Notes on the Solar Map of Asturias

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Abstract.

The Solar Map of Asturias (SMA) is the result of a research work carried out within the project ''Bio-climatic Architecture and Solar Cooling" (PSE-ARFRISOL). It is based on a correlation model, recently published, between solar irradiation and air temperature, and on the application of the software ArcGIS 9.3 for the spatial interpolation among data from 63 meteorological stations.

The paper shows that the SMA estimations predict difficulties to attain in some areas the minimum solar contribution established by the Spanish Technical Code of Building.

Those predictions are compared with the ones obtained by combining experimental data, Geographic Information Systems, and a solar radiation model able of computing the effects of shadows caused by the orography of the ground.

It is expected that the combination of both procedures may contribute to the improvement of future SMA editions.

Key words

Solar irradiation, correlation models, solar maps, Solar Map of Asturias.

1. Introduction

Several authors have shown that monthly average values of global solar irradiation on horizontal surfaces are correlated with air temperature. The models by Hargreaves and Samani [1], Richardson [2], Allen [3] and Chandel et al. [4] assume that the site elevation z and the distance to sea L are implicit parameters in factors of proportionality. Those factors of proportionality may also depend on the latitude.

A new approach recently proposed [5] is based on the following equation:

$$\frac{G}{G_0} = \mathrm{f}\left(\frac{z}{L}\right)\cdot\left(\frac{\Delta T}{T_{ref}}\right)^{0.5} \quad (1)$$

where G is the monthly average global solar irradiation on horizontal surface, G_0 is the monthly average extraterrestrial solar irradiation, $\Delta T = T_{\max} - T_{\min}$ is the difference between the monthly average maximum and minimum air temperatures, T_{ref} is a reference air temperature, and the function $\mathrm{f}(z/L)$ must be derived from experimental data.

Due to the wide net of stations with available long-term series of air temperature measurements, the equation (1) seemed to be adequate to be used as the basis for the construction of the SMA [6] at microclimate scale.

This paper summarizes how the model of equation (1) was applied for the construction of the SMA and it shows criteria that may contribute for improving future editions.

2. The Solar Map of Asturias

The SMA is the result of a research work carried out within the project ''Bio-climatic Architecture and Solar Cooling" (PSE-ARFRISOL), which is sponsored by the Spanish Science and Education Ministry and the European Regional Development Funds. The project aims at demonstrating the potential of bio-climatic techniques and solar systems to provide about 80% reduction for CO2 emissions and power consumption in five public buildings with very different climate conditions, one of which is located in the Principality of Asturias, a region of diverse orography on the northern Spanish coast.

A. Improvement of Correlation by means of a Non-Potential Function

The assumption of the potential model $\mathrm{f}(z/L) = a(z/L)^b$ led to acceptable results for meteorological stations with similar latitude, located either at relatively nearby sites in coastal areas that are close to valleys and mountains, or stations located as far as 100 km away in dry, non-mountainous areas [5].

However, the potential model may lead to uncertainties when it is applied to low elevated sites ($z \to 0$), which are close to the sea ($L \to 0$), so it had to be revised in order to obtain results with physical meaning at the definition range limits of z/L.

It was observed that the following function can be an adequate assumption, with one exponential term and three empirical parameters a, b and c, namely:

$$\mathrm{f}\left(z/L\right)=a-b\,\mathrm{e}^{-c\,z/L} \quad (2)$$

The experimental data considered to validate this model were those corresponding to the eight stations located in Asturias, previously analysed from the potential model point of view [5], as well as the ones registered in two stations located at similar latitudes near the East and West limits of Asturias, i.e. Santander and Lugo. These additional stations were included in order to justify the application of the model for the process of interpolating meteorological variables between stations, covering the whole area of the SMA.

The analysis concluded that the model based on the following equation adjusts to the experimental values with correlation indexes equal to $R^2 = 0.9983$ and $\overline{\mathrm{RMSE}} = 6.99\%$:

$$\frac{G}{G_0}=\left(4.203-2.180\,\mathrm{e}^{-0.0117z/L}\right)\left(\frac{\Delta T}{T_{\min}}\right)^{0.5} \quad (3)$$

These correlation indexes are similar to those previously obtained for the potential model, despite the fact that the new model applies for two additional stations non-located in Asturias.

Figure 1 allows the functions used in both potential and exponential models to be compared, illustrating that the second one shows an inflexion between the asymptotic values 2.023 and 4.203.
Figure 2 allows us to compare relative errors between experimental measurements and predictions by US National Aeronautics and Space Administration (NASA) [7], European Commission Joint Research Centre (JRC) [8], Meteonorm [9] and the new non-potential model, for the stations of Santander and Lugo.

Figure 3 provides both RMSE and MBE values derived from each model for the eight Asturian stations (No.1 to No.8), Santander (station No.9) and Lugo (station No.10).

In short, the use of a non-potential function to express the influence of the elevation and the distance to sea allows the obtainment of a more meaningful correlation between the clearness index and the air temperature, without reduction of accuracy. The asymptotes at the z/L definition range limits are in agreement with classical models that claimed that G/G_0 and $\Delta T^{0.5}$ can be correlated through factors of proportionality with different values for coastal or interior areas.

The extension of the model to areas with non-similar latitude requires the evaluation of the latitude influence on the correlation parameters a, b and c, which will be analysed in the future.

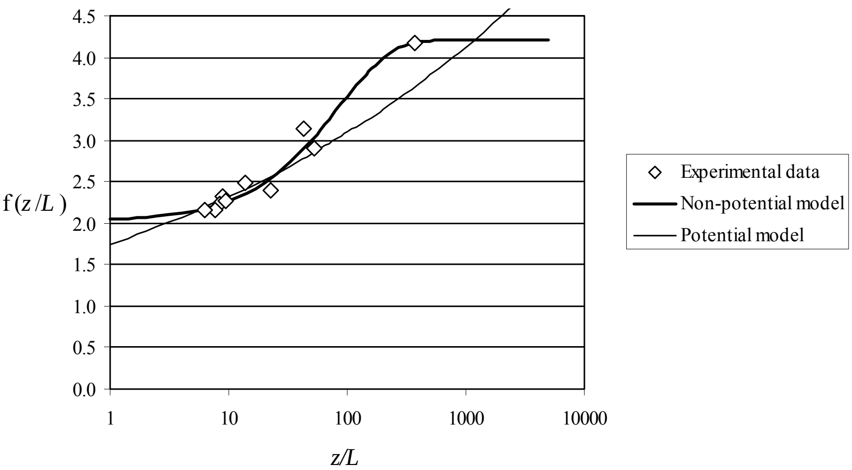

Fig. 1. Comparison between experimental data and models of f(z/L).

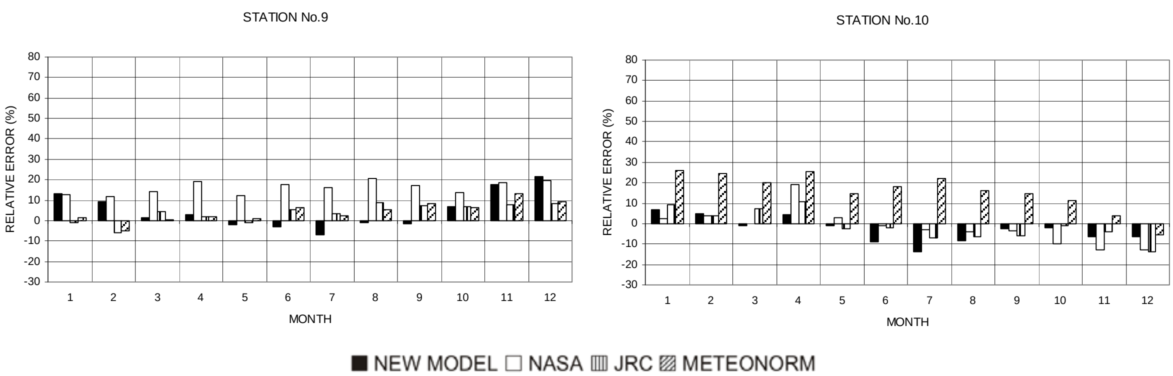

Fig. 2. Comparison between monthly relative errors for models analysed in Santander and Lugo.

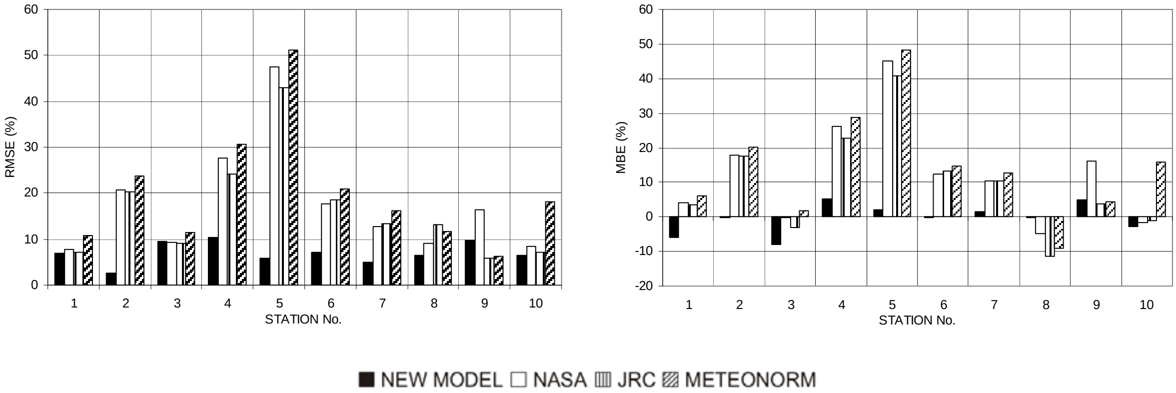

Fig. 3. Values of RMSE and MBE for models analysed in eight Asturian stations, Santander and Lugo.

B. Climatic Zones of Asturias

The SMA provides solar irradiation distributions obtained by means of the application of the software ArcGIS 9.3 [10] to the spatial interpolation among data from 63 meteorological stations.

The Spanish Technical Code of Building (STCB) classifies the Spanish territories in five climatic zones in function of the mean daily values of yearly global solar irradiation, *H* (Table I).

According to the STBC, the Principality of Asturias is practically included in the Zone I, except for some Southwest areas, which are in the Zone II. However, the SMA shows a yearly global solar irradiation distribution with some differences (Figure 4).

Table I. - Global solar irradiation in STBC climatic zones

ZONE	MJ/(m^2·day)	kWh/(m^2·day)
I	$H < 13.7$	$H < 3.8$
II	$13.7 \leq H < 15.1$	$3.8 \leq H < 4.2$
III	$15.1 \leq H < 16.6$	$4.2 \leq H < 4.6$
IV	$16.6 \leq H < 18.0$	$4.6 \leq H < 5.0$
V	$H \geq 18.0$	$H \geq 5.0$

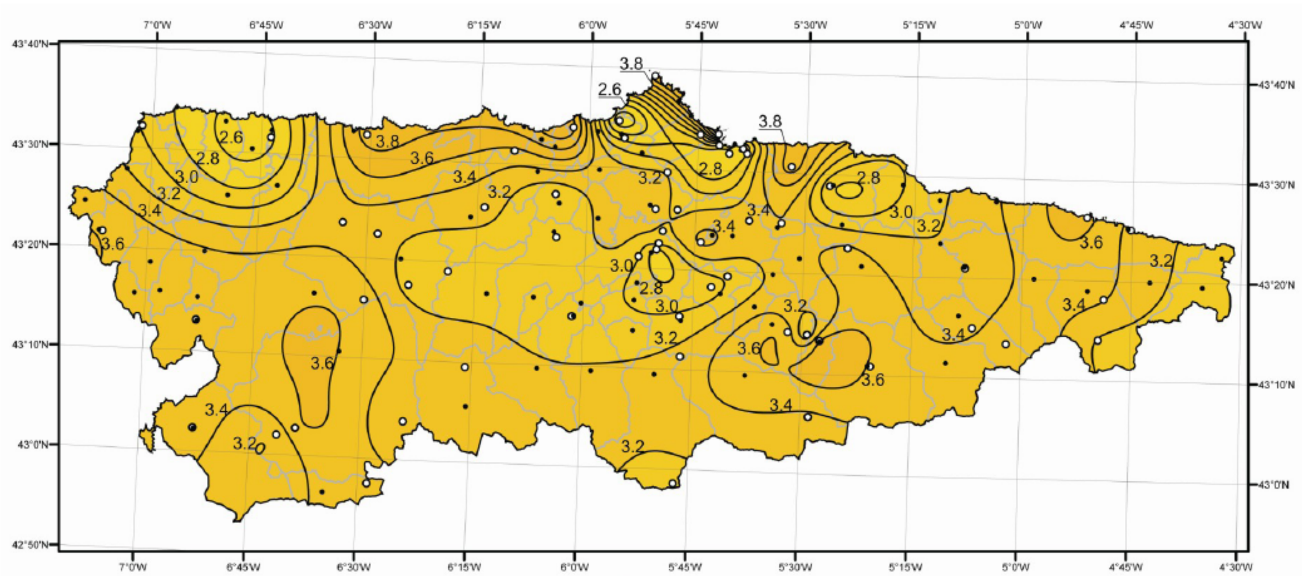

Fig. 4. Map of yearly global solar irradiation on horizontal surface (SMA), kWh/(m^2·day).

To facilitate the comparison, it is interesting to consider the same interval between climatic zones used in the STCB, that is to say, 0.4 kWh/(m^2·day). This criterion, which is similar to the one proposed for the analysis of solar irradiation in Galicia [11], leads to 6 climatic zones. Table II and Figure 5 show the surfaces and percentages corresponding to each zone. It is observed that more than 60% of the Asturian surface presents values of irradiation lower than 3.4 kWh/(m^2·day). Therefore, the SMA evidences difficulties to attain in some areas the minimum solar contribution established by the STCB for water heating and photovoltaic generation [12].

On the other hand, the sites with highest yearly irradiation values seem to be at a reduced coastal area located at both sides of Cape Peñas. This observation may be in agreement with the case of some coastal municipalities of Galicia, where areas near to the sea present highest irradiation values than the mean value of the municipality [11]. Despite this observation, it must be noticed that the sites with lowest yearly irradiation values seem to be also at coastal areas, namely, around Navia and Avilés.

Table II. - Global solar irradiation in climatic zones derived from the SMA

ZONE	kWh/(m^2·day)	Surface (km^2)	%
-II	$H < 2.60$	108	1.0
-I	$2.6 \leq H < 3.0$	833	7.8
0	$3.0 \leq H < 3.4$	5768	54.4
I	$3.4 \leq H < 3.8$	3745	35.3
II	$3.8 \leq H < 4.2$	156	1.5
III	$H \geq 4.2$	3	0.0

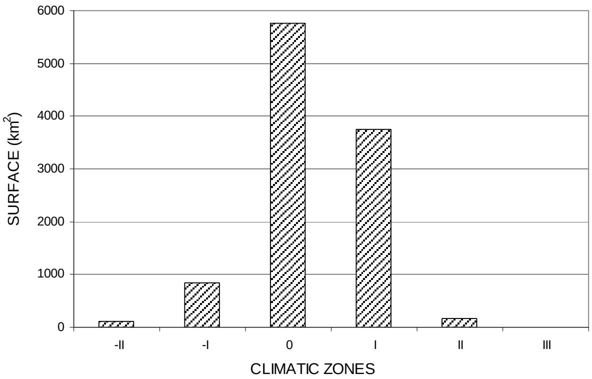

Fig. 5. Surface of climatic zones derived from the SMA

3. Influence of Orographic Shadows in the Solar Map of Asturias

The effects of shadows caused by the orography of the ground can be studied by means of combining experimental data, Geographic Information Systems, and models of solar radiation. The present section summarizes results derived from the application of the software ArcGIS 9.3 [10] to the Digital Elevation Model (DEM) of the Principality of Asturias, 25 x 25 m, UTM zones 29 and 30, format GRID ARC/INFO, 2005 version, provided by the Land Information System of the Principality of Asturias (SITPA). The solar radiation calculations were performed using the 'Solar Radiation' tool [13] [14]. Pending of research which is currently under development, the parameters of beam and diffuse transmission assumed for these calculations were those derived from the analysis of long-term irradiation series at the meteorological station of Oviedo-El Cristo [15].

Figure 6 shows the influence of orographic shadows in the SMA. Table III and Figure 7 show the surfaces and percentages corresponding to each climatic zone. It is evidenced that more than 90% of the Asturian surface presents irradiation values lower than 3.4 kWh/(m^2·day) after considering the influence of orographic shadows.

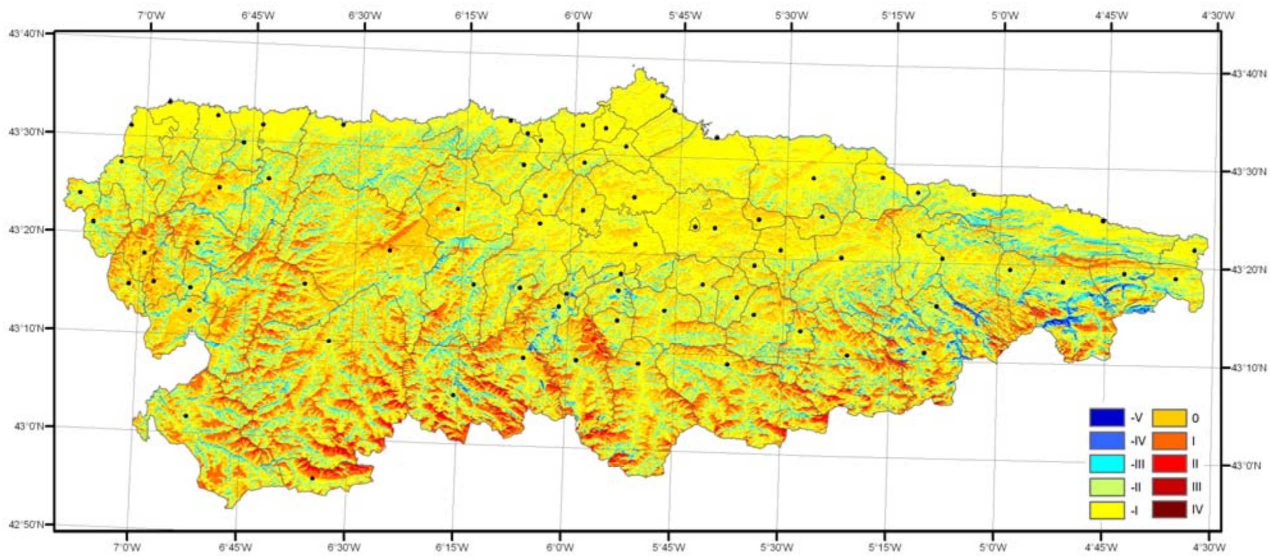

Fig. 6. Map of yearly global solar irradiation on horizontal surface, computed by 'Solar Radiation', kWh/(m^2·day).

Table III. - Global solar irradiation in climatic zones, computed by 'Solar Radiation'

ZONE	kWh/(m^2·day)	Surface (km^2)	%
-V	$H < 1.4$	23	0.2
-IV	$1.4 \leq H < 1.8$	144	1.4
-III	$1.8 \leq H < 2.2$	739	7.0
-II	$2.2 \leq H < 2.6$	2002	18.9
-I	$2.6 \leq H < 3.0$	3993	37.6
0	$3.0 \leq H < 3.4$	2710	25.5
I	$3.4 \leq H < 3.8$	850	8.0
II	$3.8 \leq H < 4.2$	151	1.4
III	$H \geq 4.2$	7	0.1

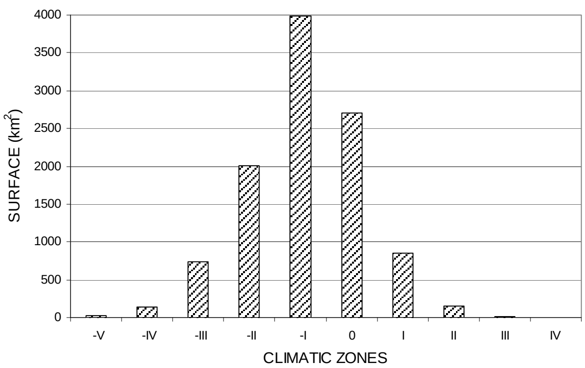

Fig. 7. Surface of climatic zones, computed by 'Solar Radiation'

4. Conclusions

Correlation models based on equation (1) provide solar irradiation data based on air temperature measurements, which may be used to build solar maps at microclimate scale in areas where a wide net of stations with long-term series of air temperature measurements is available. For ten meteorological stations in a Northern coastal area of Spain, the best results have been obtained assuming a non-potential approach for the function of the ratio between the elevation and the distance to sea.

This procedure has been applied for the construction of the Solar Map of Asturias, which provides solar irradiation distributions obtained by means of the application of the software ArcGIS 9.3 to the spatial interpolation among data of 63 meteorological stations.

The SMA figures allow predicting difficulties in some areas to attain the minimum solar contribution established by the Spanish Technical Code of Building for water heating and photovoltaic generation, since more than 60% of the Asturian surface presents values of irradiation lower than 3.4 kWh/(m^2·day).

Another procedure to analyse the solar irradiation distribution at microclimate scale consists in combining experimental data, Geographic Information Systems, and solar radiation models able to compute the effects of shadows caused by the orography of the ground.

The application of this second procedure allows us to estimate that more than 90% of the Asturian surface might present irradiation values lower than 3.4 kWh/(m^2·day). At first sight, this method provides a more detailed solar map, but conclusions about its accuracy cannot be considered definitive, since it depends on the assumption of the applicability of the same diffuse solar irradiation model for all Asturias.

The improvement of future editions of the SMA is expected from the combination of both aforementioned procedures and from data updated by means of analysis on diffuse solar irradiation in Asturias, which are currently under development.

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