Comparison between Measurements and Model Simulations of Solar Radiation at a High Altitude Site: Case Studies for the Izaña BSRN Station

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Abstract. In this work we have carried out a comparative study of shortwave downward radiation (SDR) measurements and simulations obtained with the radiative transfer model (RTM) LibRadtran in order to be used as a model quality control at Izaña BSRN (Baseline Surface Radiation Network). We selected cases corresponding to the most common atmospheric conditions at the Izaña station (IZA), we analyzed: clear-sky and African dust intrusions. The input parameters for the model, such as a total ozone column, surface albedo, water vapour column and aerosols parameters, were measured at IZA. The results of the two clear-sky case studies (16 May and 26 October 2010) analyzed here show an underestimation of the simulations for the SDR global and direct for solar zenith angles (SZA) lower than 70°. The maximum relative differences for SDR global, direct and diffuse are 6%, 2% and 6%, respectively. For dust intrusion case studies (22 July 2009 and 10 July 2010) and for SZA lower than 70°, the simulations of the direct normal component are slightly overestimated. For the SDR global, direct and diffuse components, the maximum relative differences are 1%, -1% and 8% for 22 July 2009 respectively, and 5%, 4% and 3% for 10 July 2010. The overall results of the RMSE for the global direct and diffuse components are 3%, 10% and 4% and 2%, 3% and 5% for both atmospheric situations. These results show a reasonably good agreement between simulations and measurements.

Keywords: Solar radiation, Izaña station, Radiative transfer model, BSRN, Global radiation, Direct radiation and Diffuse Radiation.
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INTRODUCTION

The comparison between shortwave downward radiation (SDR) measurements and simulations from radiative transfer models (RTM) has been largely developed in the last decades. We are interested in the analysis of solar radiation Baseline Surface Radiation Network (BSRN) data, and in this context one of the most recent works [1] show differences between observed and modeled direct and diffuse SDR of -1.8% and 5.2%, respectively, during cloud-free periods at the Payerne BSRN site. The mean differences of modeled minus observed global SDR are small (<1%) and within the instrumental error. [2] found mean differences between model and measurements of 2 W/m^2 (+0.2%) for the direct irradiance, 1 W/m^2 (+0.8%) for the diffuse irradiance, and 2 W/m^2 (+0.3%) for the global irradiance at Cabauw (Netherlands) BSRN site.

The main goal of the present work is to make detailed comparisons between estimated radiation from *LibRadtran* model and high-quality radiation observations for the SDR global, direct and diffuse, and to study their capabilities for modeling the solar radiation field at a high altitude (2367 m a.s.l.), in order to apply it in the quality control protocol. Particularly, we selected cases corresponding to the most common atmospheric conditions at the Izaña BSRN, we analyzed: clear-sky and African dust intrusions.

SITE MEASUREMENTS AND INSTRUMENTS

The Izaña Atmospheric Observatory (IZA) is part of the Global Atmospheric Watch (GAW) program and is managed by the Izaña Atmospheric Research Center (IARC) belonging to the Meteorological State Agency of Spain (AEMET). It is located in Tenerife Island (Canary Islands) at 28.3°N, 16.5° W, 2.367 m a.s.l. IZA is located above a quasi-permanent inversion layer, consequently it offers excellent conditions for in situ measurements of trace gases

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and aerosols under "free troposphere" conditions and atmospheric observations by remote sensing techniques. The environmental conditions (stable total column ozone, very low column water content and low aerosols content) and the high frequency of clean and pristine skies make IZA optimal for calibration and validation activities.The radiation site in Izaña is part of BSRN since 2009. In IZA SDRs are measured with different types of instruments. The global and diffuse SDR are measured with unshaded and shaded Kipp and Zonen CM-21 Pyranometers. The direct SDR is measured with a Kipp and Zonen CH-1 Pyrheliometer placed on a sun tracker with a tracking accuracy of 0.1°.

RADIATIVE TRANSFER MODEL AND INPUT PARAMETERS

The model used in this work is *LibRadtran* model. It is a complete software package containing an extended set of tools for radiative transfer model calculations in the Earth's atmosphere. Its main tool is the *Uvspec* program [3], that we will refer to as the *LibRadtran* model.

This model is divided into three main parts: the first part provides the optical properties needed as input for the radiative transfer equation (RTE) solver, including atmospheric properties, ozone profiles, surface pressure, cloud properties, temperature, etc. The second one solves the RTE based on different possible methods using the aforementioned optical properties, and calculated the radiances, irradiances and actinic fluxes. The last part of the code applies different elements to the output of the RTE solver such as convolution with a slit function, correction for Earth-Sun distance or multiplication with the extraterrestrial solar irradiance.

For the estimations of SDR we have used as RTE solver Disort2 (Discrete Ordinates Radiative Transfer 2.0), which is based on the multi-stream discrete ordinates algorithm developed by [4] for SZA≤70° and Sdisort for SZA>70° which introduces corrections due to the sphericity of the Earth described by [5]. The extraterrestrial solar flux was selected from Kurucz [6] and the absorption cross section of ozone used was the Bass and Paur [7]. The profiles of the atmospheric gases O_2, H_2O, CO_2 and NO_2 were taken from standard atmosphere "afglms" (Midlatitude Summer) [8]. However the temperature, atmospheric pressure and total column ozone were taken from the monthly average profiles of the "Izaña average atmosphere". These profiles have been computed using long-term ozonesonde series (1992-2007) of the Santa Cruz de Tenerife (36 m a.s.l.) station, located 28 km to the north-east from IZA Observatory. *LibRadtran* model calculations were performed for a spectral range of 300 to 2600 nm with a step of 1 nm.

The total column ozone is obtained with Brewer spectroradiometers. Since 2003 IZA is the Regional Brewer Calibration Center for Europe (RBCC-E) and the total ozone program at Izaña station is part of the Network for the Detection of Atmospheric Composition Change (NDACC). The ozone variation is very low throughout the day and therefore we take the daily mean value as input of the model. The instrumental uncertainty is ± 1 D.U.

The aerosol parameters considered in this work are: AOD, the scattering albedo ω_o and the asymmetry parameter, g, which are measured at IZA, since this station belongs to RIMA-PHOTONS European networks federated to AERONET. Measurements of the AOD are performed with CIMEL sunphotometers and the ω_o and g parameters are retrieved by the inversion AERONET algorithm [9]. We utilized constant values for ω_o and g, of 0.90 and 0.85 ,respectively. The measurements at 940 nm are used to derive the water vapour column. In this work we have considered AOD at 550 nm, this input has an accuracy ±0.01 for wavelengths greater than 440 nm and the uncertainty in water vapour column is 10% [10,11].

In this work, we selected cases corresponding to the most frequent atmospheric conditions at the IZA, we analyzed: clear-sky conditions (2 cases studies; 16 May and 26 October 2010) and African dust intrusions (2 cases studies; 22 July 2009 and 10 July 2010). Table 1 shows the mean and standard deviation values of input parameters in the case studies. We utilized the daily mean values of ozone column and surface albedo, but instantaneous values for AOD (550 nm) and water vapour. During days affected by dust intrusions the column water vapour increases due to the absence of the inversion layer that allows the ascent of the humid air from the lower layers of the atmosphere.

TABLE (1). Mean and standard deviation values of input parameters in the case studies. (Clear-sky: 2010-05-16 and 2010-10-26; Dust Intrusion: 2009-07-22 and 2010-07-10).

Date	AOD (550 nm)	Water Vapour (mm)	Ozone Column (D.U.)
2010-05-16	0.024 ± 0.002	1.147 ± 0.142	340 ± 5
2010-10-26	0.005 ± 0.001	4.122 ± 0.191	258 ± 1
2009-07-22	0.339 ± 0.068	9.081 ± 0.191	289 ± 1
2010-07-10	0.415 ± 0.172	8.533 ± 0.911	291 ± 2

RESULTS AND CONCLUSIONS

Figure 1 and Figure 2 show a comparison between observations and model simulations of SDR global, direct and diffuse under clear-sky and dust intrusions conditions, respectively.

For clear-sky days (Figure 1), the SDR direct is underestimated by the model, while SDR global and diffuse do not present the same behavior during the day. For SZA≤70°, the RMSE is 31 W/m^2 (4%), 37 W/m^2 (4%) and 2 W/m^2 (5%) for 16 May 2010 for the SDR global, direct and diffuse, respectively, and 5 W/m^2 (1%), 13 W/m^2 (1%) and 1 W/m^2 (2%) for 26 October 2010 for the SDR global, direct and diffuse, respectively. These results are within the instrumental error and uncertainty associated with each input parameter. AOD values are very small and they are within the CIMEL instrumental error, 0.024±0.002 for 16 May 2010 and 0.005±0.001 to 26 October 2010 (Table 1).

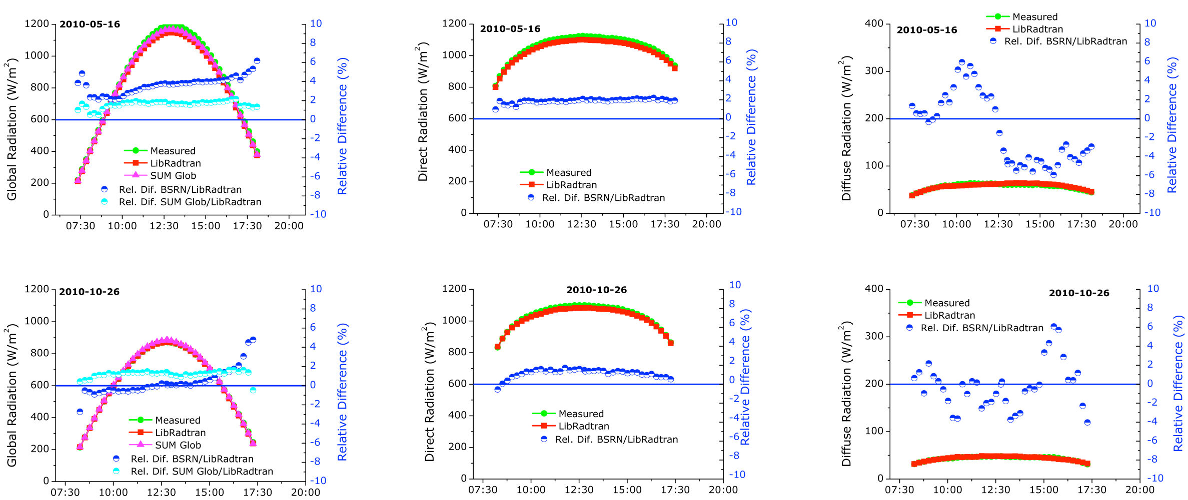

FIGURE 1. Comparison between global, direct and diffuse radiation measurements (the green line) and simulations performed with *LibRadtran* model (the red line) in clear-sky days. Also is represented the sum of direct and diffuse component, SUM Glob (the magenta line). ((a) Top panels 16 May 2010 and (b) bottom panels 26 October 2010). The blue and cyan dots show the relative difference (measurements-simulations/measurements).

For dust intrusions days (Figure 2), the SDR direct is overestimated in both days. For SZA≤70°, the maximum relative differences are 1%, -1% and 8% with corresponding RMSE of 7 W/m^2 (1%), 26 W/m^2 (4%) and 13 W/m^2 (5%) for 22 July 2009 for the SDR global, direct and diffuse, respectively, and the maximum relative differences are 5%, 4% and 3% with corresponding RMSE of 18 W/m^2 (2%), 9 W/m^2 (1%) and 4 W/m^2 (1%) for 10 July 2010 for the SDR global, direct and diffuse, respectively.The differences obtained between measurements and simulations are within the uncertainty of measurements for the global and direct SDR for SZA lower than 70°. These differences can be explained by the uncertainties attributed to the extraterrestrial spectrum, the instrumental error and the uncertainty in the input parameters of the simulations.The results in both case studies show a reasonably good agreement between simulations and observations, being always within the instrumental error for the SDR global and direct.

The discrepancies found for the SDR diffuse are due to the uncertainties of observations and input parameters, mainly the AOD, due to the very low AOD values. In the dust intrusion days the SDR diffuse observed and simulated shows a smaller difference than the clear-sky days. In clear-sky days the AOD values are lower than the instrumental error. This may explain the differences found between measurements and models for SDR diffuse case [12].

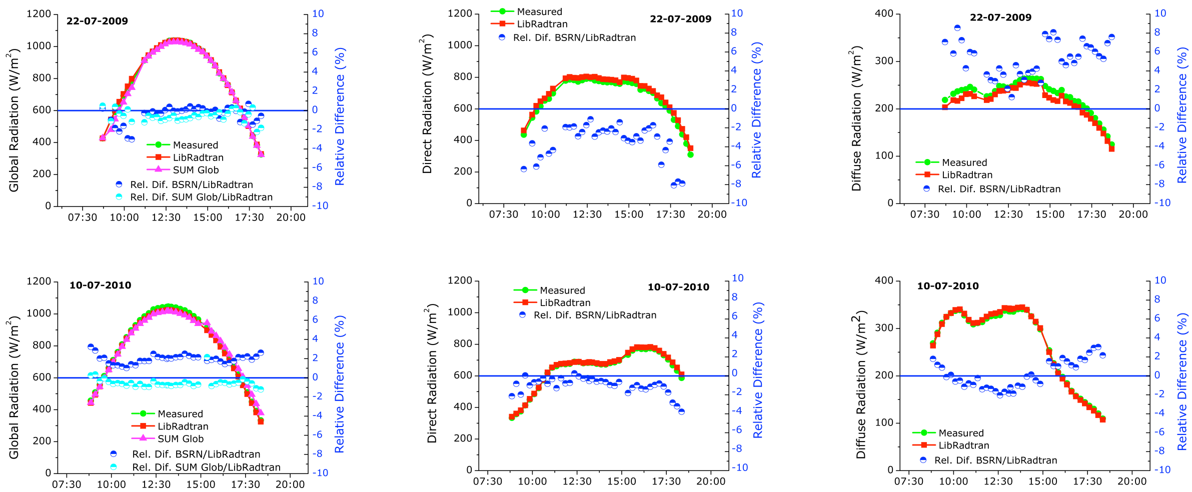

FIGURE 2. Comparison between global, direct and diffuse radiation measurements (the green line) and simulations performed with *LibRadtran* model (the red line) in dust intrusions. Also is represented the sum of direct and diffuse component, SUM Glob (the magenta line). ((a) Top panels 22 July 2009 and (b) bottom panels 10 July 2010). The blue and cyan dots show the relative difference (measurements-simulations/measurements).

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