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ANALYSIS OF GHI VARIABILITY FROM WRF-SOLAR FOR THE THREE CITIES OF AMAPÁ

Summary

This study evaluates the performance of the WRF-Solar model in estimating global horizontal irradiance (GHI) at three locations in the Brazilian state of Amapá. Simulations were performed using WRF-Solar and the results were compared with data from three solarimetric stations. Representative months of the Typical Meteorological Year were estimated for Macapá coordinates using the National Solar Radiation Database. The results showed that the Dudhia scheme performed better in rainy conditions, particularly in AP03, whereas the FARMS algorithm tended to overestimate GHI and performed better during the dry season in AP01 and AP04. This reflects the influence of seasonal and local variability on model accuracy. WRF-Solar proves to be a promising tool for solar energy planning in Brazil.

Keywords: Solar Energy, Numerical Modeling, WRF, FARMS

1. Introdution

The Brazilian energy scenario has witnessed a significant increase in the use of renewable sources, which currently supply around half of domestic demand, with biomass, hydroelectric, wind and solar energy all playing important roles. While wind generation is mainly concentrated in the Northeast, accounting for more than 80% of national production, the Northern region, although not yet part of the wind market, has a considerable share of solar photovoltaic energy production, surpassed only by the Northeast. In the context of the Northern region, the state of Amapá has been operating a photovoltaic plant since 2017. Historically, Amapá depended on diesel thermoelectric plants for electricity generation, but expanded its capacity with the installation of hydroelectric plants and connected to the National Interconnected System (SIN) in 2015.

Although its connection to the SIN, Amapá's obsolete electrical infrastructure and susceptibility to climatic events has led it to face major blackouts, culminating in a collapse in 2020 that severely impacted the lives of the population and the local economy. This fragility emphasizes the urgency of diversifying the state's energy matrix, exploiting the potential of renewable sources, particularly solar energy, given its privileged location on the equator. In this sense, atmospheric forecasting models such as WRF-Solar are essential for accurately assessing this potential, considering the challenge of the region's significant cloud cover. Previous research has already attested to the ability of WRF-Solar to carry out solar irradiance simulations in Brazil (Amorim *et al.*, 2024; Emiliavaca *et al.*, 2024), with greater accuracy compared to other versions of the WRF model. Given this panorama, the primary objective of this investigation is to analyze the efficiency of WRF-Solar in estimating the specific solar energy potential for the state of Amapá.

2. Materials and Methods

2.1 Study Area – Data Colletion

Amapá has the largest area of native vegetation in Brazil and a predominantly tropical climate (Am), influenced by the Intertropical Convergence Zone (ITCZ), a key meteorological system in the region (Alvares *et al.*, 2013). In terms of solar energy, the Brazilian Atlas indicates greater availability of horizontal irradiation in the second half of the year, with average monthly values exceeding 5.0 kWh/m²/day between August and November (Pereira *et al.*, 2017; Amorim *et al.*, 2024).

Three solarimetric stations were installed in different municipalities of the state of Amapá: Santana (AP01), Laranjal do Jari (AP03), and Maracá Jipioca Island (AP04). The installation of these stations has been completed, and since then, data collection and quality control procedures have been carried out continuously, following the guidelines of Long and Shi (2008).

2.2 Mesoscale atmospheric modeling: WRF-Solar

WRF-Solar is an adaptation of the WRF model designed for solar energy applications. It integrates variables such as global horizontal irradiance (GHI, referred to as SWDOWN), as well as the FARMS (Fast All-sky Radiation Model for Solar Applications) algorithm for estimating surface irradiance (Xie *et al*., 2016). In this study, GHI estimates from FARMS (referred to as SWDOWN2) were also analysed.

The representative months of the Typical Meteorological Year (TMY) were estimated for the coordinates of Macapá from the NSRDB (National Solar Radiation Database), which is maintained by NREL (National Renewable Energy Laboratory) (Sengupta *et al*., 2018), according to the methodology of Amorim et al. (2024). This methodology demonstrated the effectiveness of TMY in representing large areas with point data.

Sensitivity tests in rainy and dry periods informed the selection of physical parameterisations for Amapá: WSM6 microphysics; RRTM longwave and shortwave radiation (Dudhia and FARMS); and cumulus schemes (Grell-Devenyi and Kain-Fritsch) (Amorim *et al*., 2024).

Two domains (6 km and 2 km) were used, with the focus being on a 2 km resolution covering the entire state. The simulations used ERA5 data from the ECMWF (Centre for Medium-Range Weather Forecasts) (Hersbach *et al*., 2020), discarding the first 24 hours of spin-up. All 12 months of the TMY were simulated individually and all processing took place at NPAD/UFRN.

The performance of WRF-Solar was assessed using normalised mean bias error (NMBE), is a statistical measure that is often used to evaluate the performance of a model by quantifying the average difference between predicted and observed values, as defined by Wilks (2006).

3. Results and Discussion

The analysis of the normalized mean bias error (NMBE) revealed significant differences in the performance of the Dudhia (GHI1) and FARMS (GHI2) schemes across three locations in Amapá (Tab.1). The Dudhia scheme performed better in Santana and Maracá-Jipioca during the first half of the year, and in Laranjal do Jari throughout the entire year, indicating good adaptation to local conditions, especially during the rainy season. In contrast, FARMS tended to overestimate GHI—a pattern also reported in the literature (Amorim *et al*., 2024) - likely due to its limitations in representing cloud cover (Gueymard and Jimenez, 2018). Nevertheless, it showed relatively better performance at AP01 and AP04 during the dry season, suggesting sensitivity to more stable atmospheric conditions. These results underscore the role of local and seasonal factors in model performance and the importance of regional tuning in climate-variable areas like Amapá.

Table 1: Normalized Mean Bias Error (NMBE) between observed GHI and WRF-Solar simulations using the Dudhia and FARMS algorithms for stations AP01, AP03, and AP04 during representative months.

	Dudhia AP01	FARMS AP01	Dudhia AP03	FARMS AP03	Dudhia AP04	FARMS AP04
JAN	-0.06	0.08	0.03	0.09	0.03	0.17
FEB	-0.04	0.12	0.03	0.12	-0.03	0.17
MAR	-0.02	0.11	0.04	0.13	-0.02	0.13
APR	-0.05	0.11	0.00	0.12	0.02	0.20
MAY	-0.07	0.10	0.02	0.15	-0.07	0.10
JUN	-0.07	0.05	-0.03	0.08	-0.10	0.02
JUL	-0.09	0.02	-0.03	0.07	-0.08	0.04
AUG	-0.09	0.02	-0.05	0.03	-0.08	0.02
SEP	-0.08	0.03	0.03	0.08	-0.04	0.05
OCT	-0.07	0.02	0.02	0.06	-0.07	0.01
NOV	-0.07	0.03	0.05	0.11	-0.13	-0.03

4. Conclusions

The use of atmospheric modelling tools, such as the WRF-Solar model with implementations such as the FARMS algorithms, supports the continuity of research on renewable energy in the state of Amapá, contributing to the understanding and improvement of solar radiation forecasting in the region.

5. References

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