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Impact of atmospheric aerosol loads on Concentrating Solar Power production in arid-desert sites

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Abstract

The accurate quantification of direct normal irradiance (DNI) and the production of time series of DNI have a key role during the planning and designing stages of CSP plants. Satellite derived data are frequently used for that purpose. One of the important sources of uncertainty for satellite derived DNI is the accuracy in the quantification of aerosol optical depth, one of the most important parameters that contribute to solar radiation attenuation at the Earth's surface. This topic can be extremely important in desert and arid places where sudden and large increase of aerosol optical depth can be eventually expected. This work presents an analysis of the uncertainty about the knowledge of aerosol optical depth in Sede Boqer and Tamanrasset, its contribution to the uncertainty of DNI values estimated from Meteosat imagery, and finally the impact on the CSP plant energy dispatched. Reference plants for CSP parabolic trough and CSP tower technologies have been modelled with SAM with no thermal storage system, and a GEMASOLAR plant-type has been also modelled as an example of tower plant with large thermal storage system. The results have shown that in Tamanrasset the sudden and eventual high peaks of aerosol optical depth resulted in an important decrease of the daily energy produced by the plant; this reduction is not always observed when satellite derived DNI is used to input meteorological conditions in SAM due to the underestimation of the aerosol optical depth. The use of large thermal storage system notably reduces the impact of these phenomena on the CSP power plant output.

Keywords: Atmospheric aerosols; Concentrating Solar Power; DNI uncertainty; Satellite derived solar radiation

1. Introduction

Solar energy is becoming a high promising technology for electricity generation with an important penetration worldwide in the renewable energy mix and with very good expectances for the near future. In particular, concentrating solar power technology (CSP) is nowadays a feasible technology with an increasing deployment in many developed and emerging countries (Siva Reddy et al., 2013), in part due to its stable response and good dispatchability, particularly when a thermal storage system is added to the solar field.

CSP technologies need high and stable levels of direct normal irradiation (DNI) in order to be competitive with other technologies. In this sense, arid or desert sites at low latitudes are potential targets for CSP plants due to the high level of solar irradiation and the very low frequency of cloudy days. In consequence, large and important projects and initiatives are growing in MENA (Middle Eastern and North African) region (Kost et al., 2012; Trieb et al., 2012; Liqreina and Qoaider, 2014), such

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as the so called DESERTEC Foundation (http://www.desertec.org/).

Therefore, accurate knowledge of DNI is needed for addressing successfully the different stages of a CSP project, from site selection to plant performance simulations through DNI time series of hourly or even sub-hourly values (Stoffel et al., 2010). Unfortunately, the database of measurements of DNI is rather scarce worldwide (in both spatial density and time), and particularly in MENA region, making use of different retrievals to supply the solar radiation information needed. Among them, satellite based methods for estimating the different components of the solar radiation are among the most widely used approaches for supplying both global horizontal (GHI) and direct normal irradiances (Mueller et al., 2004; Rigollier et al., 2004; Polo et al., 2008; Blanksby et al., 2013; Perez et al., 2013). A very good comparative study is presented by Ineichen for several providers of satellite based information (Ineichen, 2014).

The uncertainty of solar radiation derived from satellite images is normally higher for DNI than for GHI estimations. There are several sources of uncertainty in the quantification of DNI, but one of the most relevant with remarkable impact in arid and desert sites is consequence of the inaccurate atmospheric aerosol data that are used as input to satellite models (Gueymard, 2011, 2012a; Suri and Cebecauer, 2011). Cebecauer et al. (2011) present detailed information of the various possible sources of uncertainty in DNI modelling, and concerning aerosols in sunny regions they recommend to use daily aerosol data in order to significantly reduce the uncertainty in DNI estimation. Aerosols are, under cloudless conditions, the most contributors to solar radiation attenuation. This is particularly true in desert regions, where clear sky conditions are mostly prevalent. Thus, inaccurate determination of eventual high loads of aerosols can produced important errors in direct normal irradiance computation. The parameter that governs the attenuation of solar radiation due to atmospheric aerosols is the aerosol optical depth (AOD), which is an important input to many radiative models. The effect of aerosols on DNI in Europe under clear sky conditions has been reported by Nikitidou et al. (2014) remarking the increase of DNI (brightening effect) due to the decreasing tendency of AOD over Europe.

This work presents a study of the impact of uncertainty in AOD determination on CSP electricity generation in desert and arid sites. For that purpose two specific sites in the MENA region with enough ground measurements available have been selected: Sede Boqer (Israel) and Tamanrasset (Algeria). Both have instrumentation of high quality and host BSRN (Baseline Surface radiation Network) and AERONET (Aerosol Robotic Network) stations, so that accurate DNI and AOD measurements are available. Computation of DNI using Meteosat satellite imagery has been performed in both sites and the AOD input has been provided by MACC (Monitoring Atmospheric Composition and Climate). Finally, simulation of the power generated by CSP plants has been estimated using System Advisor Model (SAM) for reference plants in parabolic trough and central receiver technologies without thermal storage system. In addition, simulation of the energy produced by a GEMASOLAR plant-type have been also performed for illustrating the mitigation capacity of the thermal storage for the aerosol loads.

2. Experimental data

The selected sites for the study must accomplish the following features: to be placed in an arid or desert region, to have accurate measurements of DNI and to have also accurate measurements of AOD. Tamanrasset and Sede Boqer stations were selected since they belong to BSRN and to AERONET network and they offer long time measurements of both DNI and AOD with higher accuracy than other sources of information. Hourly values of global horizontal, direct normal and diffuse irradiances have been collected in both stations for the period 2009–2011. The quality of the data have been analysed following the recommendations of the BSRN (McArthur, 1998). In the case of

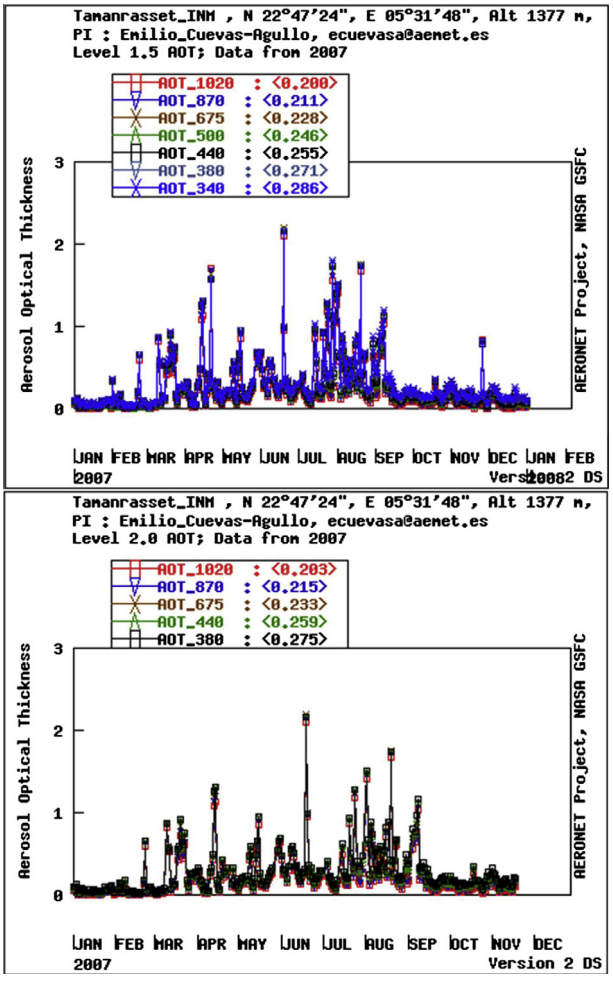

Fig. 1. Comparison of Aeronet Level 1.5 and Level 2.0 for Tamanrasset site (image obtained from http://aeronet.gsfc.nasa.gov/).