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Developing a database using METEOSAT data for the delivery of solar radiation assessments at ground level

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ABSTRACT: An information system, called HelioClim, is offered for answering the needs for long-term time-series of solar radiation data. These data originate from the processing of spaceborne observations made in the visible range by geostationary satellites to derive solar radiation available at ground level. The recent method Heliosat 2 is used. It offers several improvements in operation and accuracy with respect to previous methods. Typical bias for irradiance for a month is 3 W m^{-2} . A database is being produced, covering the Eastern Atlantic Ocean, Europe and Africa from 1985 onwards and for each day. This database is accessible through the SoDa service on a free basis (<http://www.soda-is.com>).

1 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 (Fontoynt *et al.*, 1998;

Heidt *et al.*, 1998; Cros and Wald, 2003), there is still a discrepancy between user needs requirements and availability of solar radiation data (Wald and Mayer, 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 a software to exploit it.

This paper presents briefly the Heliosat-2 method, which converts satellite images into global irradiation maps. It then presents the climatological database building. Finally, we describe the exploitation software of that database.

2 SOLAR RADIATION MAPPING FROM SATELLITE IMAGES: THE HELIOSAT-2 METHOD

Once properly processed, such Meteosat images can produce maps of solar radiation which are more accurate than those obtained from interpolation of measurements of radiation made at ground level (Perez *et al.*, 1997; Zelenka *et al.* 1999). Several methods are available for this processing. When

operated on a routine basis, many of them exhibit several drawbacks, one of them being the poor accuracy in irradiance (Rigollier and Wald, 1999a).

A new method, called Heliosat-2, has been designed that is capable of processing long time-series of images acquired by the series of sensors aboard the Meteosat satellites. The method is using the same principle than several methods of proven quality (Pastre, 1981; Möser and Raschke, 1983, 1984; Cano *et al.* 1986; Diabaté *et al.* 1988; Beyer *et al.*, 1996; Stuhlmann *et al.*, 1990; Delorme *et al.* 1992). With respect to these methods, Heliosat-2 offers several improvements in operation and accuracy. These improvements are due to several causes.

Main improvement is due to an accurate calibration of the Meteosat data to convert them into radiances and reflectances. More physical description of the optical processes was made possible by the calibration step; known proven models are implemented in the method. The will-proven ESRA model describing the irradiation under clear-skies is used (Rigollier *et al.* 1999; Geiger *et al.* 2002). The optical effects of the atmosphere are modeled by the Linke turbidity factor. We use a new database of monthly values of the atmospheric optical turbidity for clear skies available on cells of 5' of arc angle in size at SoDa web site: <http://www.soda-is.com> (Lefèvre *et al.* 2003; Remund *et al.* 2003). We use terrain elevation TerrainBase (NGDC-NOAA). The model for the irradiation under heavily covered skies calls upon climatological knowledge (Rigollier and Wald, 1999b). Observations of Taylor and Stowe (1984) were used to model the spatial distribution of radiances of the very thick clouds. Changes in ocean albedo due to sun glitter are taken into account.

We made comparisons between satellite-derived assessments and measurements performed in the world radiation network in Europe and Africa. The results depend upon several parameters; the type of data (high-resolution or B2 format) and the number of pixels whose values are averaged for the comparison with the irradiation measurements.

As for the high-resolution data, assessments were compared to observations made by 60 stations in Europe for one year. The bias and root mean square error (RMSE) for the assessment of the irradiance for a month are equal to respectively 2 and 11 $W m^{-2}$ on cells of 5' of arc angle in size (approx. 10 km at mid-latitude). The RMSE may decrease down to 4 $W m^{-2}$ if assessments are averaged over cells of 0.5° of arc angle.

3 DESIGN AND BUILDING OF HELIOCLIM

3.1 The B2 format

The processing of satellite data may prove to be very time and memory consuming; depending upon the

provider, the costs for purchasing data may also be important. Eumetsat agreed to provide us Meteosat images in the reduced resolution ISCCP-B2 (Schiffer and Rossow, 1983, 1985) format from 1985 up to now. Spatial support information of these B2 images is a pixel of 10 km in size available every 60 km in each direction (figure 1).

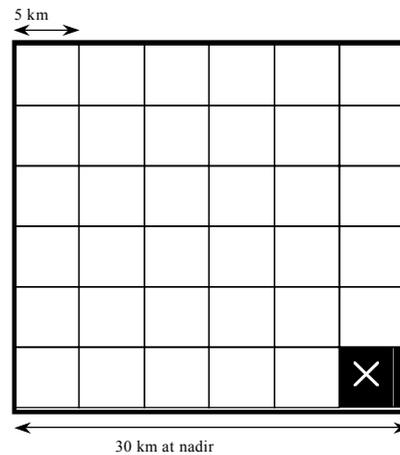


Figure 1. Scheme showing the sub-sampling in the B2 format.

Such images are available every 3 hours. These images cover one third of the earth, including Europe, Africa and Atlantic Ocean (figure 2).

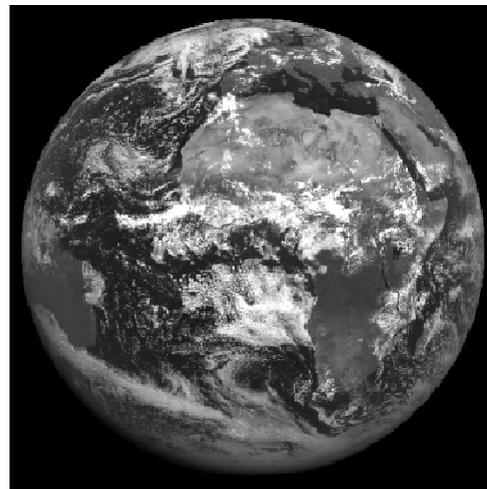


Figure 2: B2 format image

Satellite-derived assessments performed from B2 images give worse results. Comparisons were performed using 60 stations in Europe and 30 stations in Africa for the same year. The bias and RMSE are better than respectively 3 and 17 $W m^{-2}$ for one month and a cell of 5'. The RMSE decreases to 9 $W m^{-2}$ for cells of 0.5° in size.

3.2 Design of the database

From 1985 up to now, the time-series of images represents about 6 billions of values to be processed

by Heliosat-2 and they must be stored in an appropriate database. Pixels outside of the earth images and unusable for the processing are rejected; there remains approximately 118 500 pixels per image. This number may be compared to the 70 sites offering daily values for a period of similar duration that are available for Europe (ESRA 2000) and the 30 stations in Africa with daily values for more than four years available through the WMO World Radiation Data Center (WRDC).

An important aspect of the requirements is that the large majority of customers requested time-series for a specific location and not time-series of gridded (maps) values. We decided to discard the image structure and to shape the database to facilitate the search for time-series for a given location. The requested location is usually not a B2-pixel. It follows that answering a request needs the extraction of time-series of the nine neighbourhood B2-pixels and the interpolation of each daily value.

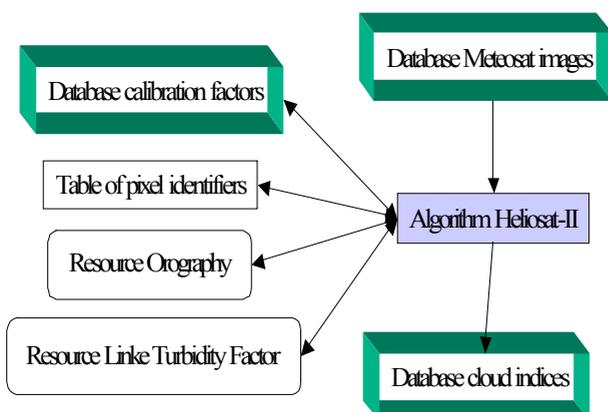
The cloud index (Cano *et al.* 1986) has been selected to be stored into the database. This value ranges from -0.2 to 1.1. It is a convenient value to compute global irradiation. It can be included in a byte. This value is stored with the number of the slot associated, which needs one more byte. Finally, one year of solar data is stored in a file of one gigabyte. These files are in a binary format. Each record is identified by a number comprised between 1 and 118500 called "pixel identifier" and each field corresponds to the julian day of the year (figure 3).

Pixel identifiers	Julian days				
	1	2	3	...	366
1	<i>For each slot (cloud index, slot number value)</i>				
2					
3					
...					
...					
118500					

Figure 3: Scheme of a yearly file of data, each couple of values (slot, cloud index) is stored in a cell identifiable by the pixel identifier and the julian day

3.3 Building of data files

B2 images were quality-controlled by visual inspection for geometrical superimposition, for radiometric defects (the so-called "fishes") and any other aspects. Then an automatic process performs the first steps of the Heliosat-2 method and converts the



Meteosat images into cloud index images. These temporary images feed the cloud index database. It performs on a series of images contained in a given directory.

Figure 4: Operational scheme of the cloud indices database building

The image files were named in such a way that the name contains all information that is necessary for the processing, namely instant of acquisition by the sensor. For each image, there is a request to the database of the calibration coefficients through a call to the server www.helioclim.net. Heliosat-2 algorithm needs values of the Linke turbidity factor and the orography. The software calls also these databases through the SoDa server. Figure 2 recapitulates the process of the cloud indices storage.

4 EXPLOITATION OF THE DATABASE

To exploit this database and answer user request, an exploitation software was devised that executes itself quickly. It is triggered by a request send by the SoDa intelligent system (SoDa-IS, Wald *et al.* 2002). The customer connects to the web server SoDa and the SoDa-IS builds automatically the interface appearing in the standard browser. The SoDa-IS transmits geographical coordinates and time period selected to the exploitation software via the HelioClim server. This software extracts the cloud index value from the 9 nearest pixels around the desired location, computes the irradiation for these 9 pixels by calling resources necessary for Heliosat-2: the ground elevation and the turbidity of Linke.

Inputs	Outputs
Latitude	Daily irradiation
Longitude	Irradiance over a day
Year	Daily broadband atmospheric transmittance (clearness index)
Month1	Monthly mean of daily irradiation
Month2	Irradiance over a month
	5-day sum of daily irradiation
	10-day sum of daily irradiation
	Monthly sum of daily irradiation

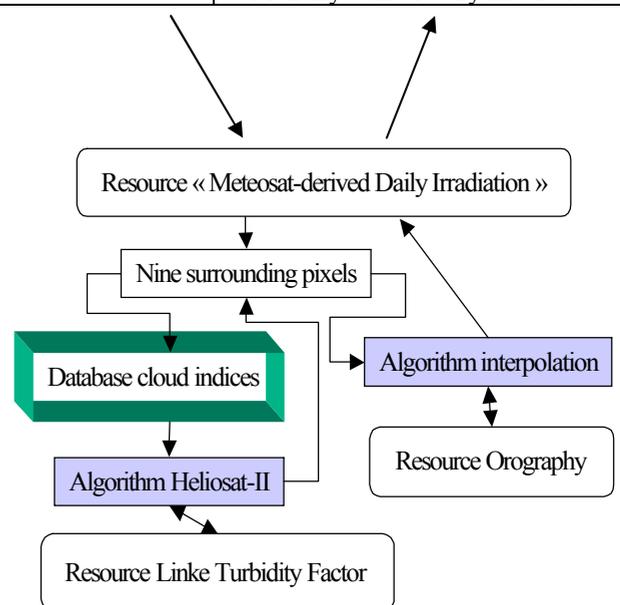


Figure 5: Scheme of the database exploitation

These data are available through the SoDa server (Wald 2000). Then, the software proceeds to a spatial interpolation (Lefèvre *et al.* 2002) for each instant and constructs the resulting time-series. Figure 5 presents the exploitation scheme.

Outputs are various values of the irradiation (daily sum, monthly mean, 5-day sum of daily irradiation, 10-day sum of daily irradiation, monthly sum...). These values are then XML encoded and sent to the SoDa-IS for delivery to the customers.

5 CONCLUSION

We built a database and its software exploitation. This database gives solar data covering Europe, Africa and Atlantic Ocean from 1985 onwards with a resolution of 5 minutes of arc angle (about 10 km at mid-latitude). These data are available on a free basis via the SoDa server. Validation was performed by comparing the outputs of the SoDa server to ground measurements for one year. The bias and the relative RMSE are respectively 3 and 17 W.m^{-2} for the irradiance over one month. Efforts are underway for a validation over a period of 12 years for sites in Europe and Africa.

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