HelioClim-3: a near-real time and long-term surface solar irradiance database

Bella Espinar, Philippe Blanc, Lucien Wald, Benoît Gschwind, Lionel Ménard, Etienne Wey, Claire Thomas, Laurent Saboret

HelioClim-3: a near-real time and long-term surface solar irradiance database

B. Espinar[1], P. Blanc[1], L. Wald[1], B. Gschwind[1], L. Ménard[1], E. Wey[2], C. Thomas[2], L. Saboret[2]
[1] MINES ParisTech, CEP – Centre Energétique et Procédés, Sophia Antipolis, France, *bella.espinar-bocquet@mines-paristech.fr*
[2] TRANSVALOR, Sophia Antipolis, France

***Abstract*—HelioClim-3 is a database containing surface solar irradiance assessed every 15 min from images taken by the Meteosat series of satellites since 2004. It covers Europe, Africa and Atlantic Ocean. In average, comparison with hourly measurements made in meteorological stations yields a correlation coefficient greater than 0.9, a relative root mean square error (rRMSE) around 20% of the mean measured irradiance and a relative mean bias error (rMBE) below 2%. HelioClim-3 can be accessed via the SoDa Service (www.soda-is.org). The availability and quality of HelioClim-3 data should help in performing steps towards a better knowledge of the surface solar irradiance and its variations over recent years.**

NOMENCLATURE

GCOS: Global Climate Observing System
GMES: Global Monitoring for Environment and Security
HC-3: HelioClim 3
SSI: Surface solar irradiance (W/m^2)
UTC : Universal Time Coordinated

INTRODUCTION

The *surface solar irradiance* (SSI) is the power received from the sun at ground per surface unit (W/m^2). It was identified as an essential climate variable by the Global Climate Observing System (GCOS) in August 2010. That means that SSI is a parameter of key importance for understanding and monitoring the global climate system. In addition of such climatology applications, the SSI is of high interest in domains as varies as solar energy, health, architecture, agriculture, oceanography or forestry [1].

The solar resource is the energy source most abundant and the most distributed over the Earth's surface. Fig. 1 exhibits the yearly irradiation, i.e. the energy received during a year per surface unit. The spatial distribution of the irradiation is mostly zonal: values tend to increase from high latitudes towards the equator. One may observe heterogeneities in this distribution mostly due to cloud cover or dust storms. This heterogeneity also exists at finer scales. The spatial distribution is also temporally variable, since it depends on the hour in the day, the day in the year and on the atmospheric conditions, which are highly variable in time.

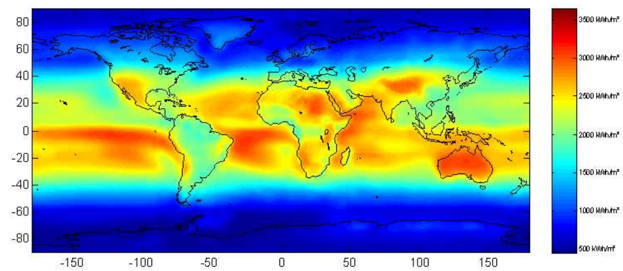

Fig. 1. Spatial distribution of the yearly irradiation, in kWh m^{-2}. This figure illustrates the worldwide spatial variability of the solar resource (© MINES ParisTech, 2006).

SATELLITE IMAGES FOR SOLAR IRRADIANCE ESTIMATION

Due to spatial and temporal variability of SSI, its assessment requires continuous and densely distributed observations. Meteorological offices have set up networks of ground-based pyranometric stations. The geographical distribution of these stations is evenly distributed in space, and there are large areas without any ground stations [2]. The existent ground stations are insufficient in number to assess the spatial variability of the SSI over large areas.

The SSI may be estimated from images acquired by meteorological satellites: several studies demonstrate the superiority of the use of such data compared to interpolation methods applied to spatially and temporally sparse measurements performed within a pyranometric network [3, 4].

The Meteosat series of geostationary satellites provide synoptic views of Europe, Africa and Atlantic Ocean for meteorological purposes. Visible channel images clearly depict clouds and more generally the optical state of the atmosphere (Fig. 2) and they are currently used to assess the SSI in operational way with both high spatial and temporal resolutions.

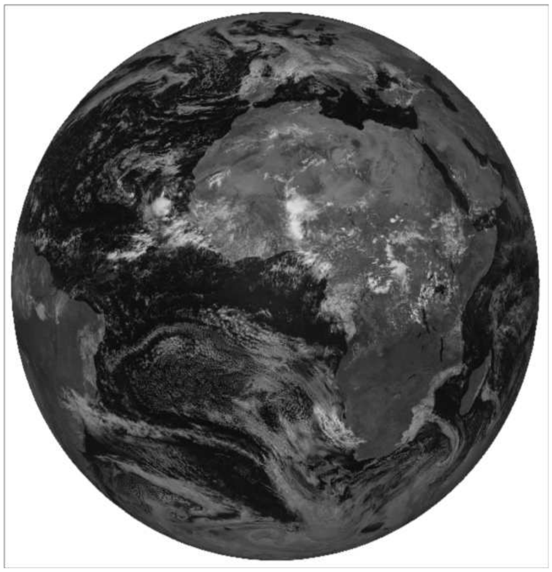

Fig. 2. Example of a Meteosat image in the visible channel, taken on 7 September 2010, at noon (1200 UTC). Radiance increases from black to white. The area scanned by geostationary satellites is around one third of the Earth's surface. © Eumetsat, 2010.

A. SSI estimation from satellite images

There are several well-performing methods for converting the satellite images into SSI. The outputs of a sensor aboard a satellite are the result of the ensemble of interactions of radiation with the atmosphere and the ground, during the downward and upward paths of the radiation. A method is called inverse when it attempts to estimate elements of this ensemble from the sensor outputs. It exploits the fact that radiances measured by the sensor are correlated to the extinction of the solar radiation.

Other possible approach is the direct modeling, where the various optical processes occurring along the path of the light from the outer space towards the ground (molecular and aerosol scattering, gas absorption, ground reflection…) are modelled by the means of a radiative transfer model.

B. Principle of the Heliosat-2 method

The Heliosat-2 method is a well-known method of inverse type easy to implement and to operate. It is based on the general fact that the appearance of a cloud over a pixel results in an increase of reflectance in visible imagery. The principle is that the attenuation of the downwelling shortwave irradiance by the atmosphere over a pixel is determined by the magnitude of change between the reflectance that should be observed under a very clear sky and that currently observed [5, 6].

THE HELIOCLIM-3 DATABASE

This communication deals with the HelioClim-3 (HC-3) database. It contains SSI values with a step of 15 min for every pixel of Meteosat images since 2004. The pixel size is 3 km at nadir and increases towards the limits of the image.

This radiation database is an initiative of MINES ParisTech to increase knowledge on the SSI and to offer SSI values for any site, any instant over a large geographical area and long period of time, to a wide audience [1].

Meteosat images are received in near-real time every 15 min and are processed by the means of the Heliosat-2 method to yield 15-min SSI. These 15-min values are stored and further exploited on request. When necessary, summarization to hourly, daily, monthly and yearly values is performed on-the-fly.

A model has been developed to assess the uncertainty of the HC-3 estimates [7]. This information is provided with the SSI.

The process is fully automated and operational. The processing chain has been duplicated at MINES ParisTech and Transvalor to ensure reliability and meet requirements in delivery and quality of service expressed by customers. The two chains are under the responsibility of Transvalor. The current version is HC-3v3.

Additional processing is made on-the-fly on request to correct for differences in altitude between the mean elevation of the Meteosat pixel and the requested site [8] or to compute the direct and diffuse components of the SSI on an inclined surface using algorithms recommended by the European Solar Radiation Atlas [9].

PERFORMANCE OF THE HELIOCLIM-3 DATABASE

The 15 min and hourly values of HC-3 have been extensively validated against corresponding measurements made by pyranometers in meteorological networks or others. The results were exploited to derive the model for uncertainty. However, no article has yet been published on this validation, though the results for 29 sites -26 in Europe, one in the Middle East, one in North Africa, one in South Africa- are published on the SoDa Service (www.soda-is.com/eng/help/helioclim3_uncertainty_eng.html).

In average, comparison in hourly basis yields a correlation coefficient greater than 0.9, a relative root mean square error (rRMSE) around 20 % of the mean SSI measured at stations and a relative mean bias error (rMBE) below 2 %.

We present here a subset of these stations located in different solar climates [9, 10] for a more detailed discussion (Fig. 3). Their coordinates are given in Table 1; stations are organized from North to South.

Stations	***Latitude (°)***	***Longitude (°)***	***Altitude (m a.s.l.)***	***Country***
Toravere	58.25	26.47	70	Estonia
Hamburg	56.63	10.00	16	Germany
Camborne	50.22	-5.32	88	United Kingdom
Kishinev	47.00	28.82	205	Moldavia
Payerne	46.82	6.95	491	Switzerland
Agen	44.20	0.62	100	France
Carpentras	44.08	5.06	100	France
Sede Boqer	30.91	34.78	500	Israel
Tamanrasset	22.80	5.43	1378	Algeria
De Aar	-30.67	23.99	1287	South-Africa

Table 1. Ground-measuring stations used for comparison.

Statistics of comparison are shown in Table 2. One may note as a whole that there is no clear trend in bias or RMSE with latitude. RMSE is ranging from 70 W/m² to 90 W/m². With the exception of Payerne and Sede Boqer, the bias is positive (overestimation) and varies between 0 W/m² and 15 W/m². Correlation coefficient is always greater than 0.92. Good results are achieved for the two stations with elevation greater than 1000 m: Tamanrasset and De Aar.

This is a very satisfactory result which demonstrates the consistency in space of the quality of HC-3v3, taking into account the discrepancy expected because of the different natures of the compared data sets and the single pixel used in HC-3 for SSI estimates.

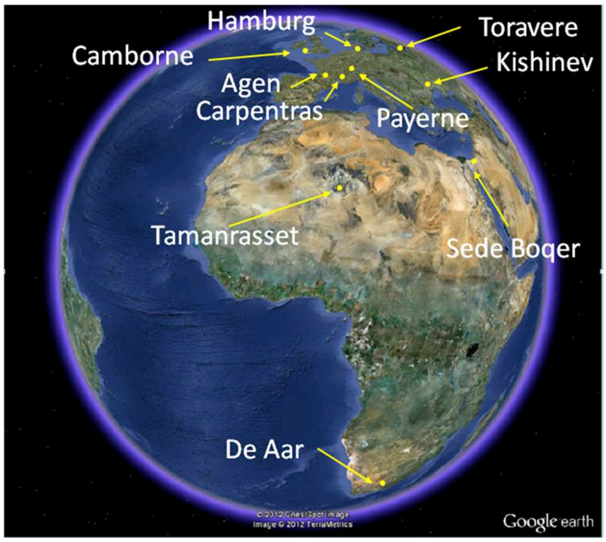

Fig. 3. Location of the 10 stations discussed here.

Stations	*Mean measured irradiance (W/m²)*	*Bias (W/m²)*	*Relative bias (%)*	*RMSE (W/m²)*	*relative RMSE*	*Correlation coefficient*
Toravere	305	1	0 %	87	29 %	0.9189
Hamburg	312	0	0 %	69	22 %	0.9465
Camborne	318	6	2 %	69	22 %	0.9541
Kishinev	362	8	2 %	76	21 %	0.956
Payerne	414	-31	-8 %	86	21 %	0.9502
Agen	363	6	2 %	68	19 %	0.9629
Carpentras	426	0	0 %	71	17 %	0.9661
Sede Boqer	540	-30	-6 %	70	13 %	0.9773
Tamanrasset	618	8	1 %	68	11 %	0.9764
De Aar	529	15	3 %	77	15 %	0.9706

Table 2. Comparison between HC-3v3 and ground-based measurements of hourly mean of SSI (in W/m²). RMSE: root mean square error. Relative values refer to the mean measured SSI.

Discrepancies observed for Payerne and Sede Boqer may have several explanations. We do not retain the possibility of calibration defects as a major cause because the stations are known to be well-attended and maintained. There are a number of parameters in the Heliosat-2 method that influence its quality [11, 12]. The ground albedo, the albedo of the brightest clouds, and the optical properties of the clear atmosphere are the most prominent. Ground albedo is difficult to assess [6] and we know that this was not done properly for Sede Boqer because of its complex topography. A correction factor has been implemented for this case and similar ones. This correction is not efficient enough to remove the bias. Another influence is the natural variability of the SSI in space and time. The larger the variability, the greater the chances of having a large discrepancy. This is the case in Payerne where fragmented cloud cover is often present. The small clouds cannot be seen in a Meteosat pixel and the entire pixel is believed to be cloudy. The SSI is often underestimated and the bias is negative and large.

DISSEMINATION

Creating a climatological database of SSI involves acquiring satellite images, processing these images and disseminating the estimated SSI.

The SoDa Service (www.soda-is.com) is the means to disseminate the HC-3 database. The SoDa Service is operational since 2003 [13] and is widely used by communities interested in solar radiation: there were approximately 40 000 unique visitors to the web site in 2011. The SoDa Service offers access to many resources: databases and applications in solar radiation. Transvalor is managing this community portal since 2009 and has established a helpdesk.

HC-3v3 data can be retrieved as time-series for a given site through a standard Internet browser or using machine-to-machine automated processes. Access is for pay, except for the whole year 2005. There are approximately 40 registered companies and approximately 2 millions of requests have been satisfied in 2011, not taking into account the requests made by MINES ParisTech or Transvalor for their own research and studies, including collaboration with other researchers and construction of maps. This demonstrates that HC-3 is filling a need and is a reward for the efforts made for almost two decades.

CONCLUSION AND PERSPECTIVES

The HelioClim-3 database provides accurate values of SSI for Africa, Europe, and the Atlantic Ocean. Comparison with measurements at ground level shows that HC-3v3 offers satisfactory results, in line with the most advanced similar databases. In average, comparison in hourly basis yields a correlation coefficient greater than 0.9, a relative root mean square error (rRMSE) around 20 % and a relative mean bias error (rMBE) below 2 %.

A service is currently developed for the European Commission for the provision of SSI under the GMES (Global Monitoring for Environment and Security) program. HC-3v3 and the SOLEMI database are the two databases currently offered by this service [14].

The availability of these time-series for virtually any location in the field-of-view of the Meteosat satellites should help any community interested in climate applications to perform steps towards a better knowledge of the SSI and its variation over recent years.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under Grant Agreement no. 218793 (MACC project) and no. 283576 (MACC-II project). We thank the World Radiation Data Center and the Baseline Surface Radiation Network for providing ground data.

REFERENCES

Blanc Ph., Gschwind B., Lefèvre M., Wald L., The HelioClim project: Surface solar irradiance data for climate applications. *Remote Sensing*, 3, 343-361, 2011; doi:10.3390/rs3020343.

Blanc, Ph., Gschwind, B., Lefèvre, M., Wald, L., 2011. Validating Meteosat-derived surface solar irradiance in Mozambique. In Proceedings of the 30th Symposium of the European Association of Remote Sensing Laboratories, Ed. Halounova L., held in Prague, Czech Republic, 30 May – 2 June 2011, A. A. Balkema Publisher.

Perez R., Seals R., Zelenka A. "Comparing satellite remote sensing and ground network measurements for the production of site/time specific irradiance data", *Solar Energy*, vol. 60, 1997, p. 89-96.

Zelenka A., Perez R., Seals R. and Renné D., "Effective accuracy of satellite-derived hourly irradiances", *Theoretical and Applied Climatology*, vol. 62, 1999, p. 199-207.

Raschke, E.; Gratzki, A.; Rieland, M. Estimates of global radiation at the ground from the reduced data sets of the International Satellite Cloud Climatology Project. *J. Climate* **1987**, *7*, 205-213.

Rigollier, C.; Lefèvre, M.; Wald, L. The method Heliosat-2 for deriving shortwave solar radiation from satellite images. *Solar Energy* **2004**, *77*, 159-169.

Wald L., Blanc Ph., Espinar B., Gschwind B., Lefevre M., Menard L., Wald F., Hoyer-Klick C., Schroedter-Homscheidt M., Thomas C., Early achievements towards an automatic assessment of the uncertainty in solar irradiation using web services. In Proceedings of the 25th EnviroInfo Conference 'Environmental Informatics', 5-7 October 2011, Ispra (VA), Italy. Pillman W., Schade S., Smits P. (Eds). Part 1, pp. 309-318. Publisher Shaker Verlag, Aachen, Germany, 2011.

Abdel Wahab M., El-Metwally M., Hassan R., Lefèvre M., Oumbe A., Wald L., Assessing surface solar irradiance in Northern Africa desert climate and its long-term variations from Meteosat images. *International Journal of Remote Sensing*, 2009, 31 (1), p. 261-280.

European solar radiation atlas, 2000, includ. CD-ROM. Edited by J. Greif, K. Scharmer. Scientific advisors: R. Dogniaux, J. K. Page. Authors: L. Wald, M. Albuisson, G. Czeplak, B. Bourges, R. Aguiar, H. Lund, A. Joukoff, U. Terzenbach, H. G. Beyer, E. P. Borisenko. Published for the Commission of the European Communities by Presses de l'Ecole, Ecole des Mines de Paris, France.

Diabaté L., Blanc Ph., Wald L., Solar radiation climate in Africa. Solar Energy, 76, 733-744, 2004.

Espinar, B.; Ramírez, L.; Polo, J.; Zarzalejo, L.F.; Wald, L. Analysis of the influences of uncertainties in input variables on the outcomes of the Heliosat-2 method. Solar Energy 2009, 83, 1731-1741.

Lefèvre, M.; Diabaté, L.; Wald, L. Using reduced data sets ISCCP-B2 from the Meteosat satellites to assess surface solar irradiance. *Solar Energy* **2007**, *81*, 240-253.

Gschwind, B.; Ménard, L.; Albuisson, M.; Wald, L. Converting a successful research project into a sustainable service: The case of the SoDa Web service. *Environ. Model. Softw*. **2006**, *21*, 1555-1561.

C. Hoyer-Klick, M. Lefèvre, A. Oumbe, M. Schroedter-Homscheidt, L. Wald. User's Guide to the SoDa and SOLEMI Services. Towards the "solar energy radiation resources MACC-RAD Service" 2010. Available at http://www.gmes-atmosphere.eu/documents/deliverables/r-rad/D_R-RAD_2.1_1.RAD.MACC.v1.0.pdf.