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Comparison of global irradiance measurements of the official Spanish radiometric network for 2006 with satellite estimated data

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Abstract

The monthly average values of daily global irradiance measured in broadband at 40 stations of the National Radiometric Network of the Spanish Meteorological Agency have been compared with the monthly values of SIS (Surface Incoming Shortwave radiation) of the Climate Monitoring-Satellite Application Facility for 2006. It is calculated by the data from the instrument Spinning Enhanced Visible and Infrared Imager of the Meteosat Second Generation satellite and of the Advanced Very High Resolution Radiometer of the NOAA polar satellites. The results show a great similarity between the data from both sources of information, and the discrepancies found are around 5%. The aim of such a comparison is to evaluate the suitability of the use of the SIS data for the elaboration of an atlas of solar irradiance available in Spain.

Key words: global irradiance, AEMET, CM-SAF SIS, EUMETSAT, comparison

1 Introduction

Studies aimed at characterizing and understanding the Earth's climate require the accurate measurement of different climate variables with a global coverage and high spatial resolution for a period of time long enough. These conditions can only be achieved with the use of data based on measurements from space, which are obtained through meteorological satellites located in geostationary and polar orbits. These are the only data available that have sufficient resolution in oceans and sparsely populated areas. At present the series of data from these satellites are beginning to have an acceptable temporal range, with measurements available from the early 80's. Therefore, today the use of these series of satellite data can be considered for the elaboration of climate analyses. The demand of accuracy in the measurements increases as the time scale considered increases, so that the climate characterization studies at decade-scale require data with a resolution of one order of magnitude higher than the accuracy required for studies of interannual fluctuations (Schulz et al., 2009).

The only objective method that quantitatively evaluates the accuracy of the algorithms applied to the gross satellite data for the calculation of the data derived from shortwave incident surface irradiance, is through validation studies of those irradiance data calculated with in-situ irradiance measurements obtained in radiometric ground stations. SIS (Surface Incoming Shortwave Radiation) is the solar irradiance in the band 0.2-4.0 μm on horizontal surface, at ground level. In this work, the validation of data for 2006 of the SIS product from the Satellite Application Facility on Climate Monitoring (CM-SAF) of EUMETSAT has been carried out, with measurements from 40 stations of the National Radiometric Network (NRN) of the Spanish Meteorological Agency (AEMET).

The CM-SAF performs annual periodic validations to monitor the accuracy and quality of the products produced. The natural variability of the products over the region covered by the CM-SAF is generally not well represented in comparison with the data from ground stations. Specifically, there is a noticeable lack of reference radiometric stations on surface that carry out measurements of radiative fluxes that can be used for comparison and validation with the CM-SAF operational products. For example, in 2009, only data from 4 European stations of the BSRN network (Baseline Surface Radiation Measurement) in near real time were used

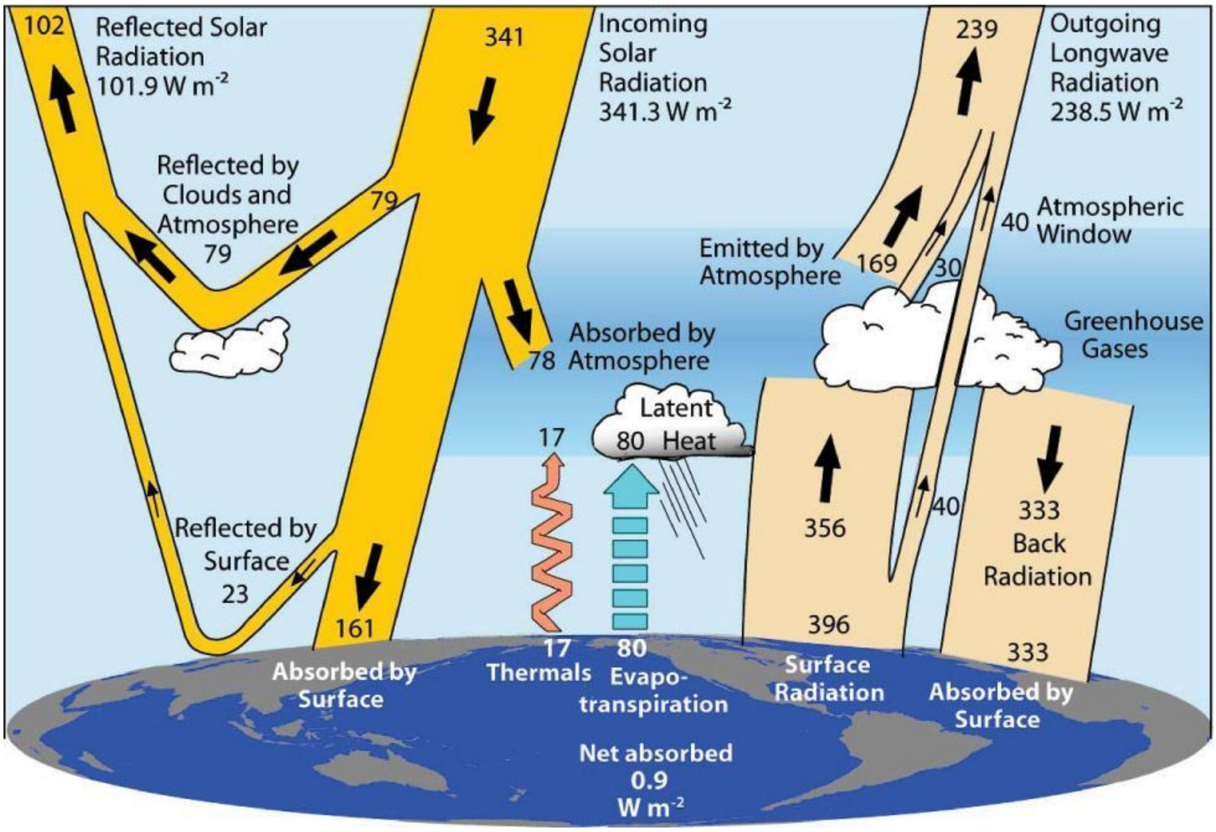

Figure 1. Mean radiative balance of the Earth-Atmosphere system. It shows the shortwave irradiance to the left and the outgoing longwave irradiance to the right (Trenberth et al., 2009).

for the annual monitoring of stability and homogeneity of the radiative products. These stations are located at Payerne (46.81°N, 6.94°E), Carpentras (44.05°N, 5.03°E), Lindenberg (52.22°N, 14.12°E) and Cabauw (51.97°N, 4.91°E). The latest results show that over 90% of the differences in the SIS values with respect to the monthly average values measured at ground stations are below 10 W m^{-2}, which is the upper uncertainty limit defined as objective by the CM-SAF (CM-SAF, 2010).

The added value of this study with regard to the existing validations referenced at the BSRN network stations is that the comparisons of SIS values were made with stations of the AEMET NRN, with a much higher density of sites than the reference network BSRN. On the other hand, the AEMET radiometric stations follow a rigorous protocol of periodic calibration and maintenance activities that is described in detail in Section 2.

The results of this study show similar results to the periodic validations performed by the CM-SAF using stations of the global reference network BSRN. They show an acceptable quality of SIS product with deviations of around 5% compared with ground measurements, and meet the accuracy requirements proposed by the CM-SAF and considered a requisite for the development of climate analysis (Mueller et al., 2009).

Therefore, these results support the appropriateness of using the CM-SAF SIS variable for the development of mean fields of shortwave incident irradiance in Spain, as well as the detection of possible trends, the calculation of monthly and seasonal averages and other studies related to the natural or the anthropogenic variability of surface radiative fluxes.

Some basic concepts and ideas about the earth-atmosphere radiative balance are reminded below and illustrated in Figure 1. The global short-wave irradiance 0.2 to 4.0 μm is the solar energy that reaches the Earth's surface after all the processes of absorption and dispersion that occur along the path through the atmosphere. At the top of the atmosphere, the shortwave irradiance is on average 341 W m^{-2}. The absorption of shortwave irradiance of the incident energy due to molecules, aerosols and clouds is about 23% (78 W m^{-2}) and contributes to global warming. Backscattering and reflection into space processes due to clouds represent 23% (79 W m^{-2}). Therefore, 54% (184 W m^{-2}) of the irradiance reaches the Earth's surface where, depending on the reflective properties of the surface, about 7% (23 W m^{-2}) of the incident energy is

Figure 2. National Radiometric Network of the Spanish Meteorological Agency (AEMET).

reflected. Thus, the resulting mean albedo of the Earth-atmosphere system, including the backscattering, reflection due to clouds and the reflection on Earth's surface processes is 23% + 7% = 30% (102 W m^{-2}).

From the 54% (184 W m^{-2}) of the shortwave irradiance reaching the Earth's surface, on average, 30% (55 W m^{-2}) occurs as direct irradiance, and 27% (49 W m^{-2}) as diffuse irradiance.

2 National broadband radiometric network

The NRN depends on the National Radiometric Center (NRC) which in turn is part of the AEMET. The NRN currently consists of 51 radiometric stations. Figure 2 shows the radiometric stations that constitute the NRN, indicating the measurement variables obtained in each of them. Forty radiometric stations (see Table 1), have been selected for this study, with monthly data for global and diffuse irradiance in 2006, in order to carry out a comparative study of these measurements with those obtained by the SEVIRI radiometer of the satellite Meteosat Second Generation (MSG) and the Advanced Very High Resolution Radiometer (AVHRR) of NOAA satellites.

The measurements of the following variables are carried out in the main radiometric stations of the NRN: global, diffuse and direct irradiance; infrared and ultraviolet B irradiance (UVB). Direct, global, diffuse and infrared irradiance sensors are mounted on an automatic solar tracker as shown in Figure 3, which consists of shading units, consisting of balls held together with rods that cast their shadows on a pyranometer to obtain diffuse irradiance. These sensors are the pyranometers to measure global and diffuse irradiance, the pyrgeometer for measuring infrared irradiance and direct irradiance pyrheliometer.

These equipments are connected to an acquisition system that stores the data every minute, which in turn are transmitted in real time through the internal AEMET network to the NRC.

There are also secondary stations with measurements of global and diffuse irradiance, and in some cases UVB.

Throughout 2005 there was a process of modernization of the NRN which lead to the acquisition of new sensors and equipment and their installation in different locations in the network.

The calibration program is a biannual plan in which all sensors in the visible range (pyranometers and pyrheliometers) and infrared sensors (pyrgeometers) of the network

Table 1. Spanish Meteorological Agency (AEMET) radiometric stations used for the study.

Indicative	Name	Longitude	Latitude
B278	Palma (Aep. Son Sant Joan)	2° 44' 38"E	39° 34' 00"
24B954	Sant Josep (Aep. Eivissa)	1° 22' 12"E	38° 52' 41"
0201D	Barcelona (CMT)	2° 12' 05"E	41° 23' 27"
0016A	Aep. Reus	1° 10' 44"E	41° 08' 59"
1428	Santiago	8° 25' 37"W	42° 53' 58"
367	Aep. de Girona	2° 45' 37"E	41° 54' 05"
1479I	Corón	8° 48' 13"W	42° 34' 52"
1014	Aep. de Fuenterrabia	1° 47' 25"W	43° 21' 24"
1024E	San Sebastián	2° 02' 22"W	43° 18' 27"
1082	Aep. de Bilbao	2° 54' 21"W	43° 17' 53"
1111	Santander (CMT)	3° 47' 59"W	43° 29' 30"
1249I	Oviedo	5° 52' 24"W	43° 21' 13"
1387	A Coruña	8° 25' 10"W	43° 22' 02"
2030	Soria	2° 28' 00"W	41° 46' 00"
2422	Valladolid	4° 46' 00"W	41° 39' 00"
2867	Salamanca	5° 29' 46"W	40° 56' 44"
3194U	Madrid C. Universitaria	3° 43' 27"W	40° 27' 10"
3469A	Cáceres	6° 20' 22"W	39° 28' 20"
4121	Ciudad Real	3° 55' 11"W	38° 59' 22"
4478G	Badajoz	7° 00' 42"W	38° 53' 10"
1495	Vigo	8° 37' 55"W	42° 13' 25"
5530E	Aep. de Granada	3° 46' 35"W	37° 11' 24"
5960	Aep. de Jerez de la Frontera	6° 03' 48"W	36° 44' 45"
5973	Cádiz	6° 15' 37"W	36° 29' 55"
4642E	Huelva	6° 54' 35"W	37° 16' 48"
6156	Málaga (CMT)	4° 28' 49"W	36° 43' 09"
6325O	Aep. de Almería	2° 23' 17"W	36° 50' 35"
7178I	Murcia	1° 10' 10"W	38° 00' 10"
7031	S. Javier	0° 48' 08"W	37° 47' 12"
8019	Aep. de Alacant	0° 33' 20"W	38° 17' 09"
8414A	Aep. de València	0° 28' 16"W	39° 29' 22"
9091O	Aep. de Vitoria	2° 43' 22"W	42° 53' 02"
9170	Logroño	2° 19' 51"W	42° 27' 06"
9771C	Lleida	0° 35' 42"E	41° 37' 33"
2661	León	5° 38' 58"W	42° 35' 20"
3260B	Toledo	4° 02' 58"W	39° 53' 05"
8178D	Albacete	1° 51' 39"W	39° 00' 25"
9263D	Pamplona	1° 38' 21"W	42° 46' 06"
9433	Zaragoza	1° 04' 18"W	41° 40' 44"
9981A	Tortosa	0° 29' 29"E	40° 49' 14"

are compared with standard sensors that are also previously calibrated biannually at the *Physikalisch-Meteorologisches Observatorium* in Davos, declared World Radiation Center (WRC) (http://www.pmodwrc.ch/) in 1971 by the World Meteorological Organization (WMO, World Data Center for Radiation in St. Petersburg).

The calibration of the standard sensors in the WRC Davos is performed using a global primary standard instrument of radiation (model PMO2). Likewise, and in order to detect possible instrument drifts, an additional regular monitoring of the standard sensors is carried out using a secondary standard (model PMO6) available for that purpose in the NRC.

The calibration procedure of the network pyranometers is done by direct comparison with the standard sensors through outside measurements using the sun as a source of radiation for several days. The calibration process leads to the modification, if any, of the constant of the equipment or calibration factor, i.e. the conversion factor of the signal in millivolt to irradiance values in W m^{-2}.

Apart from the calibration process described above, the data are inspected daily and corrected from possible instrumental errors or errors of the acquisition system, using specific software with adequately defined filters. On the other hand, the instrumentation is checked weekly following a complete maintenance routine, the same for

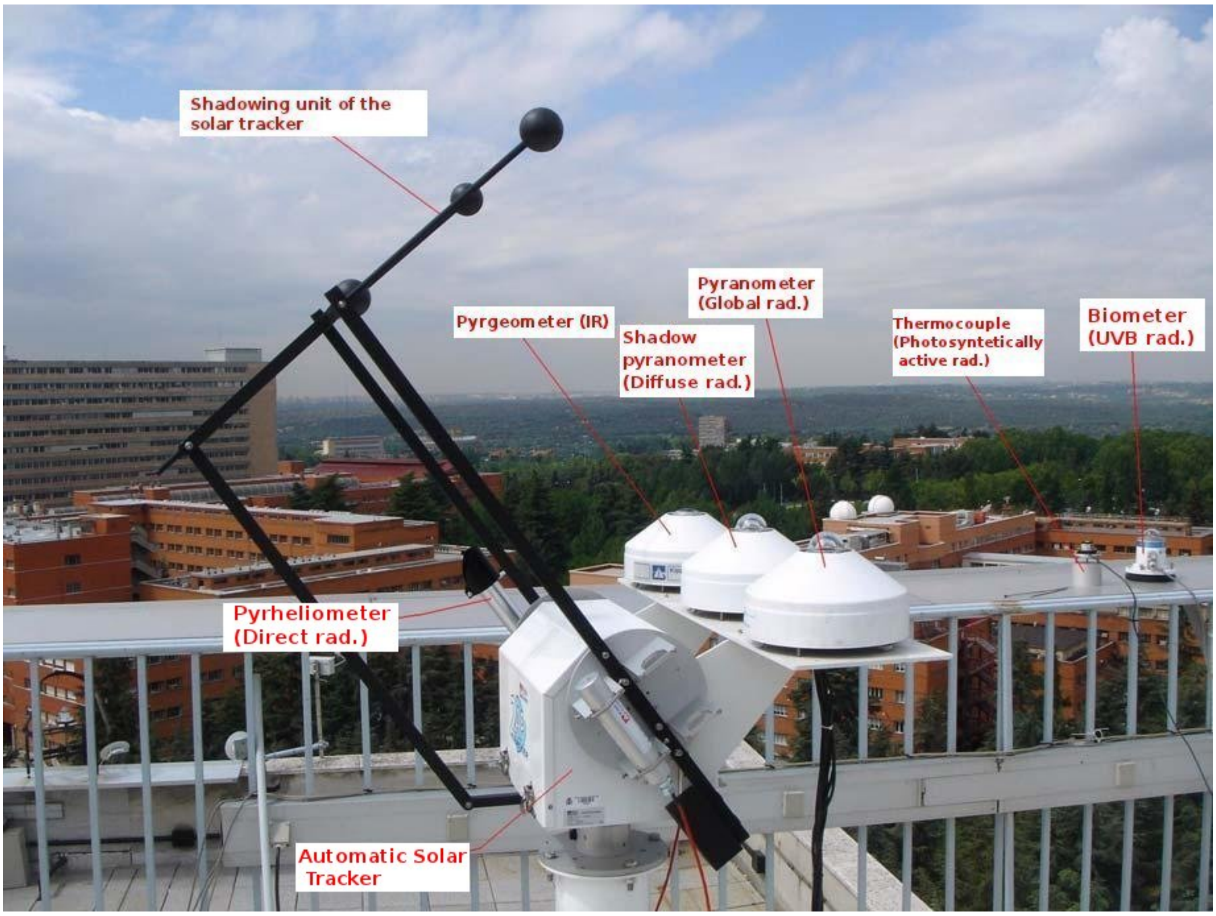

Figure 3. Instruments and sensors of a full radiometric station of the Spanish Meteorological Agency (AEMET).

the entire network, which includes cleaning of the domes of the pyranometers and revision of the ventilation systems and the data acquisition system, among other maintenance tasks. The calibrated and refined data are finally sent to the AEMET and WMO databases.

Global irradiance is defined as the solar irradiance received from a 2π steradians solid angle on a horizontal surface. Global irradiance includes radiance received directly from the solar disk and the diffuse irradiance scattered by the atmosphere.

Radiometric stations are equipped for the measurement of global and diffuse irradiance with Kipp-Zonen pyranometers, models CM-11 and CM-21, with a spectral range of 305-2800 nm and an uncertainty of $\pm$ 2%. Table 2 shows information on the technical specifications of the pyranometer CM-11 and CM-21.

3 Satellite Application Facility on Climate Monitoring (CM-SAF)

In November 1992, EUMETSAT created the network of SAF (Satellite Application Facilities) specialized centers, in order to obtain a better use of the data from meteorological satellites by developing algorithms and software used to obtain meteorological products that complement those produced and distributed by the central EUMETSAT in Darmstadt. Each SAF center is specialized in a type of products and led by a National Meteorological Service. There are currently 7 approved SAF projects in operation:

- SAF on Support to Nowcasting and Very Short Range Forecasting.
- SAF on Oceans and Sea Ice.
- SAF on Climate Monitoring.
- SAF on Numerical Weather Prediction.
- SAF on Land Surface Analysis.
- SAF on Ozone and Atmospheric Chemistry Monitoring.
- SAF on GRAS Meteorology.

In this work we have used data from the CM-SAF, led by the German Meteorological Service (*Deutscher Wetterdienst*, DWD).

The CM-SAF was created to generate and continuously archive a series of climate data, in order to characterize the state of the climate and its variability and make an analysis and diagnosis of climate parameters to identify and

Table 2. Technical specifications of the CM11 and CM21 Kipp-Zonen pyranometers installed in the Spanish Meteorological Agency (AEMET) radiometric stations.

	CM-11	CM-21
Spectral range	305-2800 nm	305-2800 nm
Response time (95%)	12 s	5 s
Instability (change/year)	± 0.50%	± 0.50%
Linearity deviations (0-1000 W m^{-2})	± 0.60%	± 0.20%
Dependence of sensibility with temperature	± 1%	± 1%
Estimated precision for daily measurements	± 3%	± 2%

understand changes in the climate system. On the other hand, it was intended to provide input for climate models in order to study various processes of the climate system on a European and global level and for climate prediction.

The CM-SAF provides climate data for some of the 44 climatic variables defined as Essential Climate Variables by the Global Climate Observing System in the United Nations Framework Convention on Climate Change. Specifically, the variables provided by the CM-SAF include cloud parameters, surface albedo, surface radiative fluxes and, at the top of the atmosphere, atmospheric temperature and humidity (Schulz et al., 2009). There are two categories of data available that are known as products and datasets. The products are data validated using ground stations and are provided in nearly real time, with sufficient precision to make studies of variability in diurnal and seasonal timescales. For studies in which trend assessments and interannual variability are required, it is necessary to use the data category called dataset. Datasets are data corrected due to instrumental changes in successive satellites and other subtler effects such as drifts in spectral responses of the instruments or small changes in measurements due to slight changes in the orbit of the satellites.

For this work we have used data of the SIS product of the SAF-Climate whose calculation is based on the Pinker and Laszlo (1992) and Mueller et al. (2004) methods. The principle of energy conservation in an atmospheric column allows us to estimate atmospheric transmissivity in broadband from the reflectivity at the top of the atmosphere. Measurements of the instrument Geostationary Earth Radiation Budget in the MSG are used to obtain reflectivity at the top of the atmosphere. SIS values monthly averaged for 2006 with a spatial resolution of 15 km were used for this study. Figure 4 shows an example of monthly average values of SIS.

The basic idea of the algorithm to obtain the SIS is that there is a relationship in the 0.2 to 4.0 μm band between the reflectivity (R) at the top of the atmosphere, which can be obtained directly from measurements recorded by satellites, and the atmospheric transmissivity (T) or ratio between the irradiance at the surface and the corresponding irradiance at the top of the atmosphere. Once this ratio is known, it is possible to calculate T and surface irradiance, i.e. the SIS. Therefore, there are relationships such as:

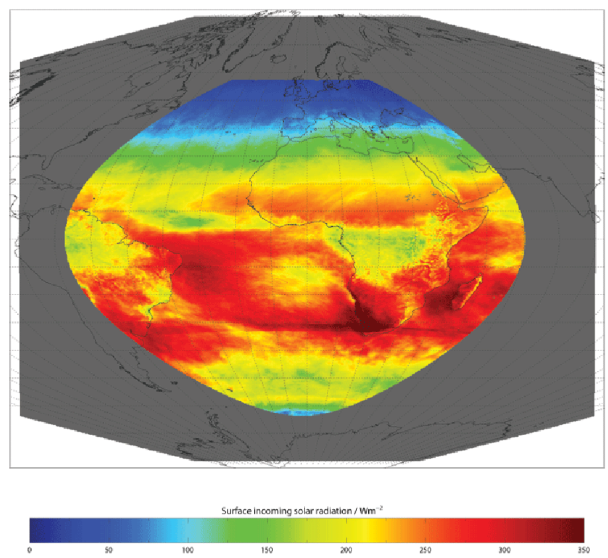

Figure 4. Example of SIS product (Surface Incoming Shortwave Radiation) of the Climate Satellite Application Facilities for day 01/11/2006 at 00:00 UTC.

$$T = f_i(R) \qquad (1)$$

where R is the reflectivity at the top of the atmosphere, T is the atmospheric transmissivity and i = 1,..., N represents each of the different surface-atmosphere conditions characterized by the following parameters: surface albedo, amount of absorbent gases in the atmosphere (ozone, water vapor) and diffusing particles (molecules, aerosols, cloudy drops). These relationships between T and R are calculated beforehand through a radiative transfer model (Mayer and Kylling, 2005) and some tables (LUT, Look-Up Tables), previously obtained, which are then used to calculate T as a function of R for each of the conditions of observation. The reason for the use of pre-calculated tables for the calculation of atmospheric transmissivity instead of directly making the calculations using the radiative transfer model is solely to save computational time, since the amount of satellite data to produce homogeneous series of high quality data useful for climate studies is enormous. The application of the algorithm to obtain the SIS takes into account various pre-calculated cloudy

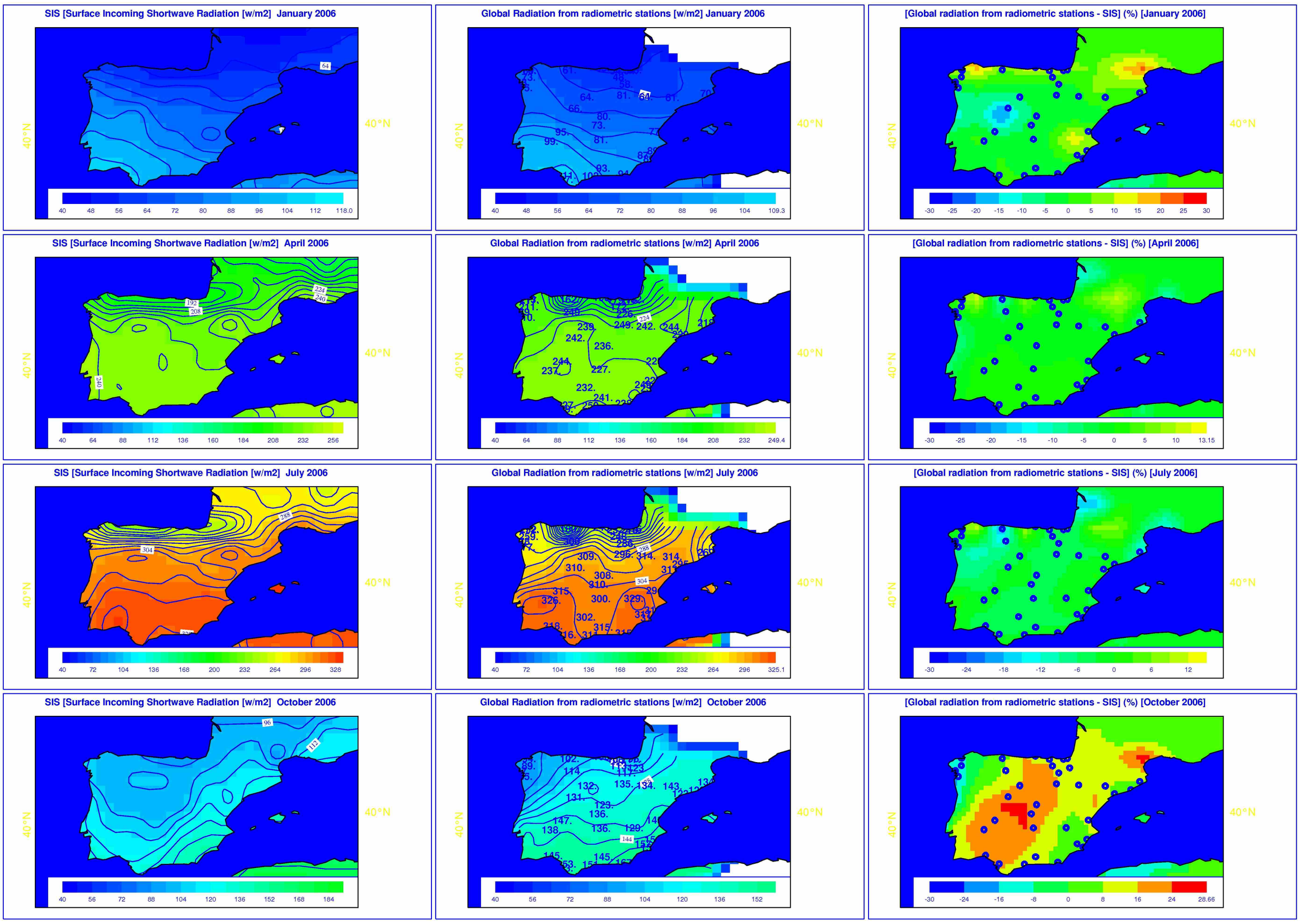

Figure 5. Comparison of the daily monthly averages of the Surface Incoming Shortwave radiation (SIS) values with the daily monthly averages of global irradiance of the National Radiometric Network for the months of January, April, July and October of 2006. First column: SIS values; second column: measurements of the Radiometric Network; third column: percentage difference.

parameters such as cloud mask, pressure in the cloud top and cloud type, using two different schemes for the calculation of surface irradiance as the pixels are with clear or cloudy sky (Mueller et al., 2009).

The next step is to obtain R from albedo measurements at the top of the atmosphere, obtained by satellite radiometers, in the case of cloudy pixels. In the case of clear sky, only the surface albedo is used, in order to minimize the effect of uncertainties in the surface albedo (Mueller et al., 2004).

Finally, the tables previously obtained for atmosphere-surface conditions prevailing at the moment of the measurement are used to obtain T, and this value is used to estimate SIS through the expression:

$$SIS = E_0 \cos(\Theta) T \quad (2)$$

where E_0 is the solar irradiance at the top of the atmosphere (Solar Constant), Θ is the zenith angle and T is the atmospheric transmissivity.

For the calculation of the tables, the radiative transfer model used is the libRadtran (Mayer and Kylling, 2005). Inherent symmetries in the relationship between different atmospheric states and transmissivity were taken into account in order to identify a set of processes that are linearly independent between them and thereby reduce the number of entries in the tables, with the additional saving in time calculation. The processes that can be considered as linearly dependent have been treated using parameterizations to estimate their influence on transmissivity and therefore on surface radiance. This is the case of water vapor and ozone, for which fixed values are defined in the tables and then parameterization formulas were used to take into account the influence of their variations in the SIS values (Schulz et al., 2009) and (Mueller et al., 2009).

The LUT to obtain the SIS product were calculated for 3 different cloud optical depths, 10 aerosol optical depths, 6 zenith angles and 7 surface albedos. Note that, for now, only aqueous clouds at fixed altitudes and with different thicknesses have been taken into account, but the different optical properties of clouds with ice particles were not included

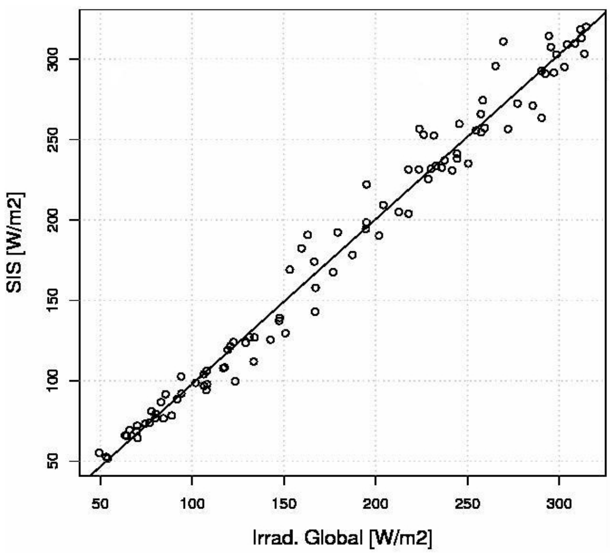

Figure 6. Linear correlation line of the irradiance satellite data (Surface Incoming Shortwave radiation, SIS) vs global irradiance data from the 8 radiometric stations for 2006. $R^2 = 0.979$, RMSD = 12.5 W m^{-2}, MAB = 9.1 W m^{-2} (5%).

in the calculations. This should be taken into account when considering potential sources of error in estimating the SIS.

4 Comparison of measurements of the radiometric stations with the CM-SAF SIS measurements

In order to evaluate the accuracy of the algorithm to obtain the CM-SAF SIS and the suitability of the use of these data in addition to those from the NRN, a comparison of the daily monthly average of the SIS with the corresponding measurements of global irradiance for all the stations indicated in Table 1 for the year 2006 was done.

Figure 5 shows, for four selected months, the daily monthly averages of the SIS in the first column, the corresponding data of global irradiance measured in the radiometric stations in the second column, and the percentage difference between the measurements and the SIS values, as well as the locations of the radiometric stations used, in the third column.

In general, a very good concordance is observed between the values from the two sources of information, with a great similarity in the latitudinal gradients of global irradiance observed, and even some similar structures in the contouring of the measurements are reproduced. The fields of percentage differences show a predominant green color indicating very low values. Even in the months of maximum insolation (May, June and July), when there are also larger latitudinal gradients of irradiance, a good concordance between data is observed and similar structures are reproduced.

Perhaps the only exception is the month of October, when there is an appreciable difference between the mea-

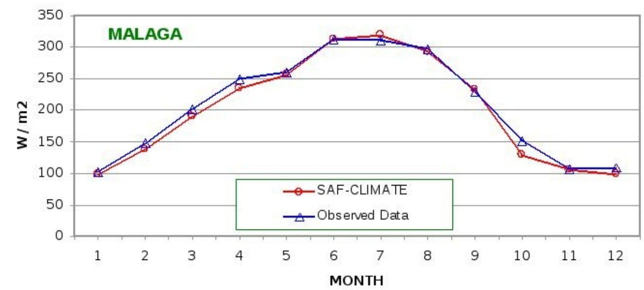

Figure 7. Evolution of the daily monthly average values of the Surface Incoming Shortwave radiation (SIS) (red line) together with the global irradiance values (blue line) for the meteorological station in Málaga.

surements in the center of the peninsula. These discrepancies could be due to the fact that the algorithm used to calculate the SIS does not take into account ice clouds yet.

The CM-SAF conducts periodic validations of the data produced mainly using reference stations within the network BSRN at different sites in Europe and Africa, covering different climates and land types. In Europe only 6 radiometric stations are used to perform these validations, and only one of them is located in Spain, the Solar Platform of Almeria, which was accepted in the BSRN network in 2006. The reports of these validations can be consulted on the official website of the CM-SAF (www.cmsaf.eu.de, Documentation). Based on the accuracy requirements that were considered necessary for the development of climate analysis, the CM-SAF has set as target an accuracy of 10 W m^{-2} in the monthly mean values of shortwave irradiance (Mueller et al., 2009). Table 3 shows the results of the comparison of the monthly mean values of the SIS data for 2006 with the monthly mean irradiance values obtained at 8 radiometric stations of the AEMET network. These stations were chosen so that they can be considered as a representative sample of the study area. Table 4 shows a summary of the relative deviations in the various statistic indicators. As it can be observed, the MAB (Mean Absolute Bias) and the MBD (Mean Bias Deviation) are maintained in most cases below the threshold set by the CM-SAF, and the results are similar to those obtained in the official validations of CM-SAF. On the other hand, the MAB, as a percentage with respect to land values, remain in the order of 5% as it could be estimated in Figure 5. Likewise, we can see that the mean systematic error, indicated by the value of MBD is on average negligible. The value close to the unit of the square of Pearson's Correlation Coefficient is equally remarkable, indicating an excellent correlation between in-situ data and satellite values. This good correlation can also be seen in Figure 6, where all the monthly values for the 8 locations defined in Table 3 are represented vs the SIS values interpolated at these locations, obtaining a value of the square of Pearson's Correlation Coefficient of 0.979.

Table 3. Comparison of the monthly average values for 2006 of Surface Incoming Shortwave radiation (SIS) product data vs monthly average values of global irradiance in-situ from 8 Spanish Meteorological Agency (AEMET) radiometric stations. The definitions of the acronyms used in the table are Mean Absolute Bias (MAB), Mean Bias Deviation (MBD) and Root Mean Standard Deviation (RMSD).

Radiometric station	Latitude	Longitude	SIS average (W m^{-2})	in-situ average (W m^{-2})	MAB (W m^{-2})	MBD (W m^{-2})	RMSD (W m^{-2})	[Corr. Coeff.]^2 R^2
Almería	2° 23’ 17”W	36° 50’ 35”	199.9	205.4	7.5	-5.4	9.8	0.99
Barcelona	2° 12’ 05”E	41° 23’ 27”	184.4	171.7	14.1	12.7	19.0	0.98
Bilbao	2° 54’ 21”W	43° 17’ 53”	151.1	144.6	10.2	6.5	13.9	0.98
Coruña	8° 25’ 10”W	43° 22’ 02”	159.8	158.7	8.3	1.1	10.3	0.98
Madrid	3° 43’ 27”W	40° 27’ 10”	187.5	191.2	6.1	-3.7	8.4	0.99
Málaga	4° 28’ 49”W	36° 43’ 09”	200.6	206.5	7.6	-5.9	9.7	0.99
Valencia	0° 28’ 16”W	39° 29’ 22”	185.4	182.5	10.5	2.8	13.5	0.99
Zaragoza	1° 04’ 18”W	41° 40’ 44”	179.9	188.1	8.8	-8.2	12.1	0.99
			181.1	181.1	9.1	0.0	12.5	0.98

Table 4. Summary of the relative variations of the different statistical indicators. See the acronyms definitions in the legend in Table 3.

Radiometric station	MAB (%)	MBD (%)	RMSD (%)
Almería	3.7	-2.6	4.8
Barcelona	8.2	7.4	11.1
Bilbao	7.0	4.5	9.6
Coruña	5.2	0.7	6.5
Madrid	3.2	-1.9	4.4
Málaga	3.7	-2.8	4.7
Valencia	5.7	1.5	7.4
Zaragoza	4.7	-4.4	6.4
	5%	0%	7%

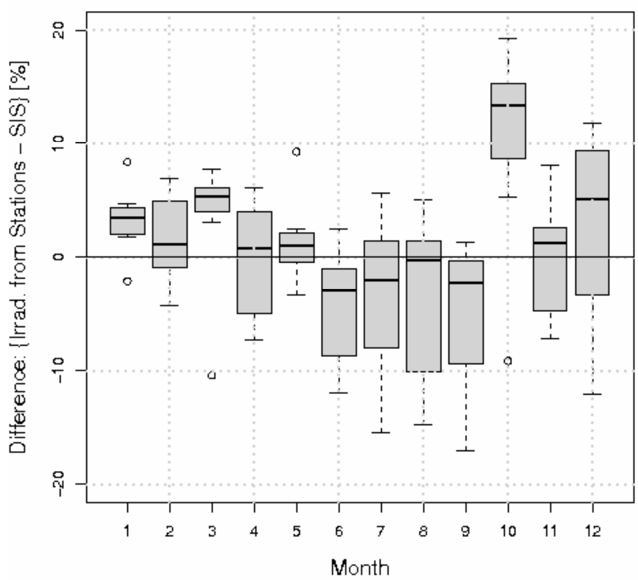

Figure 8. Differences in % of the global irradiance measurements taken in 8 radiometric stations regarding the Surface Incoming Shortwave radiation (SIS) satellite values for each month of 2006.

Figure 6 shows the linear correlation line of the SIS values compared with the irradiance monthly averages at 8 stations along with the MAB and Root Mean Standard Deviation (RMSD) values, which are of 9.1 W m^{-2} and 12.5 W m^{-2}, respectively.

In order to study the evolution of the differences over the year between the daily monthly average values of SIS and the global irradiance values observed in-situ, Figure 7 shows together: in blue, the mean global irradiance values for each month of the year for the radiometric station of Málaga; and in red, the SIS measurements interpolated to the geographical location of the radiometric station.

The close similarity of the data from both information sources must also be highlighted, even during the months of maximum variation of global irradiance. That is, during the months close to the equinoxes, March to May and September to November. Both data sources show a sharper decline in the global irradiance during the fall months, more than in that corresponding to the increase in irradiance during the spring months.

There is no systematic difference observed between the two data sources throughout 2006 except during the month of October, when there seems to be an underestimation of the SIS data regarding the measurements made in radiometric stations.

Figure 8 shows the percentage differences throughout the year using the irradiance value for the 8 selected stations. It shows again that the differences remained within 5% in most months for all stations except the systematic underestimation of the SIS data in the month of October with respect to the global irradiance measured on the ground.

5 Conclusions

The data of the SIS product from the CM-SAF, obtained from the measurements made by the instrument SE-

VIRI on board the satellite MSG and the instrument AVHRR on NOAA's polar satellites have been analyzed and compared with average monthly values of daily global irradiance measured in broadband at 40 stations of the NRN of the AEMET. The results show a great similarity in the data from both sources of information, and in general the discrepancies were found on average around 5%, in line with the results obtained in the official validations performed by the CM-SAF, which used the radiometric stations from the BSRN network as a reference. The linear correlation between satellite data of estimated surface irradiance and those obtained from ground stations is acceptable. The results of this study make the use of SIS strongly recommended for further studies, such as a solar radiation atlas, and encourage us to continue evaluating other products made by the CM-SAF project.

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