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IMPACT OF INFERRING ATMOSPHERIC PARAMETERS ON SOLAR IRRADIANCE ESTIMATION

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Article Info	Abstract
Received: 28.09.2025 *Accepted: 07.11.2025* **Keywords:** solar irradiance, atmospheric parameters, Ångström turbidity coefficient	This study focuses on the estimation of clear-sky solar irradiance available in a specific location using a parametric model. The challenge is to estimate solar irradiance at a higher resolution than the resolution at which the atmospheric parameters applied to the model input are measured. Two methods were tested to increase the resolution of the input data: hourly arithmetic averaging of measurements and linear interpolation between two measurements. The influence of averaging and interpolation of the atmospheric parameters on the clear-sky solar irradiance model accuracy was assessed. The analysis was performed on a dataset comprising ground-based measurements from the Solar Platform of the West University of Timisoara, complemented by atmospheric parameters obtained from the Aerosol Robotic Network (AERONET). Particular attention is given to the influence of Ångström turbidity coefficient, which is known to play a critical role in the attenuation of solar radiation when passing through the atmosphere. The results indicate that the use of hourly mean atmospheric parameters does not significantly compromise the overall accuracy of the solar irradiance estimates. However, due to the sensitivity of the model to aerosol-related parameters, it is advisable to employ interpolated values for the Ångström turbidity coefficient to enhance the accuracy of irradiance estimations under fast varying atmospheric conditions.

1. Introduction

Solar energy has become a key part of sustainable development. It provides a clean, abundant, and renewable alternative to fossil fuels. Its widespread use is vital for fighting climate change, cutting greenhouse gas emissions, and ensuring energy security in the long run [1]. Measuring solar irradiance accurately is important for designing and operating photovoltaic systems, solar thermal installations, and other solar technologies. In places where solar irradiance is not measured, reliable solar radiation models are essential for predicting energy output [2]. Capturing cloud properties in equations represents the main source of uncertainty in solar irradiance modeling. Another source of uncertainty comes from the poor representation of atmospheric parameters, especially aerosols. The Ångström turbidity coefficient (β) serves as a key descriptor of atmospheric aerosol amount and its influence on solar radiation [3]. This study evaluates the performance of a solar irradiance model, specifically the Paulescu-Schlett (PS) model [4], when the atmospheric parameters applied to the model input are measured with lower temporal resolution than the radiometric data. The analysis relies on ground-based radiometric and atmospheric measurements from a specific location. The study aims to understand which is the most appropriate method to increase the resolution of the atmospheric parametric time series, i.e. using hourly mean values or interpolated atmospheric parameters? The study also quantitatively evaluates how this choice impacts model accuracy. The findings help improve methods for filling the gaps in data series of atmospheric parameters to match the resolution of the radiometric data.

2. Methodology

This study examines the impact of different data processing techniques, specifically averaging and interpolation, on the accuracy of solar irradiance modeling under clear-sky conditions. The analysis is conducted using the PS parametric model [4]. Its formulation allows for accurate estimation of global solar irradiance while maintaining low algorithmic complexity, making it suitable for sensitivity studies involving atmospheric inputs. The dataset employed in this study comprises high-resolution radiometric measurements acquired on the Solar Platform of the West University of Timisoara, Romania [5]. To ensure a comprehensive representation of the atmospheric state, the model estimates solar irradiance based on ground measurements of water vapor, ozone, and the Ångström turbidity coefficient. In this study, the input parameters were obtained from the Aerosol Robotic Network (AERONET) [6]. By systematically applying averaging and interpolation procedures to these inputs, the study evaluates how such preprocessing affects the model's predictive performance, offering insights into the trade-offs between data simplification and physical accuracy in solar resource assessment.

2. 1. Solar irradiance estimation model

The PS model is a simple yet accurate method for calculating solar irradiance in clear skies. One key feature of the model is its sensitivity to aerosol factors, especially the Ångström turbidity coefficient. This coefficient is a measure of the aerosol amount in the atmosphere, and it influences the atmospheric optical depth and transmittance. The beam and diffuse solar irradiance can be computed using the following equations:

$$G_b = \varepsilon_j G_{SC} \bar{\tau}_r \bar{\tau}_a \bar{\tau}_w \bar{\tau}_{O_3} \bar{\tau}_g \cos\theta_z \tag{1}$$

$$G_d = \gamma \varepsilon_j G_{SC} (1 - \bar{\tau}_r \bar{\tau}_a) \bar{\tau}_w \bar{\tau}_{O_3} \bar{\tau}_g \cos\theta_z \tag{2}$$

where ε_j is the solar constant correction according with the sun-earth distance, G_{SC} is the solar constant, θ_z is the zenith angle, and $\gamma = 0.432$ [4].

The transmittances for every extinction process are calculated as:

$$\bar{\tau}_{O_3}(m,l) = e^{-ml[0.0184 - 0.0004ml + 0.022(ml)^{-0.66}]} \tag{3a}$$

$$\bar{\tau}_w(m,w) = e^{-mw[-0.002 + 1.67\cdot 10^{-5} mw + 0.094(mw)^{-0.693}]} \tag{3b}$$

$$\bar{\tau}_g(m) = e^{-m[-5.4\cdot 10^{-5} - 3.81\cdot 10^{-6} m + 0.0099 m^{-0.62}]} \tag{3c}$$

$$\bar{\tau}_r(m,p) = e^{-m\frac{p}{p_0}\left[0.709 + 0.0013m\frac{p}{p_0} - 0.5856\left(m\frac{p}{p_0}\right)^{0.058}\right]} \tag{3d}$$

$$\bar{\tau}_a(m,\beta) = e^{-m\beta[1.503 - 0.083m\beta + 0.3345(m\beta)^{-0.668}]} \tag{3e}$$

In addition to geographical coordinates and temporal information, the estimation of global solar irradiance requires four other parameters: surface air pressure *p*, the water vapor column content *w*, the ozone column content *l* and the Ångström turbidity coefficient *β*.

The global solar irradiance is computed as:

$$G = G_b + G_d \tag{4}$$

The influence of averaging and interpolation of the atmospheric parameters on the model accuracy is evaluated.

2. 2. Dataset

High quality radiometric data, measured on the Solar Platform of the West University of Timisoara are used to conduct this study [5]. The dataset consists of data recorded in five clear-sky days from August and September 2023.

Figure 1. FORPV experimental setup located at the Solar Platform at West University of Timisoara

The measurements were taken using the FORPV setup (Figure 1), which was specifically designed to test models used for estimating and forecasting PV power. It comprises a PV system with a total capacity of 540 Wp, consisting of four Cleversolar SPR-130 PV modules. To measure the in-plane solar irradiance, a Kipp & Zonen SMP-10 pyranometer, known for its high accuracy, is used. Meteorological data such as temperature, humidity, and wind speed are recorded using a Delta-T Devices WS-GP2 weather station. All instruments undergo a 24/7 monitoring, with data recorded at regular intervals of 4 seconds.

In order to implement the model, the dataset measured on the Solar Platform of the West University of Timisoara was completed with ground-based measurements of atmospheric parameters: water vapor column content, thickness of the ozone layer and aerosol optical depth (AOD). These parameters have been taken from Aerosol Robotic Network (AERONET) [6]. The resolution in the AERONET data series is 15 minutes. From the AOD data, the Ångström turbidity coefficient was calculated based on the empirical Ångström equation [7]:

$$AOD(\lambda) = \beta\lambda^{-\alpha} \quad (5)$$

The wavelength λ is expressed relative to $\lambda_0 = 1\mu m$. Thus, the Ångström turbidity coefficient β can be defined as the AOD at wavelength 1μm. The parameter α is called Ångström exponent and it is inversely related to the aerosol particle size. For a measurement point (defined by a timestamp) AERONET provides AOD at seven to nine wavelengths. β and α are tipically estimated from these measurements by linear interpolation of logarithm of Eq. (5): $\ln AOD = \ln\beta - \alpha\ln\lambda$. Note that α is not a parameter of the PS model.

The resolution of the AERONET dataset is lower than the resolution of the dataset measured on the Solar Platform. To apply the model to the resolution of radiometric data, it is necessary to increase the resolution of the AERONET dataset. This study deals with the procedure to be followed for completing the atmospheric data series, in order to maximize the accuracy of the PS estimates. Two procedures were tested to increase the resolution of the AERONET data series. The first procedure consists of hourly averaging of the atmospheric parameters. Hourly averages of *l*, *w*, and *β* were calculated as the arithmetic mean of the AERONET measurements available during that hour, have been applied to the PS input. The second procedure consists of assuming a linear variation of the parameters *l*, *w*, and *β* between any two successive measurement points. Values of *l*, *w*, and *β*, calculated by piecewise linear interpolation, were applied to the PS input.

3. Results and Discussions

The PS model was evaluated by comparing its output against ground-based solar irradiance measurements, using the two procedures for increase the resolution of the measured atmospheric parameters. In the first case, hourly average values of atmospheric parameters were used. These is a simplified and widely adopted method due to their lower computational demand. In the second approach, the atmospheric parameters were temporally interpolated to match the resolution of irradiance measurements, allowing the model to account for short-term fluctuations and finer-scale variability in atmospheric conditions. This dual approach enabled a comparative evaluation of how the method of matching the two data series resolution influences model accuracy.

Figure 2 illustrates the difference in how the two input methods capture atmospheric variability over time. The interpolated values reflect subtle and rapid changes throughout the day. This finer resolution allows the model to respond to short-term fluctuations that are often critical for accurate irradiance estimation. On the other hand, the hourly mean values create a stepped pattern, smoothing out the data. While averaging is a practical and commonly used approach, it can oversimplify the input data and reduce the model's sensitivity to real-time atmospheric dynamics. This comparison underscores the importance of choosing the right level of detail when preparing input data for solar irradiance modeling. During a day, the variation in ozone content in the atmospheric column is very small, so that the procedure applied, interpolation or averaging, has any relevance. This overall picture is repeated on each of the five days considered.

To quantify the impact of input data resolution on model performance, Table 1 presents the statistical indicators, normalized root mean square error (*nRMSE*) and normalized mean bias error (*nMBE*), for the estimated global solar irradiance on the test days 27, 28 of August 2023 and 7, 10, 12 of September 2023. The largest difference between statistical indicators was recorded on October 10, 2023. When using hourly mean values for the atmospheric parameters, the model yielded *nRMSE* of 5.419% and *nMBE* of -3.390%. In comparison, the interpolated inputs resulted in *nRMSE* of 5.398% and *nMBE* of -3.406%. These results reveal that the difference between the two approaches is minimal, with interpolation offering only a slight improvement in error metrics. Both input strategies produced similar levels of accuracy, and in both cases, the model exhibited a tendency to underestimate solar irradiance. This suggests that while temporal interpolation may enhance the model's responsiveness to short-term atmospheric variability, its overall impact on the model's accuracy is limited.

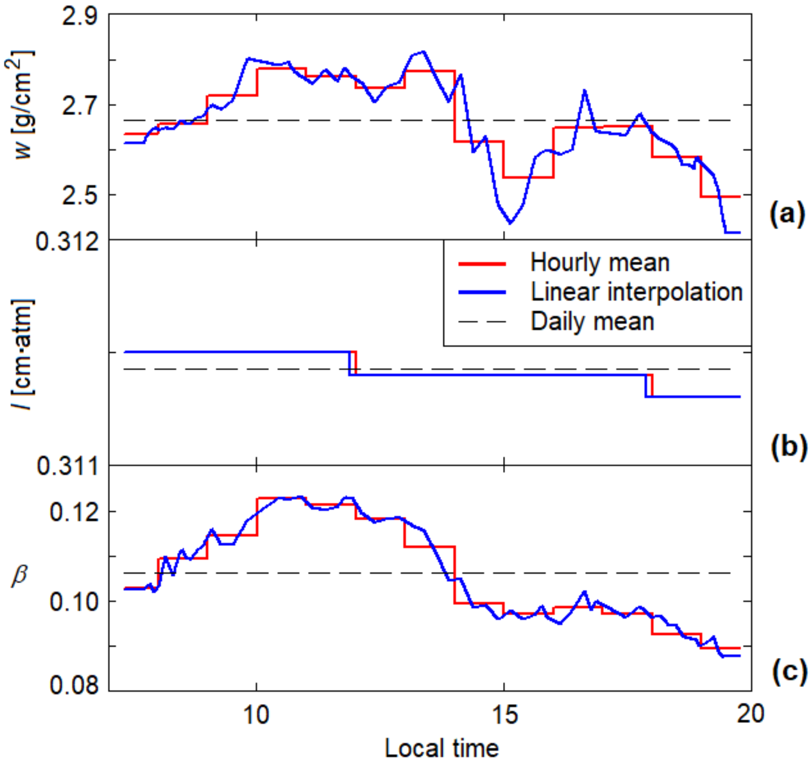

Figure 2. Hourly mean, linear interpolated and daily mean values of the atmospheric parameters on 27th of August 2023: (a) water vapur column content, (b) ozone column content, and (c) Ångström turbidity coefficient.

Table 1. Statistical indicators of accuracy for the estimated clear-sky global solar irradiance using hourly mean and interpolated atmospheric parameters at the PS input

Date	Procedure for increasing resolution	*nRMSE* [%]	*nMBE* [%]
26.09.2023	Hourly mean	7.383	-5.169
	Linear interpolation	7.387	-5.164
27.09.2023	Hourly mean	9.819	-7.873
	Linear interpolation	9.818	-7.878
07.10.2023	Hourly mean	6.134	-3.137
	Linear interpolation	6.127	-3.131
10.10.2023	Hourly mean	5.419	-3.390
	Linear interpolation	5.398	-3.406
12.10.2023	Hourly mean	11.890	-10.456
	Linear interpolation	11.892	-10.459

4. Conclusions

The comparative analysis conducted across five clear-sky days from August and September 2023 reveals that the Paulescu-Schlett model performs with similar accuracy regardless of whether hourly mean or interpolated atmospheric parameters are used as input. The *nRMSE* remained consistently similar in both cases, indicating that the model's accuracy is unaffected by the procedure used to synchronize the input data series and the radiometric data series. Although interpolated inputs allow the model to better reflect short-term atmospheric variability, the overall gain in performance is limited under the conditions examined.

Moreover, the nMBE values were similar across both input methods, consistently showing a small negative bias. This points to a systematic underestimation of solar irradiance by the model, independent of how the atmospheric parameters were processed. Such behavior may be attributed to inherent simplifications in the model.

Given the minimal differences in performance metrics, the use of hourly mean atmospheric data presents a practical alternative to interpolated inputs, offering a good compromise between data simplicity and predictive accuracy.

References

[1] D. Hao, L. Qi, A.M. Tairab, A. Ahmed, A. Azam, D. Luo, Y. Pan, Z. Zhang, J. Yan, *Solar energy harvesting technologies for PV self-powered applications: A comprehensive review*, Renewable Energy, 188 (2022) 678-697

[2] C.M. Travieso-Gonzalez, F. Cabrera-Quintero, A. Pinan-Roescher, S. Celada-Bernal, *A review and evaluation of the state of art in image based solar energy forecasting: The methodology and technology used*, Applied Sciences, 14 (2024) 5605

[3] D.G. Calinoiu, N. Stefu, M. Paulescu, G. Trif-Tordai, O. Mares, E. Paulescu, R. Boata, N. Pop, A. Pacurar, *Evaluation of errors made in solar irradiance estimation due to averaging the Angstrom turbidity coefficient*, Atmospheric Research, 150 (2014) 69-78

[4] M. Paulescu, Z. Schlett, A simplified but accurate spectral solar irradiance model, Theoretical and Applied Climatology, 75 (2003) 203-212

[5] Solar Platform of the West University of Timisoara, 2025, http://solar.physics.uvt.ro/srms/ (accessed August 2025)

[6] Aerosol Robotic Network (AERONET), 2025, https://aeronet.gsfc.nasa.gov (accessed August 2025)

[7] A. Angstrom, *Techniques of Determining the Turbidity of the Atmosphere*, Tellus, 13 (1961) 214-223.