# Solar irradiance modelling over Belgium using Regional Climate Models within the frame of a day-ahead photovoltaic production forecasting system

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## 1. Introduction

**Context :**
- Growing interest and growing photovoltaic production in European countries
- Local hazards due to over-production for low voltages networks
- Needs of photovoltaic production assessment for the management of the electricity market

**Scientific issues :**
- Modelling of solar global irradiance using Regional Climate Models
- Model (shallow) convective clouds, low clouds clearance …
- Decompose global irradiance into diffuse and direct irradiances

## 2. Regional Climate Models

**WRF-ARW v3.6**
Non-hydrostatic
Inner 5 km horizontal resolution domain nested in 15km domain
Outputs every 15 minutes
Common set-up :
Duddhia SW scheme, RRTMG LW scheme, Mellor-Yamada-Nakanishi-Niino PBL scheme
**Three different set-ups** + Mean of the 3 simulations

| | WRF-GFS 1 | WRF-GFS 2 | WRF-GFS 3 |
|---|---|---|---|
| Surface scheme : | NOAH LSM | RUC | Pleim-Xiu |
| Microphycics : | Thompson | WSM6 | WSM6 |
| Cumulus scheme : | Kain-Fritsch | Grell Devenyi | Betts-Miller-Jancic |

**Modèle Atmosphérique Régional (MAR)**
Hydrostatic
10 km horizontal resolution
Outputs every 15minutes
Set-up :
ECMWF radiation scheme, SISVAT surface model, Peter Bechtold cumulus scheme

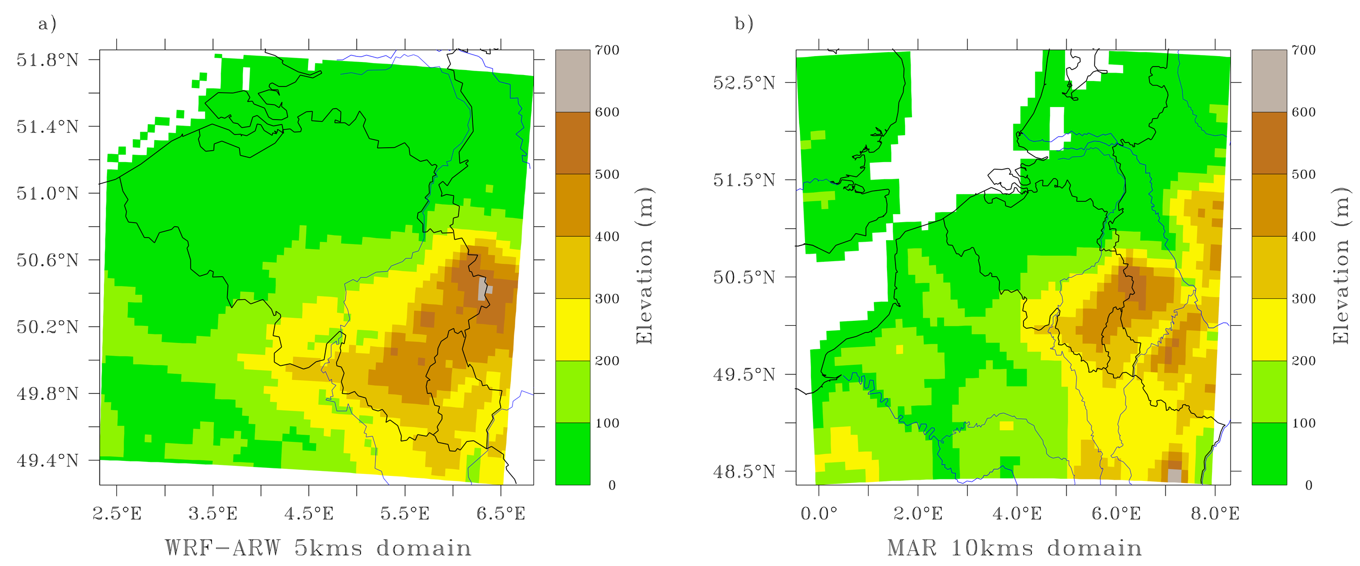


*Figure 2: a) WRF-ARW 5 kilometres inner domain : elevation in metres b) MAR 10 kilometres domain : elevation in metres*

## 3. Solar irradiance data

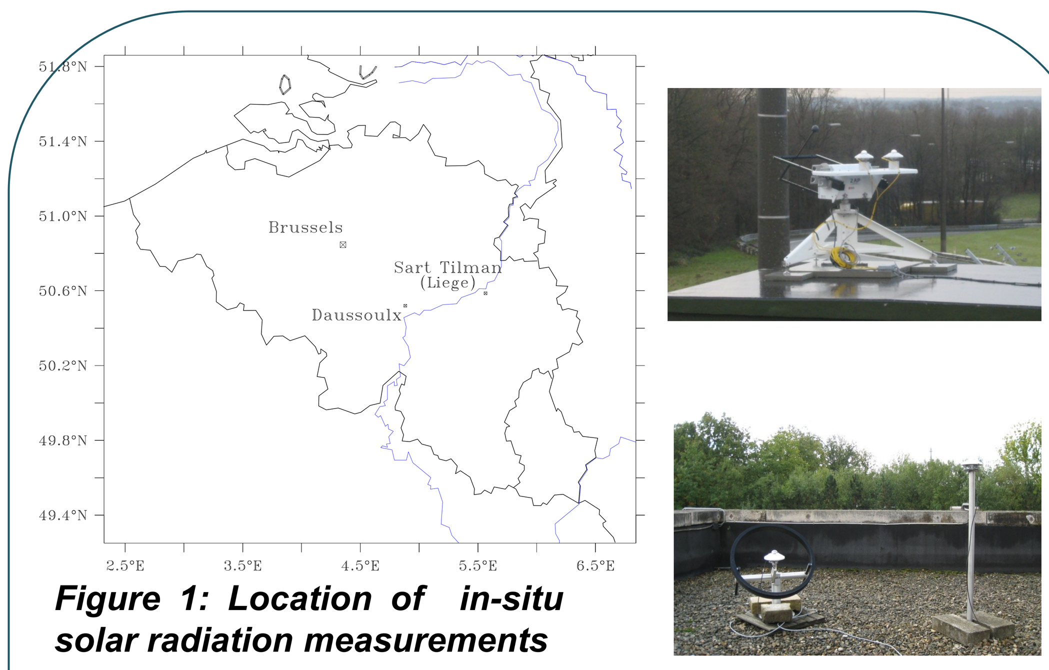


*Figure 1: Location of in-situ solar radiation measurements*

**Sart-Tilman (ST):**
- 50.586615 °N ; 5.564206 °E ; 210 m a.s.l
- Pyranometer : CM 121 Kipp & Zonen
- Diffuse radiation : CM 121 shadow ring Kipp & Zonen
- Records every 15'' → 15' mean

**Daussoulx (DAU):**
- 50.520194 °N ; 4.882925 °E ; 195 m a.s.l
- Pyranometer : 2 AP Kipp & Zonen
- Diffuse radiation : 2 AP tracker
- Records every 30'' → 30' mean

## 4. Global irradiance modelling : results

**Method :** Normalized RMSE, normalized bias, and determination coefficient ($R^2$) are computed at the 15' time scale for MAR and WRF-ARW forced by different reanalysis and by GFS data, compared to observations at Sart-Tilman and Daussoulx. Observations performed when cosine of the sun zenith angle is < 0.1 are discarded from the analysis in order to avoid less reliable measurements (different objects on the horizon).

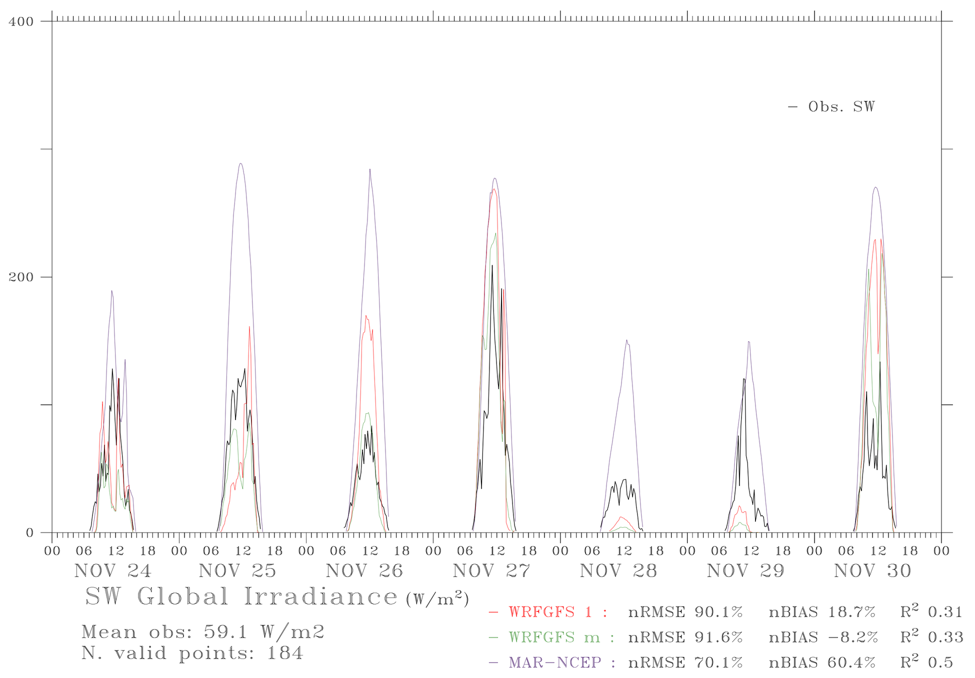


*Figure 3 : Observed (black), WRF-GFS 1st simulation (red), WRF-GFS mean (green) and MAR-NCEP2 (purple) global solar irradiance (W/m²) at Sart-Tilman for the 24th – 30th November 2013 period. Normalized RMSE , normalized bias and R² are represented in the plot.*

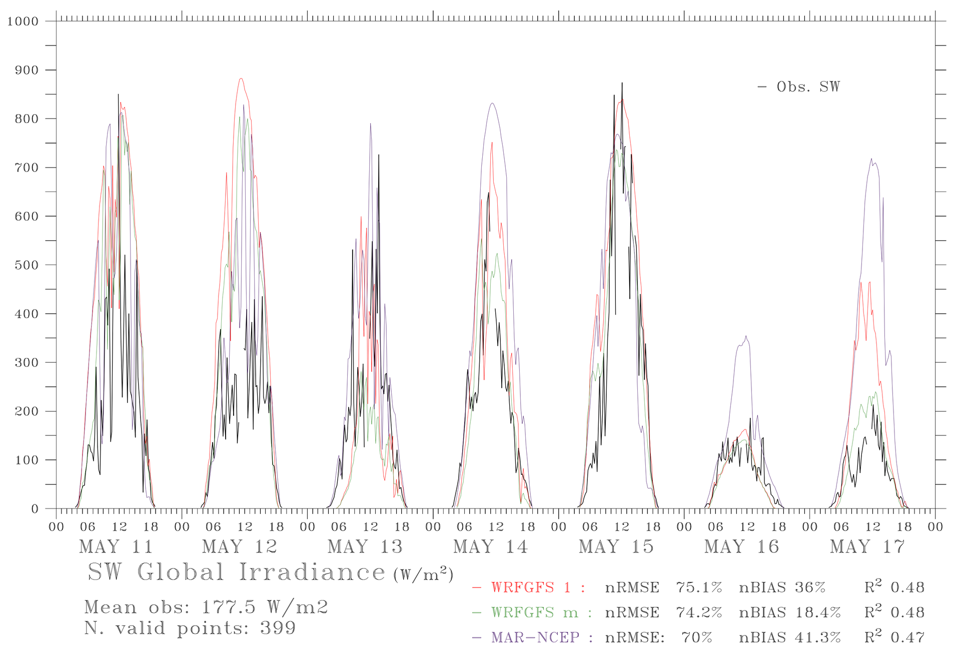


*Figure 4 : Observed (black), WRF-GFS 1st simulation (red), WRF-GFS mean (green) and MAR-NCEP2 (purple) global solar irradiance (W/m²) at Daussoulx for the 11th – 17th May 2013 period. Normalized RMSE, normalized bias and R² are represented in the plot.*

| Model | nRMSE (%) | | nBIAS (%) | | $R^2$ | |
|---|---|---|---|---|---|---|
| | DAU | ST | DAU | ST | DAU | ST |
| WRF-GFS 1 | 83 | 62 | -4 | 1 | 0.41 | 0.38 |
| WRF-GFS 2 | 99 | 75 | -30 | -23 | 0.43 | 0.42 |
| WRF-GFS 3 | 113 | 81 | -39 | -29 | 0.39 | 0.39 |
| WRF-GFS mean | 89 | 66 | -22 | -15 | 0.46 | 0.44 |
| WRF-NCEP2 | 116 | 68 | -25 | -2 | 0.28 | 0.38 |
| MAR-GFS | 77 | 55 | -2 | 3 | 0.45 | 0.47 |
| MAR-NCEP2 | 61 | 50 | 16 | 17 | 0.45 | 0.54 |

*Table 1 : Normalized Root Mean Square Error (%) , normalized bias (%) and determination coefficient for MAR and WRF-ARW and different forcings for winter time period (DJF) at Daussoulx (DAU) and Sart-Tilman (ST)*

| Model | nRMSE (%) | | nBIAS (%) | | $R^2$ | |
|---|---|---|---|---|---|---|
| | DAU | ST | DAU | ST | DAU | ST |
| WRF-GFS 1 | 45 | 49 | 18 | 25 | 0.65 | 0.51 |
| WRF-GFS 2 | 45 | 48 | 12 | 17 | 0.66 | 0.55 |
| WRF-GFS 3 | 48 | 50 | 7 | 11 | 0.64 | 0.53 |
| WRF-GFS mean | 42 | 45 | 13 | 18 | 0.69 | 0.58 |
| WRF-NCEP2 | 47 | 49 | 20 | 23 | 0.62 | 0.48 |
| MAR-GFS | 47 | 49 | 9 | 16 | 0.61 | 0.54 |
| MAR-NCEP2 | 48 | 52 | 22 | 28 | 0.56 | 0.49 |

*Table 2 : Normalized Root Mean Square Error (%) , normalized bias (%) and determination coefficient for MAR and WRF-ARW and different forcings for summer time period (JJA) at Daussoulx (DAU) and Sart-Tilman (ST)*

## 5. Diffuse fraction estimation

Decomposition of global irradiance into direct and diffuse using a sigmoid model (Ruis-Ariaz *et al.,* 2010):

1) Determination of the atmospheric clearness index (kt) :

$$kt = I_{glo} / (I_0 * Coszen)$$

With $I_{glo}$ : Global solar irradiance,
$I_0$ : Extra-terrestrial irradiance,
Coszen : Cosine of the sun zenith angle,

2) Determination of diffuse fraction (K):

$$K = 0.99 - 1.041*\exp(-\exp(2.3-4.702*kt))$$

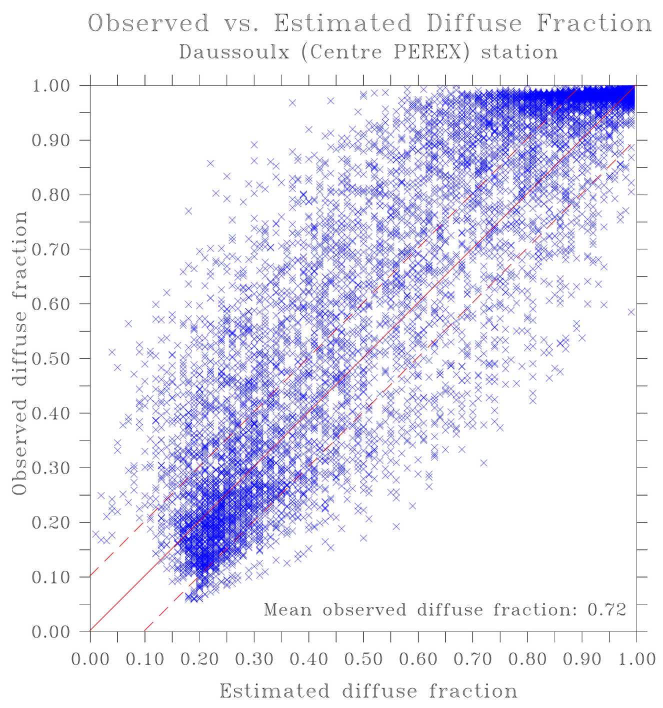


*Figure 5 : Comparison between observed diffuse fraction from Daussoulx measurements and estimated diffuse fraction from observed global irradiance. Normalized RMSE = 19.7 % ; normalized bias = -7.5% ; Coefficient of determination (R²) = 0.84*

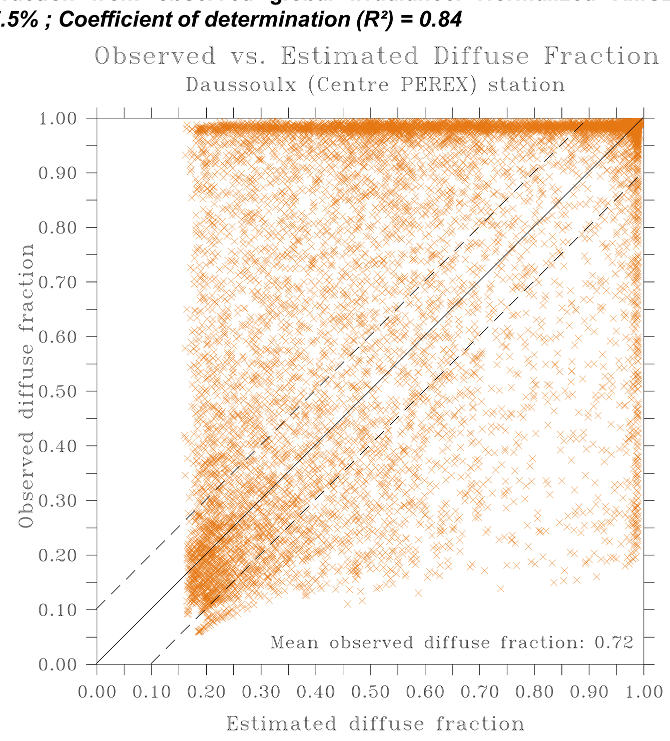


*Figure 6 : Comparison between observed diffuse fraction from Daussoulx measurements and estimated diffuse fraction from WRF-ARW mean simulation global irradiance. Normalized RMSE = 52.5 % ; normalized bias = -22.4% ; Coefficient of determination (R²) = 0.31*

## 6. Conclusions

- The mean of the different WRF-ARW simulations shows better performances in general, mainly in summer, and is more stable → « statistical » approach more suitable for solar irradiance forecasting/modelling
- Both models show in overall higher RMSE in winter. Bias is significantly negative in winter in WRF-ARW simulations (over-estimation of low clouds thickness)
- Positive bias in summer with both RCM (under-estimation of convective clouds occurrence)
- Encouraging results for firsts solar irradiance modelling over Belgium using MAR
- Diffuse fraction estimation is strongly dependent on global irradiance modelling → improvement required if modelling at 15 minutes targeted

**Perspective (short -term) :**
- Room for improvement (surface properties) and ongoing development for an adapted MAR version for solar irradiance modelling over Belgium
- Need to adapt sigmoid model adjustments to diffuse fractions observations over Belgium

## 7. References

[1] Ruiz-Arias J.A, Alsamamra H., Tovar-Pescador J. et Pozo-Vasquez D. (2010). Proposal of a regressive model for the hourly diffuse solar radiation under all sky condition. *Energy conversion and management*, **51**, 881-893

[2] Nakanishi M. and Niino H., 2004. An improved Mellor Yamada Level-3 model with Condensation physics : its design and verification. *Boundary-Layer Meteorology*, **112**, 1-31.

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