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Solar radiation simulations in the Iberian Peninsula: Accuracy and sensitivity to uncertainties in inputs of a radiative transfer model

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ABSTRACT

A radiative transfer model (RTM) is used to obtain total shortwave (SW) and erythemal (UVER) irradiances under cloudless conditions at nine Spanish locations on the Iberian Peninsula. For this purpose, various remote sensing retrievals such as ozone, aerosol optical depth, and water vapour are used as input in the RTM. The sensitivity of the simulated SW and UVER irradiances to the input uncertainties is studied repeating the same simulations but changing the inputs plus/minus their uncertainties. Sensitivity of global SW irradiance is usually below 10%, and sensitivity of global UVER irradiance is higher although it does not exceed 17%. SW and UVER irradiances are compared to measurements under cloudless conditions, with significant agreement emerging between modelled and measured, particularly for low solar zenith angles. Agreement is better for SW than for UVER. Differences between simulations and measurements are within uncertainties.

1. Introduction

A radiative transfer model (RTM) is a code, an algorithm or something similar which calculates the energy transfer of electromagnetic radiation for specific atmospheric and boundary conditions. Several models exist at present: the UVSPEC model (UV–Visible Spectroscopy) is included in the libRadtran software package [1] and offers a range of options for calculating radiative quantities in the Earth's multilayer atmosphere (freely available at http://www.libradtran.org); the TUV model (Tropospheric Ultraviolet & Visible) developed by Madronich and Flocke [2] is used over the wavelength range 121–750 nm, to calculate spectral irradiance and biologically radiative quantities using the DISORT (DIScrete Ordinates Radiative Transfer) algorithm [3] (available at http://gcmd.nasa.gov/records/UCAR_TUV.html); the SMARTS model (Simple Model of the Atmospheric Radiative Transfer of Sunshine) is a program designed to evaluate the components of solar irradiance at the surface in the shortwave spectrum under cloudless conditions. It relies on simplifications of the radiative transfer equation to give fast calculations considering only one atmospheric layer [4] (available at http://www.nrel.gov/rredc/smarts).

Radiative transfer models have a number of different uses and purposes. RTMs are used in pyranometer calibrations to correct differences caused by the instrument's spectral response [5]. Some atmospheric properties are retrieved by RTM inversions taking into account radiative measurements (e.g. [6–10]). Román et al. [11] run an RTM to obtain sky radiance at three wavelengths, these simulations being used to obtain three matrices that transform a

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raw sky image from an all-sky camera into a sky radiance map in physical units.

Erythemal ultraviolet (UVER) irradiance, the ultraviolet irradiance weighed with the erythemal action spectrum [12], and total shortwave irradiance (SW; 305–2800 nm), are usually calculated with RTMs under cloud-free conditions for various purposes. Using an RTM, de Miguel et al. [13] studied the behaviour of UVER between the SW ratio as a function of cloud properties. Madronich [14] obtained an analytic formula for clear-sky UVER irradiance through radiative transfer simulations. Mateos et al. [15] estimated SW irradiance with an RTM under cloud and aerosol free conditions to calculate surface radiative forcing of SW radiation due to clouds and aerosols. Antón and Mateos [16] used an RTM to study the effect of changes in total ozone column (TOC) on long-term SW series over the Iberian Peninsula. Several authors (e.g, [17–21]) have reconstructed UVER irradiance in the past using UVER and SW simulations under cloudless conditions with an RTM.

The use of RTMs does not usually take into account uncertainty in results caused by uncertainty in inputs. However, this uncertainty in RTM proves interesting since the results obtained by RTMs may be influenced by it. Román et al. [22,23] evaluated changes in SW and UVER simulations in the Iberian Peninsula caused by uncertainty in individual inputs: TOC, aerosol optical depth (AOD), Angstrom Exponent, single scattering albedo (SSA), and water vapour. However, the mentioned changes were not studied considering the uncertainty in all the inputs together. Moreover, the cited works did not compare the results with measurements at ground.

The main objective of the current work is to quantify sensitivity in SW and UVER simulations under cloudless conditions to the different uncertainties together in RTM inputs in the Iberian Peninsula. This paper also aims to compare SW and UVER simulations and ground-based measurements in order to observe the accuracy of the model and whether the differences are within the uncertainty generated by input uncertainties.

The paper is structured as follows: the instrumentation and data used at the various Spanish locations are presented in Section 2. Section 3 shows the principal results regarding the sensitivity and accuracy of the radiative transfer model analysed. Finally, the main conclusions are summarised in Section 4.

2. Instrumentation and data

2.1. Locations and instruments

The measurements used in this work were taken at nine Spanish radiometric stations located in the Iberian Peninsula. Eight of these stations are managed by the Spanish Meteorological Agency (AEMet), and the other, located in the village of "Villalba de los Alcores", is run by the University of Valladolid [13]. The coordinates of these stations are shown in Table 1 and are marked in Fig. 1. All radiometric stations are equipped with instruments to take UVER and SW measurements.

UVER irradiance at all the stations was measured as 30-min averages using a UVB-1 (Yankee Environmental Systems) pyranometer. The instrument output signal was converted into physical units following the two-step method explained by Vilaplana et al. [24]. Uncertainty with a coverage factor, k, of 1 for UVB-1 measurements ranges between 5.4% and 8.0% [5]. Hourly SW averages were recorded with a CM11 model (Ciudad Real), CMP11 model (Villalba), and CM21 model (the rest) pyranometer from Kipp & Zonen. The oldest SW measurements at all the stations were taken with a CM6B (Kipp & Zonen) pyranometer (replaced over time by new models) whose expanded uncertainty ($k=2$) is 8% for hourly SW values. Uncertainty with a coverage factor $k=1$ is referred to as combined uncertainty, σ, and the combined uncertainty of a measurement, X, indicates that the probability of finding the real value of the measured variable within the confidence interval $(X-\sigma, X+\sigma)$ is 68%. Uncertainty with $k=2$ is called expanded uncertainty, 2σ, and the probability of finding the real value of the measured variable within the confidence interval $(X-2\sigma, X+2\sigma)$ increases to 95%. All instruments were well calibrated on a regular basis, and instrument maintenance was performed following World Meteorological Organization (WMO) recommendations [25]: cleaning domes, bubble levelling of the instruments, and monitoring of desiccant state. Quality control of SW and UVER data, explained in [26], was applied to all databases in order to reject spurious and outlier data.

30-min UVER irradiance data were averaged hourly, and the number of total UVER and SW hourly available data is shown in Table 2. Moreover, the available period of SW and UVER irradiance records appears in Table 2, and shows that SW records commenced in 1973 in Madrid

Table 1
Characteristics of the AEMet stations used.

AEMet code	Name	Latitude	Longitude	Altitude (m a.s.l.)
4121	Ciudad Real	38°59′21″N	3°55′13″W	628
1024E	San Sebastián (Igueldo)	43°18′23″N	2°02′28″W	251
1347	A Coruña	43°21′57″N	8°25′17″W	58
3194U	Madrid (Ciudad Universitaria)	40°27′06″N	3°43′27″W	664
3469A	Cáceres	39°28′17″N	6°20′20″W	394
7178I	Murcia	38°00′07″N	1°10′15″W	61
9981A	Tortosa	40°49′14″N	0°29′29″E	44
2422	Valladolid	41°39′00″N	4°46′00″W	735
–	Villalba de los Alcores	41°48′50″N	4°55′48″W	840