Global, diffuse and direct irradiances modelling over northwestern Europe using MAR regional climate model MAR : validation and construction of a 30-year climatology

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1. Introduction

Context :
- Growing interest and growing PV production in EU countries
- Assess and manage available solar resources over space and time
- Local issues due to integration in low voltages grids and interests in forecasts (see PREMASOL project)

Modelling issues :
- Model solar global irradiance using Regional Climate Models at high resolution
- Decompose global irradiance into diffuse and direct irradiances

2. Method

RCM : Modèle Atmosphérique Régional (MAR) [1,2]
Hydrostatic - 10 km horizontal resolution
Forcing : ERA-Interim reanalysis - Outputs every 30 minutes
Set-up :
ECMWF radiation scheme, SISVAT surface model, Peter Bechtold cumulus scheme
CORINE land cover data set, increased moisture at border and in radiation scheme

Solar irradiances observations :
Data from the European Solar Radiation Atlas (ESRA) [4]
Extraction of global and diffuse radiations from the 1986-1990 period at hourly and daily time scale for the stations of :
- **Uccle**, Brussels agglomeration, Belgium (50.798 °N, 4.359 °E)
- **Braunschweig**, Lower Saxony (40 kms E. of Hannover), Germany (52.29 °N, 10.448 °E)

Statistical decomposition of global into diffuse and direct irradiances
Use of the sigmoid model from Ruiz-Arias *et al.*, (2010)[3]
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):

$$K = A - B*\exp(-\exp(C - D*kt))$$

A, B, C, D : empirical parameters from global adjustment (Ruiz-Arias *et al.,* 2010)

3. Validation : modelling of solar irradiances

Calculation of normalized* root mean square errors (nRMSE %), normalized bias (nBIAS %) and coefficient of determination (R^2) for the estimation of hourly and daily sums of global, direct and diffuse irradiances at **Braunschweig** and **Uccle** for the 1986 – 1990 period.

Global irradiance :

Hourly sums - Braunschweig

	nRMSE(%)	nBIAS(%)	R^2
Year :	14.4	3.7	0,71
Winter :	11,2	-0.2	0,66
Summer :	17,8	5,6	0,66

Tab. 1 : nRMSE, nBIAS and R^2 for the estimation of hourly sums of global irradiances at Braunschweig using MAR model for the 1986-1990 period.

Hourly sums - Uccle

	nRMSE(%)	nBIAS(%)	R^2
Year :	14.3	3.6	0,73
Winter :	12,9	-0.9	0,55
Summer :	18,4	7,6	0,68

Tab. 2 : nRMSE, nBIAS and R^2 for the estimation of hourly sums of global irradiances at Uccle using MAR model for the 1986-1990 period.

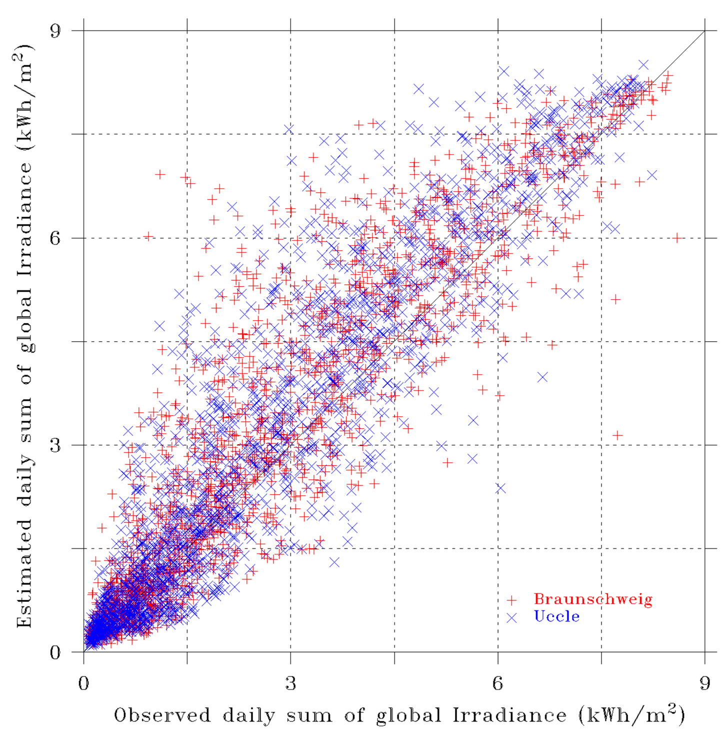

Fig. 1 : Estimated vs Observed daily sums of global irradiances at Uccle using MAR model for the 1986-1990 period (nRMSE = 12.4%, nBIAS = 5.1%, R^2 = 0.84).

Diffuse irradiance :

Hourly sums - Braunschweig

	nRMSE(%)	nBIAS(%)	R^2
Year :	11,5	-2,6	0,59
Winter :	10,4	-1,5	0,53
Summer :	14,3	-4,3	0,52

Tab. 3 : nRMSE, nBIAS and R^2 for the estimation of hourly sums of diffuse irradiances at Braunschweig using MAR model for the 1986-1990 period.

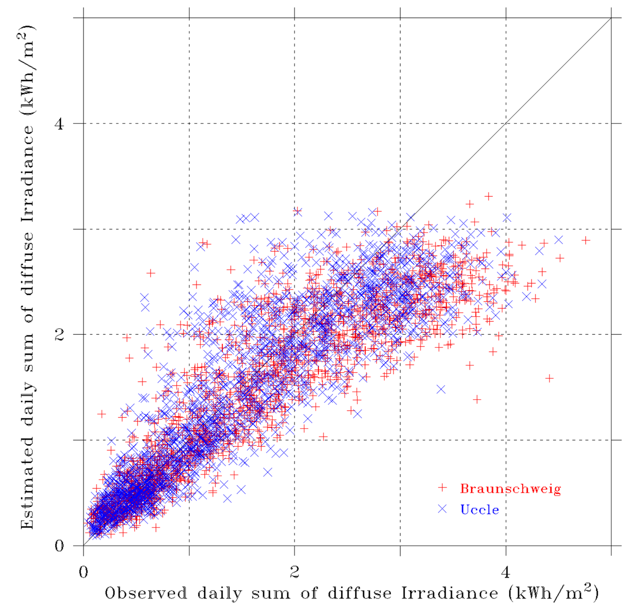

Fig. 2 : Estimated vs. Observed daily sums of diffuse irradiances using MAR model for the 1986-1990 period (nRMSE = 11.2%, nBIAS = -3.3%, R^2 = 0.78).

Direct irradiance :

Hourly sums - Braunschweig

	nRMSE(%)	nBIAS(%)	R^2
Year :	17.8	6.1	0.47
Winter :	13.1	1.1	0.4
Summer :	22.5	9.6	0.41

Tab. 4 : nRMSE, nBIAS and R^2 for the estimation of hourly sums of direct irradiances at Braunschweig using MAR model for the 1986-1990 period.

Daily sums - Braunschweig

	nRMSE(%)	nBIAS(%)	R^2
Year :	16.7	8.5	0.61
Winter :	11.9	1.5	0.54
Summer :	24	17	0.48

Tab. 5 : nRMSE, nBIAS and R^2 for the estimation of daily sums of direct irradiances at Braunschweig using MAR model for the 1986-1990 period.

*normalized by amplitude (min-max) of the observed date set

4. Solar Irradiances : 1981 – 2010 climatology over Benelux

Building of a 30-year climatology over northwestern Europe of global, diffuse and direct irradiance at 10 kilometres of horizontal resolution using MAR model – Calculation of seasonal distribution

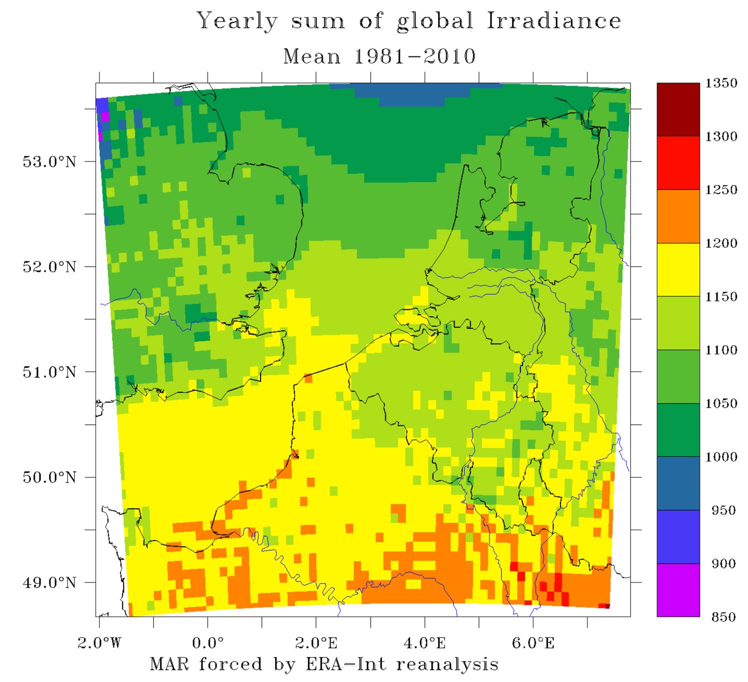

Fig. 3 : Estimated mean yearly sum of incoming global radiation (kWh/m²) over the 1981-2010 period. (! Scale : 850 – 1350 kWh/m²)

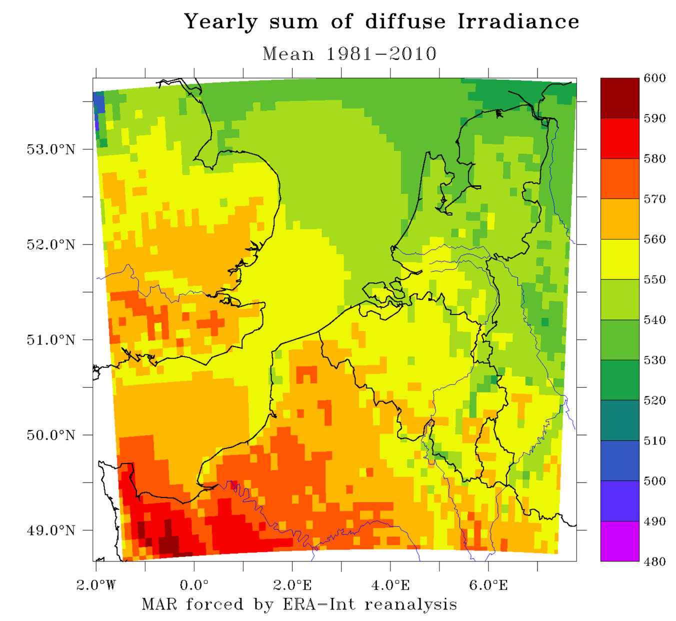

Fig. 4 : Estimated mean yearly sum of incoming diffuse radiation (kWh/m²) over the 1981-2010 period. (! Scale : 480 – 600 kWh/m²)

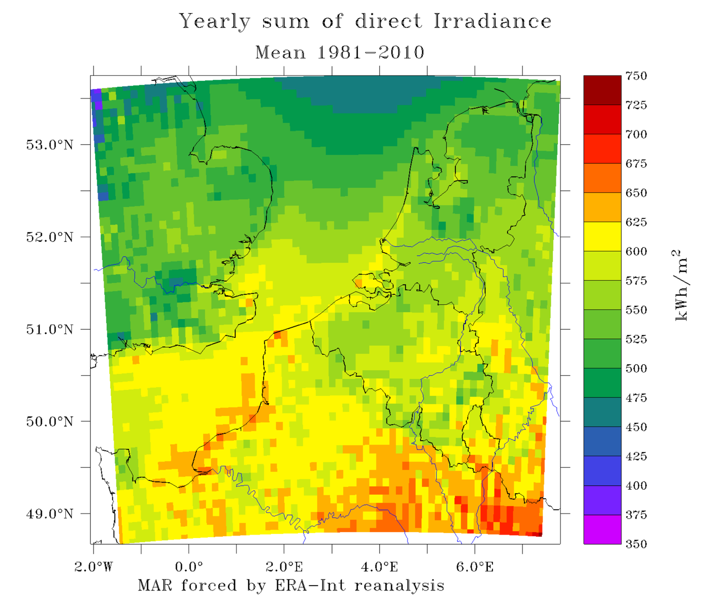

Fig. 5 : Estimated mean yearly sum of incoming direct radiation (kWh/m²) over the 1981-2010 period. (! Scale : 360 – 750 kWh/m²)

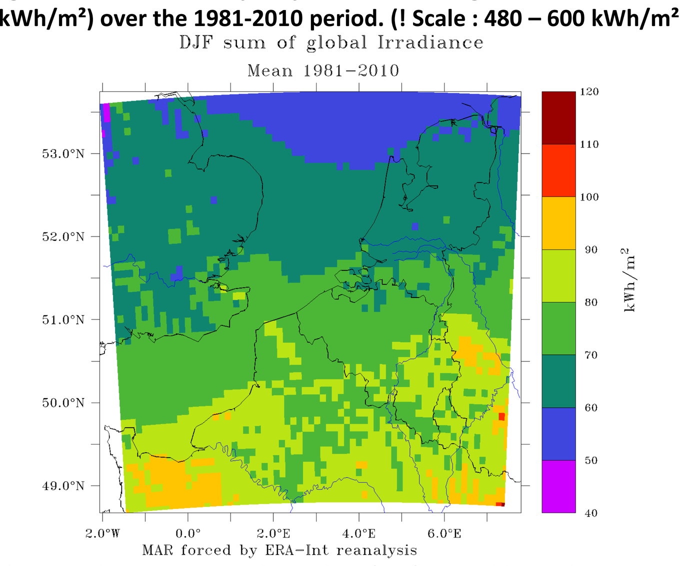

Fig. 6 : Estimated mean winter time (DJF) sum of incoming global radiation (kWh/m²) over the 1981-2010 period. (! Scale : 40 – 120 kWh/m²)

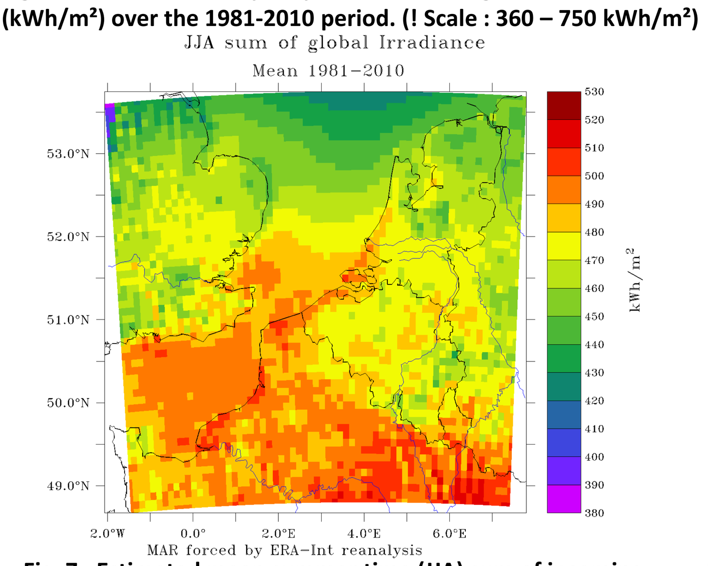

Fig. 7 : Estimated mean summer time (JJA) sum of incoming global radiation (kWh/m²) over the 1981-2010 period. (! Scale : 380 – 530 kWh/m²)

5. Trends and variability analysis

Calculation of trends and standard deviations of global irradiance over the 1981-2010 period

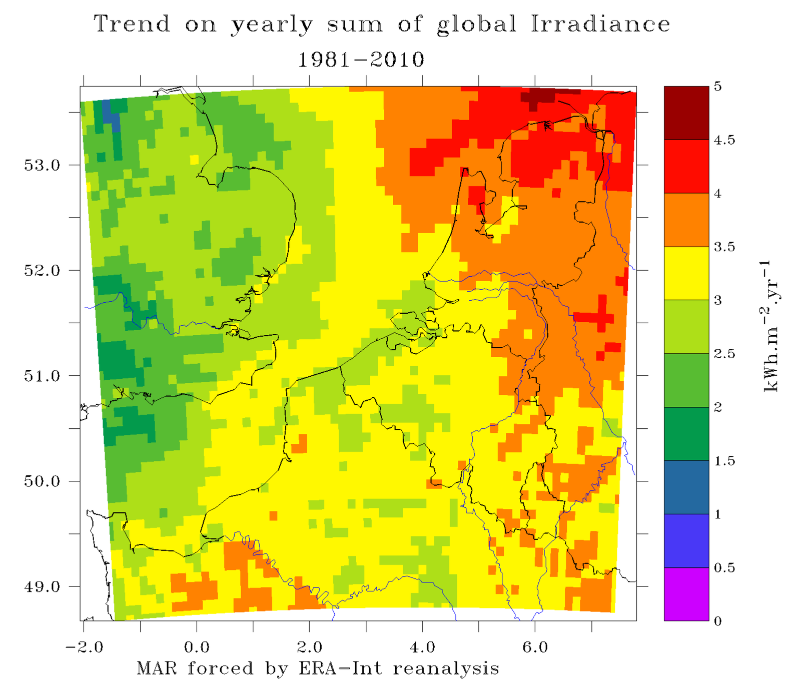

Fig. 8 : Estimated yearly trend on sum of incoming global radiation (kWh/m²/year)over the 1981-2010 period.

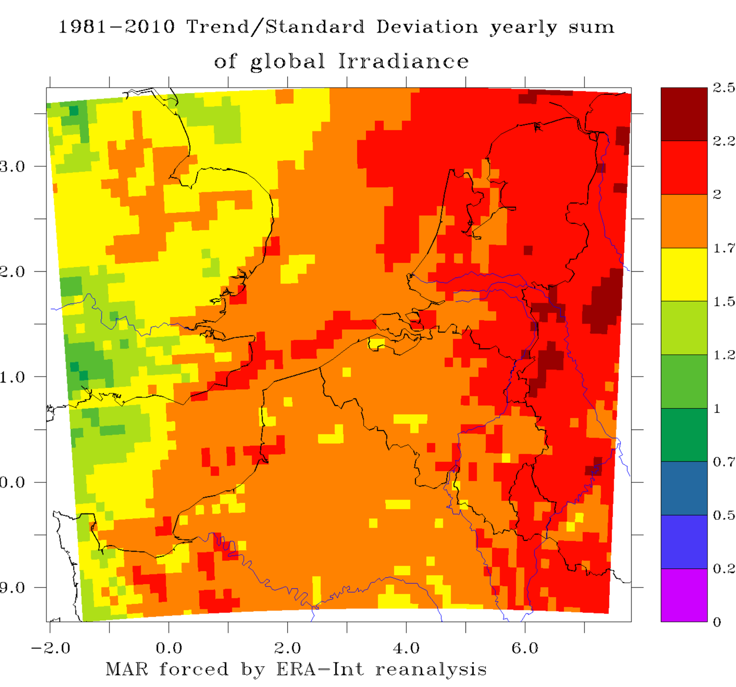

Fig. 9 : Estimated 1981-2010 trend / standard deviation of sum of incoming global radiation.

Trend is found significant using test of Snedecor and Cochran (1971)

6. Conclusions

Conclusions:
- Ability of the MAR to successfully model global irradiances at hourly and daily time scale
- Less successfully modelling of diffuse and direct irradiances : addition of the errors of two model (MAR and sigmoïd model)
- Overestimation of global irradiance in summer causing overestimation (underestimation) of direct (diffuse) irradiances → underestimation of convective clouds and their thickness in MAR model
- MAR suggests a significant positive trend in global radiation over the last 30 years in northwestern Europe (to be verified and assess possible cause)

Short-term perspectives :
- Increase vertical resolution (vertical layers) in MAR model in order to improve modelling of convective clouds
- Test more complex model for the decomposition of global into diffuse and direct irradiances
- Model intercomparisons (MAR,WRF-ARW,COSMO)

7. References

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[2] Gallée H. et Schayes G., 1994. Development of a Three-Dimensional Meso-γ primitive equation model : katabatic winds simulation in the Area of Terra Nova Bay, Antarctica. *Monthly weather review.* , **122**(4), 671-685
[3] 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
[4] Aguiar R., Albuisson M., Beyer H.G., Borisenkov E.P., Bourges B., Czeplak G., Lund H., Joukoff A., Scharmer K., Page J.K., Terzenbach U., Wald L (2000). *The European Solar Radiation Atlas*. Greif J. and Scharmer K (eds.), Les Presses, Ecoles des Mines de Paris. ISBN : 978-2-91-176221-5

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