*Proceedings of Eurosun 2004, published by PSE GmbH, Freiburg, Germany, pp. (3) 916-920, 2004*

# HelioClim: a long-term database on solar radiation for Europe and Africa

*S. Cros, M. Albuisson, M. Lefèvre, C. Rigollier, L. Wald*
*Groupe Télédétection et Modélisation, Ecole des Mines de Paris, Sophia Antipolis, France*

ABSTRACT: An information system, called HelioClim, is available for answering the needs for long-term time-series of solar radiation data. Daily irradiation values are available over Europe, Africa and Atlantic Ocean, from 1985 onwards. This database is accessible through the Soda Web service (http://www.soda-is.com) on a free basis. Meteosat satellites images are used to produce this climatological database. The method Heliosat-2 converts these images into maps of the global irradiation at ground level. A comparison was performed between irradiation values available in HelioClim and those measured by ground stations in Europe. A measuring station is not necessarily contained within a B2 pixel and an interpolation method is needed. The root mean square error (RMSE) increases as the irradiation increases and is less than 850 Wh/m², that is a relative error of 20 %, a satisfactory result compared to what can be achieved using sparse pyranometric stations only.

## INTRODUCTION

Time series of solar radiation at ground level open the way to many applications for different users. Biomass production and crop forecast, oceanography and limnology applications, urban air quality studies, sizing of space borne sensors, solar energy engineering or even the optimization of daylight use in building applications, are among the various domains needing solar radiation information.

Researchers and engineers are facing the problem of solar radiation data retrieving on various parts of the world. Several studies assessed the user needs for solar radiation data (ESRA 2000). These needs consist generally in values of hourly or daily global irradiation and their derived quantities (diffuse component, spectral distribution, spatial structure of the radiation) for various part of the world. Accordingly, databases should be available that cover the whole earth surface for several years. These data should be available at high spatial resolution (about 10 km in size) with a relative accuracy less than 20 % in root mean square error (RMSE) for the daily irradiation. The data should present a convenient and low cost access. Even if several initiatives have been made to answer these requirements (Fontoynont *et al.,* 1998; Heidt *et al.,* 1998; Cros and Wald, 2003), there is still a discrepancy between users needs requirements and availability of solar radiation data (Cros *et al.*, 2002).

We propose an answer by building an integrated information system called HelioClim. It contains a database of global irradiation routinely estimated from a times-series of Meteosat images from 1985 onwards and software to exploit it.

This paper presents briefly the Heliosat-2 method, which converts satellite images into global irradiation maps. The method is applied to satellite images for the construction of a database of global irradiations. Comparisons are performed with ground measurements.

## THE METHOD HELIOSAT-2 FOR THE MAPPING OF THE SOLAR RADIATION

The Heliosat method converts observations made by meteorological satellites into estimates of the global irradiation at ground level. The principle of the method, as well as most current methods, is that a difference in global radiation perceived by the sensor aboard the satellite is only due to a change in apparent albedo, which is itself due to an increase of the radiation emitted by the atmosphere towards the sensor.

A key parameter is the cloud index *n*, resulting from a comparison of what is observed by the sensor to what should be observed over that pixel if the sky were clear, which is related to the "clearness" of the atmosphere. In principle, it can be written as:

$n^t(i,j) = [\rho^t(i,j) - \rho^t_g(i,j)] / [\rho^t_{cloud} - \rho^t_g(i,j))]$

where

- $r^t(i,j)$ is the reflectance, or apparent albedo, observed by the spaceborne sensor for the time $t$ and the pixel $(i, j)$: $r^t(i,j) = \frac{p L^t(i,j)}{I_{0met}\, e(t) \cos q_S(t,i,j)}$, where $L^t(i,j)$ is the observed radiance,
- $r^t_{cloud}(i,j)$ is the apparent albedo over the brightest clouds,
- and $r^t_g(i,j)$ is the apparent albedo over the ground under clear skies.

If the sky is clear, the apparent albedo $r^t(i,j)$ is close to the apparent albedo over the ground and the cloud index $n$ is close to 0 (possibly negative). If the sky is overcast, the cloud index $n$ is close to 1 (possibly larger). In brief, the cloud index $n$ may be considered as describing the attenuation of the atmosphere (1 minus the transmittance). Thus, the cloud index $n$ is a very convenient tool to exploit satellite images.

The basic principle is not always verified. Other parameters may intervene, such as multiple cloud layers and dramatic changes in the ground albedo due to the snowfall or the shadow created by a neighboring cloud. The change in sensor outputs is not necessarily linked to a change in the optical state of the atmosphere or a change in the optical state does not necessarily translate into a change in the cloud index.

The albedoes used in the above equation are constructed from a time-series of satellite images. The optical state of the clear sky is given by the clear-sky models of the European Solar Radiation Atlas (ESRA, 2000; Rigollier *et al.* 2000), in the form of the global irradiation and irradiance and its direct and diffuse components and the beam and diffuse transmittances. A key input to the ESRA models is the Linke turbidity factor. This factor provides a reasonable estimation for the water vapor and aerosols optical effects.

The cloud index $n$ is related to the global irradiation on an hourly basis by the means of the clear-sky index (the ratio of the observed irradiation to the irradiation that should be observed if the sky were clear for the same day) (Rigollier, Wald 1998). From these hourly irradiations, the daily irradiation can be constructed (Raschke *et al.* 1991).

Contrary to the original Heliosat method (Cano *et al.* 1986), the approach adopted for the assessment of the cloud index and, further, of the quantities $r_g$ and $r_{cloud}$, is based upon explicit formulations of the radiance and the transmittance. These formulations make use of the modeling of the clear sky radiation, thus offering a strong consistency. This explicit approach offers several advantages. It removes many empirical parameters, compared to the versions of the original method. It makes use of recognized expressions of the radiance and the transmittance. It permits to use known values of the albedo of specific objects, or to estimate such albedoes. Similarly to the method Heliosat-1, the approach does not behave satisfactorily for sun zenithal angles larger than 75 - 78°. Though applicable, it produces larger errors.

From an operational point of view, the method Heliosat-II requests the knowledge of the Linke turbidity factor and the elevation for each pixel of the Meteosat image to be processed. This study demonstrates *a posteriori* that the Linke turbidity factor is sufficient to describe the optical state of the clear atmosphere in the broadband of the satellites Meteosat.

## COMPARISON BETWEEN RETRIEVED VALUES AND STATION MEASUREMENTS

High resolution satellite images are not used for the construction of the solar climatology because of their high cost at the beginning of the project; they are less expensive or free now. Reduced resolution data in the ISCCP-B2 format are used instead. This format was set up in the framework of the International Satellite Cloud Climatology Project (ISCCP)

(Schiffer, Rossow, 1983, 1985) part of the World Climate Research. This set is derived from the operational Meteosat images, in both visible and thermal infrared bands. The B2 reduced resolution set is produced according to the following steps:

- first, a time sampling of geostationnary images reduces the frequency of observation to synoptic three hours intervals, starting at 0000 Universal Time (UT),
- second, the higher resolution visible channel data (images of 5000*5000 pixels) are averaged to match the lower resolution of infrared channel data. This gives an image of 2500*2500 pixels instead with a resolution of 5 km,
- third, overlapping image pixels are removed,
- fourth, spatial sampling of images is performed to reduce the apparent resolution to approximately 30 km at nadir by taking 1 pixel over 6 in each direction. The value of the corresponding B2 pixel is given by the radiance of the southeastern most pixel in a 6*6 pixels square.

The images B2 are formed by pixels that are effectively pixels of original size (i. e. 5 km) but with a sub-sampling of 6 in each direction. This means that a B2 pixel is not an average of say, 30 * 30 km$^2$, but is a pixel of 5 km in size, which represents an area of 30 km x 30 km (figure 4.1).

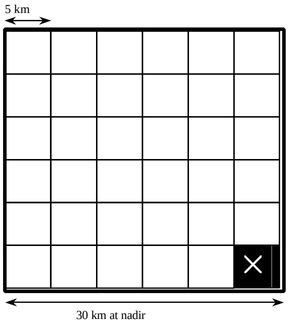

*Figure 1. Scheme showing the sub-sampling in the B2 format.*

A comparison between irradiation values retrieved by the processing of Meteosat B2 images and measured by ground stations is performed. Thirty-five stations from Europe were selected for the comparison, located in flat areas, in order to avoid the specific errors encountered in mountainous areas. These countries are Belgium, France, Germany, Hungary, Norway, Spain and United Kingdom. The meteorological offices provided global hourly irradiation values. These offices perform a screening for quality check. The formats and units were unified before comparison.

Only were used the measurements of hourly irradiation greater than 10 Wh m$^{-2}$. This value corresponds to the level of diffuse hourly irradiation for the sunset and sunrise under clear-sky at 60° N. For these hours of very low solar elevation, the measured irradiation is mainly of diffuse nature and is influenced by local conditions, including orography and the presence of nearby obstacles. By removing these values, we ensure better conditions for the validation process.

The satellite data are available every 3-hours, from July 1994 to June 1995. The satellite data were processed using the method Heliosat-2. Estimates of the global hourly irradiation were thus obtained. Only the estimates, for which the solar zenithal angle is lower than 78°, were kept for the comparison, as it has been said that the description of the physical processes is not valid below that limit. Three months were used for the comparison: January 1995, April 1995 and July 1994. From each data set of hourly irradiation, and for a given month, the daily irradiation was computed. The estimate is said valid if at least 2 hourly irradiations are used in the computation in January and April and 3 in July.

The comparisons present in this case an additional problem: a measuring station is not necessarily contained within a B2 pixel. An interpolation method is requested to estimate locally the irradiation from irradiations computed at the surrounding B2 pixels. A comparison between several methods was performed by Iehle *et al.* (1997) and they recommended the nearest-neighbor technique. The results strongly depend upon the relevance of the selected technique to the local spatial properties of the irradiation. The smoother the field, the better the assessment by the nearest-neighbor technique. In case of high spatial variations, the technique will be inappropriate as most of the standard ones. Given the properties of the areas under concern this work, the results should be regarded as the typical accuracy that can be achieved. Lower accuracy will be find in cases of large variations in orography or juxtaposition of local climate.

Given the two time-series, and for all stations together, we compute the difference (measured - estimated) in several ways for daily irradiation for a given month, for all the days, and for the monthly mean of daily irradiation. For each parameter, the differences have been computed and are summarized in the Table 1.

| Information type | Month | Mean value | Bias | RMSE | Correlation coefficient | Nb. of obs. |
|---|---|---|---|---|---|---|
| Daily irradiation | Jan 95 | 984 | -7 (-1%) | 291 (30%) | 0.89 | 345 |
| | Apr 95 | 3401 | 245 (7%) | 730 (21%) | 0.91 | 1044 |
| | Jul 94 | 5797 | 237 (4%) | 852 (15%) | 0.86 | 954 |
| Monthly mean of daily irradiation | Jan 95 | 892 | -99 (-11%) | 225 (25%) | 0.85 | 19 |
| | Apr 95 | 3402 | 241 (7%) | 350 (10%) | 0.92 | 35 |
| | Jul 94 | 5792 | 250 (4%) | 399 (7%) | 0.86 | 34 |

*Table 1 Differences between measured and estimated values in Wh m$^{-2}$ for B2 images.*

The correlation coefficient is high in all cases, from 0.85 to 0.92. The bias is negative (overestimation) in January and positive for April and July (underestimation). It is less than 250 Whm$^{-2}$ in absolute value, i.e. less than 7% in relative value. The high relative value of the bias for the monthly mean of daily irradiation for January is believed to be caused by the low number of samples (19), since by definition, the bias should be equal for daily irradiation and for the monthly mean. The RMSE (root mean square error) increases as the irradiation increases. It is larger for the daily irradiation than for the monthly mean. For daily values, it amounts to 852 Wh m$^{-2}$ in July, i.e. 15% of the mean daily irradiation. The RMSE for monthly mean is smaller and the maximum is 399 Wh m$^{-2}$ in July, i.e. 7%.

## CONCLUSION

These results demonstrate clearly that the method Heliosat-2 may apply to the images in B2 format with a satisfactory accuracy. The B2 images may even be used to assess the hourly irradiation. However, given the poor sampling in time of these images, it may be recommended to limit their use to the assessment of daily irradiation or to the irradiation for larger periods. Even with their low resolution in time and in space, B2 images are able to provide useful information to create a solar climatological database. The HelioClim project has already produced more than eighteen years time series of solar irradiation maps of Europe, Africa and Atlantic ocean, starting from 1985. This constitutes a unique database in that type of solar information. The database can be accessed through the SoDa web service: http://www.soda-is.com.

## REFERENCES

Cano D., Monget J.M., Albuisson M., Guillard H., Regas N., and Wald L., 1986, A method for the determination of the global solar radiation from meteorological satellite data, *Solar Energy*, **37**, 31-39.

ESRA, *European solar radiation atlas*, 2000. Fourth edition, 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, Paris, France.

Iehlé A., Lefèvre M., Bauer O., Martinoli M., and Wald L., 1997, Meteosat: A valuable tool for agro-meteorology, Final report for the European Commission, Joint Research Centre, Ispra, Italy.

Rigollier C., Wald L.,1998, Towards operational mapping of solar radiation from Meteosat images, *In* Proceedings of the EARSeL conference: Operational remote sensing for sustainable development, May 11-14 1998, Enschede, The Netherlands.

Rigollier C., Bauer O., Wald L., 2000, On the clear sky model of the 4th European Solar Radiation Atlas with respect to the Heliosat method, *Solar Energy*, **68** (1), 33-48.

Schiffer, R.A. and Rossow, W.B., 1983, The International Satellite Cloud Climatology Project (ISCCP): The first project of the World Climate Research Programme. *Bulletin American Meteorological Society*, 64, 779-784.

Schiffer, R.A. and Rossow, W.B., 1985, ISCCP global radiance data set: A new resource for climate research. *Bulletin American Meteorological Society*, 66, 1498-1503.

Cros S., Wald L., 2003, Survey of the main databases providing solar radiation data at ground level*. In Proceedings of the 23rd EARSeL Symposium*, Ghent, Belgium, 2-4 June 2003.

Cros S., Wald L., Mayer D., 2002, The availability of irradiation data, presented at Energy International Agency, Task II - Operational Performances of PV systems, Wien, Austria, September 2002. Revised Version, October 2003.

Fontoynont M., Dumortier D., Heinemann D., Hammer A., Olseth J., Skartveit A., Ineichen P., Reise C., Page J., Roche L., Beyer H.G., Wald L., 1998, Satel-Light: a WWW server which provides high quality daylight and solar radiation data for Western and Central Europe, *In Proceedings of the 9th Conference on Satellite Meteorology and Oceanography*. Published by Eumetsat, Darmstadt, Germany, EUM P 22, 434-435. http://www.satellight.com

Heidt F.D., Teichmann C., Büchler P., Schulze-Kegel D., 1998, Satellite-based solar radiation data go Internet*, In Proceedings of the second ISES-Europe Solar Congress*, EuroSun'98.

Raschke E., Stuhlmann R., Palz W., Steemers T.C., 1991, Solar Radiation Atlas of Africa, A. Balkema, Rotterdam, The Netherlands, 155 p.