VALIDATION OF MSG DERIVED SURFACE INCOMING GLOBAL SHORT-WAVE RADIATION PRODUCTS OVER BELGIUM

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Abstract

Appropriate information on solar resources is very important for a variety of technological areas, such as: agriculture, meteorology, forestry engineering, water resources and in particular in the designing, sizing and monitoring of solar energy systems. Solar radiation is observed by means of networks of meteorological stations. However, the availability of observed solar radiation measurements has proven to be spatially and temporally inadequate for many applications. Only space-based observations can deliver a global coverage of the global irradiation impinging on horizontal surface at the ground level. Because only geostationary data allow to capture the diurnal cycle of the solar irradiance at the Earth's surface, we evaluate in the present study if MSG derived surface incoming global short-wave radiation could valuably complement the in situ solar measurements network of the Royal Meteorological Institute of Belgium and thereby improving the spatio-temporal distribution of the surface incoming global solar radiation over Belgium.

Down-welling short-wave radiation at the Earth's surface operationally retrieved from MSG imageries by the Land Surface Analysis Satellite Applications Facility (LSA-SAF) and the Satellite Application Facility on Climate Monitoring (CM-SAF) were evaluated over Belgium together with an upgraded formulation of the Heliosat surface global irradiance retrieval scheme proposed by MeteoSwiss in the framework of CM-SAF. Two years (2008 and 2009) of ground based and satellite retrieved data have been intensively compared in order to determine the best suited satellite derived radiation product over Belgium.

INTRODUCTION

Traditionally, solar radiation is observed by means of networks of meteorological stations. Costs for installation and maintenance of such networks are however very high and national networks comprise only few stations. Consequently the availability of observed solar radiation measurements has proven to be spatially and temporally inadequate for many application. Several authors have shown the potentialities of the images of the Earth taken by polar-orbiting and geostationary satellites for mapping the global solar radiation impinging on a horizontal surface at the ground level (e.g., Zelenka et al., 1999; Perez et al., 2002; Pinker et al., 1995). Because only geostationary data allow to capture the diurnal cycle of the solar irradiance at the Earth's, we evaluate in the present study if MSG derived surface incoming global solar radiation could valuably complement the ground-based solar measurements network of the Royal Meteorological Institute of Belgium (RMIB) and thereby improving the spatio-temporal distribution of the surface global solar radiation over Belgium.

Indeed, geostationary satellites such as Meteosat provide cloud information in a high spatial and temporal resolution. Such satellites are, therefore, not only useful for weather forecasting, but also for the estimation of solar irradiance, since the knowledge of the radiance reflected by clouds is the basis for the calculation of the transmitted irradiance. The satellite radiometer measures within a given solid angle the radiation scattered back to space by the system Earth-atmosphere. This quantity is a measure of the planetary albedo and is inversely related to the atmospheric transmission of solar radiation. Since surface solar radiation irradiance is strongly determined by the transmission characteristics of the atmosphere, a strong complementarity between global irradiance and the satellite signal is given.

MSG DERIVED SURFACE INCOMING GLOBAL SHORT-WAVE RADIATION PRODUCTS

Within the Satellite Application Facility (SAF) network, the down-welling short-wave radiation at the Earth's surface is operationally retrieved from MSG imageries by three decentralized SAFs: the Ocean and Sea Ice SAF (OSI-SAF, www.osi-saf.org), the Land Surface Analysis SAF (LSA-SAF, land-saf.meteo.pt) and the SAF on Climate Monitoring (CM-SAF, www.cmsaf.eu). To retrieve the same parameter, the different SAFs use their own algorithms and different ancillary input data. Sea surface being out of the scope of our study, we have chosen to concentrate our investigation on the LSA-SAF and CM-SAF products and extend the validation exercise to an additional non operational product currently in development at MeteoSwiss.

The LSA-SAF surface radiation product (Geiger et al., 2008) is generated every 30 min and distributed to the users in near real-time at the SEVIRI pixel spatial resolution. The operational CM-SAF surface solar radiation product (Mueller et al., 2009) is an off-line product provided on a 15 x 15 km sinusoidal grid in daily and monthly average. The monthly mean diurnal cycle is also provided. Because of the relatively coarse spatial and temporal resolution of the CM-SAF operational product, intermediate CM-SAF values (R. Mueller, personal communication) were considered in the present study, namely instantaneous hourly CM-SAF solar surface irradiance remapped onto 3 x 3 km, 9 x 9 km and 15 x 15 km grids.

In the framework of the CM-SAF an upgraded formulation of the Heliosat (Cano et al., 1986; Beyer et al., 1996; Hammer et al., 2003; Rigollier et al., 2004) method which converts reflectance measured by the 'visible' channel of Meteosat to global radiation at the ground was proposed by Dürr and Zelenka (2008) to account for the alpine terrain of Switzerland. The old Heliosat method failed in wintertime, when snow is covering the surface under clear skies. Indeed, due to their high reflectance snow covered pixels are falsely classified as overcast, which leads to a remarkable error in the global irradiance values. The MSG channels give the opportunity to discriminate snow from clouds and to reduce this error source. MSG has another opportunity to gain a better quality in the derived surface irradiance, namely the higher resolution in space and time compared to MFG. Dürr and Zelenka (2009) have supplemented the Heliosat method by implementing a highly sensitive snow detection algorithm in combination with an algorithm for cloud detection over snow-covered areas. Fog presence with or without snow, also deserves special attention. Furthermore, effects of the surrounding terrain such as shadowing and the altitude-dependence on the surface shortwave downward radiation is taken into account in the retrieval scheme. An upgraded version of the Dürr and Zelenka (2009) algorithm was run over a spatial domain ranging from 49.0^{o}N to 51.5^{o}N in latitude and from 2.75^{o}W to 6.5^{o}W in longitude in order to generate surface global irradiance data over Belgium at the MSG High Resolution Visible (HRV) channel spatial resolution. The original HRV geolocation performed by the EUMETSAT ground segment is only accurate up to $\pm$ 3 HRV pixels. Based on the result of a landmark-based georeferencing procedure over the Alpine region applied to each individual HRV time slot, all the MSG HRV images were shifted by -2 horizontal and -1 vertical pixels which was the best long term match for Switzerland as such a HRV shifts have also proved to provide a better HRV geolocation over Belgium than given by the original EUMETSAT geolocation. The MSG time resolution used for the calculation was 15 minutes, hence a maximum number of 96 slots is available each day. Two years of MSG data has been processed (i.e., 2008 and 2009, respectively).

COMPARISON OF THE MSG RETRIEVALS WITH THE GROUND MEASUREMENTS

Two years of data (2008 and 2009) have been used to evaluate the performance of the three retrieval algorithms against ground data at 13 measurements sites (see Table 1 for the sites locations). All in situ data were integrated to bring them into a 10 min time step and only global horizontal solar irradiance values which have succeeded the RMIB quality control procedures for solar radiation data (Journée and Bertrand, 2010a) were considered. To ensure that the comparisons were made between comparable data, special attention was given to the coherence of the data, the precision of the time acquisition, and the synchronization of the different data sets with the ground measurements. For each value estimated from the MSG data, the corresponding nearest time-stamped ground value was considered; this means that the satellite image was acquired within the ground 10 min integration period. Instantaneous satellite retrievals were then evaluated against the averaged values of the in situ measurements within the 10 min integration period. While the different satellite datasets do not exhibit the same temporal resolution, the same number of values is used to evaluate the three satellite retrievals. More specifically, the error statistics are calculated from all timestamps with a solar elevation angle greater than 10^o as in Ineichen et al. (2009) for which the ground and the three satellite retrievals were simultaneously available.

Table 1: **Location of the RMIB ground stations involved in the comparisons with MSG derived global solar radiation**

Station Name	**Lat.** (^{o}N)	**Long.** (^{o}E)	**Alt.** (m)
Middelkerke	51.198	2.869	3
Beitem	50.905	3.123	25
Melle	50.976	3.825	15
Uccle	50.798	4.359	101
St.-Katelijne-Waver	51.076	4.526	10
Dourbes	50.096	4.596	233
Ernage	50.583	4.691	157
Retie	51.222	5.028	21
Humain	50.194	5.257	296
Saint-Hubert	50.040	5.405	557
Diepenbeek	50.916	5.451	39
Buzenol	49.621	5.589	324
Mont Rigi	50.512	6.075	673

Because of the possible non-uniformity of the surface global radiation within the MSG pixel, size of the blocks of pixels centered on the location of the pyranometer could influence on the comparison. Accordingly, the comparisons were performed at various spatial resolutions as indicated in Table 2. The same error statistics as in Journée and Bertrand (2010b) were used to evaluate the MSG retrievals. The absolute error statistics are derived from all available all-sky data with a solar elevation angle greater than 10^o. The relative error statistics are further restricted to all ground-based measurements greater than 30 W.m^{-2}. It is worth pointing out that the absolute error statistics provided in table 2 are normalized by the average of the considered ground measurements.

Table 2: **Comparison between instantaneous irradiance retrieved by the three different algorithms with the corresponding 10 min averaged ground measurements. Error statistics are calculated at various spatial resolutions. MBE, MAE and RMSE are normalized by the mean surface solar radiation value measured from the ground.**

	MBE	**MAE**	**RMSE**	**rMBE**	**rMAE**	**rRMSE**
LSA-SAF 1x1 SEVIRI pixel	-0.0052	0.2342	0.342	0.0944	0.366	0.630
LSA-SAF 2x2 SEVIRI pixels	-0.0055	0.2313	0.337	0.0963	0.362	0.623
LSA-SAF 3x3 SEVIRI pixels	-0.0058	0.2246	0.326	0.0952	0.352	0.605
CM-SAF 3x3km	-0.0090	0.2083	0.318	0.0820	0.312	0.540
CM-SAF 9x9km	-0.0099	0.2028	0.307	0.0839	0.303	0.522
CM-SAF 15x15km	-0.0115	0.1983	0.298	0.0841	0.296	0.506
MeteoSwiss 1x1 HRV pixel	-0.0946	0.2461	0.364	-0.0552	0.333	0.505
MeteoSwiss 3x3 HRV pixels	-0.0949	0.2342	0.342	-0.0529	0.315	0.476
MeteoSwiss 5x5 HRV pixels	-0.0951	0.2284	0.332	-0.0488	0.304	0.457
MeteoSwiss 7x7 HRV pixels	-0.0947	0.2265	0.330	-0.0439	0.299	0.447
MeteoSwiss 9x9 HRV pixels	-0.0942	0.2260	0.330	-0.0390	0.296	0.441

Table 2 indicates that, on the average, the results from the different spatial sampling strategies considered differ by only a few percents (absolute variation of the RMSE, for instance, are lower than 1.6% (LSA-SAF), 2% (CM-SAF), and 3.4% (MeteoSwiss)). Table 2 highlights a slightly better performance of the CM-SAF instantaneous hourly values with respect to the two others retrievals schemes. This ten-

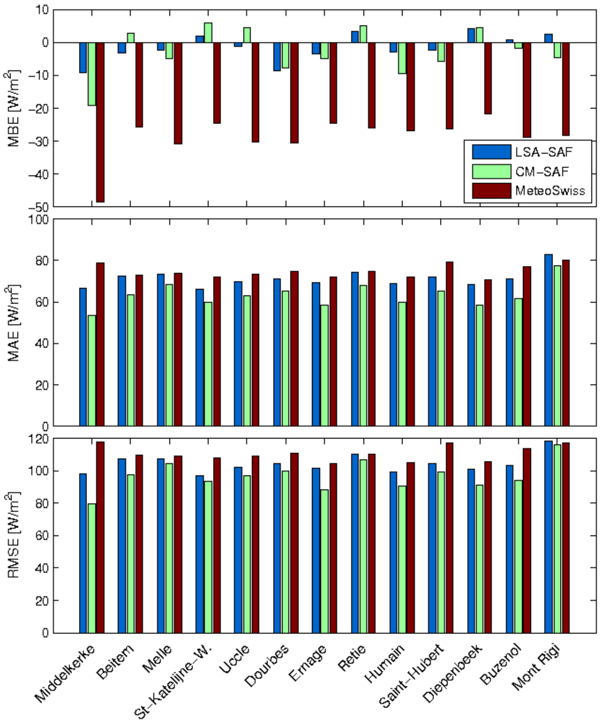

Figure 1: **Satellite derived - ground measured mean bias error (MBE), mean absolute error (MAE) and root mean square error (RMSE) for all the locations and the retrievals algorithms. Results are given at the finest spatial resolution of each products**

dency is observed at each station site as illustrated in Figure 1. While on the average, the CM-SAF and LSA-SAF products slightly underestimate ground values (by about -1% for the CM-SAF and by -0.6% for the LSA-SAF, respectively), the MeteoSwiss algorithm systematically underestimates ground measurements (underestimation of about -9.5% on the average). Such an underestimation could possibly be due to an inadequate shadow detection when applying the algorithm over a non-mountainous area as it is the case in Belgium. This point is currently under investigation.

Besides the instantaneous values, comparison between satellite retrievals and ground measurements can also be performed on longer temporal horizons by considering integrated values over a given time period. Table 3 presents the comparison between daily cumulated surface solar irradiation retrieved by the three algorithms with the corresponding daily ground measurements. Note that instantaneous satellite data were integrated over the day by means of a trapezoidal integration. Clearly, as for the instantaneous satellite retrievals, the size of pixel aggregate has, on the average, only a limited impact on the final result. By contrast, Table 3 reveals that the accuracy of the satellite estimations increases when considering cumulated daily values rather than instantaneous values. One reason for this observation is that the time integration reduces the uncertainties inherent to the comparison of point measurements against pixel values.

Finally, the performances of the retrieval algorithms as a function of sky conditions and seasons are evaluated for data cumulated on a daily basis in Figure 3 left panel and right panel, respectively. Note that the sky-type classification is made upon the average of the modified clearness index of Perez et al. (1990). It turns out from Figure 3 that both the CM-SAF and LSA-SAF products overestimate the surface solar irradiance in overcast situations, whereas they underestimate it in case of clear skies. One reason for this well-known observation (e.g., Ineichen et al., 2009) is probably that the atmospheric aerosol load assumed during the retrieval process (i.e., fixed visibility for the LSA-SAF or climatology for the CM-SAF) tends to overestimate the actual aerosol condition for clear skies and thus to underestimate the surface solar irradiance. Regarding the seasons, the performance of the CM-SAF and LSA-SAF retrievals tends

Table 3: **Comparison between daily cumulated surface solar irradiation retrieved by the three different algorithms with the corresponding daily ground measurements. Error statistics are calculated at various spatial resolutions. MBE, MAE and RMSE are normalized by the mean surface solar radiation value measured from the ground.**

	MBE	**MAE**	**RMSE**	**rMBE**	**rMAE**	**rRMSE**
LSA-SAF 1x1 pixel	-0.0195	0.0841	0.114	0.0323	0.141	0.247
LSA-SAF 2x2 pixels	-0.0191	0.0839	0.114	0.0336	0.142	0.248
LSA-SAF 3x3 pixels	-0.0191	0.0815	0.110	0.0335	0.139	0.245
CMSAF 3x3 km	-0.0018	0.0801	0.109	0.0099	0.125	0.204
CMSAF 9x9 km	-0.0205	0.0787	0.106	-0.0138	0.123	0.196
CMSAF 15x15 km	-0.0220	0.0767	0.103	-0.0146	0.121	0.193
MeteoSwiss 1x1 pixel	-0.1050	0.1264	0.179	-0.1017	0.158	0.214
MeteoSwiss 3x3 pixels	-0.1053	0.1251	0.177	-0.1018	0.157	0.211
MeteoSwiss 5x5 pixels	-0.1052	0.1244	0.176	-0.1013	0.155	0.209
MeteoSwiss 7x7 pixels	-0.1047	0.1239	0.175	-0.1003	0.155	0.208
MeteoSwiss 9x9 pixels	-0.1042	0.1236	0.175	-0.0990	0.154	0.207

to decrease during the winter time while no significant difference is found for the MeteoSwiss algorithm between the fall and winter seasons. Snow falls and snow cover durations have been particularly pronounced in Belgium during the winters 2008 and 2009. Due to their high reflectance snow covered pixels tend to be falsely classified as overcast, which leads to a remarkable error in the global irradiance values. Only the MeteoSwiss retrieval scheme accounts for a a highly sensitive snow detection algorithm in combination with an algorithm for cloud detection over snow-covered areas.

CONCLUSIONS

The current version of the MeteoSwiss algorithm systematically underestimates ground measurements when applied over Belgium. We strongly suspect a possible drawback in the shadow detection scheme when running the algorithm over a non-mountainous region as Belgium. Some adaptations are currently tested to fix the problem. By contrast, both the LSA-SAF and the CM-SAF products overestimate the ground data in overcast situations, whereas they underestimate it in case of clear skies. This could be related to the atmospheric aerosol load assumed during the retrieval process (e.g., fixed visibility for the LSA-SAF and climatology for the CM-SAF algorithms, respectively) which tends to overestimate the actual aerosol state for clear skies and thus to underestimate the surface solar irradiance. The performance of the LSA-SAF and the CM-SAF decrease during the winter time while no significant difference is observed for the MeteoSwiss algorithm between the fall and the winter seasons therefore stressing the importance to account for a sensitive snow detection algorithm in combination with an algorithm for cloud detection over snow-covered areas in the retrieval scheme. Our results indicate that there is not a unique size of pixel aggregate giving the best results. It is possible at one time to get better agreement with one resolution and at other times better agreement with a different resolution. By contrast, accuracy of the MSG derived estimations increase when considering cumulated rather than instantaneous values, the time integration reducing the uncertainties inherent to the comparison of point measurements against pixel values. In overall, the CM-SAF product exhibits the better agreement with the ground measurements over Belgium.

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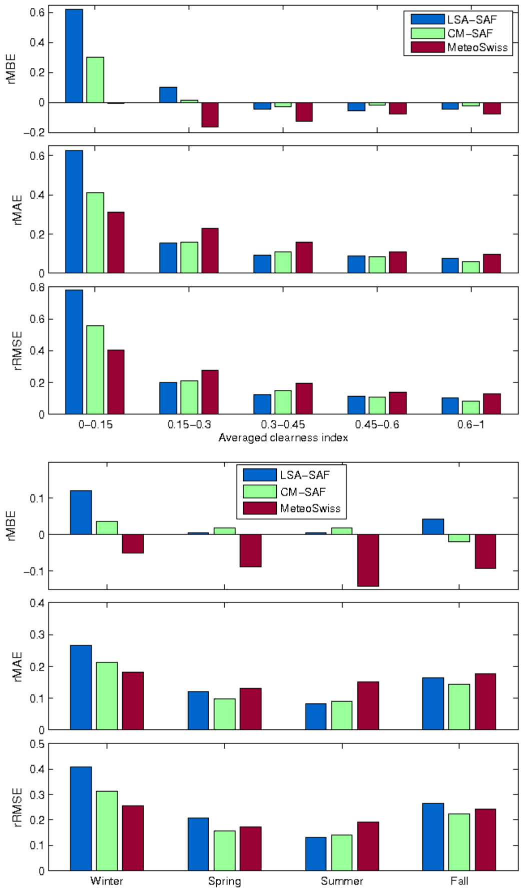

Figure 2: **Distribution of the satellite derived - ground measured relative mean bias error (rMBE), relative mean absolute error (rMAE) and relative root mean square error (rRMSE) as a function of sky conditions (left panel) and seasons (right panel)**

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