

Validation of libRadtran and SBDART models under different aerosol conditions

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Abstract. This study is aimed at analyzing the performance of the radiative transfer models libRadtran and SBDART for estimating the shortwave (285-2800 nm) irradiance under different aerosol conditions. For that purpose, measurements of downward irradiance at the Earth's surface in Évora and the corresponding model simulations have been compared for six selected days (03-08-2003, 15-08-2004, 24-08-2004, 18-07-2005, 19-08-2007 and 17-05-2010). The comparison between measured and simulated values shows a highly significant correlation, with determination coefficient between 0.999 and 1 for both models and slope very close to unity (between 0.992 ± 0.004 and 1.017 ± 0.003 for libRadtran, and between 0.997 ± 0.004 and 1.024 ± 0.002 for SBDART), supporting the validity of the models in the estimation of irradiance in the shortwave spectral range. Relative differences between the simulated and measured irradiances with respect to the measured values have also been calculated, being most of the differences for the six days lower than 0.2 %. These small differences could be associated with experimental errors in the measurements as well as uncertainties in the input values given to the models, particularly those related with the aerosol properties. Also, relative differences between models have been calculated, obtaining values lower than 0.1 %. SBDART model slightly overestimates the libRadtran simulations. The notably good agreement between simulated and measured irradiances indicates that both models can be used to estimate irradiance, provided that the models are fed with highly reliable-quality data.

1. Introduction

It is well known the general interest for accurately quantifying the effects of atmospheric aerosols on the energy balance of the Earth-atmosphere system. Their role involves the attenuation of solar radiation through scattering and absorption processes, and also the modulation of terrestrial radiation by scattering, absorbing and emitting. Atmospheric aerosols also indirectly affect the radiation balance by influencing the cloud formation and their properties. According to the Intergovernmental Panel on Climate Change 2013, the total aerosol radiative forcing is estimated to be -0.9 [-1.9 to -0.1] W m^{-2} [1]. Therefore, a global cooling effect due to the aerosols is now relatively well established, despite the uncertainties still remaining. Thus, accurate and reliable measurements and scientific assessment are still the order of the day.



Estimations of irradiance provided by reliable radiative transfer codes are of great interest in order to analyze the aerosol effects in the radiative balance of the Climate System. They are also of great interest when no measurements are available. Therefore, the aim of this study is to analyze the performance of the radiative transfer models libRadtran [2] and SBDART [3] for estimating the shortwave irradiance under different aerosol conditions over Évora station, Portugal. This work is organized as follows: a brief description of the study region and instrumentation is presented in section 2; dataset and methodology are provided in section 3; results are discussed in section 4. Finally, conclusions are given in section 5.

2. Study region and instrumentation

Évora radiometric station is installed in the Geophysics Center Observatory in Évora, with geographical coordinates: 38.6° N, 7.9° W, 293 m a.s.l. This station is located near the center of a small town with about 60000 inhabitants, about 100 km eastward from the Atlantic west coast. Évora is influenced by different aerosol types, namely urban as well as mineral and forest fire aerosol particles [4-9]. Évora station is managed by the Évora pole of the Institute of Earth Sciences, at the University of Évora (Portugal).

This station is equipped with an Eppley Black & White pyranometer and CIMEL CE-318 sunphotometers, among several other radiometric instruments. The Eppley Black & White pyranometer measures the global shortwave irradiance (285-2800nm) every 10 seconds and records 10 minutes averages. The uncertainty associated with this instrument is estimated to be about 5% encompassing calibration, temperature and cosine characteristics of the radiometer. The CIMEL CE-318 sunphotometer is integrated in the NASA AERONET (Aerosol Robotic NETwork) network [10]. It takes direct sun measurements with a 1.2° full field of view at 340, 380, 440, 500, 675, 870, 940 and 1020 nm, and measures of sky radiances in the almucantar and principal planes geometries, at 440, 675, 870 and 1020 nm. More details about this instrument are given by [10]. In this study, aerosol optical depths (AOD), Ångström α exponent (440-870) (α), single scattering albedo (ω), asymmetry factor (g) and precipitable water vapor column (PWC) provided by Cimel sunphotometer are used as inputs to the radiative transfer models for simulating the irradiance in the shortwave spectral range and to analyze the aerosol concentration of each day.

3. Dataset and methodology

In this study the reliability of the version 1.7 of the libRadtran [2] and of the version 2.4 of the SBDART [3] models for estimating the shortwave irradiance during days with different aerosol concentrations has been analyzed. This was done through the comparison between 10-min averages of the measured downward irradiance at the surface and the corresponding model simulations, only it takes into account measurements and simulations with zenith angle lower to 80°. Previously, the aerosol properties over Évora station have been analyzed and six days with different aerosol concentration and without cloud have been selected. Most days correspond to summer, when it is easier to find cloudless days and with aerosol measurements.

The inputs are the same in the two models: AERONET level 2.0 aerosol optical properties, precipitable water vapor column (PWC) and surface albedo, as well as total ozone column provided by the Ozone Monitoring Instrument (OMI). The level 2.0 aerosol properties used as input were: α and β Ångström coefficients (α is obtained here for the 440 and 870 nm wavelength range and the turbidity β from α and value and aerosol optical depth, AOD, at 1020 nm), and the aerosol optical depth for all wavelengths. Also, the asymmetry parameter (the average value of this parameter for the four wavelengths available (440, 675, 870 and 1020 nm) was used). The level 2.0 AERONET single scattering albedo, $\omega(\lambda)$, dataset is quite limited because only cases where AOD at 440 nm is greater than 0.4 are considered, which is very unusual in Évora. Therefore, a typical value of aerosol single scattering albedo equal to 0.95 for all wavelengths was used in model calculations of irradiance. This value corresponds to the average value in the level 2.0 data of Évora and it is consistent with previous observations reported for this station [9]. The surface albedo considered is that described for the same

station in Obregón et al. (2015) [11]. The other variables taken into account in setting up the model simulations are the following: the extraterrestrial irradiance values (obtained from Gueymard (2004) [12]), profiles of temperature, air density, ozone and other atmospheric gases (taken from the midlatitude summer/winter standard atmospheres) and the radiative transfer equation solver (the discrete ordinate method of Stamnes et al. (2000) [13], DISORT2 with 16 streams, was used). To obtain the 10 minutes input values, interpolations from the existing AERONET properties values were made.

In addition, radiation was measured by an Eppley pyranometer installed at the Évora Geophysics Center Observatory in Évora. Only cloud-free measurements corresponding to solar zenith angle lower than 80° have been considered in this study.

4. Results and discussion

The days selected in this study to analyze the performance of the models for estimating the shortwave irradiance are shown in Table 1. This table also shows the daily average values of AOD 440 nm and α during the six days. On 03-08-2003 and 24-08-2004 AOD present very high values, 0.34 and 0.39 respectively. Simultaneously, the values of α for these days are the smallest, 0.54 and 0.21 respectively, indicating the coarse mode predominance. These values indicate the influence of aerosol from desert areas during these days. During the others four days of the study, the concentration of aerosols is lower and the values of α is higher, indicating that particles are smaller. During these four days there is great variety of situations, because AOD values range between 0.03 and 0.14, and α values range between 0.94 and 1.83.

Table 1. Daily average values of AOD and α for the six days used in this study.

DATE	AOD 440 nm	α (440-870)
03-08-2003	0.34	0.54
15-08-2004	0.03	0.94
24-08-2004	0.39	0.21
18-07-2005	0.06	1.73
19-08-2007	0.14	1.83
17-05-2010	0.06	1.28

Figure 1 shows the comparison between the 10-min averaged downward irradiance measurements and simulated values. Measured and simulated values show a highly significant correlation, with determination coefficients between 0.999 and 1 for both models and slopes very close to unity (libRadtran between 0.992 ± 0.004 and 1.017 ± 0.003 and SBDART between 0.997 ± 0.004 and 1.024 ± 0.002). These values clearly support the validity of the models in the simulation of irradiances in the shortwave spectral range. This behaviour is also seen in Figure 2, where the temporal evolution of the 10-min averaged measurements and corresponding model simulations are shown.

Figure 3 shows the relative differences between the downward irradiance measurements and the corresponding simulated values for each day (red and blue dots). The relative differences between both models have been also represented (black dots). Relative differences between the simulated and measured irradiances with respect to the measured values indicate that most of the differences for the six days are lower than 0.2 %. These small differences could be associated with experimental errors in the measurements as well as with uncertainties in the input used in the model, particularly related with the actual aerosol properties. Also, relative differences between models have been calculated, obtaining values lower than 0.1 %. The SBDART model slightly overestimates the libRadtran simulations. The notably good agreement between simulated and measured irradiances indicates that both models can be used to estimate irradiance, provided that the models are fed with highly reliable data.

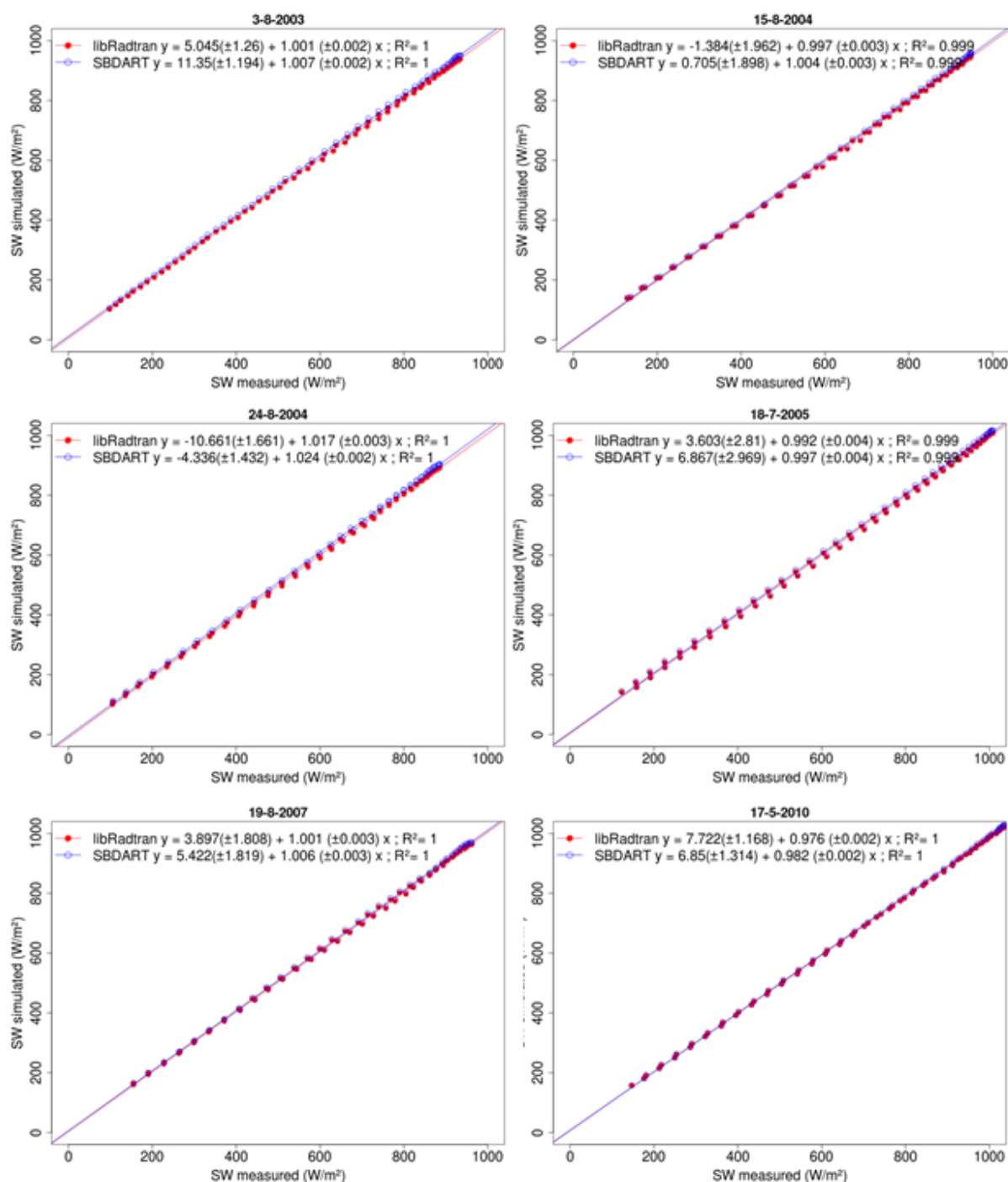


Figure 1. Comparison of simulated SW irradiances with the corresponding measurements. The solid lines represent the regression line for each model. The regression equations and determination coefficients are also included.

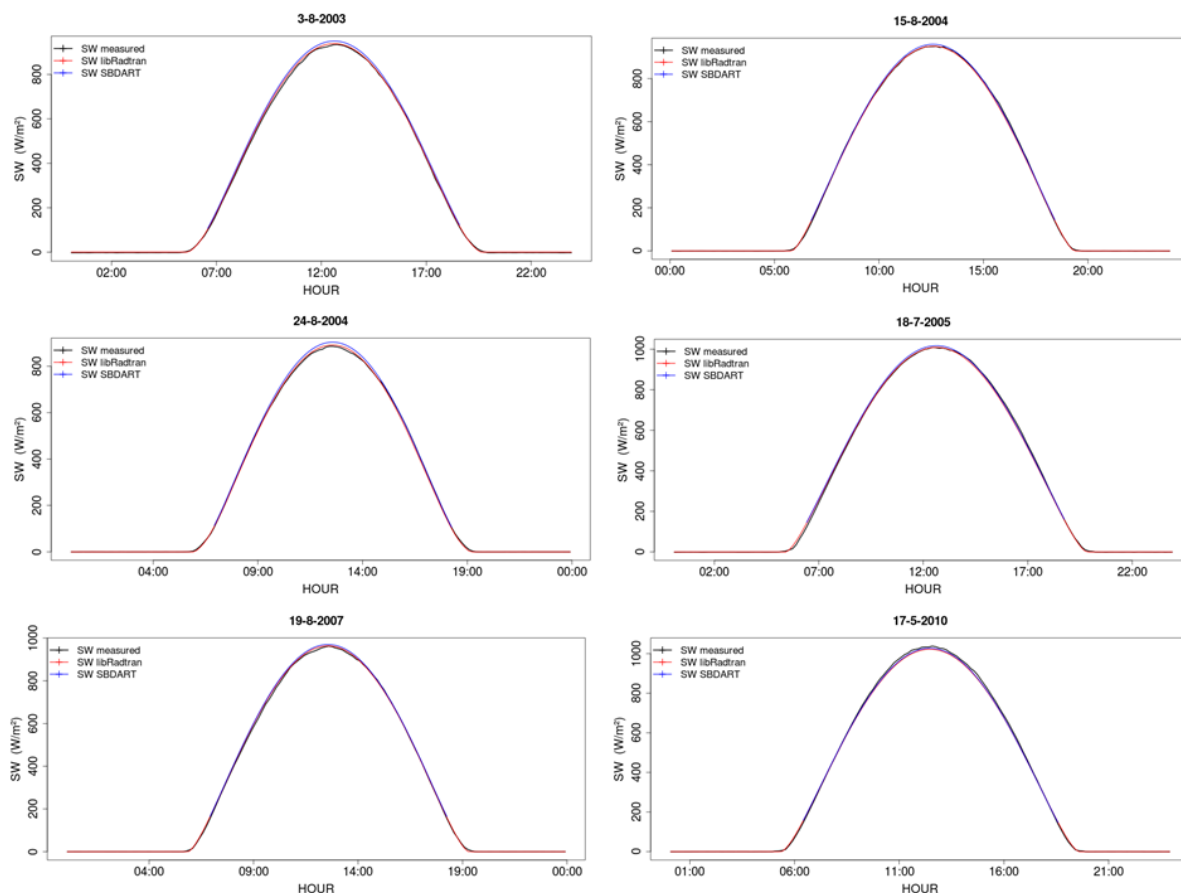


Figure 2. Temporal evolution of simulated and measured SW irradiances.

5. Conclusions

This study contributes to the estimation of downward irradiance, at the surface, in the shortwave spectral range, with libRadtran and SBDART models. The reliability of these models has been validated by the comparison between simulated and measured values observed over Évora under different aerosol concentrations. Determination coefficients between 0.999 and 1 for both models and slopes very close to unity (libRadtran between 0.992 ± 0.004 and 1.017 ± 0.003 and SBDART between 0.997 ± 0.004 and 1.024 ± 0.002) were obtained. Relative differences between the simulated and measured irradiances, with respect to the measured values, also confirm the reliability of the model, with most of the differences lower than 0.2 %. Also, relative differences between models have been calculated, resulting in values lower than 0.1 %.

The notably good agreement between simulated and measured irradiances indicates that both models can be used to estimate solar irradiance, provided that the models are fed with highly reliable data. These estimations can be used when no irradiance measurements are available and in future works to calculate aerosol radiative forcing values and analyze their effects in the radiative balance of the Climate System.

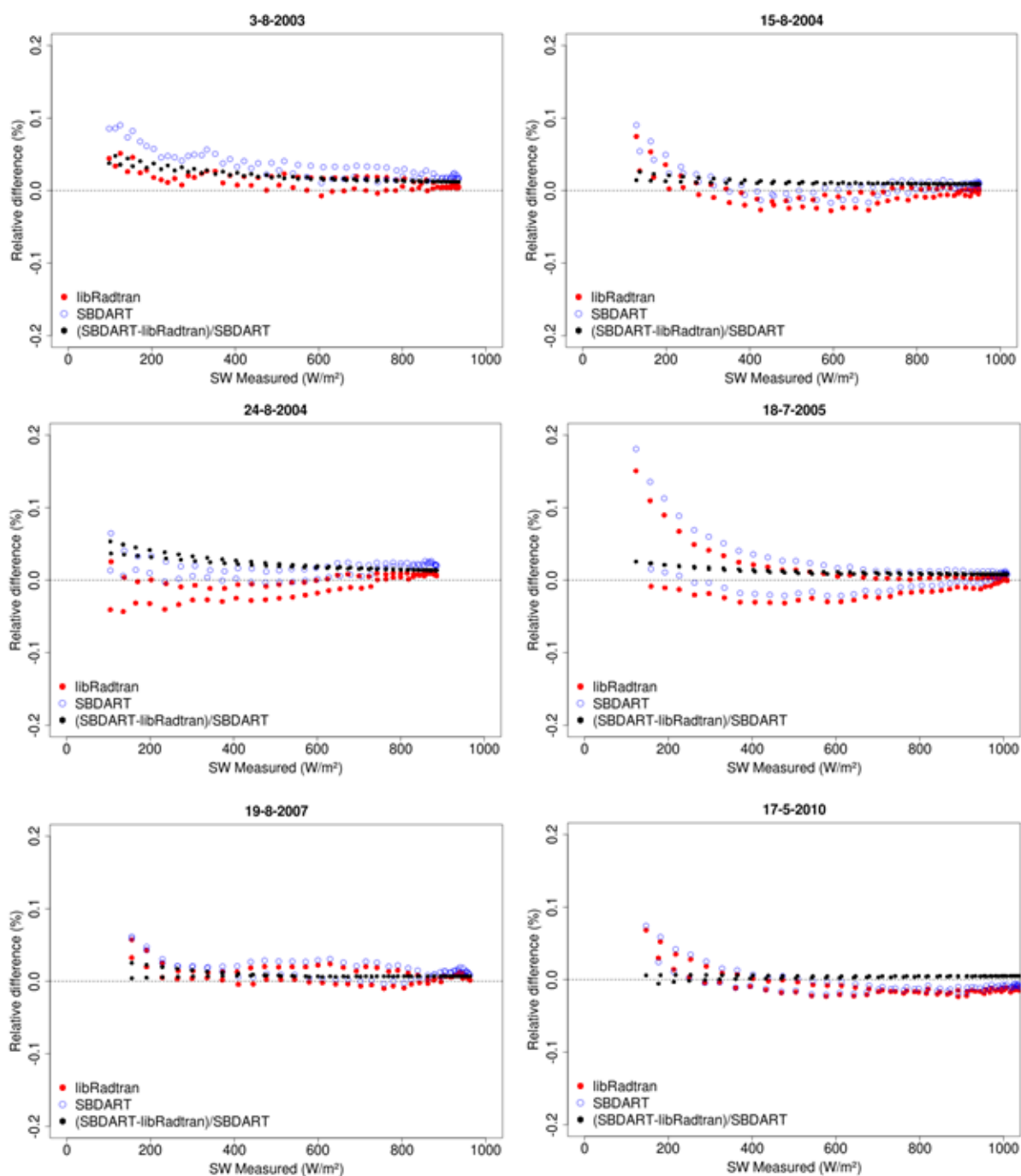


Figure 3. Relative differences between 10-min averaged measurements of downward irradiance at the surface and corresponding model simulations. The relative differences between models are also shown in these graphs (black filled dots).

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