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Forecast for surface solar irradiance at the Brazilian Northeastern region using NWP model and artificial neural networks

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ABSTRACT

There has been a growing demand on energy sector for short-term predictions of energy resources to support the planning and management of electricity generation and distribution systems. The purpose of this work is establishing a methodology to produce solar irradiation forecasts for the Brazilian Northeastern region by using Weather Research and Forecasting Model (WRF) combined with a statistical post-processing method. The 24 h solar irradiance forecasts were obtained using the WRF model. In order to reduce uncertainties, a cluster analysis technique was employed to select areas presenting similar climate features. Comparison analysis between WRF model outputs and observational data were performed to evaluate the model skill in forecasting surface solar irradiance. Next, model-derived short-term solar irradiance forecasts from the WRF outputs were refined by using an artificial neural networks (ANNs) technique. The output variables of the WRF model representing the forecasted atmospheric conditions were used as predictors by ANNs, adjusted to calculate the solar radiation incident for the entire Brazilian Northeastern (NEB) (which was divided into four homogeneous regions, defined by the Ward method). The data used in this study was from rainy and dry seasons between 2009 and 2011. Several predictors were tested to adjust and simulate the ANNs. We found the best ANN architecture and a group of 10 predictors, in which a deeper analyzes were carried out, including performance evaluation for Fall and Spring of 2011 (rainy and dry season in NEB, mainly in the northern section). There was a significant improvement of the WRF model forecasts when adjusted by the ANNs, yielding lower bias and RMSE, and an increase in the correlation coefficient.

1. Introduction

Brazil is located in the tropical region and receives large solar irradiation throughout its huge territory. Fig. 1 presents a relative comparison between solar irradiation in Brazil and Europe. The annual average of daily total solar irradiation is larger in Brazilian Northeastern region than and in areas where the solar energy market is far more advanced, such as Germany and the Iberian Peninsula. Besides that, the inter-annual variability is lower due to the tropical location and typical climate observed mainly in region [38,47]. Tiepolo [58] and Viana et al. [61] pointed out that photovoltaic (PV) power plants could be cost-effective all over Brazil. Applications like PV power plants and concentrated solar power plants (CSP) in the arid area of Northeastern region, grid-connected micro and mini-generation of electricity in municipalities are examples for feasible exploitation of solar resources [35,37,39].

Despite the abundant solar resource and the high value that can be attributed to grid-connected PV systems in commercial areas of urban centers in Brazil, the installed PV capacity is meager and restricted to universities and research institutes. PV generation amounts to only 0.01% of the Brazilian electricity matrix, around 12,000 kW [1].

PV applications have a promising future in commercial urban tropical and subtropical regions where high midday air-conditioning loads show a typical energy demand curve similar to that of the daily cycle of surface solar irradiation. Another important feature of solar energy resources in Brazil is that the incident surface solar irradiation achieves higher levels during

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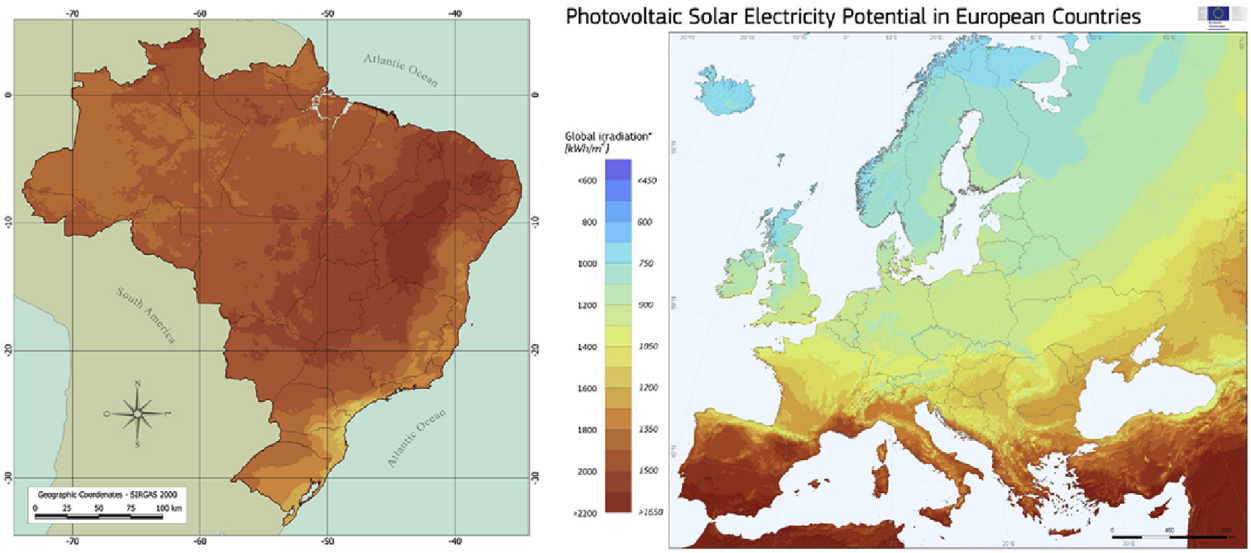

Fig. 1. Maps for annual average of daily solar irradiation in Brazil (left) and Europe (right) (source: adapted from Refs. [47,17]).

summer, when the peak load in the distribution lines is higher. This is a typical feature in most metropolitan areas and large cities in Brazil [38]. Currently, the Brazilian government is discussing how to support and stimulate the solar energy market in Brazil, and national policies are being implemented to regulate the smart gridding technology. Energy auctions for solar energy are being held in order to increase the share of solar energy in the national electricity energy matrix, and stimulate the energy sector to invest and develop solar energy application projects.

Another important future application for PV generation lies on remote areas such as in the Brazilian Amazon region, which is not yet connected to the Brazilian interconnected electricity distribution system. There are currently only a few hundreds of mini-grids operated by independent power producers (IPPs) or local state utilities in the Brazilian Amazon, which cover the main share of local demand. In these regions, all the electricity is generated by fossil fuel power plants but most of them are not easily accessible, increasing cost and decreasing reliability of electricity supply. However, the potential for using PV systems is huge, estimated at tens to hundreds of MWp if only a fraction of the existing Diesel oil plants would adopt some PV to an optimum Diesel/PV mix [39,47].

Presently, several energy companies are evaluating the economic feasibility and planning to operate solar power plants (PV, concentrated PV and CSP) in the Brazilian Northeastern and Mid-West regions. In order to contribute to this effort, INPE (Brazilian National Institute for Space Research) and several universities are working to provide reliable scientific data on solar energy assessment and spatial and temporal variability. INPE released the Brazilian Atlas of Solar Energy in 2006 and is currently preparing the revised edition to deliver a 15 years series of satellite-derived solar irradiation data, taking into consideration typical climatic conditions in Brazil as well as aerosol load information during dry season released by biomass burning events.

The main obstacles to the commercial use of solar energy power generation in Brazil are related to high investment required if compared to conventional generation technologies (primarily hydraulic which accounts for more than 60% of Brazilian electricity matrix), and the lack of reliable and scientific information on its spatial and temporal variability [36]. The solar energy price is expected to fall during the next years due to technological advances and market demand [61]. In addition, the management of solar power plants and electricity distribution systems will request accurate short-term solar energy forecasts as to solar energy share grows.

Reliable forecasts of surface solar irradiance are a key topic that Meteorology services can provide for energy planning and decision-making processes. The issue is to provide more precise and reliable information on future availability of solar resources in order to optimize electricity generation and distribution systems. Several methodologies were developed to provide solar radiation forecast at high temporal resolutions and short-term horizons [22,51]. Some of them are based on numerical weather prediction (NWP) models using parameterizations to simulate the radiative atmospheric processes. Nevertheless, solar radiation forecasts provided by NWP models for one or two day lead times have shown large deviations from ground data acquired at solarimetric sites [24]. The major factors responsible for such deviations are related to the solar radiation dependence on clouds and weather conditions which intrinsically involve non-linear physical processes [25].

This work aims to present a methodology to reduce deviations of solar irradiance forecasts provided by the NWP model by using Artificial Neural Networks (ANNs) as a statistical post-processing method. Artificial neural networks are data-driven instead of model-driven techniques, as the results provided by them depend on the available data used to feed the ANN. Artificial neural networks have been applied to renewable energy assessment, forecasting and designing [30].

Tymvios et al. [59] compared several statistical models and concluded that ANN systems were a promising alternative to traditional approaches for estimating global solar radiation, especially in cases where solar radiation measurements are not readily available. According to Sfetsos and Coonick [54]; the ANN systems are able to predict the solar radiation time series more effectively than the conventional procedures based on the clearness index. The authors observed that the forecasting ability can be further enhanced with the use of additional meteorological parameters such as temperature and wind direction. Mihalakakou et al. [41], Hocaoglu et al. [26]; and Martins et al. [37] also described different methodologies using ANNs to provide quite reliable short-term forecasts for surface solar radiation. Many research articles