Modeling of cloudiness based on the difference between the theoretical solar irradiance and the real solar irradiance on the earth's surface for the installation of photovoltaic energy projects

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Abstract. Considering that the solar irradiance on the surface is a direct indicator of cloudiness [1], we proceeded to make a model that determines the cloudiness, contrasting the differences that are generated between the theoretical solar irradiance estimated on the surface [1][2] and real solar irradiance recorded on the surface. To evaluate the quality of the model, the real cloud values and the estimates were contrasted in a dispersion diagram, both in eighths at the daily average level, obtaining a correlation coefficient of 0.7. The modeling of cloudiness is a relevant variable for the installation of photovoltaic energy projects.

1. Introduction
We must consider that the solar irradiance on the surface of the planet is a direct indicator of cloudiness, in the present study we proceeded to model the cloudiness, contrasting the theoretical solar radiation with respect to the real both at the surface level, assuming that the resulting solar irradiance of the difference between the theoretical solar surface irradiance and the real solar surface irradiance, is directly proportional to the cloudiness. The modeling of cloudiness is a relevant variable for the installation of photovoltaic energy projects.

To model the cloudiness and verify the aforementioned, it proceeded to perform the following process:

- It proceeded to estimate the theoretical solar irradiance on the surface for the sector under study at the hourly level.
- Surface real solar irradiance databases were prepared at the hourly level, in which all values less than zero are assumed to be zero.
- The theoretical and real solar irradiance were contrasted, at this point the time differences were adjusted.
- We proceeded to estimate the cloudiness taking into consideration that this is proportional to the differences between the theoretical and real solar irradiance on the surface, the

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smallest difference in irradiance is assumed as zero cloudiness and the greatest difference in cloudiness is assumed as eight.

- Analysis of the correspondence between the theoretical and real cloud data.
  The place where the previous steps were applied to model the cloudiness was in the Tres Quebradas located in the Republic of Argentina, with data captured in 2017.

2. Results
Based on the above steps, the modeling data obtained:

2.1. Calculation of the theoretical solar surface irradiance for the sector under study at hourly level
The graphs of the calculations of theoretical solar irradiance on the surface of the earth, based on the equations of Spencer, Cooper, Perrin, Lamm, Walreaven with modifications of Michalsky [1] [2], are the following:

![Theoretical solar irradiance](image1.png)

**Figure 1.** Theorical solar surface at hourly level.

Figure 1, the theoretical solar irradiance on the surface in W/m² is observed for the locality under study.

2.2. Preparation of databases of real solar irradiance on surface at hourly level
We proceeded to order the data of the meteorological station of the National Meteorological Service of the Republic of Argentina, for the sector under study, the data are.

![Real solar irradiance](image2.png)

**Figure 2.** Real solar surface irradiance at hourly level
Figure 2 shows the actual solar irradiation on the surface in W/m², for the locality studied.

2.3. Contrast between theoretical and real solar irradiance, adjustment of time differences and correspondence at the hourly level

We proceeded to adjust the theoretical solar irradiance with respect to the real one in a shift of 6 hours (Solar time + 6 hours), and then proceeded to perform the correlation analysis between the aforementioned variables, resulting in the following linear equation of regression.

\[
\text{Real Irradiance} = \text{Theoretical Irradiance} \times 0.803 - 10.71
\]

Equation 1, present a correlation coefficient of 0.946.

2.4. Cloudiness Estimation

Considering that the present study assumes that the cloudiness is proportional to the differences between the theoretical and real solar irradiation on the surface, their differences at the hourly level were calculated, which are presented in Figure 3:

Figure 3. Differences between theoretical and real surface.

Figure 3 shows that the lowest irradiance difference value is 0 W/m² and the highest irradiance difference is 1081 W/m². Taking into account that the cloudiness will be measured in eighths, the smallest difference irradiance will assume the value of 0 eighths and the greatest difference in irradiance will assume the value of 8 eighths, as shown in Figure 4.

Cloudiness

Figure 4. Modeled cloudiness.
In Figure 4, the cloudiness modelled in eighths.

2.5. Analysis of the correspondence between the theoretical and real cloudiness data

![Theoretical cloudiness vs Real Cloudiness](image)

**Figure 5.** Theorical cloudiness vs real cloudiness.

3. Discussion
The results of the present study can be improved through the use of remote sensors.

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References
[1] J Boland 2008 *Modeling Solar Radiation at the Earth’s Surfac* Springer
[2] J Holton 1990 *Introducción a la meteorología dinámica* INM