ Statistical difference

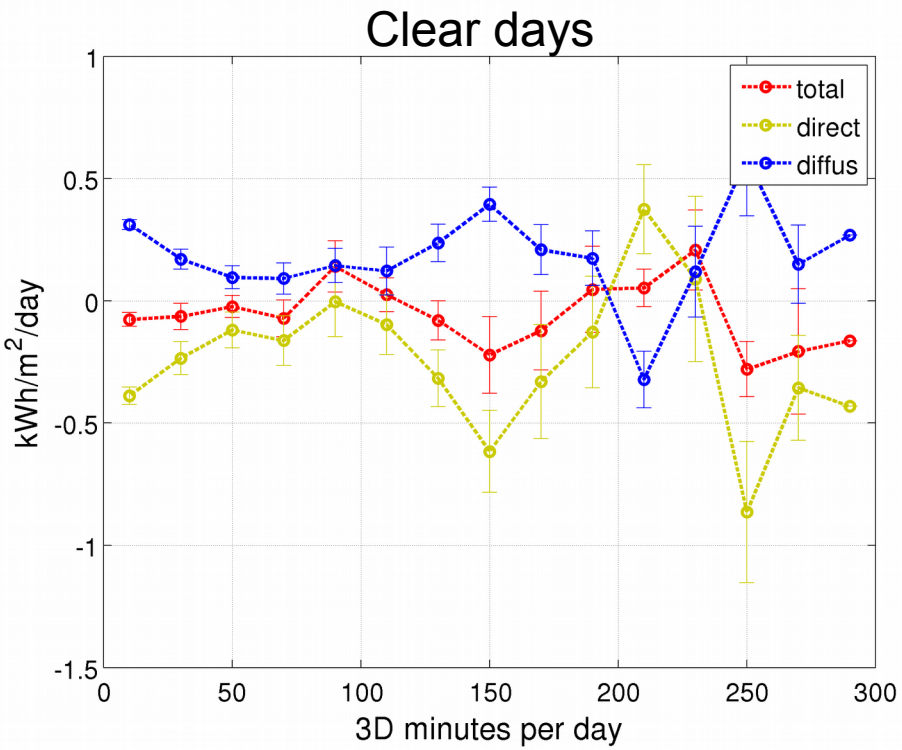


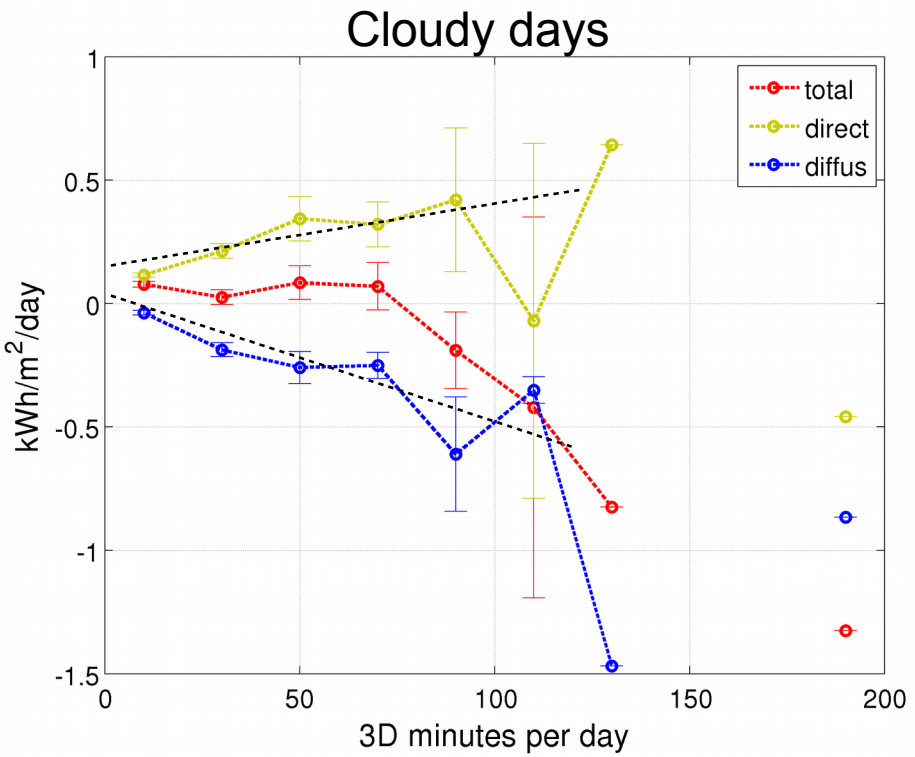


Strong evidence of a bias with compensation, with changing sign

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 = $45\%^{+3}_{-2}\left(55\%^{+2}_{-3}\right)$ of total irradiance
  - Mean annual transmittance: $46\% \pm 2\%$
  - Mean monthly transmittance: 24% → 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

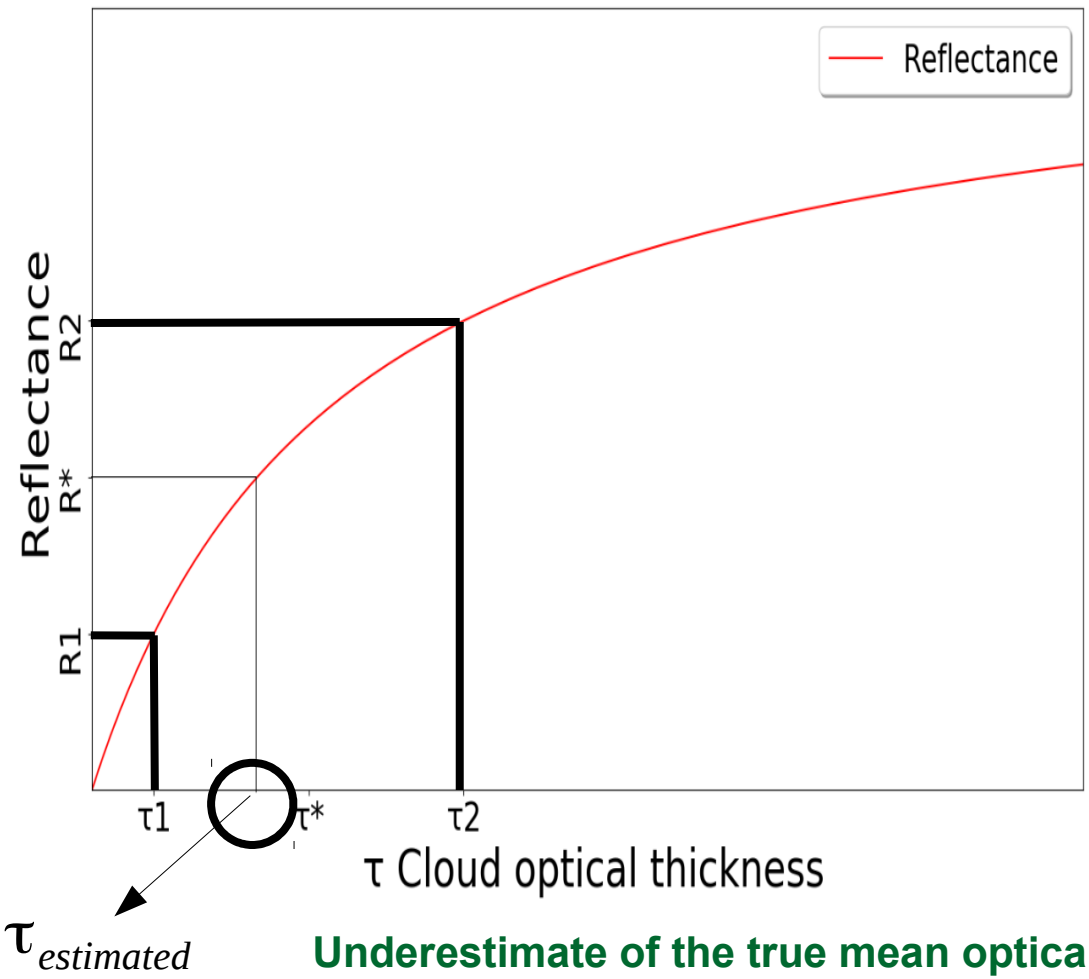
- Analyse further the climatology of the solar irradiance
- Obtain atmospheric transmittance per cloud type thanks to the synergy with lidar and other instruments
- Compare with other solar satellite-based products
- Analyse further 3D effects on solar irradiance

Thanks for your attention !

And thanks to

and JRC for their nice website

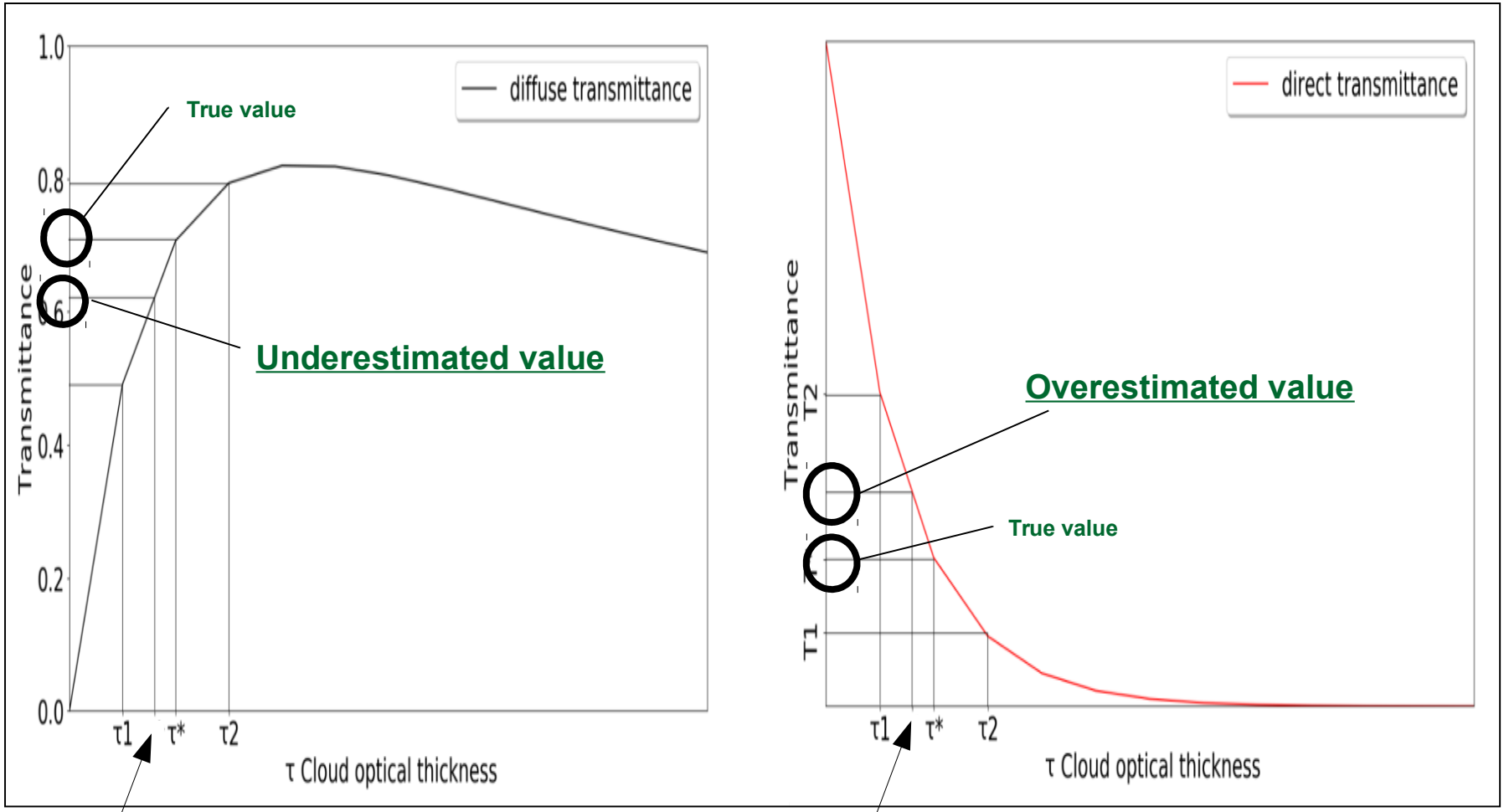
Effects of cloud heterogeneity



Underestimate of the true mean optical thickness

Effects of cloud heterogeneity

Diffuse radiation **Direct radiation**



$\tau_{estimated}$ $\tau_{estimated}$

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

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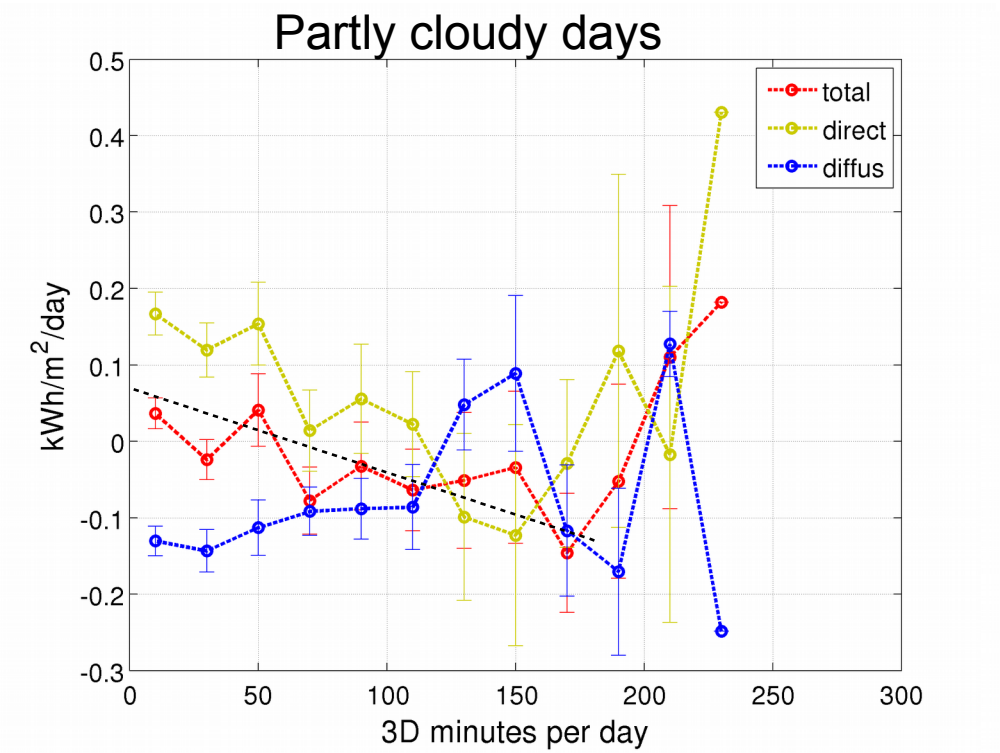
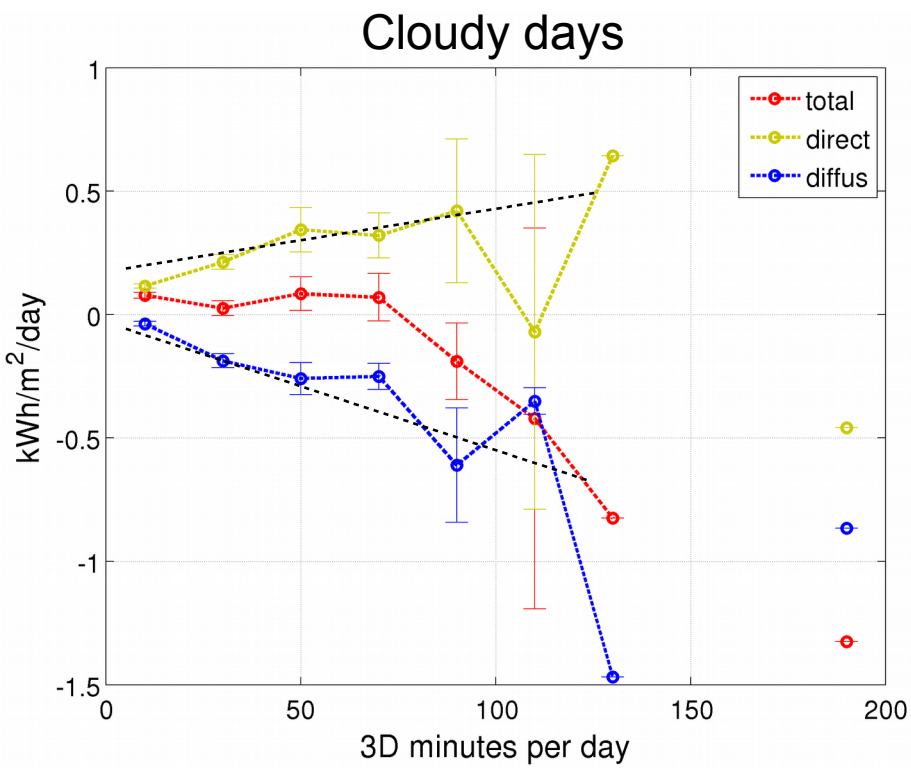
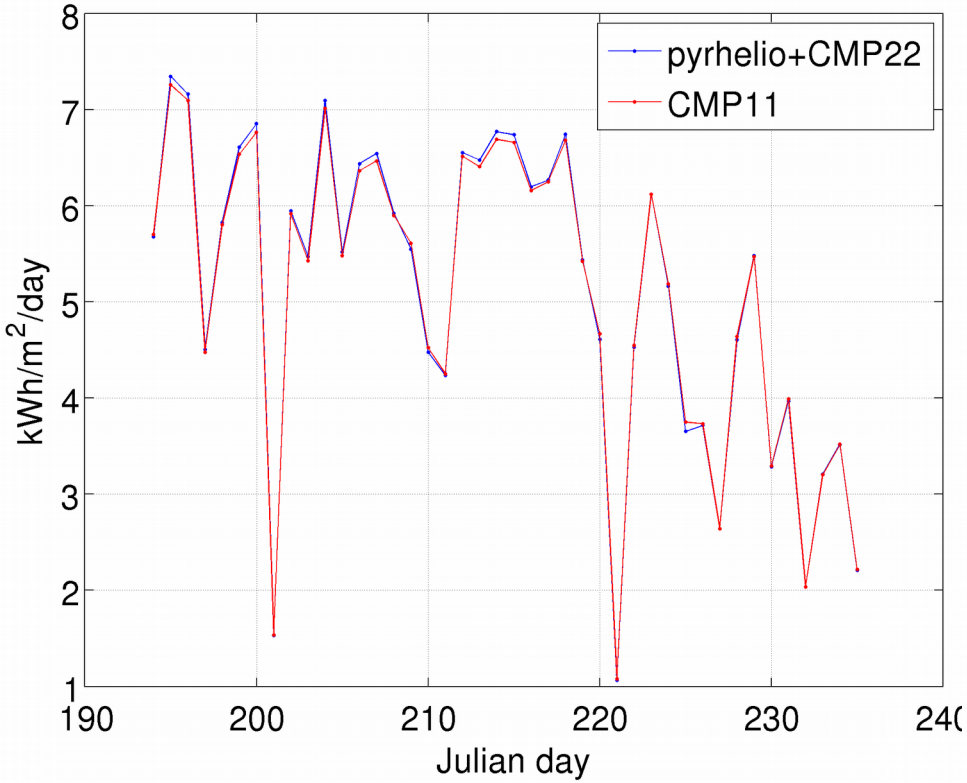




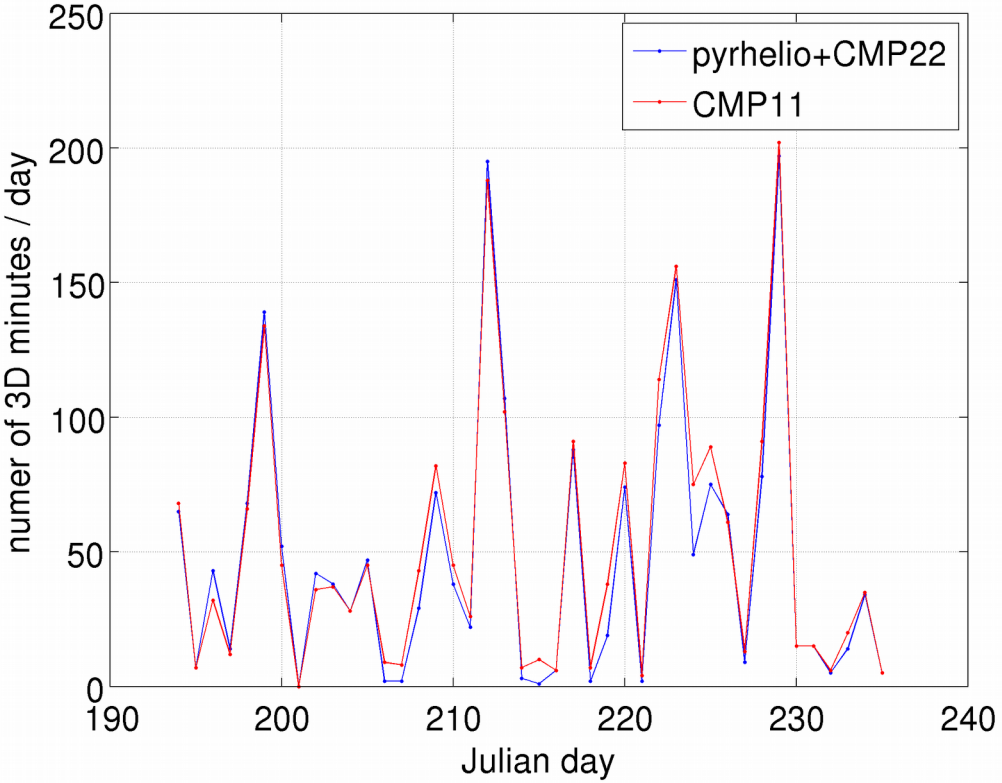
Strong evidence of a bias with compensation, with changing sign 3D minutes: an issue for cloudy cases

Comparison pyrheliometer + CMP22
vs
CMP11 without shadower

Total energy – days in 2018



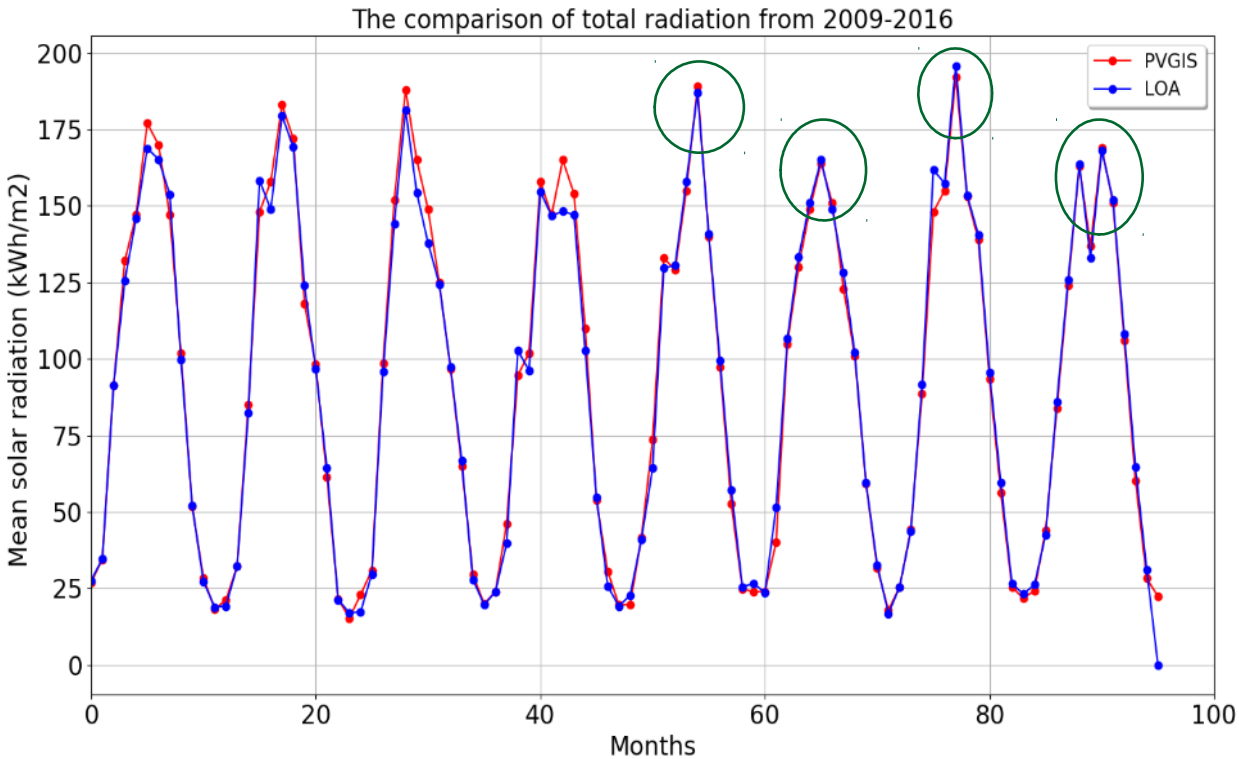
Number of 3D minutes – days in 2018



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.

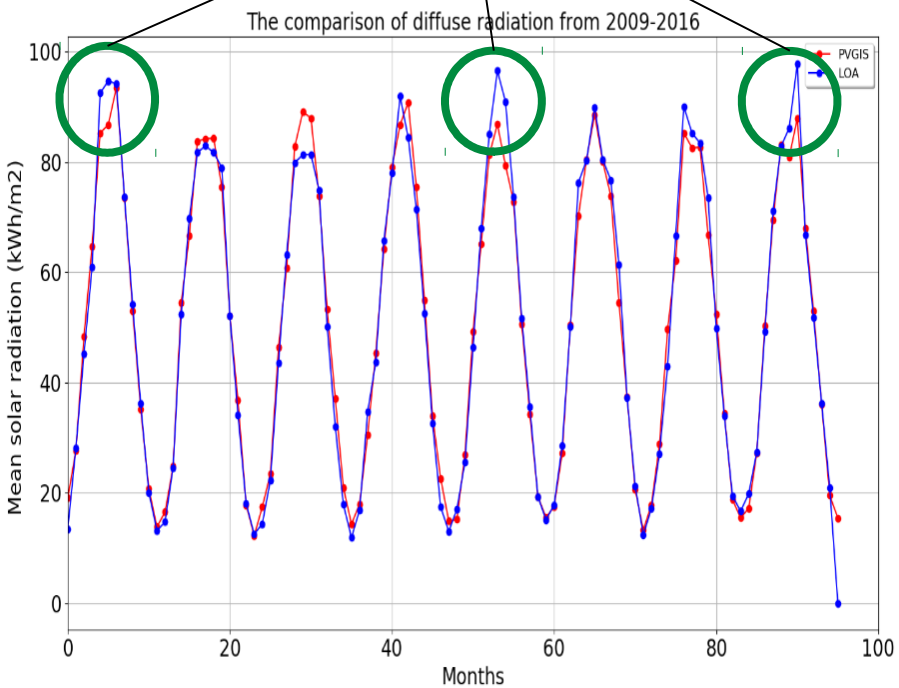


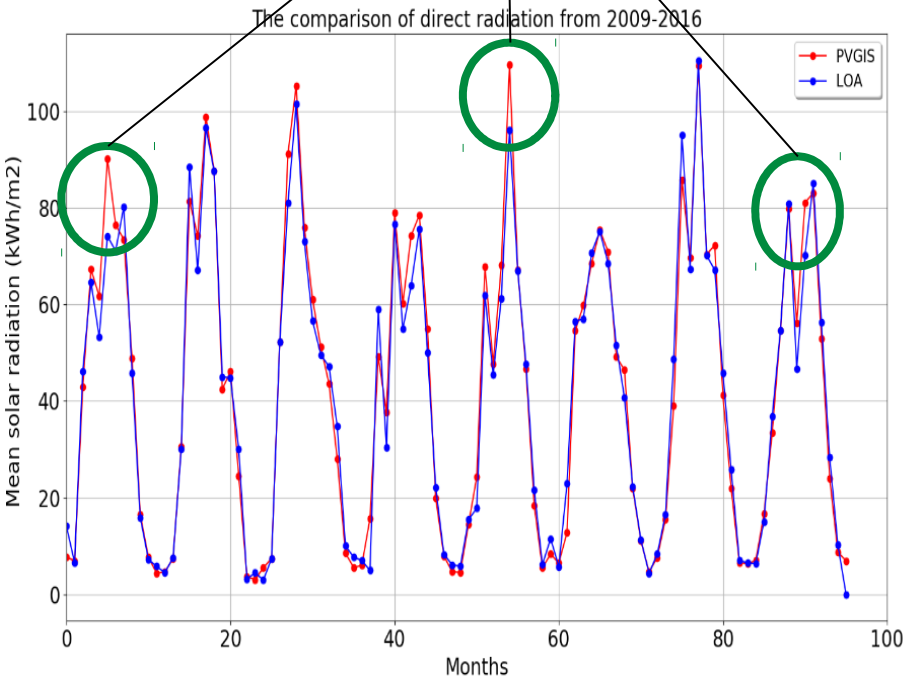
Comparison between solar irradiance from in-situ (LOA) and from satellite measurements (PVGIS)

1) Monthly data : over 8 years

The diffuse radiation is underestimated

The direct radiation is overestimated



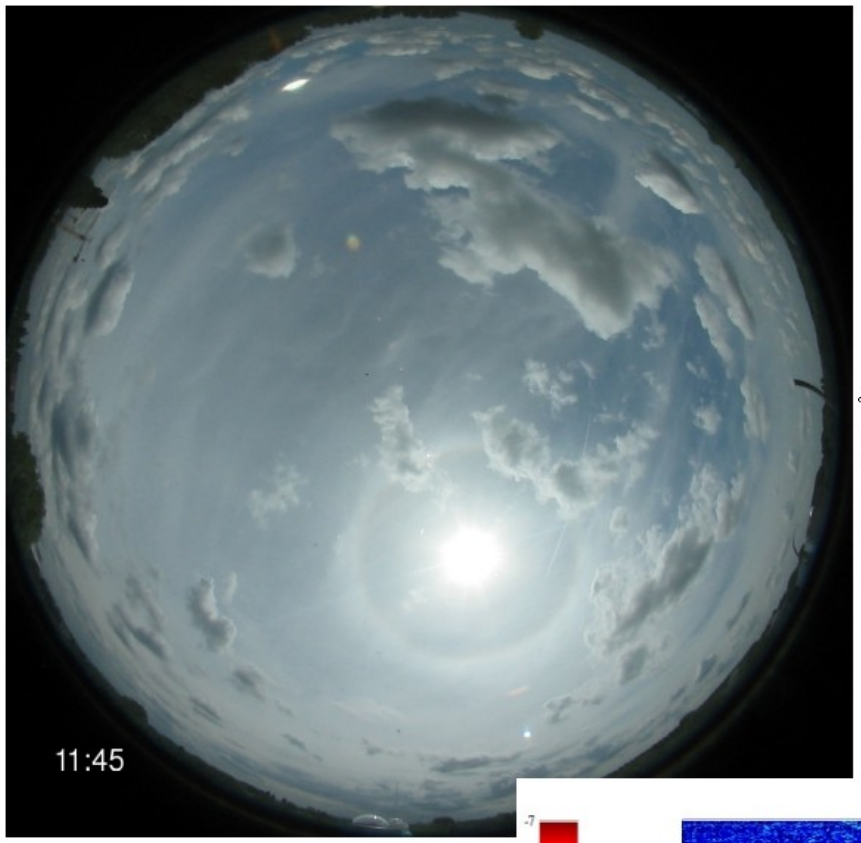


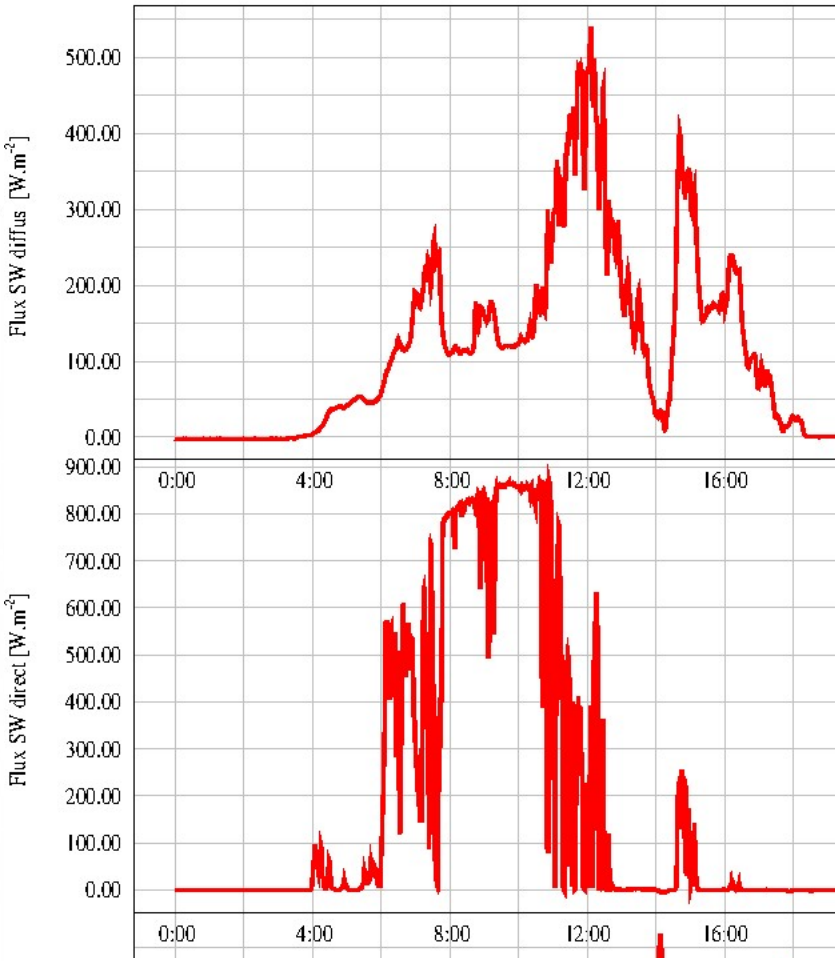
The bias seems to compensate

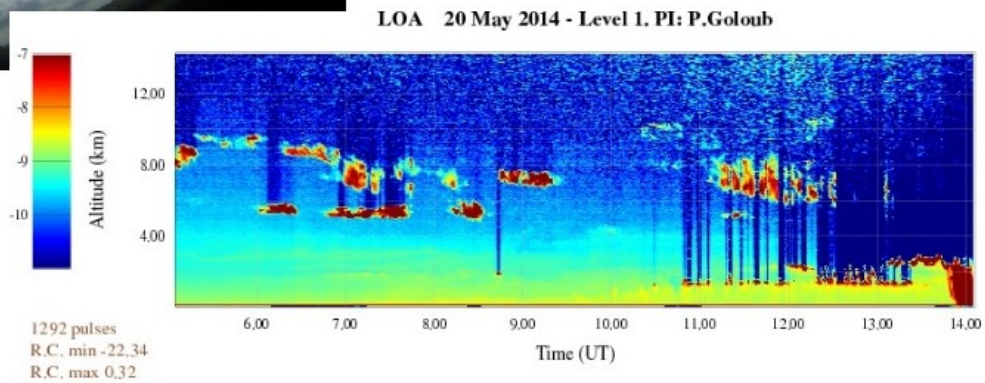
EXEMPLE

20 mai 2014

Cirrostratus







	TOTAL Kwh/m2	Direct Kwh/m2	DiffusE Kwh/m2
20/05/14	4.89	2.64	2.25