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Reliability of day-ahead solar irradiance forecasts on Reunion Island depending on synoptic wind and humidity conditions

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Abstract

Day ahead solar irradiance forecasting is essential to manage solar energy systems and assist decision-making. Available global and mesoscale Numerical Weather Prediction (NWP) models show limitations for regions with high complex terrain in solar irradiance forecasts, due to the usual coarse resolution of the models and the difficulties in reproducing the correct physics (in terms of cloud evolution) at the correct moment. This is the case of Reunion Island (21°S, 55.5°E) a 60-km wide tropical island located in the Southwest of the Indian Ocean basin.

This work explores the use of NWP thermodynamic variables at synoptic scale as predictors of solar irradiance as they are commonly considered robust and well predicted by these models. Our analyses show that the diurnal cycle of solar irradiance on Reunion Island is sensitive to synoptic wind and relative humidity at 700 hPa (RH_{700}). Moreover, this sensitivity varies depending on the site location on the Island with respect to synoptic wind direction. Hence, stations that are most exposed to synoptic wind, show greatest sensitivity. From these results, we have developed an empirical-statistical downscaling (ESD) method for day-ahead local-scale solar irradiance forecast and forecast reliability for the Reunion Island case, which searches for past analogous conditions of synoptic wind and RH_{700}. Our study uses 12 years of ECMWF reanalysis data together with ground-based measurements at 21 stations on the island. Forecasting results for 4 of these stations plus an aggregate virtual station (derived as the mean of 11 coastal stations) show that the ESD method outperforms a climatology-based method in all cases. The contribution of this method for solar irradiance forecasting and its reliability are discussed.

Keywords: Tropical atmospheric dynamics; Synoptic wind and humidity conditions; Solar irradiance variability; Day-ahead solar irradiance forecasting

1. Introduction

Day-ahead forecast of solar irradiance and photovoltaic (PV) production is needed to manage solar and other energy sources plants, necessary to cover consumption demand in a given region.

The main factor affecting the photovoltaic production is the solar resource, commonly represented by solar irradiance and irradiation, which vary with the latitude, the day of the year and the day time. The solar resource is largely modulated by atmospheric components. Clouds modulate solar irradiance in all time and space scales.

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The high variability in solar irradiance induced by clouds can be considered the primary cause for both intermittency and non-guaranteed nature of photovoltaic energy (e.g., Kleissl, 2013). In this sense, weather and cloudiness forecasting are the main keys for PV plant and electric grid management. Better forecasting tools are at the base of further solar energy integration in the electrical grid improvement.

This work focuses on the need for high spatial resolution day-ahead solar irradiance forecast for tropical islands and, in particular, for the Reunion Island (Southwest of the Indian Ocean basin).

Among existing approaches, forecasts based on Numerical Weather Prediction (NWP) are the most appropriate in the day ahead forecast horizon (Lorenz and Heinemann, 2012). However, NWP forecasting scores have shown highly variable dependency on the climate and meteorological characteristics of the site of interest. Root mean Square error (RMSE) can vary from about 7% (relative to the mean measurement), for arid regions, to greater than 60% for cloudy mountain regions (Perez et al., 2013; Kleissl, 2013). This has also been reported for the case of Reunion Island. Diagne et al. (2014) found relative RMSE values of 37.2% and 57.3% for a coastal site and a near mountain site, respectively, for a one-year day-ahead hourly solar irradiance forecast when using the direct output of NWP runs (with the Weather Forecast & Research (WRF) model).

Reunion is a small island (60 km width) with complex orography in which local dynamics plays a main role in cloud processes. As a consequence, cloudiness and solar irradiance can be very different between two points, a few km apart in hourly and daily scales (Badosa et al., 2013). Thus, the available NWP global models, which have spatial resolution of some tenths of km, have been proved not appropriate for this kind of regions, if applied directly. Downscaling methods are needed to obtain finer spatial resolutions.

Dynamical downscaling consists of using the output of a global NWP model to run a limited-area NWP model, whose spatial resolution is typically a few km. The high resolution NWP model is able to solve local physical processes either explicitly or through parameterizations. Dynamical downscaling is demanding in terms of expertise and computing resources. It has, in particular, the challenges of (1) choosing physical configurations adapted to the site of interest and (2) even if this was achieved, dealing with the fact that clouds are rarely forecasted at the correct location at the correct time. This is known as the double penalty issue (e.g. Jolliffe and Stephenson, 2012). These issues make forecasting reliability from local-area high-resolution models variable, and forecasting highly depend on cloudiness regimes. As an example Lara-Fanego et al. (2012) reported RMSE from below 10% under clear-skies to 50% for cloudy conditions using the Weather Research & Forecasting model in Southern Spain with 3 km spatial resolution.

Complementary to dynamical downscaling, empirical-statistical downscaling (ESD) consists in deriving local scale forecasts from large-scale NWP global models using statistical relationships with local-scale observations (Benestad et al., 2008). These relationships can be established in many ways, within two main categories: linear (simple multivariate methods, regression, canonical correlation analyses, etc.) and non-linear techniques (cluster analyses, analog methods, Neural networks, etc.). In all cases, the ESD method requires the selection of large-scale parameters that can be (or converted into) predictors of local scale predictands, herein the solar irradiance. The quality of the forecast will depend on the reliability of the predictor.

The present work investigates the influence of large-scale atmospheric parameters (i.e. conditions encountered upstream of Reunion Island, hereafter referred to as synoptic conditions) on the local solar irradiance and its variability at diurnal time scale, and presents an ESD method based on past analogous synoptic conditions identification to perform day-ahead solar irradiance forecasts on Reunion Island to derive forecast reliability.

Analog-based methods (also known as k-nearest-neighbour k-NN) have been developed for forecasted quantities such as precipitation (e.g., Zorita and Von Storch, 1999) and tropical cyclone tracks (e.g., Fraedrich et al., 2003) but rarely to forecast solar radiation (Inman et al., 2013); and mainly using endogenous parameters (that is, only parameters derived from solar radiation past data). Actually, to our knowledge, this is the first time that this method is developed to forecast the diurnal cycle of solar irradiance with exogenous parameters (others than solar radiation based parameters).

The atmospheric thermodynamic context for Reunion Island is exposed in Section 2 as the basis of the research for parameters as predictors. Section 3 presents statistical analyses with these synoptic parameters to assess their variability and their impact on the local-scale. The relationships between the selected synoptic parameters and the diurnal cycle of local-scale solar irradiance are presented in Section 4. In Section 5, we present the day-ahead solar irradiance ESD forecasting method that uses synoptic parameters as predictors. Forecast reliability is discussed. Conclusions are presented in Section 6.

2. Atmospheric thermodynamic context for Reunion Island: searching for the key synoptic variables

Reunion Island (21°S, 55.5°E) has a complex orography, with two high altitude summits (3070 m and 2560 m) separated by a 1500 m plateau.

Due to its tropical location, the descending branch of the Hadley cell affects the large-scale dynamics around Reunion and the main regime is thus characterized by large-scale subsidence (Badosa et al., 2013). The island is thus directly affected by a high atmospheric pressure system, known as the Mascarene High whose influence partially vanishes in Austral Summer, as the Inter Tropical