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Optimal combination of gridded and ground-observed solar radiation data for regional solar resource assessment

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Abstract

Proper quantification of the available solar resource is essential for the diverse development phases of any solar power plant. At local scale, the solar resource is best assessed from ground radiometric stations. At regional-to-continental scales, however, satellite-based techniques are currently the most suitable approach. Solar radiation evaluation using numerical weather prediction (NWP) models presents some advantages over satellite-based techniques. Nonetheless, gridded solar radiation estimates using either satellite-based or NWP-based techniques still produce biased estimates which are often much higher for the latter. Therefore, a correction needs to be applied before these gridded values are usable for solar applications, especially for NWP-based estimates. This contribution introduces an original method based on the optimal interpolation technique to adjust gridded solar radiation estimates consistently with concomitant radiometric ground observations. The method's performance is demonstrated using NWP-based gridded estimates with 10-km spacing of global and direct monthly irradiation data during the 10-year period from 2003 to 2012 over continental Spain and the Balearic Islands. It is shown that the proposed methodology produces adjusted gridded values that are (or nearly always are, in the case of direct irradiation) within the expected measurement uncertainty of the ground observations, provided a sufficiently large number of observations is available for correction. For the studied region and these NWP-based gridded datasets, our findings suggest that a homogeneous mean distance between ground observations of 100–150 km can result in unbiased gridded estimates.

Keywords: Solar resource assessment; Optimal combination; NWP; Ground observations

1. Introduction

Solar resource assessment is the characterization of the solar radiation amount that is available over a region or specific location during a generally long period of interest. Many details on the whole multistep process that is involved in the practice of solar resource assessment are provided elsewhere (e.g., Stoffel, 2013; Kleissl, 2013). Solar radiation is important for several applications and fields of knowledge, such as architecture, agriculture, forestry, ecology, hydrology, meteorology, and energy. Particularly, a proper solar resource assessment is of paramount

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importance in the diverse development phases of any solar power plant, from the early feasibility stage – in which the use of accurate datasets is crucial – up to the final design, financial evaluation, commissioning and operational phases, when bankable results with low uncertainty are required (McMahan et al., 2013; Vignola et al., 2013).

The solar resource is best evaluated from radiometers deployed at ground stations, assuming they are properly maintained and well-calibrated. Thereby, when a sufficient density of ground stations is available, interpolation methods are appropriate to evaluate the solar resource over a region (Zelenka et al., 1992a,b,c; Rehman and Ghori 2000; Apaydin et al., 2004; Bosch et al., 2008; Alsamamra et al., 2009; Ruiz-Arias et al., 2011a; Gutierrez-Correa et al., 2014). Radiometers, however, are costly to maintain – then, availability of measurements is rather scarce – and the measurements are representative only of a limited area around the radiometer location. Actually, some authors (Perez et al., 1997; Zelenka et al., 1999) have estimated that, when the distance between stations becomes more than ≈30 km, solar resource assessments based on satellite techniques are preferable.

During recent decades, satellite-based techniques have become the standard method for solar resource assessment at regional, continental or global scale (Cano et al., 1986; Diabaté et al., 1989; Beyer et al., 1996; Hammer et al., 2003; Pereira et al, 1996; Perez et al., 2002; Schillings et al., 2004; Lefèvre et al., 2007; Polo et al., 2008; Ruiz-Arias et al., 2010a; Cebecauer et al., 2010; Viana et al., 2011; Dekker et al., 2012: Perez et al., 2013; Miller et al., 2013; Linares-Rodríguez et al., 2013). However, these methods still suffer from limitations, originated partly from the still insufficient three-dimensional description of the microphysical and optical properties of clouds. This fact is particularly limiting for the computation of direct normal irradiance. In addition, the availability of historic satellite records suitable for solar radiation assessment is often rather short. Therefore, although satellite-based methods have reached a remarkable degree of maturity and reliability (Ineichen, 2014), local correction procedures (also known as site adaption methods or record extension methods) using more reliable local ground observations are required to assure the bankability of the satellite-derived solar radiation estimates.

It has been shown, for instance, that the use of local observations of aerosol optical depth (Gueymard et al., 2012) and daily aerosol optical depth estimates rather than monthly values (Cebecauer et al., 2010) lead to improved solar radiation estimates, very particularly, for direct normal irradiance. Alternatively, correction methods of satellite-derived solar radiation estimates based on existing overlapping observations of solar radiation (both in space and time) from ground radiometers have been proposed (Meyer et al., 2008; Bender et al., 2011; Gueymard et al., 2012; Wey et al., 2011; Mieslinger et al., 2014; Šúri and Cebecauer, 2011). In these methods, a model, which is generally a function of the satellite-based solar radiation estimates, is fitted against concurrent ground observations. Then, the model is extrapolated to non-overlapping periods of data to correct the satellite estimates. These methods, however, do not generally consider the usual decrease of temporal auto-correlation while the time lag between the model's training period and the correction period increases, which can result in over- or under-corrections. This fact is particularly critical for the case of direct normal irradiance, in which inter-annual variability is usually much higher than for global irradiance (Lohmann et al., 2006; Pozo-Vázquez et al., 2011; Gueymard, 2012). As a consequence, the correction model, which is trained for a limited period, may be of little validity for a different period. In addition, the application of this methodology is restricted to the cases in which overlapping ground observations exist. This may not always be the case, particularly at remote sites. Therefore, the correction step has to be typically postponed while an observing period of, ideally at least one year, is completed. Alternatively, nearby observations can be used for the correction as long as the spatial covariance structure of the simulated data errors and ground observation errors is considered. In this sense, and on larger spatial scales, methods to fuse satellite-derived data and corresponding ground observations have started to surface a few decades ago. Recent studies include those proposed by Wald et al. (2003), Journée et al. (2012), and Blanksby et al. (2013) for solar radiation, or Chatterjee et al. (2010) and Ruiz-Arias et al., 2013b for aerosol optical depth.

Numerical Weather Prediction (NWP) models represent an alternative to the satellite-based approaches for the regional assessment of solar radiation (Linares-Rodríguez et al., 2011; Ruiz-Arias et al., 2011b, 2013a). Very importantly, in addition to solar resource assessment, NWP models can also be used to provide solar radiation forecasting from a few hours to days ahead (Lara-Fanego et al., 2012a,b; Perez et al., 2013). They have some other potential advantages over satellite methods, such as the possibility to evaluate solar radiation at global scale over longer periods than satellites – up to several decades backward – , and the fact that NWP models perform a comprehensive simulation of the whole atmospheric system, including ancillary variables such as wind, temperature or relative humidity. Nonetheless, the accuracy of NWP models at computing surface solar radiation is still significantly less than what is achievable with the current satellite-based models (Lohmann et al., 2006; Kennedy et al., 2011; Jia et al., 2013; Bojanowski et al., 2014). However, where surface solar radiation observations are available, both NWP-based and satellite-based estimates can be corrected by means of data fusion techniques, as mentioned above.

This contribution proposes a correction method based on data assimilation techniques (Kalnay, 2003; Lahoz et al., 2010) in which a gridded estimate of solar radiation is corrected in the vicinity of ground observations based on the structure of the spatial covariance of the errors in both the gridded dataset and ground observations. The method