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Coupling digital terrain to radiative transfer model to assess surface solar radiation at high resolution scale: validation of GIS module r.sun in Galicia

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Abstract. When estimating solar radiation at regional scale, topography plays a very important role as it modifies radically the spatial distribution of insolation. For this reason, radiative transfer models need to be coupled to a digital terrain model. This work pretend to validate one of the most outstanding GIS tools with the complex Galician topography. Several data proceeding from different satellites were used as inputs. The accuracy of r.sun module was tested for both cloudless and overcast conditions. The results achieved point out the good accuracy of r.sun, especially under clear skies.

Key words

Radiative Transfer Model, remote sensing, Geographical Information Systems, solar climatology

1. Introduction

Solar radiation incident on the Earth's surface is the result of several interactions between the incoming energy and atmosphere and surface. At global scale, the latitudinal gradients are caused by the geometry of the planet and by astronomical relationships. At local scale, topography is the most important factor in modifying the spatial distribution of insolation. Variability in elevation, slope and orientation of the surfaces create strong gradients. Accurate and spatially distributed solar radiation data are needed for various applications, such as climatology, building design and photovoltaics.

In literature, different approaches to evaluate and assess the effect of topography on the incoming solar radiation may be found. Among them, the GRASS module r.sun [1] stands out for its capabilities and for its open source concept.

Taking as reference several works found in literature [2], [3], this study pretends to apply them in order to verify, for the first time ever, the precision and reliability of r.sun in Galicia (NW Spain). Using as input a high resolution Digital Terrain Model (DTM) and climatologic data proceeding from satellite measurements, an accurate validation of r.sun has been carried out for both cloudless and overcast sky conditions.

2. Analysis tools

A. GIS package GRASS

Maps are generated by GIS package GRASS (http://grass.fbk.eu). Among the utilities included in this software, r.sun module stands out for its relevance in helping estimate solar radiation. This module allows calculating the reflected, diffuse and direct components of irradiance. These parameters, as well as the sunshine hours, are computed taking into account the topography of the region. To achieve this goal, a clear-sky radiative transfer model (RTM) is used.
r.sun provide instantaneous and daily values, depending on the user's requests. The inputs needed are, albedo, Linke turbidity coefficient TL and a DTM.
Despite of using a clear sky model, estimations of solar radiation under overcast conditions are also possible, provided that information about cloud cover is available.

B. Satellite ancillary data

Surface albedo data are provided by the Climate Monitoring Satellite Application Facility (www.cmsaf.eu) as monthly averages for the period 2005-2009. Those data have 15 km resolution and are derived from the NOAA, METOP and MSG satellites. Meteosat Second Generation High Resolution Visible channel was also used to detect clear sky days over Galicia to validate r.sun module under cloudless conditions.

Monthly values of Linke turbidity coefficient proceed from the Helioclim project (www.helioclim.org). Those data, originally proceeding from in-situ measurements and satellites, have been obtained through different interpolation techniques, have 5 km resolution and cover the period 1954-2001.

C. Insolation data derived from satellite and ground measurements

Previously derived [4] monthly averages of insolation from satellite images and calibrated with ground based pyranometers were also used. Satellite data have a time span of 23 years and the set of ground measurements is made up by 28 pyranometers located all over Galicia. Those data were used as input for r.sun to take into account the effect of clouds. Insolation values from ground measurements were also used to validate the r.sun outputs.

3. Methodology

Products generated using RTM coupled with DTM are the following:

A. Maps for cloudless conditions

Monthly maps of global insolation and sunshine hours were generated to estimate the maximum values these parameters can reach in Galicia. To achieve that, r.sun was executed for each day of the year and then the monthly values were obtained. A 270 m resolution DTM was used. In order to take into account the turbidity of the atmosphere, monthly values of Linke turbidity coefficient TL were used. In particular, TL values were collected in 70 locations of Galicia, corresponding to interesting climatic places. Those values were normalized at sea level, then interpolated by splines techniques and finally corrected by the altitude of the sites. Finally, monthly maps of TL were obtained.

B. Maps for overcast conditions

Monthly maps were generated taking into account the cloud effect on insolation derived from calibrated satellite data [4]. A clear sky index, Kc, has been 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. The values of Kc were used as correction factor for the clear sky model.

4. Results

A. Maps for cloudless conditions

The accuracy of r.sun module has been tested against 15 cloudless days observed in Galicia by Meteosat High Resolution Visible channel. The results obtained by r.sun were compared to ground based pyranometers located all over Galicia. The validation of the model has been carried out by statistical analysis of Mean Biased Error (MBE), Mean Absolute Error (MAE) and Root Mean Squared Error (RMSE). Results are shown in Table I:

Table I. – Temporal validation of r.sun module for clear sky conditions

Date	MBE [%]	MAE [%]	RMSE [%]
01/05/2009	1.06	5.67	6.24
02/05/2009	0.91	5.92	6.13
05/05/2009	-1.22	5.08	5.49
30/05/2009	-0.81	3.89	4.48
31/05/2009	-2.89	3.35	4.59
01/06/2009	-3.51	4.01	4.72
21/06/2009	-3.94	3.98	4.84
11/08/2009	1.85	4.31	5.29
14/08/2009	4.33	5.91	6.79
22/08/2009	2.54	4.3	5.11
29/08/2009	0.71	4.62	5.31
05/09/2009	2.91	6.16	7.77
25/09/2009	5.34	8.91	10.88
14/10/2009	0.08	8.52	10.11
16/10/2009	-3.44	9.56	10.84
AVG	**0.26**	**5.55**	**6.57**

Table I points out the high accuracy of the estimations made by r.sun for cloudless days. The estimation is better from June to September, probably due to the minor presence of local haze, not detected by the satellite.

Fig. 1 illustrates the annual distribution of the theoretical insolation in Galicia estimated by r.sun. The latitude effect can be easily noticed, as the insolation grows southwards. It must be pointed out that, at the same latitudes, the Rias Baixas zone, in the southwest, receives more radiation than the interior. This is due to the atmospheric climatology, characterized by a clearer atmosphere (low TL) in the Rias Baixas.

Figure 1 also points out how the Galician topography affects the received insolation: as expected, the north faces receive less radiation than the south ones. This feature is even more evident during wintertime (Fig. 6), when the sun is low on the horizon. This is due to the fact that in wintertime the sun hits less the north faces and hits the south faces more perpendicularly.

The annual estimation of the sunshine hours is represented in Fig. 2. Even though the latitudinal effect is not so evident, topography still plays a key role in modulating the amount of sunshine hours in Galicia; thus north faces and canyons are zones poorly hit by the sun. In this case, no validation has been carried out, since the distribution of the sunshine hours only depends on astronomical relationships and topography. Anyway, the results obtained seem to agree with both factors.

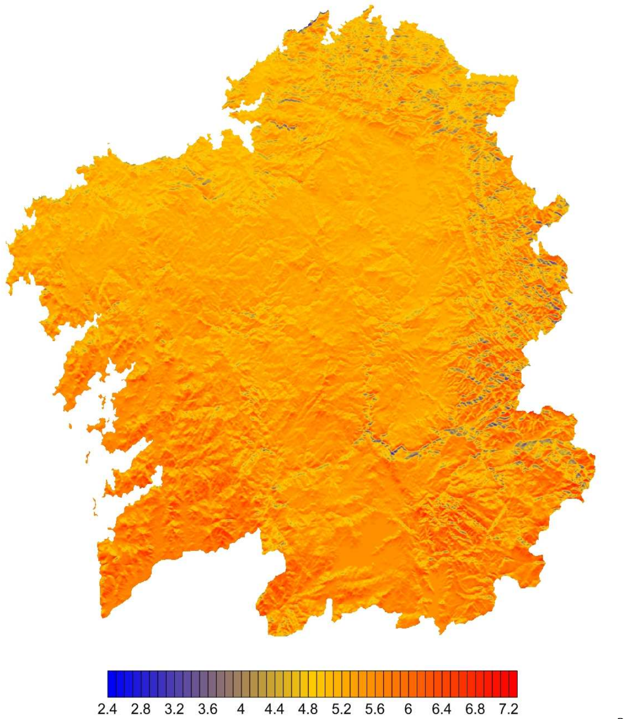

Fig. 1. Global Insolation for cloudless sky conditions [kWh m^{-2} d^{-1}] – Annual average

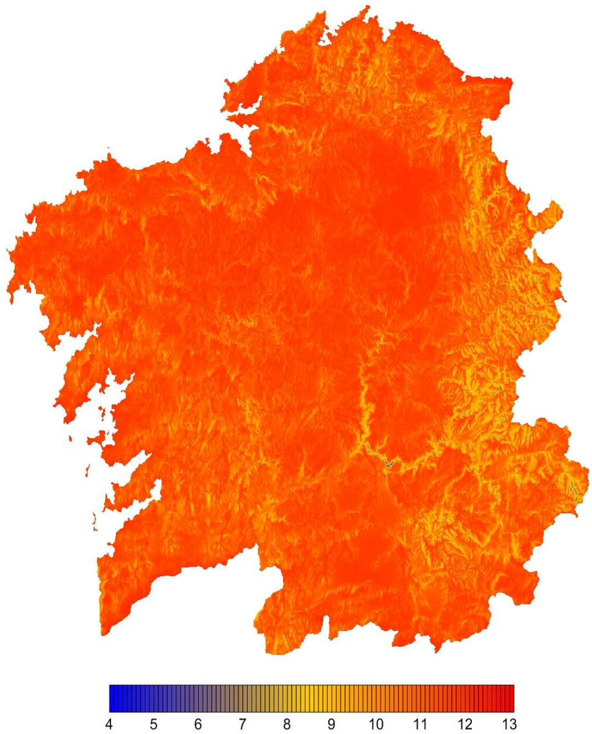

Fig. 2. Sunshine hours for cloud sky conditions – Annual average

B. Maps for overcast conditions

The results of the validation of r.sun taking into account the effect of clouds are shown in Tab. II and Fig. 3. These maps estimate the solar surface radiation taking into account the effect of both topography and cloud climatology. Comparing Fig. 3 with the insolation estimated by satellite and pyranometers (Fig. 4), it may be noticed that, as expected, both pictures show the same pattern. However, the values of insolations are slightly different. In particular, Fig. 3 spreads over a wider range than Fig. 4. This is because of the high resolution MDT (270m) versus the 5 km satellite resolution.

The attenuating effect caused by clouds appears evident especially in summertime, (Fig. 5), where only local clouds in the north are present. In wintertime, the effect is less evident due to a more uniform cloud cover. Anyway, comparing the potential to the cloud-modulated surface insolation (Fig. 6 and 7, respectively), it may be noticed that in wintertime clouds reduce the incoming solar radiation by (40-50)%. In summertime (Fig. 5 and 8), the attenuation is less (20-30%) excepting in the north, where it can reach 40%. Comparing the results of Table II to the satellite data (Table III), r.sun, provides better accuracy than satellite data only. Yet, satellite data calibrated with ground measurements still represent the best set to estimate solar radiation in Galicia [4].

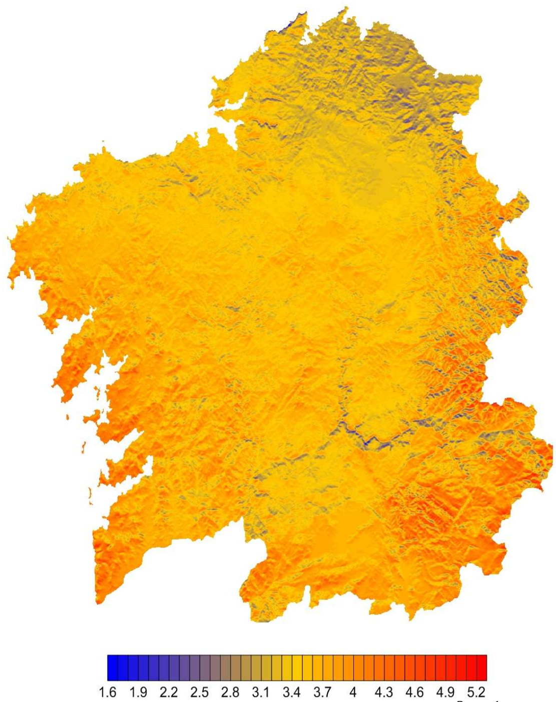

Fig. 3. Global Insolation on DTM [kWh m^{-2} d^{-1}] – Annual average

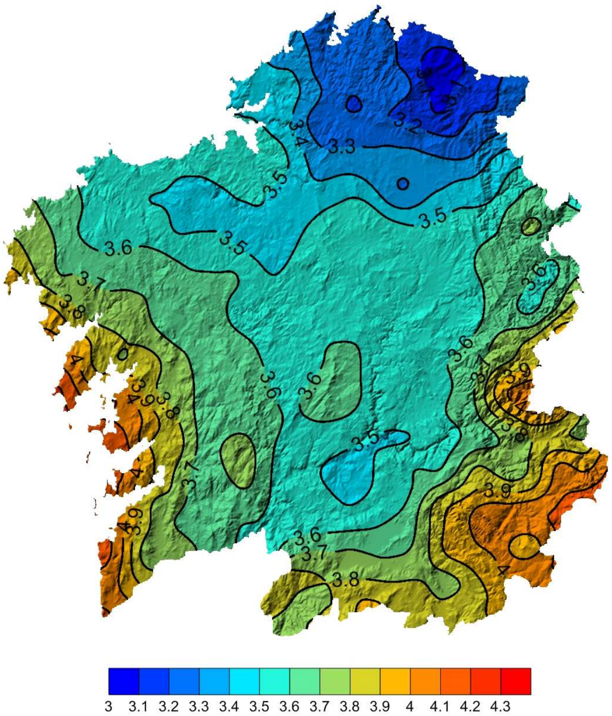

Fig. 4. Global Insolation estimated by satellite and corrected with pyranometers [kWh m^{-2} d^{-1}] – Annual average [4]

Table II. – Temporal validation of r.sun module for overcast sky conditions

Month	MBE [%]	MAE [%]	RMSE [%]
Jan	3.35	14.56	17.64
Feb	-2.08	9.85	11.85
Mar	-4.34	7.9	9.87
Apr	-0.25	5.42	7.07
May	0.27	4.35	5.79
Jun	-1.79	5.7	6.99
Jul	-2.69	6.18	7.58
Aug	-2.49	4.88	6.48
Sep	-3.79	6.08	7.44
Oct	-5.7	9.83	11.35
Nov	-2.07	10.11	12.14
Dec	-1.3	12.16	14.79
Avg	**-1.91**	**8.09**	**9.92**

Table III. – Temporal validation of insolation estimated by satellite [4]

Month	MBE [%]	MAE [%]	RMSE [%]
Jan	1.57	9.5	12.78
Feb	-15.14	15.14	16.25
Mar	0.74	6.57	7.97
Apr	4.34	5.84	7.21
May	7.61	8.12	9.75
Jun	3.16	7.23	10.01
Jul	0.43	6.67	9.02
Aug	-1.21	6.79	9.2
Sep	-10.71	11.75	13.65
Oct	-8.82	10.67	12.97
Nov	5.02	7.03	9.31
Dec	11.85	12.06	13.77
Avg	**-0.01**	**8.95**	**10.99**

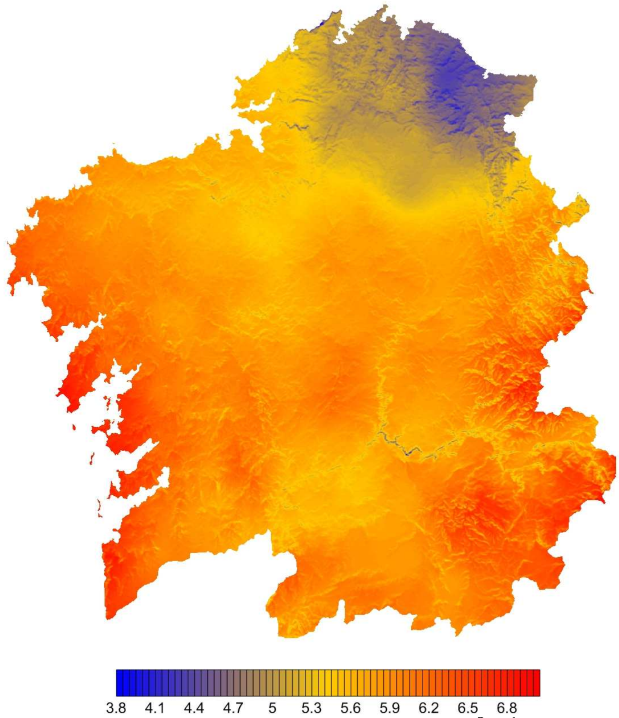

Fig. 5. Daily global Insolation on DTM [kWh m^{-2} d^{-1}] for June – overcast conditions

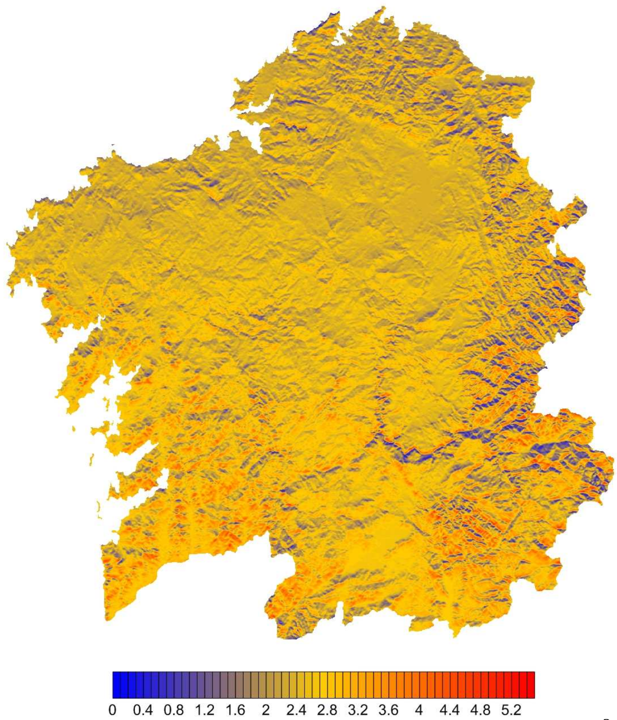

Fig. 6. Global Insolation for cloudless sky conditions [kWh m^{-2} d^{-1}] January

Fig. 7. Daily global Insolation on DTM [kWh m^{-2} d^{-1}] for January – overcast conditions

Fig. 8. Global Insolation for cloudless sky conditions [kWh m^{-2} d^{-1}] June

5. Conclusions

This study demonstrates that coupling a radiative transfer model with a digital terrain model is a valid choice to estimate solar radiation at high resolution scales. Actually, GRASS module r.sun uses topography to obtain solar radiation and sunshine hours with a very high resolution. From this side, the only limit of r.sun is given by the resolution of the DTM: if a very detailed DTM is provided (or even including buildings) r.sun may represent an extremely powerful tool for dimensioning tasks.

This work also points out that, under cloudless sky conditions, r. sun provides quite accurate estimation of global solar radiation (average MAE and RMSE are 5.55% and 6.57% respectively). This feature is relevant for climatologic studies too: the present paper shows that in Galicia the solar radiation is strongly modulated not only by latitude and topography, but also by atmospheric turbidity. This fact explains why the Rias Baixas zone receives more insolation than other locations at equal latitudes.

Under overcast conditions, r.sun is biased by the proper estimation of the cloud cover, but the results achieved demonstrate still good accuracy (MAE and RMSE: 8.09% and 9.92%, respectively). All these evidences prove that r.sun is a very useful tool for estimating solar radiation under any sky condition.

References

[1] Hofierka J., Sùri M., (2002). The solar radiation model for open source GIS: implementation and applications. GRASS users conference. Trento, Italy 11-13 september 2002.

[2] Nùnez M., Reyes J., Marroquìn A., Ramiro A. (2004). Mapas de valores medios mensuales de irradiaciòn solar estimados para Extremadura a partir de otros datos meteorològicos. XXVIII Jornadas cientìficas de la Asociaciòn Meteorològica Espanola. Badajoz, Spain, 11-13 february 2004.

[3] Batlles F., Polo J., Rosiek S., Zarzalejo L., Martìnez M., Ramìrez L., Bosch J., Espinar B., Pozo D. (2006). Estimaciòn de la radiaciòn global diaria en zonas de topografìa compleja utilizando modelos digitales del terreno e imàgenes de Meteosat: comparaciòn de resultados. XXIX Jornadas cientìficas de la Asociaciòn Meteorològica Espanola. Pamplona, Spain, 24-26 April 2006.

[4] Pettazzi A., Salsòn 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