Introducing the Solar Radiation Atlas of Galicia, the ultimate resource to assess and exploit solar radiation in Galicia (NW Spain)

A. Pettazzi, S. Salsón

MeteoGalicia, Galician Weather Service

Consellería de Medio Ambiente, Territorio e Infraestruturas - Xunta de Galicia

Rúa Roma, nº 6 - 15707 Santiago de Compostela (Spain)

Phone/Fax number:+0034 881 999646, e-mail: alberto.pettazzi@meteogalicia.es, santiago.salson@meteogalicia.es

Abstract. The need to exploit the solar resource properly leads to the creation of easy-to use tools, such as maps, that must estimate the incoming solar radiation with the highest accuracy and reliability. State of the art technologies – including meteorological satellites, advanced software and high precision pyranometers – allows estimating the solar resource with high precision and accuracy, taking into account not only the climatic features of a region, but also its topography.

This work collects, for the first time, a highly detailed analysis of the solar radiation in Galicia (NW Spain), using 23 years long series of satellite data put side by side with in situ measurements distributed all across the region. Insolation maps and other derived products (cloud cover, clearness index and sunshine hours) are going to be distributed for free to anyone interested in.

Key words

Solar Atlas, satellite measurements, Geographical Information Systems, solar climatology, Spain

1. Introduction

Solar energy represents the main source of renewable energy available on Earth. Despite of its abundance, exploiting the solar resource is conditional on technology, geographical features and on the climate of a region. All these reasons make mandatory the knowledge of the amount of the solar energy as well as its spatial and temporal distribution.

The need to take proper advantage of solar energy lead to the creation of easy-to use tools, such as maps, that allow quick yet precise estimation of the parameters that affect solar exploitation systems. Recently, the rapid growth of Geographic Information Systems (GIS), made this tasks easier.

In literature, several works dealing with the estimation of the solar resource may be found. At European scale, the first Solar Radiation Atlas remounts to 1979. Currently, the reference is represented by the ESRA (European Solar Radiation Atlas) that provides solar radiation maps obtained by interpolation/extrapolation techniques. For Spain, the official reference is a 28 years old mapset derived from ground based measurements [1]. At regional scale, a previous work was carried out, deriving surface insolation from Meteosat MSG-1 images for the period 2002-2004 [2]. To achieve that, satellite data were calibrated against one pyranometer and validated against another one located in two different points of Galicia, extending the results for a 30 000 km² area. Although [2] estimated for the first time the solar radiation in this region, it showed some limitations. First, the time span considered, 3 years, is too short to draw conclusion at climatologic scale. Moreover, the calibration and the validation sets, made up by only one pyranometer each, are far too small to reproduce the real pattern of the insolation.

Taking as reference these and more works found in literature, this study pretends to apply them in Galicia. Concretely, satellite data over a 23 years period were analysed as well as the measurements from 28 ground based pyranometers located all over the region. Those measurements, together with GIS tools, are intended to provide the most reliable and complete data set of solar radiation in Galicia

2. Contents of the Atlas

The Atlas provides different mapsets, monthly and annual averages, of several parameters dealing with solar radiation. In addition to the graphical products, maps are

also provided in digital format (Geotiff) for quantitative use of the products.

Products offered are:

A. Potential Insolation and sunshine hours maps

These maps were computed by GIS GRASS module *r.sun*, taking as inputs climatic values of albedo, atmospheric turbidity and a Digital Terrain Model (DTM; resolution: 270 m). Monthly averaged albedo data proceed from Climate Monitoring Satellite Application Facility (www.cmsaf.eu) and cover the period 2005-2009 with 15 km resolution. Atmospheric turbidity is provided by the Linke Turbidity coefficient TL collected from the Helioclim project (www.helioclim.org), covering the period 1954-2001 at 5 km resolution. The maps of potential insolation and sunshine hours provide information about the maximum theoretical values permitted by the complex Galician topography.

B. Climatic Insolation maps

Obtained from Meteosat satellites (time span: 1985-2008). Insolation values provided by satellite were calibrated and validated against two different data sets made up by 14 pyranometers each located all over Galicia

C. Potential Insolation maps coupled with satellite cloud cover estimations

This product combines the results of climatic insolation maps with a DTM. Maps show the effect of the climatic features (clouds, haze, turbidity, ...) that modulate the solar radiation over the Galician topography.

D. Climatic Clearness Index maps

Obtained from climatic Insolation maps and clear sky model. Clearness Index, K_T , defined as the fraction of extraterrestrial radiation that reaches the ground, is a parameter that indicates not only the availability of the solar resource, but also the variability of the atmospheric conditions in a particular place.

E. Fractional cloud cover maps

Obtained from satellite images (time span: 2005-2009). These data were provided by Climate Monitoring Satellite Application Facility (www.cmsaf.eu/) and represent a joint effort of the Finnish, Swedish, Swiss, Belgian, German and Dutch meteorological services.

3. Products overview

Figures 1-6 illustrate the annual values of the products this Atlas provides; the monthly maps are available in the complete version of the Atlas. Depending on the product, different calibrations and/or validation processes have been carried out, using two specific data sets (Fig. 7). A brief description of the methodology is reported in each section.

Uncertainties analysis (Mean Biased Error, Mean Absolute Error and Root Mean Squared Error) was also performed.

A. Potential Insolation and sunshine hours maps

Fig. 1 shows the annual average of the potential (clear sky conditions) insolation over Galicia as estimated by the *r.sun* module. Those results have been validated, for cloudless days only, against the pyranometer included in the validation set. Table I resumes the results, annually averaged. Additional information may be found in [3]. The results point out the high accuracy achieved by the maps; the clearer is the day (free from local haze), the better are the estimations. As expected, this product is not only influenced by latitude, but also turbidity and topography play an essential role in modulating the radiation. For these reasons, Rias Baixas region (SW of Galicia) receives more radiation than the inland, located at the same latitude, due to clearer atmospheric conditions. Topography plays also an important role, since north faces receive less radiation than the south ones, fact that can be hardly noticed from satellites.

Fig. 1. Global Insolation for cloudless sky conditions [kWh m⁻² d⁻¹] – Annual average

Table I. – Validation of the products included in the Atlas. Annual averages

Product	MBE [%]	MAE [%]	RMSE [%]
Potential Insolation	0.26	5.55	6.57
Calibrated Satellite	-1.47	5.9	7.54
Sat. and Topography	-1.91	8.09	9.92
Previous Atlas	0.49	9.35	10.96

Fig. 2 depicts the annual average of the theoretical sunshine hours. The product only relies on topography, latitude and astronomical relationships, so it has been validated only visually. As expected, the less sunlit zones are the north faces and the canyons.

Fig. 2. Sunshine hours for cloudless sky conditions – Annual average

B. Climatic Insolation maps

The annual average of the insolation estimated by the Meteosat Satellites is shown in Fig. 3. Satellite data have been calibrated against 14 pyranometers. The calibration process included different interpolation techniques, such as splines, Kriging and residuals. The monthly maps have been validated against the corresponding data set; the results are reported in Table I.

As expected, merging satellite data with ground measurements improves the accuracy of the satellite estimations. Analysing the monthly trends of insolation, maximum values are found in July and minima in December.

Moreover, the latitude effect is modulated by topography and climate. The former, cause high irradiation values on the mountains and low values in valley and canyons. In addition, a clean and cloud free atmosphere is responsible for the high values recorded in the Rias Baixas region. On the contrary, clouds and local haze causes the low values of insolation that characterize the northern zone of Galicia. This effect is more evident during the summer months. More details may be found in [4].

Table I also includes the comparison between the present Atlas and the previous one [2]. It is clear the improvement of the accuracy provided by the present Solar Radiation Atlas of Galicia.

Fig. 3. Global Insolation [$\text{kWh m}^{-2} \text{d}^{-1}$] estimated by satellite and calibrated with ground measurements– Annual average

C. Potential Insolation maps coupled with satellite cloud cover estimations

Fig. 4 illustrates the annual average of insolation obtained by the r.sun module taking into account the cloud cover. In order to input the cloud cover into r.sun, a scaling factor had to be created. This parameter, called Clear Sky Index is defined as the ratio between ground and clear sky insolation. In this case, the ground insolation is the one estimated by satellite and calibrated with ground stations. The clear sky insolation is estimated by r.sun at 5 km resolution, in order to match the resolution of the satellite data.

As for the other products, the results achieved were compared against the validation set; Table I illustrates the annual averages. More details may be found in [3].

From Table I it may be noticed that also these maps show good accuracy in estimating the solar radiation in Galicia. As expected, the results are worse than the calibrated satellite data set since the r.sun module drags the uncertainties associated with the module itself plus the errors of the satellite-pyranometers data. Anyway, the good accuracy achieved points out the reliability of r.sun in estimating the insolation at high resolution even for overcast conditions.

D. Climatic Clearness Index maps and Fractional cloud cover maps

Fig. 5 and Fig. 6 depict the annual average of the monthly maps of Clearness Index and Cloud Cover Fraction, respectively. Due to the lack of similar data sets, these results could not be validated quantitatively.

Anyway, it can be stated that both products reflect the reality since they reflect the same pattern of the other products.

Fig. 4. Global Insolation on DTM[kWh m-2 d-1] for overcast conditions – Annual average

Fig. 5. Clearness Index – Annual average

4. Conclusions

The present Atlas was born with the purpose of providing the very up-to-date dataset parameters related to solar radiation for Galicia. Thus, monthly and annual maps were elaborated. This task has been carried out by means of

satellite products, ground based measurements and GIS tools.

Considering the entire set of products, it may be stated that they all reflect the same pattern, pointing out how topography and climate modulate the latitude effect. For these reasons, the highest values of insolation are recorded in the south western edge of Galicia (Rias Baixas), whereas the lowest ones are found in the northern edge.

Fig. 6. Cloud Fraction – Annual average

Fig. 7. Location of the calibration (red) and validation (blue) sets

Results also show the good accuracy achieved by the entire set of products. In particular, it has to be pointed

out the importance of calibrating the satellite estimations with ground measurements. With respect to previous studies, the maps presented in this work represent a noticeable improvement in the knowledge of the parameters related to solar radiation in Galicia.

The Maps presented in this work, together with the monthly data sets, the detailed calibration and validation processes are included in the Solar Radiation Atlas of Galicia, published by the Xunta de Galicia, and available free of charge at <http://meteogalicia.es/observacion/atlasrs/atlasrsIndex.action>. The maps are also offered in digital format, allowing companies and researchers to improve the development of renewable energies, solar resource in particular, in Galicia.

References

- [1] Font Tullot I. (1984). Atlas de la radiación solar en España. Instituto Nacional de Meteorología, Ministerio de Transportes, Turismo y Comunicaciones. Madrid
- [2] Vázquez Vázquez M., Santos Navarro J. M., Prado Cerqueira M. T., Vázquez Ríos D., Rodrigues Fernandes F. M. (2005). Atlas de radiación solar de Galicia. Universidad de Vigo
- [3] Pettazzi A., Salsón S. (2012). Coupling digital terrain to radiative transfer model to assess surface solar radiation at high resolution scale: validation of GIS module r.sun in Galicia. International Conference on Renewable Energies and Power Quality (ICREPQ'12). Santiago de Compostela (Spain), 28th to 30th March, 2012
- [4] Pettazzi A., Salsón S. (2012). Merging remote sensing data with in-situ measurements of global solar radiation: the right path to estimate the solar resource in Galicia. International Conference on Renewable Energies and Power Quality (ICREPQ'12). Santiago de Compostela (Spain), 28th to 30th March, 2012