



Short-term forecasts of GHI and DNI for solar energy systems operation: assessment of the ECMWF integrated forecasting system in southern Portugal

Francis M. Lopes^{a,b,*}, Hugo G. Silva^{a,b,c}, Rui Salgado^{b,c}, Afonso Cavaco^d, Paulo Canhoto^{b,c}, Manuel Collares-Pereira^{a,b,c,d}

^a Renewable Energies Chair, University of Évora, IIFA, Palácio do Vimioso, Largo Marquês de Marialva, Apart. 94, 7002-554 Évora, Portugal

^b Earth Sciences Institute, University of Évora, Rua Romão Ramalho, 59, 7000-671 Évora, Portugal

^c Department of Physics, School of Sciences and Technology, University of Évora, Rua Romão Ramalho, 59, 7000-671 Évora, Portugal

^d Portuguese Solar Energy Institute, IIFA, Palácio do Vimioso, Largo Marquês de Marialva, Apart. 94, 7002-554 Évora, Portugal

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ABSTRACT

Solar energy is key factor in the demand for clean energy development and management. In particular, global horizontal irradiance (GHI) and direct normal irradiance (DNI) are the foremost important solar resource components that need to be well characterized in order to seek an efficient operation of photovoltaic and concentrated solar power plants, respectively. The objective of the present work is to assess the quality of short-term (24 h) forecasts from a global Numerical Weather Prediction (NWP) model regarding the GHI and DNI components for solar energy applications. Forecast accuracy for the Integrated Forecasting System (IFS), the global model of the European Centre for Medium-Range Weather Forecasts (ECMWF), was verified through the comparison of the predicted hourly values with the corresponding ground-based measurements in southern Portugal. In this study, results from one year of IFS data are analysed, yielding a general good agreement between model and four ground-based measuring stations. High correlations occur particularly for GHI whilst DNI simulations are predominantly hindered by cloud and aerosol representation (i.e. the radiative effects of clouds tend to be underestimated by the model and the radiative effects of the aerosols are overestimated by the model under very clear atmospheric conditions), being closely linked to the parameterization of absorption and scattering phenomena as function of cloud and aerosol type and dimension. Relative differences of annual availabilities for GHI are found between $\sim 0.16\%$ to $\sim 2.12\%$ whilst for DNI values ranging from $\sim 7\%$ to $\sim 12\%$ are found. The respective correlations coefficients are around 0.95 for GHI and between 0.65 and 0.77 for DNI. Regional irradiation maps of GHI and DNI are presented, showing that NWP predictions are an important tool for the operation of electricity generation systems based on solar energy.

1. Introduction

Modern numerical weather forecasting can be separated into three categories: short-, medium- and long-term. Short-term forecasts are carried out to predict the weather over the next day or two. Medium-term are referred to predictions from three days to about two weeks ahead, while long-term forecasts can go up several months ahead in predicting the weather.

In order to perform forecasts, a combination of computer models and weather observations is used to simulate the atmospheric state and its evolution through the integration in the time domain of the

constitutive and state equations that describe the physical phenomena in the atmosphere. During the last decades, there has been technological advances with continuous improvements in the quality of numerical models and solar radiation measuring equipment at ground-level, including the methods used for weather forecasting (Kalnay, 2003). In this context, forecasts of environmental energy fluxes, such as solar irradiance, for time-scales spanning from 1 to 2 days (hourly resolutions) are one fundamental approach for an efficient integration of renewable energy resources into existing energy supply structures. In particular, photovoltaic (PV) and non-concentrating solar thermal systems, which use both the direct and diffuse components, need global

* Corresponding author at: Renewable Energies Chair, University of Évora, IIFA, Palácio do Vimioso, Largo Marquês de Marialva, Apart. 94, 7002-554 Évora, Portugal.

E-mail addresses: fmlopes@uevora.pt (F.M. Lopes), hgsilva@uevora.pt (H.G. Silva), rsal@uevora.pt (R. Salgado), afonso.cavaco@ipes.pt (A. Cavaco), canhoto@uevora.pt (P. Canhoto), collarespereira@uevora.pt (M. Collares-Pereira).

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horizontal irradiance (GHI) forecasts while all concentrating solar photovoltaic (CPV) and thermal (CST) technologies require direct normal irradiance (DNI) forecasts (Schroedter-Homscheidt et al., 2016). PV, CPV and CST systems demand high GHI and DNI forecasting accuracy for an efficient management of solar energy harvesting, which occurs mainly under clear sky conditions (Ramirez and Vindel, 2017; Troccoli and Morcrette, 2014; Ruiz-Arias et al., 2014; Schroedter-Homscheidt et al., 2013; Collares-Pereira and Rabl, 1979).

The GHI consists in the direct and diffuse irradiances on a horizontal plane at the Earth surface (Quaschnig, 2003). The diffuse component is commonly defined as diffuse horizontal irradiance (DHI) and can be directly calculated through DNI and GHI. The DNI component is defined as the solar direct irradiance that is received on a plane normal to the sun's rays over the total solar spectrum (Blanc et al., 2014), and is typically measured as the incoming beam from the Sun's disc and circumsolar irradiance within a 2.5° cone around the sun's center (WMO, 2008). For PV systems, the knowledge of GHI resource and prediction of solar energy generation allows to provide a higher power output under cloudy and clear sky conditions. Additionally, information about GHI availability is important to predict the energy output of PV systems and to help the mitigation of possible power fluctuations that can occur in electric grid injections (Pascual et al., 2015). In the case of CPV and CST systems, which have the advantage of having a higher energy storage capacity (Forrester, 2014), knowledge of DNI is fundamental if clear sky conditions occur. Forecasting DNI is important mainly for CST plants operation in order to reduce the uncertainty of solar power plant outputs due to solar irradiance intermittency (Law et al., 2014) and to optimize the necessary CST electrical energy generation (on time scales of few minutes to few hours) and maximize the energy output for a given day. In other words, there is the utility side where DNI predictions are important to project the impact of a possible sudden interruption in the grid and also to predict the total electricity needed in the grid. In fact, for medium and long-term periods such predictions are important for the power plant's operation and its energy dispatchability, i.e. the capability of a power plant to carry out energy outputs in the grid to increase economic return by delivering electricity during the more demanding and valuable periods (Ramirez and Vindel, 2017).

With the growth of the solar energy sector, in particular CST technologies, there has been a simultaneous increased interest and development in Numerical Weather Prediction (NWP) models in order to understand the spatio-temporal variation of solar irradiance and to perform short-term predictions of DNI (e.g. Ruiz-Arias et al., 2016; Schroedter-Homscheidt et al., 2009; Troccoli and Morcrette, 2014). For that matter, the forecast horizon, together with data quality control, is an important feature for an appropriated prediction. For instance, NWP models can provide accurate short-term forecasts above a forecast horizon of 6 h (in the upper limit of nowcasting, which is typically below 1-h) while artificial neural networks can perform accurate forecasts below the 6-h mark. However, current state-of-the-art NWP models have more difficulty in predicting DNI than GHI due to deviations mainly related to the representation of clouds (cloud cover and type) which are aggravated during overcast periods (Schroedter-Homscheidt et al., 2013). This generally affects the current NWP models, for example the European Centre for Medium-Range Weather Forecasts (ECMWF) global model, the Weather Research and Forecasting (WRF) model and the non-hydrostatic mesoscale (Meso-NH) model. Moreover, aerosol content is one key component that is not correctly taken into account, in detail, in operational NWP modelling (Mulcahy et al., 2014). However, it can induce substantial DNI variation as the result of scattering and absorption of radiation as well as the interaction with cloud microphysical and dynamical processes (Fan, 2016). For instance, these variations in DNI can reach a reduction of 80–90% in extreme events such as desert dusts (Kosmopoulos et al., 2017). Mukkavilli (2018) has recently shown that extreme dust events depicting large DNI mean bias overpredictions are found to be 4.6 times higher than background results. Under clear sky conditions, NWP

models also reveal that aerosol component is essential to obtain accurate estimations of surface irradiance, with improvements found to be up to 58% and 76% in GHI and DNI, respectively, as described by Jimenez and Hacker (2016). Troccoli and Morcrette (2014) have used the ECMWF Integrated Forecasting System (IFS) model (Mozdzyński and Morcrette, 2014) to predict DNI with satisfactory results after a simple post processing bias-correction procedure which allowed to substantially enhance the model performance. An important improvement in the IFS would be the use of coupled modules for aerosol and chemistry, as those developed within the Copernicus Atmosphere Monitoring Service (CAMS), allowing to use a prognostic aerosol scheme initiated by an aerosol data assimilation system. However, the use of such prognostic aerosol schemes has a high impact on the IFS efficiency, since the computational cost can increase more than 50% (Bozzo et al., 2017). For this reason, a monthly climatological description of the aerosol component is currently the most viable approach. Along with all the necessary corrections and improvements concerning cloud and aerosol representation within NWP, it is also important to quantify the forecast error of a model. To that end, the use of forecasting metrics, such as the mean square error skill score (as described in Section 2), reflect a suitable measure of forecasting skill that should be taken into account regarding forecast inaccuracies (Coimbra et al., 2013).

Another approach to improve forecasting precision should be by enhancing the ECMWF model through the use of a hybrid nowcasting system composed by a higher resolution NWP model and the use of an all-sky image (ASI) system (Seiz et al., 2002). The latter is comprised by a cloud tracking system as the one currently operational in Mitra (near Évora, Portugal) through the use of four ASI cameras, and soon to be implemented for further studies. Cloud shadow cameras have also been recently used for the prediction of GHI and DNI in Spain (Kuhn et al., 2018). Such methods can allow to generate more refined short-term forecasts of GHI and DNI for solar energy applications than the previous state-of-the-art (e.g. Cheng, 2016; Marquez and Coimbra, 2012; Chow et al., 2011).

This work is focused on the grid manager's point of view for the next 24-h horizon of available GHI and DNI by analysing model predictions with four ground-based measuring stations and, ultimately, by producing irradiance maps. This is of particular relevance for DNI due to the fact that there is still the need for development in the prediction of this solar resource as such tool can enhance the knowledge and investment in the energy and environmental sectors. Moreover, forecasts of hourly solar irradiance produced by the ECMWF global model for the next 24-h are here assessed with data from a network (DNI-A project, reference ALT20-03-0145-FEDER-000011), which was designed and installed for the operationalization of solar power plants, rather than Baseline Surface Radiation Network (BSRN) records (Roesch et al., 2011), which were typically installed for solar assessment only. As first step for the operationalization of existing and future solar energy applications in semi-arid and arid regions, this study aims to provide advice and optimization through the forecast of regional irradiation maps performed by the IFS model. The present study is not restricted to one region since it has the potential to contribute for a better management of solar electrical power plants demanding high accuracy forecasts in other regions with high solar potential such as near the equator and in arid climates away from major sources of pollution such as south of the Iberian Peninsula, northern and southern Africa, Australia, south and north America. The study is focused in southern Portugal, a semi-arid region (Chambel et al., 2007), where the climate is mostly of the Mediterranean type (Csa, according to the Köppen classification), with a small area within the mid-latitude steppe (Bsk) category (Lopes et al., 2016). Maximum temperatures can reach between 31 and 35 °C on average during July and August, often reaching values close to 40 °C, or even higher. The synoptic circulation in the region during the summer months is dominated by the frequent development of the shallow Iberian low-pressure system inside a larger scale high-pressure system,

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