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Measurement and Analysis of Broadband UVB Solar Radiation in Spain

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ABSTRACT

Measurements of broadband UVB irradiance (290–315 nm) at 14 locations in Spain for the period 2000–2009 have been used to generate instantaneous, hourly and daily values of irradiance (W m^{-2}) and radiant exposure (kJ m^{-2}). These measurements, and its statistical indices, have been analyzed. For the UVB irradiance, the values corresponding to July (maximum) and December (minimum) have been analyzed as representative of the year during the whole period for all locations. For the UVB radiant exposure, the temporal evolution of daily values has been evaluated for all locations to estimate an average yearly behavior. The accumulated radiant exposure for an average year has also been studied for each location. Finally, to determine possible trends in the evolution of the UVB levels, the linear regressions for the mean daily values for all locations have been determined.

INTRODUCTION

UVB radiation causes many biological and chemical processes, which are generally damaging to living organisms in different ways (1–5). The effects of UVB radiation on human beings are mainly observed in the skin, eyes and immune system (5–9). The most common effect of overexposure to UVB radiation is severe sunburn, which leads to higher body temperature, erythema and others ailments *ca* 16 h after the exposure (10–12). Moreover, chronic skin overexposure to UVB radiation provokes photoaging (13–15) and other premalignant conditions (16–24).

Although the effects of UVB radiation on human beings have been widely studied, there are also many studies of its effects on animals and vegetation. For example, the impact of UVB radiation has been studied on small animals, such as plankton (25), invertebrates and marine fish (26) and amphibians (27,28), among others. The impact of UVB radiation on vegetation changes with species and crops. As many species grow in a wide latitude range, the natural variation in the plants' genetics, which are found in environments with high UVB radiation, is a natural resource to increase their resistance to UV radiation (29). In particular, the effects of an increase of UVB radiation have been studied on very small plants, such as cyanobacteria, phytoplankton, microalgae and other aquatic organisms (30), and algae (31). The effects of UVB radiation on bigger plants, herbaceous or woody, have also been studied (32–36).

Fewer studies have been dedicated to the changes caused by UVB radiation, on natural ecosystems, as the effects of UVB radiation on an ecosystem level are worse known than on a molecular or organism level. Many important consequences can be indirect effects of the high UVB radiation through changes in the chemical composition and shape of the plants, or through changes in the abiotic environment. These indirect effects can include changes in the sensitivity of plants to be attacked by insects and pathogen elements both in natural and agricultural ecosystems. The indirect effects of UVB radiation on plants causing changes in their shape or function usually appear through genetic alteration rather than as damage to them. The production of some crops can decrease due to high UVB radiation, but other varieties are not affected. This effect can be difficult to evaluate for forests if the UVB effects are accumulated over several years. The effects of an elevated UVB radiation must be considered together with other climatic changes such as the increase of temperature or CO_2 levels, which can modify the response to UVB radiation, especially in vegetation (37–39), but also in animal microorganisms (40).

Despite the great impact of UVB radiation on ecosystems and living organisms, few measurements of UVB radiation are registered all over the world. Usually, the measured parameter is the ultraviolet erythemal radiation (UVER), which represents the response of human skin to erythema or sunburn. These measurements are made with radiometers, spectroradiometers and Brewer spectrophotometers (41–45), and only a few studies have analyzed strictly UVB measurements (46–50).

The objective of this study was to analyze the UVB measurements made in 14 locations of the Iberian Peninsula during 10 continuous years by the Spanish UVB Radiometric Network (41), managed by the State Agency of Meteorology of Spain (AEMET).

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MATERIALS AND METHODS

The Spanish UVB Radiometric Network (41) was installed in 1998 by the State Agency of Meteorology (AEMET; formerly known as the National Institute of Meteorology [INM]), and nowadays it is composed by 26 stations which measure UVB radiation and 7 stations that also measure ozone. In this study, to work with homogeneous data series, we have only considered measurement stations with little difference in latitude (the stations in the Canary Islands have not been considered) and coincident data during a period of 10 years (2000–2009). The geographical coordinates and elevations above sea level for the 14 measurement stations considered are detailed in Table 1. Although the measurements were registered over 10 years (2000–2009) for all the stations, several of them have small periods without data (Table 1). The geographical distribution of the considered measurement stations is not homogeneous, with a great number of stations in the Mediterranean coast and wide areas without covering.

Table 1. Coordinates of the stations of the Spanish UVB Radiometric Network and available data during the period 2000–2009.

Stations	Latitude	Longitude	Altitude (m)	Period without data
A Coruña	43°21′N	8°25′W	67	
Santander	43°28′N	3°49′W	79	
Valladolid	41°39′N	4°46′W	740	Year 2003
Zaragoza	41°38′N	0°55′W	250	Years 2008 and 2009
Barcelona	41°38′N	2°12′E	60	Year 2000 and half year 2006
Madrid	40°27′N	3°44′W	680	
Roquetas	40°49′N	0°30′E	44	Half years 2000 and 2001, and years 2002 and 2005
Palma de Mallorca	39°33′N	2°37′E	10	Years 2008 and 2009
Valencia	39°29′N	0°23′W	23	
Ciudad Real	38°59′N	3°55′W	628	
Badajoz	38°53′N	6°58′W	186	Half year 2000, and year 2001
Murcia	38°00′N	1°10′W	69	
El Arenosillo	37°10′N	6°73′W	41	Years 2000, 2001, 2002, 2003, and half year 2006
Málaga	36°43′N	4°29′W	61	Half year 2000, and year 2002

The UVB radiation is measured using UVB-1 radiometers by YES (Yankee Environmental Systems), which have a spectral range of 280–400 nm, and these measurements are daily transmitted, processed and stored in the National Radiometric Centre in Madrid. For the determination of total UVB irradiance the manufacturer provides a detailed tabulation of the weighting factors as a function of the solar zenith angle for the UVB-1 instrument (51).

The calibration of the YES UVB-1 radiometers is periodically performed at the National Radiometric Centre in Madrid, and it consists of the measurement of the angular and spectral response of the radiometer indoor, and a comparison with a reference YES UVB-1 radiometer and a Brewer spectroradiometer outdoor. The calibration result is a global constant and a calibration matrix, which is a function of the solar zenith angle and the total column ozone.

RESULTS AND DISCUSSION

Analysis of UVB irradiance values

The study of the most representative statistical indices of UVB irradiance has been carried out for all the measurement stations. Monthly statistics for the whole measurement period (2000–2009) were calculated using daily values. The most representative statistical indices are analyzed. The skewness (a measure of the asymmetry of the probability distribution of a real-valued random variable) and the kurtosis (a descriptor of the shape of the probability distribution) of the distribution have also been studied.

For all the 14 measurement stations, the monthly statistics have been analyzed. As an example, Tables 2 and 3 show the results obtained during July and December at solar noon. Those months usually present the highest and lowest records of UVB irradiance for all the stations (Table 4). Only in Barcelona the UVB irradiance is slightly higher in June than in July. The values of the arithmetic mean and the median (described as the numerical value separating the higher half of the probability distribution from the lower half) are very similar, with the difference between them following no pattern for any month. On July, these differences represent always $<3\%$ of the mean value (*e.g.* Madrid, Ciudad Real, Valencia and Murcia). In some stations, these relative differences reach values between 3% and 5% at the beginning and the end of the day, (*e.g.* A Coruña, Santander, Valladolid, Zaragoza, Badajoz, Palma de Mallorca, El Arenosillo and Málaga). There are some stations where these relative differences reach 3% and 4% only in specific cases at solar noon (Barcelona [twice],

Table 2. Statistical indices of the hourly UVB irradiance, in July, at solar noon for each location.

	Mean	SD	Median	Mx	Mn	Q_1	Q_3	$Q_3 - Q_1$	V	P5	P95	Kurtosis	Skewness
A Coruña	1255	128	1242	1544	1026	1169	1349	179	7.1	1099	1482	−0.4	−0.4
Santander	1224	124	1217	1514	952	1126	1318	191	7.8	1054	1401	−0.2	−0.1
Valladolid	1623	94	1646	1788	1375	1558	1692	133	4.1	1463	1737	0.3	−0.7
Zaragoza	1498	75	1525	1601	1341	1447	1563	115	3.8	1363	1591	−0.7	−0.6
Barcelona	1317	110	1362	1460	1039	1274	1388	113	4.3	1089	1430	0.8	−1.2
Madrid	1665	64	1683	1769	1482	1625	1708	83	2.5	1567	1748	0.7	−0.8
Roquetes	1419	155	1466	1617	1007	1331	1521	189	6.6	1140	1612	0.5	−1.0
Palma	1451	102	1460	1608	1208	1382	1519	136	4.7	1287	1604	−0.4	−0.3
Valencia	1389	80	1410	1515	1206	1339	1449	110	4.0	1258	1507	−0.6	−0.4
Ciudad real	1726	87	1753	1855	1486	1671	1793	121	3.5	1574	1824	1.0	−1.0
Badajoz	1680	69	1697	1793	1479	1657	1727	69	2.1	1549	1751	1.7	−1.2
Murcia	1584	75	1589	1687	1350	1561	1629	68	2.1	1459	1685	2.5	−1.2
Arenosillo	1644	113	1675	1825	1346	1593	1727	133	4.0	1410	1781	1.3	−1.1
Malaga	1564	77	1585	1679	1358	1524	1604	79	2.6	1404	1665	1.5	−1.1

Table 3. Statistical indices of the hourly UVB irradiance, in December, at solar noon for each location.

	Mean	SD	Median	Mx	Mn	Q_1	Q_3	$Q_3 - Q_1$	V	P5	P95	Kurtosis	Skewness
A Coruña	160	23	166	374	112	211	315	103	19.7	167	359	−0.8	0.1
Santander	168	21	169	400	138	194	283	88	18.6	154	329	−0.1	0.5
Valladolid	209	23	208	514	161	257	394	136	20.9	182	466	−0.9	0.1
Zaragoza	217	29	217	543	198	285	410	124	17.8	222	492	−0.2	0.4
Barcelona	218	23	213	527	242	289	399	109	15.9	254	496	0.0	0.9
Madrid	238	20	236	517	213	315	459	144	18.7	235	508	−1.0	0.1
Roquetes	218	47	220	525	253	337	436	98	12.7	288	506	−0.6	0.0
Palma	268	33	272	491	262	336	402	65	8.8	301	476	−0.2	0.4
Valencia	238	31	245	538	254	329	418	88	11.8	268	488	−0.2	0.3
Ciudad real	286	23	280	649	260	371	519	148	16.7	293	588	−0.5	0.2
Badajoz	275	36	276	595	271	371	492	121	14.0	298	571	−0.7	0.2
Murcia	307	31	312	636	335	401	503	101	11.2	338	582	−0.2	0.5
Arenosillo	348	53	359	695	300	432	590	157	15.4	321	680	−0.8	0.1
Malaga	343	34	340	655	364	425	542	117	12.1	373	605	−0.9	0.2

Roquetes and Badajoz [once]). On December, these differences are in all cases $<3\%$ at A Coruña, Santander, Palma de Mallorca, Ciudad Real, Badajoz and Murcia. Relative differences between 3% and 5% are observed close to sunrise and sunset in Barcelona, Madrid, Roquetes, Valencia and El Arenosillo. Differences greater than 3% and up to 7% were observed occasionally at noon at Zaragoza (once), Valladolid, Barcelona, Roquetes and Valencia (twice) and El Arenosillo (three times).

In July, the absolute maxima oscillate between 1460 mW m^{-2} in Barcelona and 1855 mW m^{-2} in Ciudad Real, whereas the absolute minima vary from 953 mW m^{-2} in Santander to 1486 mW m^{-2} in Ciudad Real. The difference (in percentage) between the values of the absolute minimum and the P_5 percentile vary between 1.9% (Valencia) and 12.5% (Murcia). These are systematically larger than those observed between the absolute maxima and P_{95} percentiles, which vary between 0.3% (Badajoz) and 7.0% (Santander). The absolute extreme values (maximum and minimum) have been compared against their corresponding quartile values (Q_3 and Q_1, respectively) to understand if they are representative of the UVB records for all the stations. The differences between the Q_1 quartiles and the absolute minima vary from 7% (Madrid) to 21% (Roquetes), with a mean value of 12%. The mean value of the difference between the Q_3 quartiles and the absolute maxima is 5%, and oscillates between 2% (Valladolid) and 12% (Santander). Therefore, these maximum and minimum values can be considered representative of the UVB irradiance at solar noon as they are not uncommon extreme values for July.

In December, the absolute maxima of the UVB irradiance observed at noon vary from 374 mW m^{-2} in A Coruña to 696 mW m^{-2} in El Arenosillo, whereas the absolute minima are between 112 mW m^{-2} in A Coruña and 365 mW m^{-2} in Malaga. As it happened for July, the difference between the values of the absolute minimum and the P_5 percentile is systematically larger than that observed between the absolute maxima and P_{95} percentiles. These differences vary from 1.5% (Madrid) to 17% (Santander), with a mean value of 6.6% (for the absolute minima and P_5), and from 1% (Murcia) to 49% (A Coruña), with a mean value of 11.7% (for the absolute maxima and P_{95}). The comparison of the extreme values with their corresponding quartiles shows a mean value of 39% for the difference between the Q_1 quartiles and the absolute minima, and a variation between 10% (Barcelona) and 88% (A Coruña). The differences between the Q_3 quartiles and the absolute maxima oscillate from 11% (Madrid) to 29% (Santander), and show a mean value of 19%. These values are greater than those observed in July, indicating that the extreme values of the UBV irradiance at solar noon are less representative in December than in July.

The coefficient of interquartilar variation (V index, defined as $V = 100\ (Q_3 - Q_1)/(Q_3 + Q_1)$), which is a nonparametric measurement that does not depend on the shape of the population distribution, has been used to study the variability of the UVB irradiance at solar noon. It can be observed that July presents low values of the V index, meaning high stability, that fluctuate between 2.1 in Badajoz and Murcia and 7.8 in Santader, with a mean value of 4.2. Less stability is observed in December, with the V index varying from 8.8 in Palma de Mallorca to 20.9 in Valladolid, with a mean value of 15.3. This higher value of the V index in December is due to the major presence of clouds during winter, leading to less stability in the UVB levels.

The skewness in July is low, and always displays negative values, indicating that the UVB irradiance values at noon are slightly shifted to the left of the arithmetic mean. It exceeds the unity only in Roquetes and Ciudad Real (−1.0), El Arenosillo and Málaga (−1.1) and Barcelona, Badajoz and Murcia (−1.2). In December, the skewness is lower than that obtained in July, and always displays positive values, which indicates that the UVB irradiance values at solar noon are slightly shifted to the right of the arithmetic mean. It only displays a value greater than 0.5 in Barcelona (with a value of 0.9).

The kurtosis in July displays values generally <1 for all the stations. It only takes values >1 in the southern part of the Iberian Peninsula: Ciudad Real (1.0), Badajoz (1.7), Murcia (1.5), El Arenosillo (1.3) and Málaga (1.5). In those cases, the distribution function of the UVB irradiance is leptokurtic, with most data close to the mean value and a larger peak than the normal distribution. In December, the kurtosis reaches unity only in Madrid (−1.0). In this month, the UVB irradiance distribution function is always platykurtic, with the data showing a weaker peak than the normal distribution function.

For each station, we have calculated the monthly averages of the hourly mean values of the UVB irradiance. The daily

Table 4. Monthly mean values of UVB irradiance (in mW m^{-2}) at solar noon for each location.

	A Coruña	Santander	Valladolid	Zaragoza	Barcelona	Madrid	Roquetes	Palma	Valencia	Ciudad real	Badajoz	Murcia	Arenosillo	Malaga
January	188	186	237	237	272	286	279	320	293	332	325	370	416	431
February	350	321	464	460	418	479	411	464	459	561	510	564	570	612
March	584	593	777	740	693	803	749	768	738	896	862	862	893	909
April	853	864	1001	1018	943	1065	978	1024	981	1157	1100	1102	1137	1136
May	1062	1041	1251	1234	1145	1286	1148	1228	1130	1345	1328	1292	1324	1301
June	1215	1174	1569	1463	1348	1538	1408	1418	1346	1630	1557	1548	1549	1529
July	1255	1224	1623	1498	1317	1665	1419	1451	1389	1726	1680	1584	1644	1564
August	1177	1107	1472	1347	1207	1521	1347	1297	1237	1589	1510	1439	1564	1387
September	887	900	1119	1074	892	1138	986	996	942	1226	1187	1095	1085	1166
October	433	509	635	660	598	688	678	711	649	785	745	760	771	822
November	259	238	329	351	342	370	393	374	374	440	444	450	510	486
December	160	168	209	217	218	238	218	268	238	286	275	307	348	343

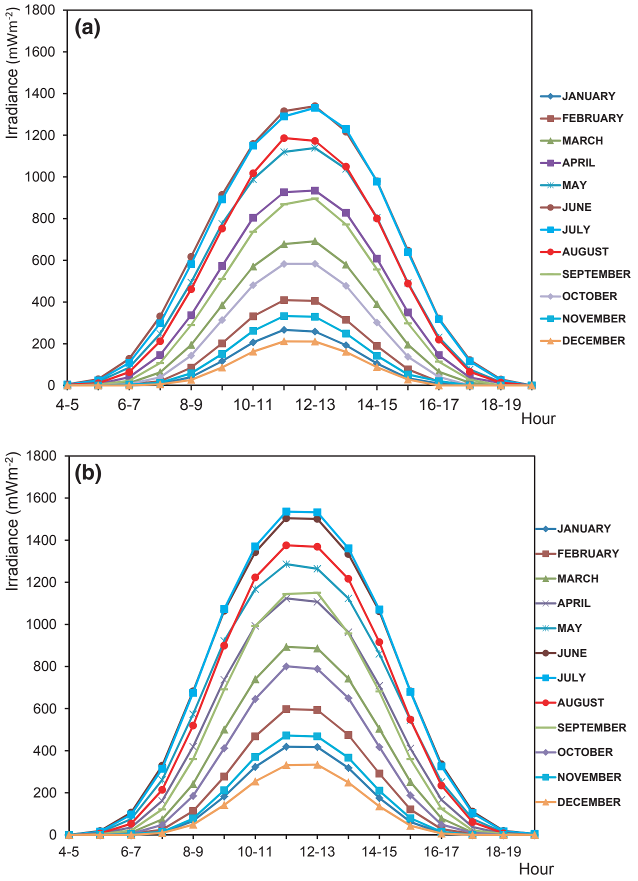

Figure 1. Daily evolution of the monthly mean hourly values of UVB irradiance (mW m^{-2}) in: (a) Barcelona and (b) Malaga.

evolution of these values for the period 2000–2009 for all the stations shows great symmetry respect to the maximum value is observed. In all cases, the peak irradiance is placed at solar noon in July, except in Barcelona, where it is observed in June. The minimum values are obtained in all cases in December. As an example, Fig. 1 shows the daily evolution of monthly mean hourly values of UVB irradiance (mW m^{-2}) during the period 2000–2009, in Barcelona and Málaga.

Analysis of UVB radiant exposure values

The most representative statistical indices of daily integrated values of the UVB radiant exposure in kJ m^{-2} have also been analyzed for all the 14 stations, similarly to the hourly irradiance analysis. The median and the arithmetic mean values are very much alike. The differences between them do not seem to follow any pattern, except that the average is always greater than the median. The relative differences range from 2% in Málaga to 10% in El Arenosillo (Huelva), with an average of 6%.

The absolute maximum values oscillate between 33966 J m^{-2} in Santander and 44122 J m^{-2} in Valencia, both in July. The Zaragoza, Madrid, Palma de Mallorca and El Arenosillo (Huelva) stations have values above 40000 J m^{-2} in June and July, as well as Valencia in June, July and August. On the other hand, the absolute minimum values oscillate between 1795 J m^{-2} in A Coruña and 6362 J m^{-2} in Málaga, both in December. The differences between the absolute minima and the P_5 percentiles (in percentage) are significantly higher than those between the absolute maxima and the P_{95} percentiles. In the first case, the differences range from 15% (Valencia) to 54% (El Arenosillo), whereas in the second case the differences are comprised between 4% (Badajoz) and 13% (Santander).

To check whether the absolute extreme values (maximum and minimum) are representative of the stations we have compared them with their respective quartiles (Q_3 and Q_1, respectively). The differences between the Q_1 quartiles and the minima range from 80% (Malaga) to 192% (A Coruña and Zaragoza), with an average of 138%, which means that the minima are atypical values of the UVB radiant exposure for all the stations. The differences between the Q_3 quartiles and the maxima oscillate between 21% (Murcia and Málaga) and 30% (Santander and Barcelona), with an average of 25%, indicating that the maxima cannot be considered representative of the UVB radiant exposure at solar noon for all the stations.

The variability of the UVB radiant exposure has been assessed by means of the V index, which fluctuates between 2.0 (Valladolid and Palma de Mallorca) and 7.0 (Roquetes, Tarragona), with an average of 3.6. The V index reaches its lowest value during summer, implying higher stability of the UVB radiant exposure, which could be due to a lesser presence of clouds during summer for all the stations.

The skewness is very low. The average values range between 0.1 and 0.3, with monthly peaks between 1.2 and −2.1. The whole set of values is slightly above the average for all the stations. Although the distribution is random, it exhibits a positive asymmetry. On the other hand, the kurtosis is also random for some stations at particular months. The average for each station is around −1.4, therefore the distribution is platykurtic. This means that the distribution has a flatter peak around its mean, which causes thin tails within the distribution.

We have calculated the radiant exposure values at each station for an average year. For this, we have used daily averages for the whole 10-year database. The daily values of the UVB radiant exposure for this average year show large shifts, suggesting that the prediction of radiant exposure is not possible on a daily scale. The monthly mean values of the UVB radiant exposure present a quite regular, but asymmetrical variation, with the maximum values occurring in June and July, whereas the minimum values occur in December. The drop in the summer–autumn period (August–November) is considerably steeper than the rise in the winter–spring period (February–June). This unevenness suggests the use of median values instead of arithmetic mean values in the statistical analysis of the data. As an example, Fig. 2 shows the annual evolution of daily mean values and monthly mean daily values of UVB radiant exposure (J m^{-2}) during the period 2000–2009, in Málaga.

In the study of the biological effects of UVB radiation, it can be interesting to know the accumulated UVB solar radiant exposure (J m^{-2}) on a time period. In our case, the accumulated UVB hourly values exceed 40000 J m^{-2} in July for the Madrid, Valencia and Palma de Mallorca stations, whereas in December only the Malaga station is above 5000 J m^{-2}. We can conclude that the maximum monthly radiant exposure occurs in July, except for Barcelona station where it happens in June. On the other hand, the minimum radiant exposure occurs in December for all stations. We have also studied the mean daily values of the accumulated UVB radiant exposure for an average year. The values oscillate between 5400 kJ m^{-2} in Santander and 7800 kJ m^{-2} in Ciudad Real (Fig. 3).

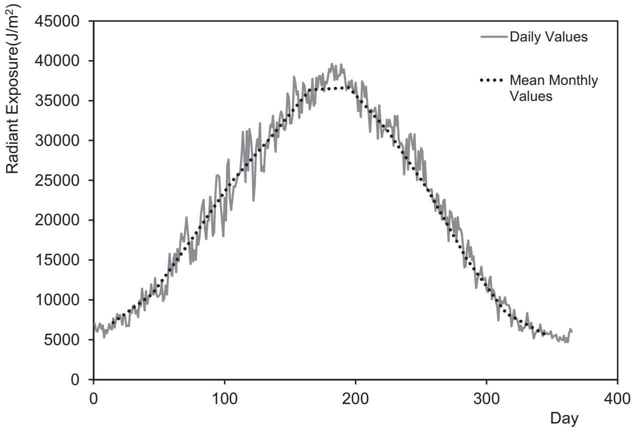

Figure 2. Annual evolution of daily mean values and monthly mean daily values of UVB radiant exposure (J m^{-2}) during the period 2000–2009 in Málaga.

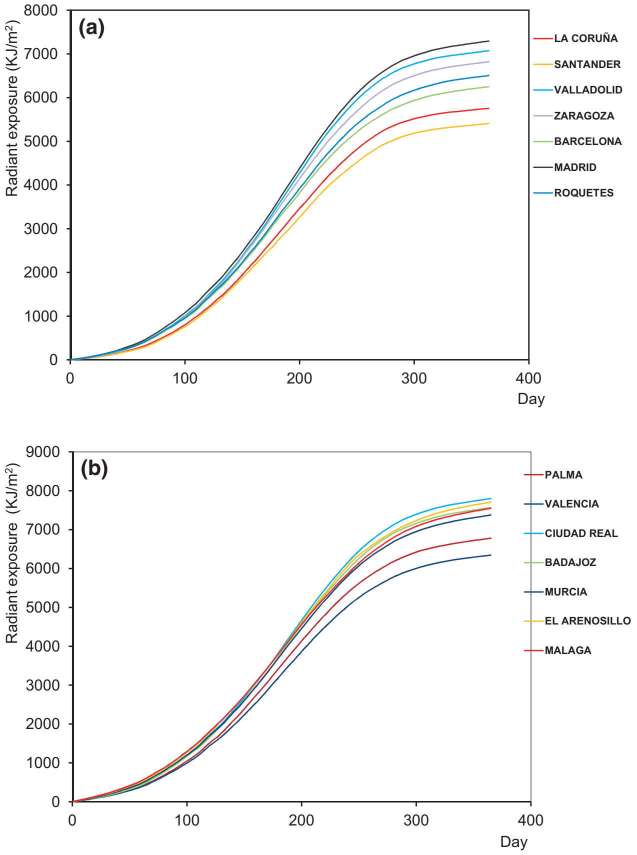

Figure 3. UVB radiant exposure accumulated during an average year (kJ m^{-2}) at: (a) A Coruña, Santander, Valladolid, Zaragoza, Barcelona, Madrid and Roquetes; (b) Badajoz, Ciudad Real, Valencia, Palma de Mallorca, Murcia, El Arenosillo and Málaga.

Figure 4. Slopes of the linear regressions between measurement stations of the cumulated values of the UVB radiant exposure during an average day, considering Malaga as the reference station.

To study the differences between the measurement stations we have created a standard year for each of them using cumulated daily values of UVB radiant exposure obtained adding up the hourly mean values calculated from the 10 year data, and then we have calculated the linear regressions for the comparison of each station with Malaga, which is considered as the reference because it is the one with the lowest latitude. Figure 4 shows the slopes of the linear least squares fittings obtained (with $R^2 > 0.93$ for all cases). The slopes for the stations close to the coast present values below 1, which indicates lower values of UVB radiant exposure than those obtained in Malaga, with values between 1% lower for Palma and 14% lower for Santander. On the contrary, the slopes for the stations located inland show values above 1, indicating greater values of UVB radiant exposure than those obtained in Malaga, with values between 3% higher for Murcia and 15% higher for Ciudad Real. These results agree with the distribution of the mean values obtained previously, and with the continentality effect, which causes that the values inland are lower than in the coast.

Table 5. Linear regressions for the annual evolution of the UVB irradiance for each location.

	Slope ($J\ m^{-2}$ per year)	Slope error ($J\ m^{-2}$ per year)	Mean value ($J\ m^{-2}$)	Slope (%)
A Coruña	−50	−6	15840	−0.3
Santander	30	120	15367	0.2
Valladolid	180	100	19462	0.9
Zaragoza	−170	−220	19567	−0.9
Barcelona	140	130	16850	0.8
Madrid	140	80	19975	0.7
Roquetes	−260	−180	18933	−1.3
Palma	100	170	18788	0.5
Valencia	30	120	15367	0.2
Ciudad real	30	70	21360	0.1
Badajoz	180	240	21175	0.9
Murcia	−110	−80	20490	−0.5
Arenosillo	300	400	22463	1.3
Malaga	−13	−230	21535	−0.1

Analysis of temporal trends in the UVB values

We have assessed the temporal trend of the UVB radiant exposure by estimating the linear regressions of the daily mean values during the year for each station. The slopes range from—(260 ± 180) $J\ m^{-2}$ per year (−0.9%) in Roquetes to (300 ± 400) $J\ m^{-2}$ per year (0.9%) in El Arenosillo (Table 5). However, Roquetes and El Arenosillo stations are not representative if we consider the existing data gaps. When we exclude those stations, the slopes also change between −0.9% (but now in Zaragoza, Fig. 5a) and 0.9% (in Badajoz, Fig. 5b). Figure 5 also includes the fitting line of the daily mean irradiance *versus* the Julian day. The daily analysis and the measurement errors discussed in Section 2 lead us to the conclusion that the radiant exposure in the Iberian Peninsula shows no significant temporal trend in the 10 years comprised between 2000 and 2009.

CONCLUSIONS

UVB irradiance (290–315 nm) values are presented for the first time for a variety of locations. These correspond to experimental measurements taken at 14 locations in Spain during the period 2000–2009. They have been used to generate hourly and daily values of irradiance ($W\ m^{-2}$) and radiant exposure ($kJ\ m^{-2}$), and analyzed to produce their most representative statistical indices.

For the irradiance, data from July (maximum irradiance) and December (minimum irradiance) have been selected as representative for the whole analyzed period. In July, both the minimum and maximum values of the UVB irradiance can be

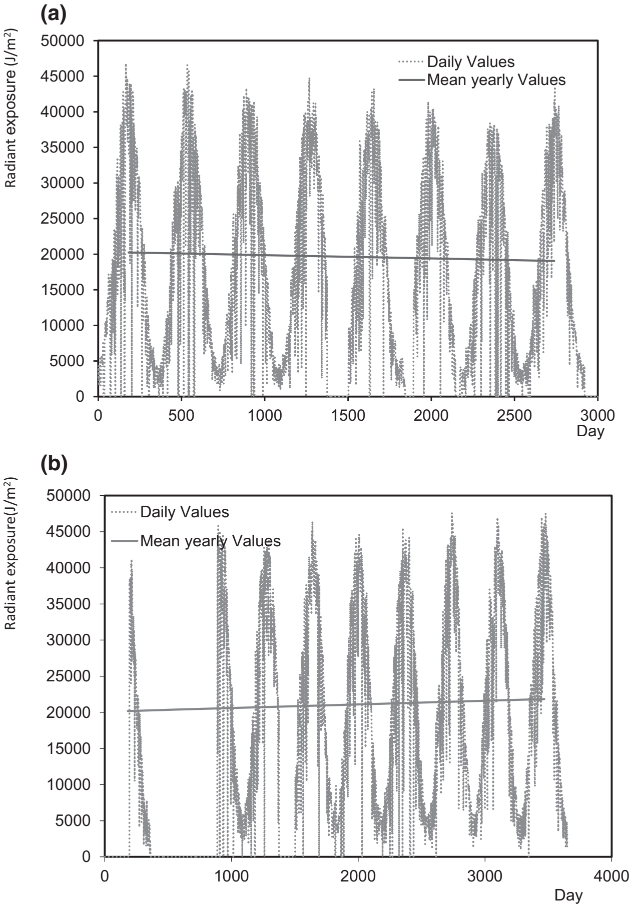

Figure 5. Daily evolution of the daily mean UVB irradiance (in mW m^{-2}) during the period 2000–2009 in (a) Zaragoza; (b) Badajoz. The straight line is the regression of the daily mean UVB irradiance *versus* the Julian day.

considered representative of the UVB irradiance at solar noon in all the locations. On the contrary, the minimum and maximum values in December cannot be considered representative of the UVB irradiance at solar noon, especially the minima.

The variability of the UVB irradiance at noon is low in July. However, in December the UVB variability is higher, which can be due to the major presence of clouds during winter. The skewness in July is very low and negative in all the locations, and in December it is still lower, although the value is always positive. On turn, the kurtosis in July shows that UVB level distributions are always leptokurtic, in opposition to the platykurtic distributions found in December.

The analysis of monthly and seasonal radiant exposure for all the locations shows equivalent results in comparison with the irradiance. The minima and the maxima are atypical values of UVB radiant exposure for all the locations. The variability of the UVB radiant exposure shows high stability. The skewness is very low. Although the distribution of values is random, the skewness is positive in average. Moreover, the seasonal mean value of the kurtosis is negative, *i.e.* slightly platykurtic.

The daily values present such a large fluctuation that it seems impossible to predict radiant exposure values for such short-time intervals. The variation of the monthly values is quite regular although asymmetrical, with the maximum values occurring in June and July, whereas the minimum values occur in December. The accumulated radiant exposure for an average year has been seasonally studied. The values vary between 5408 kJ m^{-2} in Santander and 7802 kJ m^{-2} in Ciudad Real.

Finally, to determine possible trends of the evolution of the UVB levels, the mean daily values have been linearly fitted for all the stations. Taking into account the measurement uncertainties, the slopes of the linear regressions do not show significative trends in the evolution of the UVB radiant exposure observed in the Iberian Peninsula during the period 2000–2009.

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