

COMPARING PERFORMANCE OF SOLARGIS AND SUNY SATELLITE MODELS USING MONTHLY AND DAILY AEROSOL DATA

Tomas Cebecauer¹, Richard Perez² and Marcel Suri¹

¹ GeoModel Solar, Bratislava (Slovakia)

² State University of New York, ASRC, Albany, NY (USA)

1. Introduction

Monthly data of Aerosol Optical Depth (AOD) or Linke turbidity are used in the satellite-based solar radiation models until recently, which is given by limited data availability. In 2010, European consortium working within the project GEMS and lead by ECMWF (European Centre for Medium Range Weather Forecast) introduced a first version of the new aerosol database. The continuity of the calculation is secured by the ongoing project MACC (Monitoring Atmospheric Composition & Climate). The database is operationally calculated by ECMWF and provides several atmospheric data products with a spatial resolution of 1.15 arc-degree and a time step of 6 hours. It represents the time period from year 2003 to the present time. This data set offers new possibilities for improvement of solar calculation schemes and it has been implemented in SolarGIS in late 2010.

In this paper we compare several options of using AOD in SUNY and SolarGIS solar radiation models which process Meteosat and GOES satellite data. Both models use the same clear-sky model (simplified SOLIS by Ineichen 200X) and they use multispectral satellite data for cloud index calculation (Cebecauer et al. 2010, Perez et al. 2010). The daily and monthly averaged AOD values for the selected sites and time period are tested in the models and the resulting GHI (Global Horizontal Irradiance) and DNI (Direct Normal Irradiance) are compared giving a good representation of different climate zones (Tab. 1). Intentionally the difficult sites have been chosen, to demonstrate the advantages and limits of current data models.

Tab. 1: Basic data of the validation stations

Site name	Country	Network	Model	Latit.	Longit.	Year
Bondville*	USA, IL	BSRN/SURFRAD	SUNY	40.07	-88.37	2010
Boulder	USA, CO	BSRN/SURFRAD	SUNY	40.13	-105.24	2010
Desert Rock	USA, NV	BSRN/SURFRAD	SUNY	36.63	-116.02	2010
Fort Peck*	USA, MT	BSRN/SURFRAD	SUNY	48.32	-105.10	2010
Goodwin Creek	USA, MS	BSRN/SURFRAD	SUNY	34.25	-89.87	2010
Penn State*	USA, PA	SURFRAD	SUNY	40.72	-77.93	2010
Sioux falls*	USA, SD	BSRN/SURFRAD	SUNY	43.73	-96.62	2010
Carpentras	France	BSRN	SolarGIS	44.08	5.06	2004/03-2009/11
Sede Boqer	Israel	BSRN	SolarGIS	30.91	34.78	2004/03-2006/06
Solar Village	Saudi Arabia	BSRN		24.91	46.41	2000/01-2001/12
Tamanrasset	Algeria	BSRN	SolarGIS	22.78	5.51	2004/03-2006/12
Ilorin	Nigeria	BSRN	SolarGIS	8.53	4.57	2004/03-2005/07
Upington	South Africa	ESKOM	SolarGIS	-28.45	21.24	2007/07-2009/12

All stations belong to the BSRN/SURFRAD radiometric network with high standards for measurements, meteo station in Upington is operated by Eskom, South Africa. To eliminate possible interference of snow on the accuracy of solar irradiance modeling for the following site, the winter data were not assumed. In the data quality checking, it has been identified that data for Ilorin do not have the expected quality.

2. Monthly and daily aerosol data

Aerosols are, after clouds, the second most important factor determining DNI, and to a lesser extent, GHI. Under clear skies, aerosols are the main source of attenuation for DNI. The Aerosol Optical Depth (AOD) parameter is used to characterize the overall radiative effect of aerosols. Aerosols have a high spatial and

temporal variability in both composition and quantity. Up to very recently, long-term monthly-average AOD data were used in solar radiation modeling. A serious drawback of such an approach is that long-term averages artificially remove the natural daily fluctuations, thus resulting in skewed frequency distributions of DNI and in failure to represent extreme events (Fig. 1).

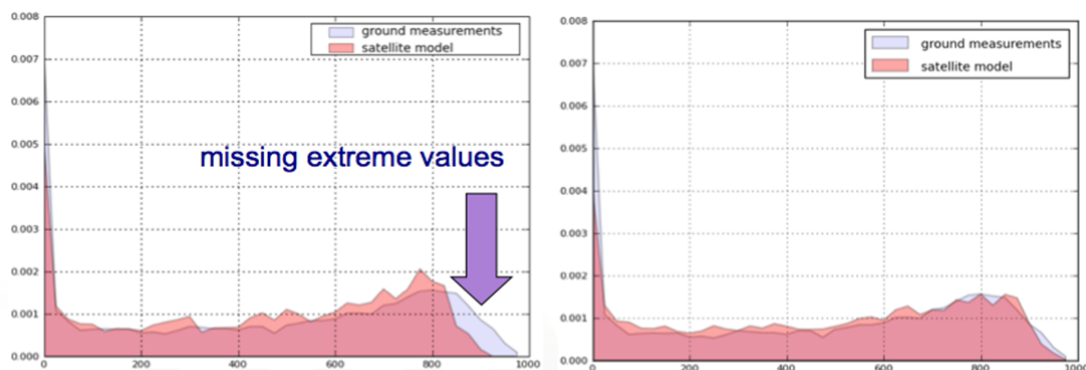


Fig. 1: Distribution of hourly DNI values for the Tamanrasset – red: modeled data, blue: ground observations. Left: data calculated using long-term monthly AOD averages, right: data calculated in operational SolarGIS using daily values. The left graph demonstrates the skewed representation of values in the range from 750 to 950 W/m².

The operational version of SolarGIS uses GEMS/MACC daily AOD data. This AOD dataset captures the variability of aerosols with a 6-hour resolution, globally. The spatial resolution of the GEMS/MACC data is 1.15 arc-degree (≈ 125 km at the equator).

The current GEMS/MACC data correctly represent the magnitude of the aerosol variability over both time and space (Cebecauer 2011), however some bias has been identified in regions with high aerosol loads. The reported issues will be dealt with in the next version (MACC2) of the aerosol chemical-transport model. At present, the daily GEMS/MACC AOD data exist only since 2003. SolarGIS still uses monthly long-term averages for older periods (Fig. 2).

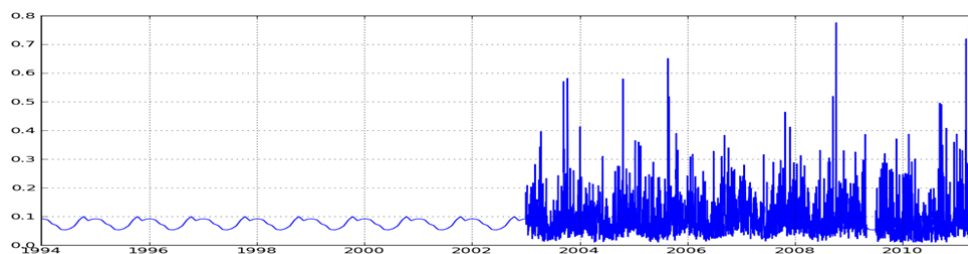


Fig. 2: GEMS/MACC AOD data for the Uppington site. Daily values are available only for the era from 2003 onwards. For the older period, long-term monthly average values are used

Use of monthly averages of AOD in the satellite model results in a uniform monthly clear-sky radiation values omitting any information about day-by-day variation. The effect of such clear-sky model parameterization is a distorted distribution of the DNI values with erroneous representation of extreme events such as very high or very low aerosol loads (Fig. 3).

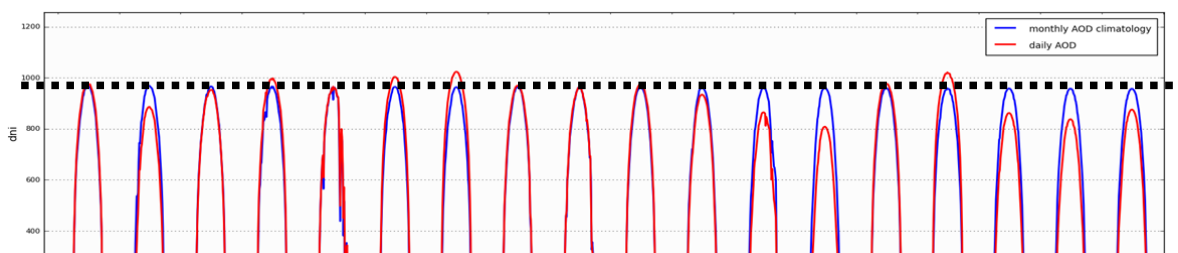


Fig. 3: 15-minute DNI profiles for 18 days, at the Uppington site. Blue: DNI calculated using long-term monthly averages; red: DNI calculated in operational SolarGIS using daily values. The red profiles demonstrate how daily variability of aerosols (AOD) strongly affects the accuracy of the estimates.

3. Method

Three options are compared, while approach for SUNY and SolarGIS model differ:

1. Monthly AOD: In the SUNY model, ASRC monthly AOD values are used as they are currently implemented in the operational model. For SolarGIS, long-term monthly AOD values are calculated by averaging of daily data. Therefore the approach differs for SUNY and SolarGIS
2. GEMS/MACC daily AOD: the original GEMS/MACC daily AOD data are used in the calculations
3. Calibrated GEMS/MACC daily AOD: Due to bias identified for some sites, the daily AOD data are corrected as follows:
 - a. In SUNY model, the daily data are corrected so as to match ASRC monthly AOD averages
 - b. In SolarGIS, the daily data are only partially corrected using AERONET data available for the region.

The data are validated for the sites listed in Tab. 1.

4. Results

In general use of daily aerosols shows improvements in ability of both models to represent hourly values of DNI and GHI as an effect of aerosol dynamics. From the viewpoint of running the operational model, the new atmospheric dataset better captures daily variability, especially events with extreme atmospheric load of aerosols. Thus it reduces uncertainty of instantaneous DNI and GHI estimates.

The main accuracy improvements are achieved in reduction of Root Mean Square Deviation (RMSD) and improved distribution function of DNI. The bias for daily values indicates a need systematic deviation of GEMS/MACC data set in some regions, especially in those with high concentration and dynamics of aerosols.

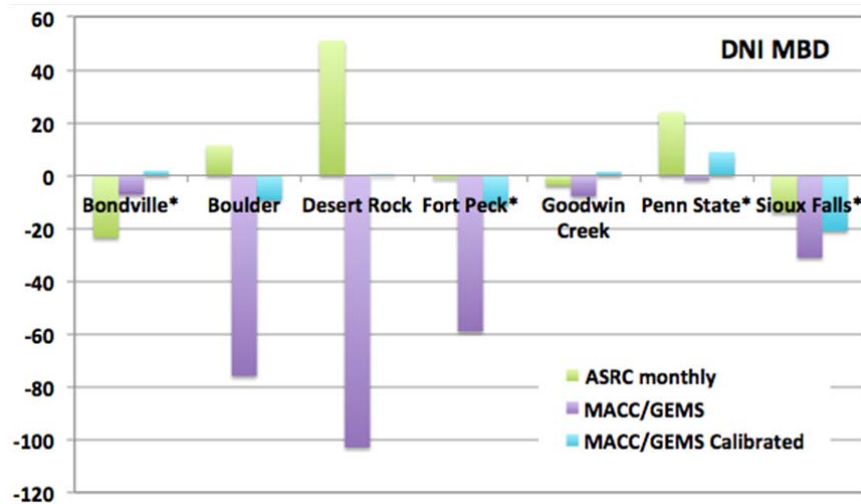


Fig. 4: Mean Bias Deviation for hourly DNI values related to SUNY model

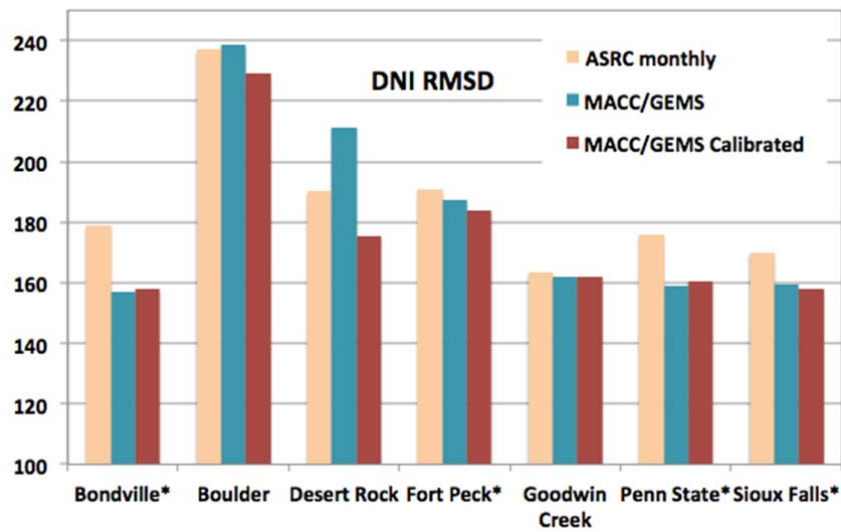


Fig. 5: Root Mean Square Deviation for hourly DNI values related to SUNY model

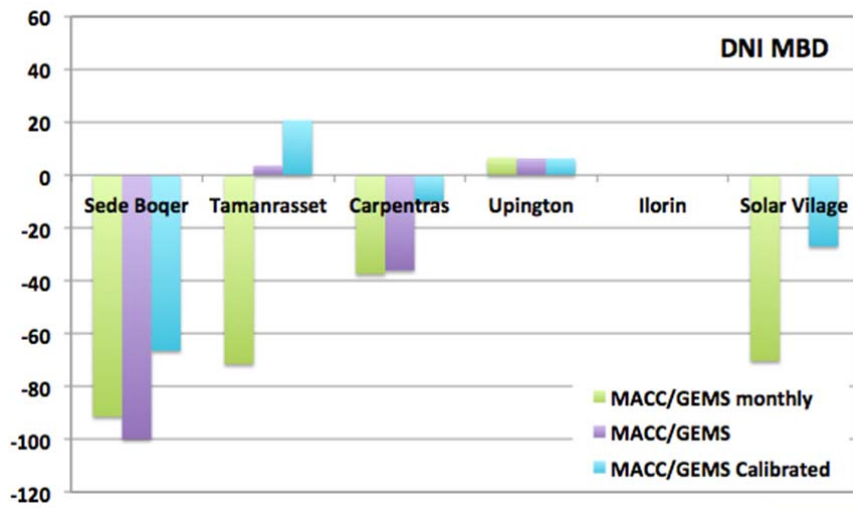


Fig. 6: Mean Bias Deviation for hourly DNI values related to SolarGIS model

The use of daily data improves representation of hourly values. Use of monthly AOD data does not allow to represent high irradiance values correctly (Fig. 8). Due to bias in AOD in some regions, correction is needed. Correction in Fig 8 and 9 is based on the regional analysis of AERONET measurements.

For the CSP and CPV projects, typically measured and satellite-based DNI data are correlated to reduce systematic deviation in the satellite data set, thus adapting them for local geographic conditions.

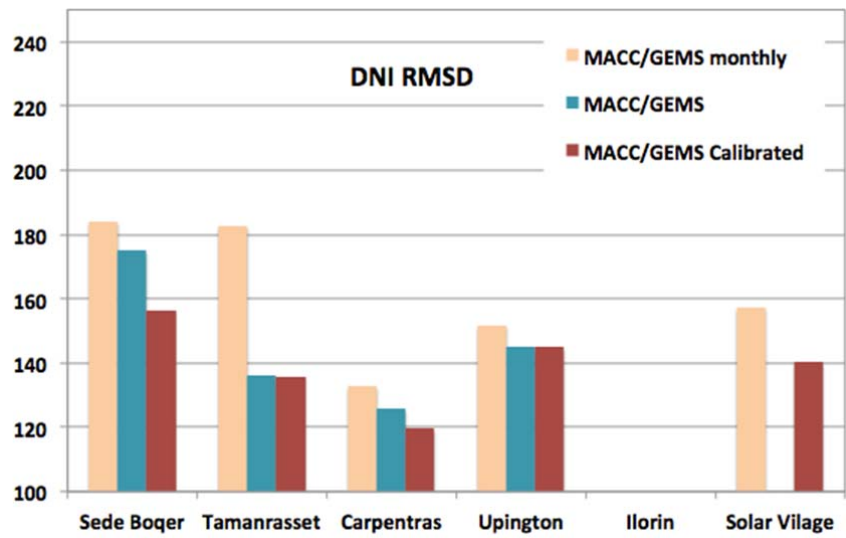


Fig. 7: Root Mean Square Deviation for hourly DNI values related to SolarGIS model

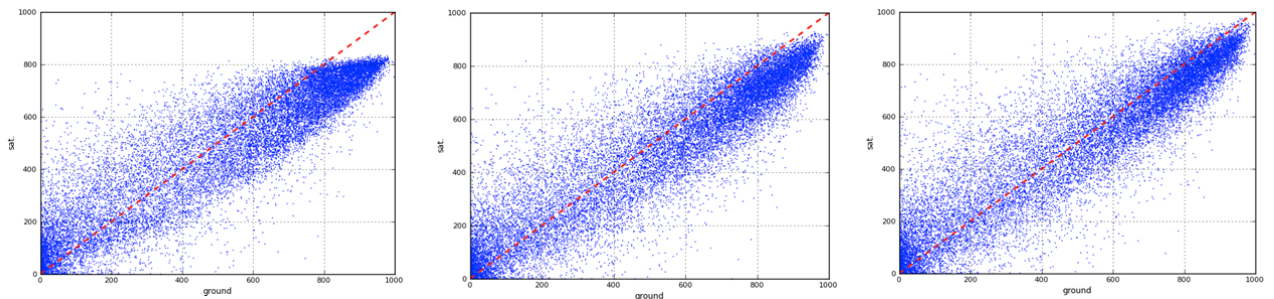


Fig. 8 Ground vs. modeled hourly values for Carpentras - Left: Monthly averaged AOD; Center: Daily AOD used in operational SolarGIS; Right: daily corrected

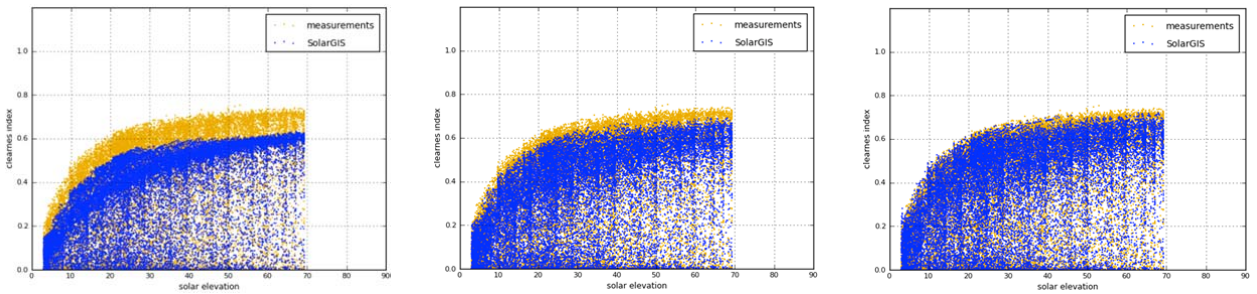


Fig. 9 Clearnes DNI index versus sun elevation (hourly values) for Carpentras - Left: Monthly averaged AOD; Center: Daily AOD used in operational SolarGIS; Right: daily corrected

Tab. 2: Results for GHI values

GHI [W/m ²]		ASRC Monthly	Daily	Daily corr.	ASRC Monthly	Daily	Daily corr.
	Mean	MBD			RMSD		
Bondville*	366	-6	0	0	87	84	85
Boulder	392	-9	-6	-4	111	113	111
Desert Rock	456	7	0	3	76	76	75
Fort Peck*	379	-1	0	0	94	93	94
Goodwin Creek	410	-4	2	2	89	89	89
Penn State*	382	-1	0	0	99	98	98
Sioux Falls*	398	-3	0	0	77	76	76

GHI [W/m ²]		Monthly	Daily	Daily corr.	Monthly	Daily	Daily corr.
	Mean	MBD			RMSD		
Sede Boqer	543	3	-1	5	56	55	55
Tamanrasset	614	-17	-2	1	58	51	52
Carpentras	365	5	3	7	48	48	48
Uppington							
<i>Ilorin</i>	<i>422</i>	<i>64</i>	<i>58</i>	<i>55</i>	<i>114</i>	<i>108</i>	<i>106</i>
Solar Vilage	535	-9		0	51		51

Tab. 3: Results for DNI values

DNI [W/m ²]		ASRC Monthly	Daily	Daily corr.	ASRC Monthly	Daily	Daily corr.
	Mean	MBD			RMSD		
Bondville*	377	-23	-7	2	179	157	158
Boulder	465	11	-76	-9	237	239	229
Desert Rock	605	51	-103	0	190	211	175
Fort Peck*	421	-1	-59	-11	191	187	184
Goodwin Creek	432	-4	-8	2	164	162	162
Penn State*	358	24	-2	9	176	159	161
Sioux Falls*	432	-14	-31	-21	170	159	158

DNI [W/m ²]		Monthly	Daily	Daily corr.	Monthly	Daily	Daily corr.
	Mean	MBD			RMSD		
Sede Boqer	621	-91	-100	-66	184	175	156
Tamanrasset	629	-71	4	21	183	136	136
Carpentras	496	-37	-36	-10	133	126	120
Uppington	651	7	6	6	152	145	145
Ilorin							
Solar Vilage	550	-70		-27	157		140

5. Conclusion

The utilization of new AOD data set from the MACC project should provide higher industry confidence in satellite-derived data products and their ability to represent different climates of the world.

Improvements in operational atmospheric calculations are ongoing and the reported deviations will be improved.

6. References

T. Cebecauer, M. Šúri, R. Perez, ASES National Solar Conference 2010, Phoenix (AZ), USA (2010).

Perez R., P. Ineichen, K. Moore, M. Kmiecik, C. Chain, R. George and F. Vignola, (2002): A New Operational Satellite-to-Irradiance Model. *Solar Energy* 73, 5, pp. 307-317P. Ineichen, A broadband simplified version of the Solis clear sky model, *Solar Energy*, 82 (2008).

J. Morcrette, O. Boucher, L. Jones, D. Salmond, P. Bechtold, A. Beljaars, A. Benedetti, A. Bonet, J.W. Kaiser, M. Razinger, M. Schulz, S. Serrar, A.J. Simmons., M. Sofiev, M. Suttie, A. Tompkins, A. Uncht,