Solar Ultraviolet Doses and Vitamin D in a northern mid-latitude.

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ABSTRACT

Solar ultraviolet (UV) radiation is one of the most important factors in the development of skin cancer in human, solar erythema and skin aging. Nevertheless, numerous studies have shown the benefits of UV solar radiation in moderate doses, such as the reduction of blood pressure and mental health, treatment of various diseases, and the synthesis of vitamin D in the skin.

This paper analyses data from solar ultraviolet erythemal (UVER) irradiance in W/m^2 measured in a northern mid-latitude as Valencia (Spain) for the period 2003-2010. To estimate effective solar UV radiation in the production of vitamin D (UVD) we used the relationship proposed by McKenzie et al., 2009. It was obtained for one month for each season the minimum exposure time needed around solar noon and at 9 UTC and 15 UTC (Coordinated Universal Time) to obtain the recommended daily dose of 1000 IU. Also, it has been calculated time for erythema induction around solar noon for the same months.

The median UVER daily dose during the summer months was 4000 J/m^{2}day, and 700 J/m^{2}day in winter. With regard to UVD, the median UVD daily dose in summer season was 7700 J/m^{2}day, and in winter it was 1000 J/m^{2}day.

Around noon in January it takes more than two hours of solar exposure to obtain the recommended daily dose of vitamin D, whereas the rest of the year range between 7 minutes on July and 31 minutes on October. For the same months around noon, exposure times to produce erythema were obtained, these being of higher value to the previous.

The results show that it is difficult to obtain the recommended vitamin D doses in winter in a northern mid-latitude, as the human body is almost entirely covered in this season.

Keywords: ultraviolet radiation, ultraviolet erythemal irradiance, ultraviolet vitamin D irradiance, ultraviolet index, vitamin D dose.

1. Introduction

Solar ultraviolet (UV) radiation is one of the most important factors in the development of skin cancer in humans, and its excessive exposure is responsible for the majority of skin cancers, up to 90% (Lucas et al., 2006), and other adverse effects such as solar erythema, skin aging, and some forms of cataracts (Juzeniene et al., 2011; Lucas et al., 2006; Norval et al., 2011; Sklar et al., 2013).

Skin cancers are an important health problem in Caucasian populations worldwide, as their incidence has increased significantly over the past 40 years (Arnold et al., 2015; Cabanes et al., 2009; Erdman et al., 2013; Garbe and Leitter, 2009; Lomas et al., 2012; Madam et al., 2010) and looks set to continue rising due to a higher exposure to UV radiation related to changes in sunbathing habits and tanning (Juzeniene et al., 2011; Norval et al., 2011).

As discussed above, an adequate daily dose of UV solar radiation is considered beneficial for health relate to the synthesis of Vitamin D (De Gruijl, 2011; Engelsen 2010; Webb et al. 2011) as many studies indicate an inverse association between mortality from many cancers and ambient UVB (Chen et al., 2010; Grant, 2006).

The formation of vitamin D is widely described in the literature (Engelsen, 2010; Holick, 2002, 2004, 2005, 2007; Holick et al., 2007). Briefly, vitamin D refers to a group of fat- soluble compounds, which most important are vitamin D_3 and vitamin D_2. Since very few foods contain vitamin D (Holick et al., 2011; Juzeniene et al., 2011), synthesis of vitamin D (specifically D_3) in the skin through the UVB irradiation of 7-dehydrocholesterol is the major natural sources of the vitamin D. In the liver, vitamin D is converted to 25-hydroxyvitamin D (25(OH)D), which is measured in serum to determine a person's vitamin D status.

The results of many studies indicate that inadequate vitamin D is associated with increased risk of many diseases in adulthood and that high vitamin D levels seems to reduce specific disease mortality rates (Chen et al., 2010; Garland et al., 2014; Grant, 2015; Hossein-Nezhad and Holick, 2013; Juzeniene et al., 2011; McDonnell et al., 2016; Pludowski et al., 2013).

In winter deficiencies can occur in the production of vitamin D due to low levels of UV radiation and the fact that people cover most of the bodies to stay warm. Thus, many researchers focus on the so-called ‘vitamin-D winter’, October to March for northern mid-latitudes (Difffey, 2010; Rhodes et al., 2010; Seckmeyer et al., 2013; Webb et al., 1988; Webb et al., 2010; Webb et al., 2011; Zittermann et al., 2010), as it is in this period when it is difficult to obtain an adequate vitamin D dose by solar exposure.

The influence of season and latitude on the cutaneous synthesis of vitamin D was studied by Webb et al. (1988) and these researchers proposed a minimum biologically effective UV dose rate for the photoconversion of vitamin D. Based on these study results, a detection threshold value of 3.46 mW m^{-2} was proposed by Engelsen et al. (2005).

Recent papers based on observational studies defined vitamin D deficiency as a 25(OH)D level of 50 nmol/L or less, and vitamin D sufficiency as 75 nmol/L or greater (Cashman et al., 2016; Garland et. al., 2014; Hossein-Nezhad and Holick, 2013; McDonnell et al., 2016). In Spain, despite being a country with many hours of sunshine, several papers have also reported a high percentage of vitamin D deficiency among various groups of the population (Cutillas-Marco et al., 2013; Galán et al., 2011; González Molero et al., 2011; Mata-Granados et al., 2008; Rodríguez-Rodríguez et al., 2011; Rodríguez-Sangrador et al., 2008). Mata-Granados et al. (2008) studied at spring the vitamin D status in 215 spanish adults and they got that 64.8% of the individuals showed 25(OH)D levels <50 nmol/L. In a study over a year and with a larger sample (1262 participants), González Molero et al. (2011) obtained that one third of the spanish population may be at risk for vitamin D deficiency. Regarding children, Rodríguez-Rodríguez et al. (2009) determined the vitamin D status of 103 schoolchildren with a result of 25(OH)D levels <50 nmol/L in 51% of the children.

This study takes place in a northern mid-latitude as Valencia (city coordinates 0° 22' W, 39º 29' N, sea level), which is located on the east coast of Spain, and due to its geographical situation receives large UV radiation doses throughout the year (Agencia Estatal de Meteorología).

The main objective of this paper is to estimate the exposure time to solar radiation to get the recommended vitamin D doses in a northern mid-latitude as Valencia. Previously, UV index (UVI) levels have been calculated and analysed relative to the season, based on the UVER irradiance measurements for the period 2003-2010. For our main aim it was estimated effective solar UV radiation in the production of vitamin D (UVD) using the McKenzie et al. (2009) model, analysing both daily and seasonal values. Then, it was calculated for one month for each season the exposure to solar radiation time needed around noon and at 9 UTC and 15 UTC to obtain the recommended daily dose of 1000 IU. Besides, it has been calculated time for erythema induction around noon for four months (one month for each season). Finally, we analysed in winter for this latitude the results obtained in the exposure time to solar radiation to get the recommended vitamin D doses.

2. Material and methods

2.1. Instrumentation

Measurements of UVER irradiance were made from the building of the Department of Earth Physics at the University of Valencia's Burjassot campus (Valencia) (coordinates 0 ° 24 ' W, 39 º 30' N, 60 m above the sea), which is located seven km northwest of the city of Valencia and within its metropolitan area. The UVER irradiance measurement period used in this study is from 2003 to 2010, and consists of 267730 records with measurements every five minutes.

To measure this UVER irradiance, a YES UVB-1 pyranometer (Yankee Environmental Systems) on a horizontal platform without hindrance or shadows was used, with a range 280-400 nm and close to the erythema action spectrum spectral sensitivity (McKinley and Diffey, 1987). Radiometer calibration uncertainty was approximately 10% (Bais et al., 2001). The cosine response error according to the manufacturer was less than 4% for solar zenith angles below 55° (Dichter et al., 1993). This instrument was calibrated at the National Aerospace Institute. This calibration consisted of a laboratory measurement of the spectral response of the radiometer and an outdoors comparison with a Brewer MKIII spectroradiometer (Hülsen and Gröbner, 2007; Vilaplana et al., 2006).

It should be noted that the YES UVB-1 has non-negligible errors for high zenith angles unless an array calibration with double entries (zenith angles, total column ozone) is used (Vilaplana et al., 2006). For a constant value of 300 Dobson Units (DU) ozone, the error given by the calibration matrix remained below 9% for zenith angles smaller than 70°. An additional calibration of the radiometer was carried out in the department of physics by making a comparison with an Optronic OL-754 double monochromator with a spectral range from 250 nm to 800 nm. The values given by the Optronics were convolved with the erythema action spectrum and then integrated and compared with the values obtained with the UVB-1 (Cañada et al., 2008; Tena et al., 2009).

The ozone data was obtained from measurements performed by TOMS (Total Ozone Mapping Spectometer) until July 2004 and by Ozone Monitoring Instrument (OMI/aura satellite) from August 2004 (http://jwocky.gsfc.nasa.gov/).

2.2. Methods

The UVI (ICNIRP, 1995: WHO, 2002) is calculated by multiplying the UVER irradiance measurement (in W/m^2) by 40. Finally, the result is expressed as the nearest whole number between 0 and 16 (no decimals) and the exposure categories according UVI levels are shown in Table 1.

>Table 1<

The time to produce erythema has been calculated using the following equation:

$$t_E(\min) = \frac{MED(J/m^2)\cdot SPF}{UVER(W/m^2)\cdot 60} \qquad (1)$$

Where SPF is the sun protection factor of any sun block applied, and MED (minimal erythemal dose) is the minimum UVER dose which causes erythema with sharply defined edges 24 hours after sun exposure and depends on skin type (Table 2). The harmful effects of UV radiation depend on both the received UV dose and on the sensitivity of the individual´s skin. European human skin is often classified into four main groups according to the skin’s ability to tan and burn (Fitzpatrick, 1988). This classification is shown in Table 2, which also gives the approximate dose (in J/m^2) required to obtain a reddening of the skin (1 MED) (Vanicek et al., 2000). Thus 1 MED varies for different skin types.

>Table 2<

McKenzie et al. (2009) demonstrated that although the UVD irradiance is not directly proportional to the UVER irradiance, it is possible to estimate the UVD from UVER using a model, and with data about the ozone content in the atmosphere and the solar zenith angle (SZA):

$$UVD = R(ozone, SZA) \cdot UVER \qquad (2)$$

The numerical values of the R function have been obtained from the cross tab (ozone content in the atmosphere and the solar zenith angle) contained in the Appendix of the article by McKenzie et al. (2009), using the CIE action spectrum for vitamin D production to 330 nm (Bouillon et al., 2006). Each pair of values of ozone and the zenith angle (the input data of the table) are interpolated and a value of R was obtained. The UVD irradiance from measurements of UVER irradiance for the period 2003-2010 was calculated using the R values for a northern mid-latitude as Valencia. There is uncertainty about the validity of extrapolating the action spectrum for vitamin D beyond the last measured point at 315 nm, by this if we consider 315 nm as the upper limit, then the R values were typically 5-10% lower and so the calculated exposure time should be increased by a similar percentage.

In this paper we assume that optimal vitamin D levels are easily maintained by a daily intake of 1000 IU of vitamin D as indicated by experts in this field (Bischoff-Ferrari et al., 2006; Holick, 2004, 2005, 2007; McKenzie et al., 2009).

In McKenzie et al. (2009) it was estimated that a full-body exposure of pale skin (type II) under high sun conditions (UVI = 10) produces 1000 IU in less than one minute This statement is based on values of Holick (2002, 2007), who considers that 1 MED full body exposure corresponds to an oral dose of 10 000–25 000 IU of vitamin D. In McKenzie et al., (2009) for a person´s skin-type II, 1 MED is accumulated in about 14 min when UVI = 12, so the vitamin D produced from this is more than 10 times the recommended daily dose of up to 1000 IU.

The time to produce the required doses of vitamin D is estimated with the following equation in accordance with equation (3) by McKenzie et al. 2009:

$$t_{UVD}(\min)=\frac{UVER(s)(mW/m^2)\cdot R(s)\cdot MED(J/m^2)}{SPF\cdot BE\cdot AF\cdot UV_{vitD}(mW/m^2)\cdot MED(s)} \quad (3)$$

where the subscript (s) indicates standard values (UVER(s)= 250 mW/m^2 for UVI=10, R(s)=2), MED(s)=250 J/m^2). SPF is the sun protection factor, and BE (body exposed area) is the fractional area of skin surface exposed (in per unit). Since vitamin D_3 production decreases with age (Godar et al., 2011), it has been included an age factor (AF) in the equation (3).

For the above time calculations we have considered the following premises: young adults (<22 years old) who are assigned an AF=1 (Godar et al., 2011); skin without protection (SPF=1); and skin type III (the most common type among the Spanish population), so one MED equals 350 J /m^2 according to COST-713 (Vanicek et al., 2000).

The vitamin D dose that adults synthetize from UV exposure depend on how much skin they expose to the sun, and it is represented by the body exposed area. It was estimated during each season following the Lund-Browder chart used to assess the burned body surface area (Lund and Browder, 1944). For summer (June, July and August) and spring (March, April and May) we used a BE of 0.25 considering face, neck, hands and arms exposed, for autumn (September, October and November) a BE of 0.15 was assumed with face, neck, hands and half arms exposed, and for winter (December, January and February) a BE of 0.1 (face, neck and hands) was used (Engelsen, 2010; Godar et al., 2011). For these estimates we have considered adults in their daily routine, not in the holiday period.

Data is analysed using the Statgraphics Plus Statistical Package v5.1 software and is expressed as median (25-75 percentiles).

3. Results

3.1. UV index in Valencia

In Fig. 1 the evolution of the UVI obtained from 5-min measurements of UVER irradiance from 9 UTC to 15 UTC for the period 2003-2010 in Valencia is shown. A seasonal variation with higher values in the summer months is observed, reaching values close to 10 in 2007 and 2009. If we study the UVI at noon, 72% of UVI summer values are higher than 6 and the median value of UVI at solar noon in summer is 7.2 (5.7-7.9), high exposure category according to the World Health Organization (2002) (Table 1). In spring, 50% of UVI values at solar noon are greater than 6 and its corresponding median is 6.0 (4.4-7.2). At solar noon, in autumn, the UVI median value is 2.0 (1.4-3.2) and 1.7 (1.3-2.5) in winter. The solar zenith angle at noon is primarily responsible for the seasonal variability of the UVI.

Fig. 1 also shows ozone content provided by OMI (NASA, 2013). The ozone content varies between 250 and 450 Dobson units (DU), and no decrease was observed during the study period. The minimum ozone content occurs in November and December (autumn), and the maximum in April and May (spring).

>Figure 1<

>Table 3<

3.2. UVER and UVD irradiance in Valencia

Fig. 2 shows the evolution of the UVD irradiance for the period 2003-2010, calculated according to expression (2) from the UVER irradiance.

>Figure 2<

If we represent the UVD / UVER ratio against solar time for two typical summer and winter days (Fig. 3) we can see that the variation of the ratio is mainly a function of the solar zenith angle. In summer if we do not consider the sunrise/sunset times the UVD/UVER ratio is approximately constant and close to 2, while the winter value is lower and varies with solar time, i.e., depending on the solar zenith angle.

>Figure 3<

For the period 2003-2010 the median UVER irradiance around noon was calculated (from 11:30 UTC to 12:30 UTC) for four months of the year (one from each season). With these values and using eq. (1) the time to produce erythema was calculated. As shown in Table 4, in July an individual with skin type III should not be more than 29 minutes under the sun in order to not induce erythema. However, in January, the same individual may remain in the sunshine for 150 minutes.

>Table 4<

The median UVD irradiance in the period 2003-2010 around noon (from 11:30 UTC to 12:30 UTC) for one month for each season was also calculated. From these values and applying eq. (3) the minimum exposure time to obtain the recommended daily dose of vitamin D (1000 IU) was obtained. It can be seen in Table 4 that around noon in January it takes more than two hours of solar exposure to obtain the recommended daily dose of vitamin D, but this time is less than that would produce erythema, so there is no risk of sunburn.

The median UVD irradiance at 9 UTC, 12 UTC, and 15 UTC was also calculated for each season of the year. Solar exposure from 9 UTC in winter requires a median period of approximately 9.7 hours and from 15 UTC about 5.7 hours, as shown in Table 5. About these values, we have to consider that the exposure times calculated based on noon values make sense since solar radiation is approximately constant in the noon hour, but this is not true at other times e.g. 9 UTC and 15 UTC when radiation changes significantly over a period of an hour or more.

>Table 5<

It should be borne in mind that these calculations were performed for skin type III – for skin type II multiply the results by 2.5/3.5 and for type IV the time required would be even greater as the multiplication factor is 4.5/3.5. It must also be taken into account that we have considered a percentage of exposed body that it is usual for the season. If the percentage of exposed body is higher, then exposure time is reduced as shown in the equation (3).

3.3. Daily and annual UV doses

The evolution of daily doses of UVER and UVD for the 2003-2010 period are presented in Fig. 4. The median value of UVER daily doses for the considered period during the summer months was 4000 J/m^2day. With regard to UVER daily doses in winter the median value was 700 J/m^2day.

>Figure 4<

With regard to UVD daily doses, the median UVD daily dose in the summer months was 7700 J/m^2day, and in winter it was 1000 J/m^2day.

Following guidelines by CIE (2014) which proposed a newly defined minimum vitamin D dose (MDD), it has been obtained the MDD considering that a full-body exposure of pale skin (type II) under high sun conditions (UVI = 10) produces 1000 IU in less than 1 min (McKenzie et al., 2009). Then, the UVER dose received in one minute would be 15 J/m^2, equivalent to a MDD of 30 J/m^2, since UVI = 10 corresponds to R = 2.

Considering an exposure of 25% of the body, for skin type II, the MDD would be 120 J/m^2, equivalent to 168 J/m^2 for skin type III. Table 6 shows the MDD presented by skin type for an exposure of 10% and 25% of the body. The MDD obtained here is similar to that reported by other studies, mentioned as standard vitamin D dose (SDD), (Fioletov et al., 2010; Terushkin et al., 2010) taking into account the different conditions associated with the above calculations and that therefore the value given by one MDD would have a range.

In winter, with 10% of the body exposed, an individual with skin type III would need a UVD dose of 420 J/m^2, and so according to the median daily dose of UVD obtained for this season (1000 J/m^2) there is enough radiation available in Valencia in winter. However, receiving sufficient exposure would mean spending many hours outdoors and since most people work indoors it would be quite difficult to be exposed to the sun for enough time.

>Table 6<

The daily median UVD irradiances at solar noon, and at 9 UTC and 15 UTC solar hours are shown in Figs 5 to 7 respectively. The UVD irradiances at solar noon are above the threshold value of 3.46 mW/m^2 indicated by Engelsen et al. (2005). The UVD irradiances at 9 UTC and 15 UTC are above the mentioned value except for a few days in January and December. These results are in concordance with other studies that indicate that there is sufficient UV radiation in the mid-latitude winter to produce the required dose of vitamin D (McKenzie et al., 2009).

>Figure 5<

>Figure 6<

>Figure 7<

Fig. 8 shows the daily median UVD dose from the 11.30 UTC - 12:30 UTC obtained for the study period. It can be seen that if there is an exposure of 25% of the body all year (MDD =168 J/m^2), the minimum dose of vitamin D for skin type III in this time slot is reached, but if only 10% of the body is exposed in winter (MDD = 420 J/m^2), as is common, then one hour is insufficient to reach this dose between November and February. By this, in a latitude above 40ºN we can consider that the length of the effective vitamin D winter ranges from November to February.

>Figure 8<

To our knowledge, this is the first study on the vitamin D doses obtained from the UVER irradiance and the exposure time to solar radiation to get the recommended Vitamin D dose, that has been done in Spain.

4. Discussion

According to our results, in summer and spring, with 25% of body exposure, about 10 minutes of solar exposure would be sufficient to meet daily requirements of vitamin D. In winter, with 10% of body exposure at solar noon it would take two hours of sun exposure for an optimal dose of vitamin D – but at 9 UTC it would require a median period of approximately 9.7 hours and at 15 UTC about 5.7 hours. On these values, we would like to clarify that the exposure times calculated based on noon values can be taken into account, but since radiation changes significantly over a period of an hour or more, at other times e.g. 9 UTC and 15 UTC, the exposures times should be considered with caution, and they have been calculated to give an idea of the high time to get the optimal dose of vitamin D. These calculated minimum exposure times should be considered only approximate. Firstly, there is some uncertainty about the applicability of the action spectrum for vitamin D and which wavelength is appropriate to use. Secondly, it should be noted that the dose of radiation needed is relative to a horizontal plane, and the human body has a somewhat cylindrical shape, and therefore horizontal radiation should be processed as indicated in the article by Seckmeyer et al. (2013) regarding the radiation received by a voxel model of a human (taking into account the complex geometry of the radiation field). Moreover, the radiation received depends on posture, body shape, and clothing. Also it should be taken into account that all skin areas of the body do not synthesise vitamin D with the same efficiency (Holick et al., 2007). There are suggestions that for obese people vitamin D is "locked away" in fat (Holick, 2004, 2005, 2007, 2011), although other authors propose its dilution in the large fat mass of obese patients to explain their typically low vitamin D status (Drincic et al., 2011). Besides, the age of individuals plays an important role in vitamin D synthesis from UV radiation, since there is a decreasing capacity to make vitamin D_3 with increasing age, having the middle age adults a 66% of the capacity of make vitamin D_3 compared with children (Godar et al., 2011). In this study we have not considered the age of the individuals, so the results should be taken with caution.

In this paper it has been shown that in winter for a northern mid-latitudes as Valencia there is sufficient UV radiation to produce sufficient vitamin D and these results are in concordance with other authors (McKenzie et al., 2009). However, this is not wholly realistic since it is difficult to obtain the recommended daily dose of vitamin D in the winter months, as indicated by many authors, because there is insufficient casual exposure and a low percentage of our body is exposed given the low ambient temperatures. Specifically, in a northern mid-latitude above 40º as Valencia, we could consider that this vitamin D winter period ranges from November to February, although others authors ranges this period from October to March (Difffey, 2010; Rhodes et al., 2010; Seckmeyer et al., 2013; Webb et al., 1988; Webb et al., 2010; Webb et al., 2011; Zittermann et al., 2010).

These findings are supported by recent studies indicating that a high percentage of the Spanish population have a vitamin D deficiency. It could due to insufficient sun exposure derived from sunscreen use, clothing, a dark skin pigmentation, and the older age of the individuals, among other factors (Binkley et al., 2007; Godar et al., 2011; González-Rodríguez et al., 2013; Holick et al., 2011; Ovesen et al., 2003); as well as the result of inadequate vitamin D intake (González-Rodríguez et al., 2013; Ortega et al., 2012).

The time obtained to produce erythema has been calculated for the same periods that vitamin D in order to check whether there was risk of sunburn when the recommended vitamin D daily dose is achieved. According to our results, around noon, that is the time of the day with the highest UVI, the time obtained for the recommended daily dose of vitamin D is less than that would produce erythema, so, in principle, there is no risk of sunburn. Anyway, it should be considered that the time obtained to produce erythema has been calculated for median days, so it should be taken with caution. For the extreme days the permissible exposure times would be much shorter.

Conclusion.

Although in summer there are plenty of sun to maintain vitamin D sufficiency, there is a vitamin D winter, even in Valencia and other means of obtaining vitamin D might be required. Therefore, from the results of our study, we can conclude that an important factor contributing to this deficiency of the Spanish population can be an insufficient sun exposure in winter season, combined with sunscreen use and clothing. So that, the results of this article would help in the knowledge of the vitamin D dose obtained from UV exposure, and the later adoption of appropriate actions such us to inform the medical group of the convenience of increasing the intake of vitamin D through diet or supplements. Anyway, there is an alternative to oral supplementation, and it is to achieve higher end of summer 25(OH)D levels (Webb et al., 2010) without increasing the risk of skin cancer, and more studies would be necessary in this field.

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Table 1

Exposure categories based on UVI (WHO 2002).

Category	**UVI**
Low	<2
Medium	3-5
High	6-7
Very High	8-10
Extreme	11+

Table 2

General characteristics of skin types and minimal erythemal dose (J/m^2) according COST-713 (Vanicek et al. 2000).

Skin type	Tan	Burn	Minimal Erythemal Dose (J/m^2)
I	Never	Always	200
II	Sometimes	Sometimes	250
III	Always	Rarely	350
IV	Always	Never	450

Table 3

Median (25-75 percentiles) values of daily total ozone content (in Dobson units) in Valencia.

ozone (DU)	Year 2003	2004	2005	2006	2007	2008	2009	2010
median	300	306	309	312	319	311	310	318
p25	289	285	290	290	301	295	295	302
p75	313	340	327	336	349	335	332	347

Table 4

Median (25-75 percentiles) values of UVER and UVD irradiance around solar noon (11:30 UTC-12:30 UTC) and time to induce erythema and to produce 1000 IU for the period 2003-2010 in Valencia for one month of each season.

Month	UVER (mW/m^2)	UVD (mW/m^2)	t_E(min)	t_{UVD}(min)
January	39 (28-44)	55 (40-69)	150 (210-130)	130 (180-100)
April	130 (94-150)	250 (180-280)	44 (62-38)	11 (16-9.9)
July	200 (190-210)	400 (370-420)	29 (31-28)	7.1 (7.5-6.6)
October	85 (62-100)	150 (110-190)	69 (95-57)	31 (42 -24)

Table 5

Median (25-75 percentiles) values of UVD irradiance at 9 UTC, 12 UTC and 15 UTC and time to produce 1000 IU of vitamin D for the period 2003-2010 in Valencia for all seasons.

		UVD (mW/m^2)	t_{vitD}(min)
Winter	9 UTC	12 (11-12)	580 (610-570)
	12 UTC	65 (65-68)	110 (110-100)
	15 UTC	21 (20-24)	340 (340-290)
Spring	9 UTC	130 (120-140)	22 (23-20)
	12 UTC	290 (270-320)	9.7 (10-8.7)
	15 UTC	130 (120-130)	22 (24-21)
Summer	9 UTC	160 (150-160)	18 (18-17)
	12 UTC	360 (360-390)	7.7 (7.8-7.1)
	15 UTC	180 (170-180)	15 (17-15)
Autumn	9 UTC	31 (25-32)	150 (190-150)
	12 UTC	92 (76-100)	51 (61-46)
	15 UTC	22 (17-27)	200 (280-170)

Table 6

Minimum daily UVD dose according skin type and for two body exposures (following McKenzie et al. 2009 guidelines).

Skin type	MDD (J/m^2) BE= 0.25	MDD (J/m^2) BE=0.10
I	96	240
II	120	300
III	170	420
IV	220	540
V	290	720
VI	480	1200

FIGURES

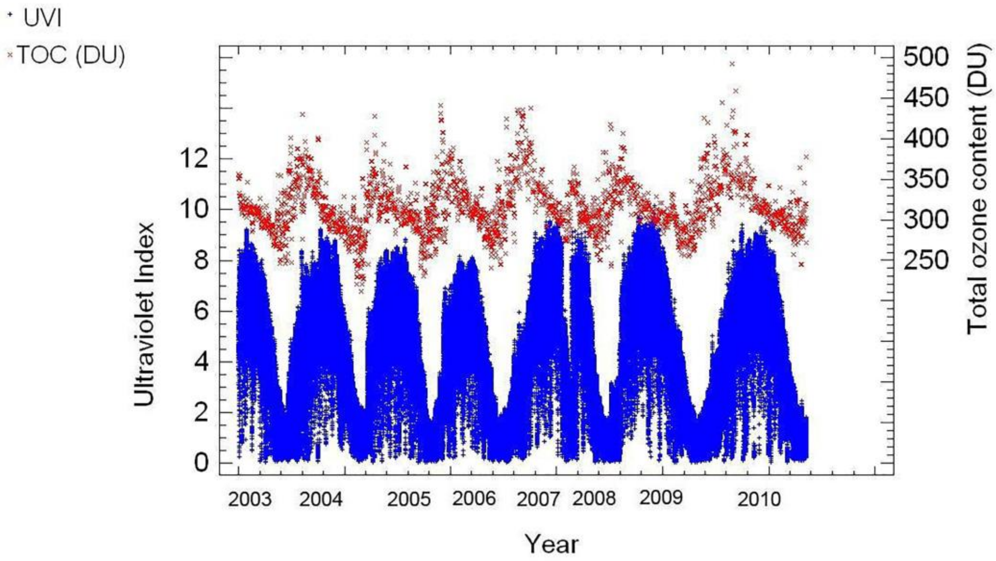

Fig. 1. UVI and total ozone content (DU) in Valencia in the period 2003-2010.

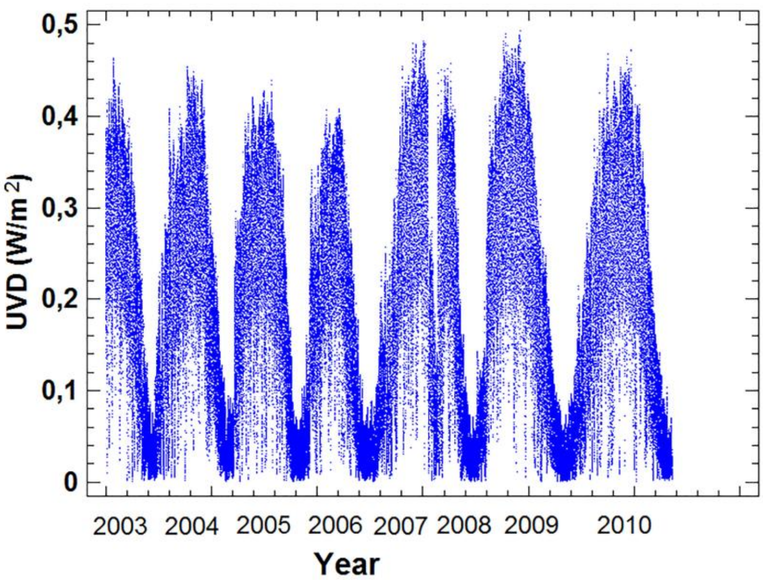

Fig. 2. UVD irradiance in Valencia for the period 2003-2010.

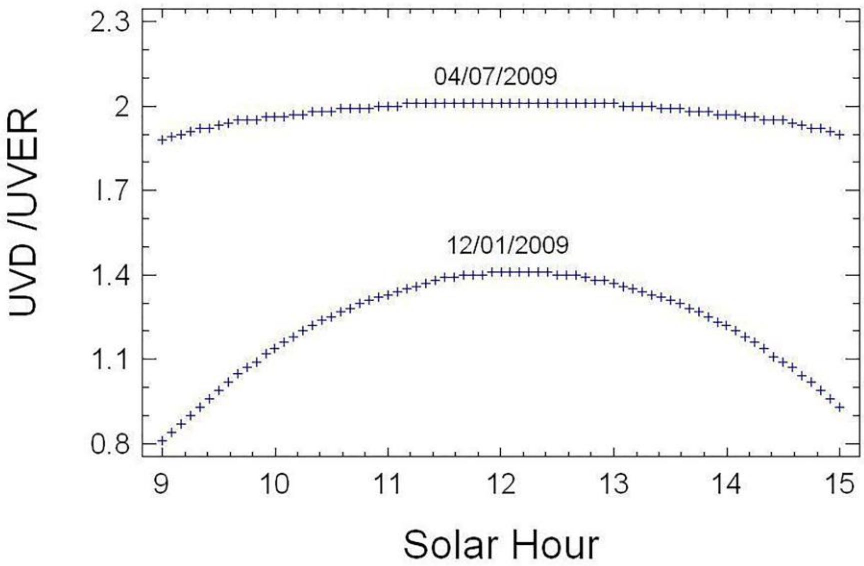

Fig. 3. UVD/UVER ratio by solar time for a winter and summer day in Valencia.

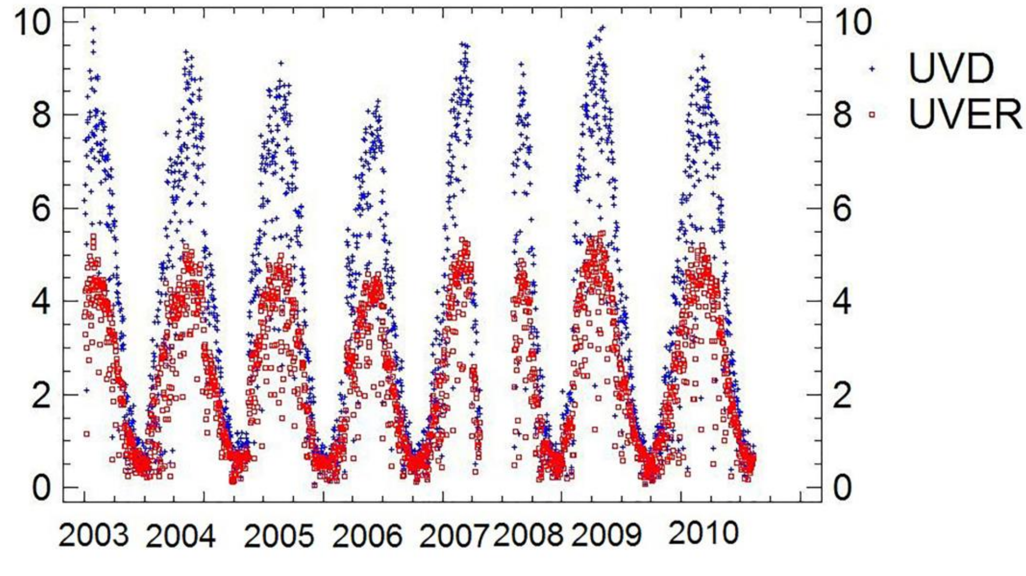

Fig. 4. Daily doses of UVD and UVER in Valencia in the period 2003-2010.

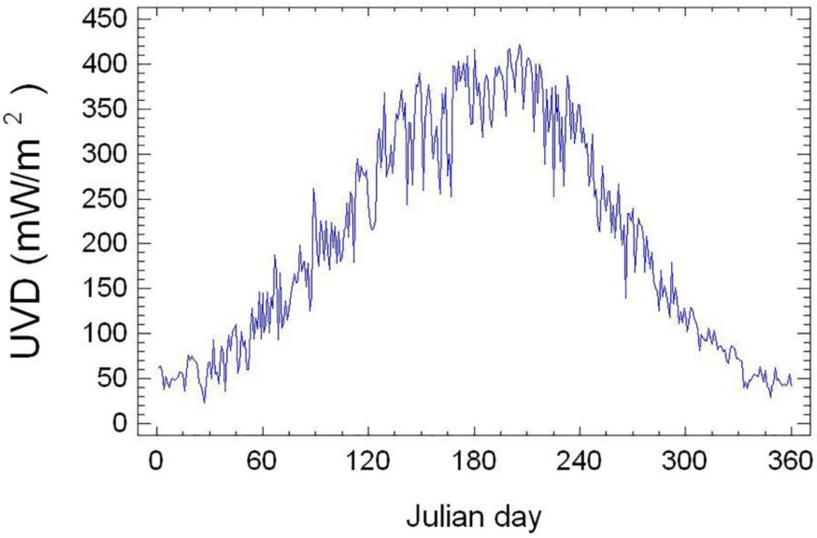

Fig. 5. Median daily UVD irradiances at solar noon in Valencia for the period 2003-2010.

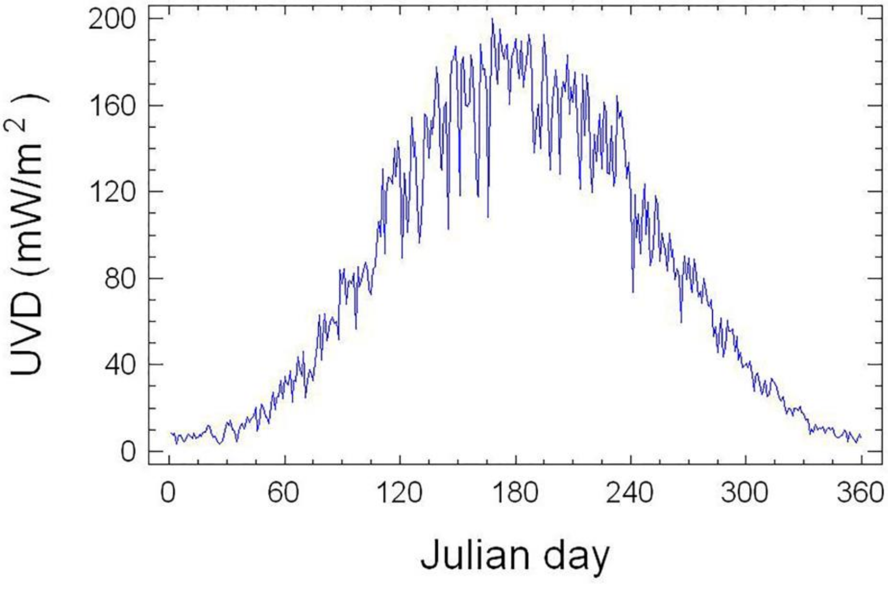

Fig. 6. Median daily UVD irradiances at 9 UTC in Valencia for the period 2003-2010.

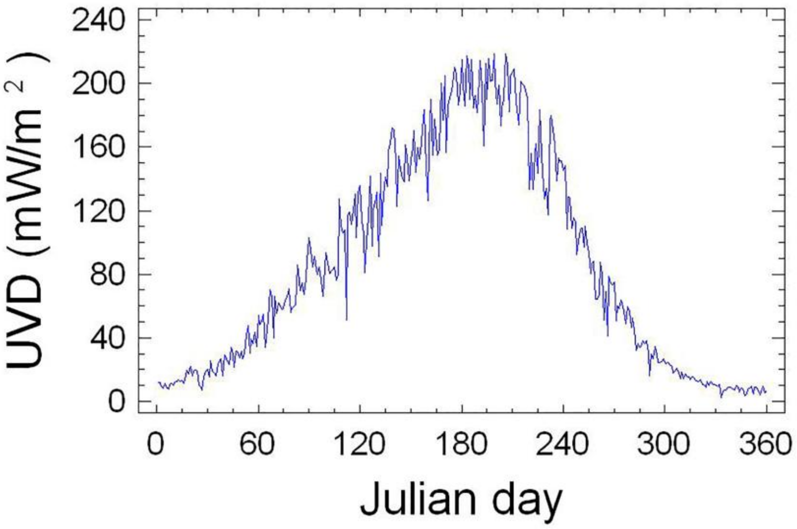

Fig. 7. Median daily UVD irradiances at 15 UTC in Valencia for the period 2003-2010.

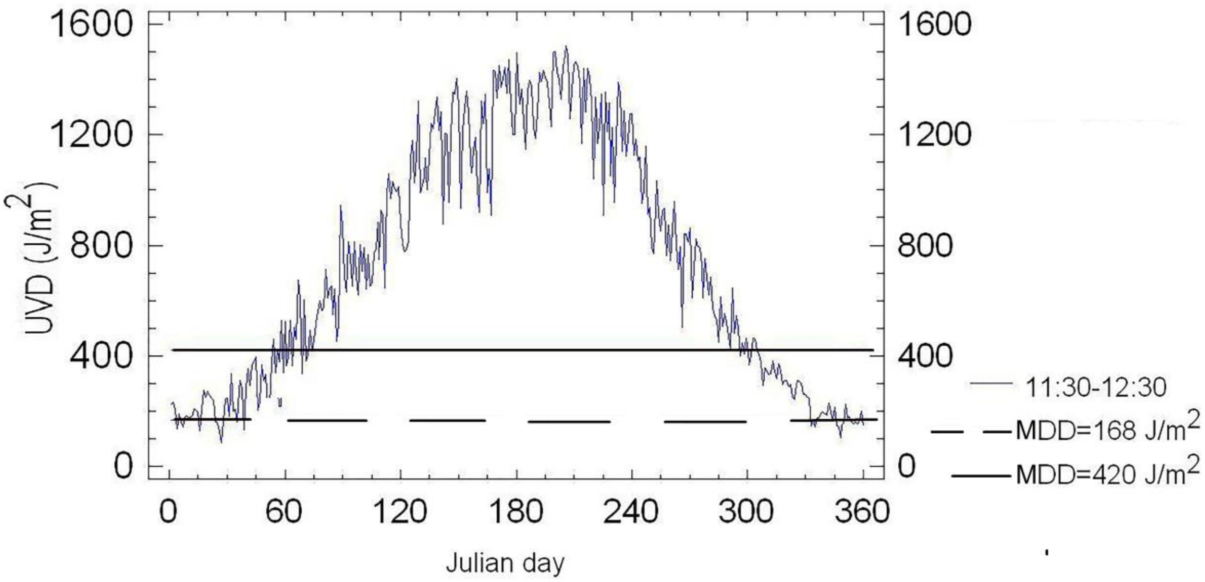

Fig. 8. Evolution of the daily median UVD dose from 11.30 UTC -12:30 UTC in Valencia for the period 2003-2010.