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# The UV Index on the Spanish Mediterranean Coast¶

**M. J. Marín[1], Y. Sola[2], F. Tena[1], M. P. Utrillas[1], E. Campmany[2], X. de Cabo[2], J. Lorente[2] and J. A. Martínez-Lozano*[1]**

[1]Solar Radiation Group, University of Valencia, Valencia, Spain
[2]Department of Astronomy and Meteorology, University of Barcelona, Barcelona, Spain

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## ABSTRACT

**An analysis is made of measured ultraviolet erythemal solar radiation (UVER) data recorded during the year 2003 by the networks of the Catalan Weather Service and the Environment Department of Valencia (both on the Spanish Mediterranean coast). Results show a latitudinal variation at sea level, of 3–4% per degree and an increase with altitude of 10% per km. Based on these data the UV Index has been evaluated for the measuring stations. The maximum experimental value of the UV Index was around 9 during the summer, although higher values were recorded at two stations, one at the highest elevation and the other at the lowest latitude. The annual accumulated doses of irradiation on a horizontal plane have been presented as well as the evolution through the year in units of energy, Standard Erythemal Doses and Minimum Erythemal Doses according to different phototypes. Lastly, the UV Index forecast, determined with a multiple scattering radiative transfer model, has been analyzed. Total agreement or only one unit of difference between measured and modelled values was found in 94% of cloud-free cases.**

## INTRODUCTION

In the middle of the 1980s, spurred by public concern following the discovery of the ozone hole in the Southern Hemisphere (1), many atmospheric researchers and medical professionals recognized the need to introduce indices for predicting the doses of ultraviolet radiation incident at ground level. Such indices are aimed at raising public awareness, through the media, of the levels of UV radiation incident at ground level and the possible harmful effects of this radiation. They constitute a simple means of expressing the intensity of UV radiation in relation to its capacity to trigger certain biological processes.

In 1995 the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in collaboration with the World Health Organization (WHO), the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP) produced recommendations redefining the UV Index (2). Subsequently the WMO (3) defined the amount of effective erythemal radiation as the spectral solar irradiance biologically weighted by the action spectrum recommended by the Commission Internationale de l'Eclairage (4,5) on a horizontal surface at ground level. Quantitatively, the UV Index is determined from the integrated erythemally weighted radiation (UVER) over all wavelengths up to 400 nm (expressed in $W \cdot m^{-2}$) multiplied by 40. It is rounded to the nearest whole number. For sloping surfaces directed toward the sun, this value could be higher than it is on a horizontal surface (6).

Forecasting of the UV Index can be done by using many different radiative transfer models, although the European Cooperation in the field of Scientific and Technical Research (COST)-713 Action of the European Commission recommends the use of multiple scattering models because these models show better agreement between simulations (7). To validate the accuracy of UV Index forecasts, it is necessary to have accurate and precise UVER measurements. Moreover, such experimental UVER values are also useful for developing a UV radiation climatology and establishing geographical and seasonal distributions of UV exposure information that is useful in many areas including human health (8,9).

At the beginning of 1999 the Spanish National Institute of Meteorology installed a measurement network based on broad-band radiometers. At present it consists of 16 UVB pyranometers and six Brewer spectrophotometers that are used to determine the total ozone column (10,11). At the same time, many autonomous regions, which in Spain currently have responsibility for many issues including the environment and tourism, have developed their own erythemal-radiation measurement networks. These regional networks complement the state network with a higher spatial resolution. Two such networks are found in the regions of Catalonia and Valencia, which together occupy a large stretch of the Spanish Mediterranean coast (see Fig. 1) and receive many of the 42 million tourists that every year visit Spain, making the Catalonia–Valencia region one of the most touristic areas of Europe.

This paper presents an analysis of the UV Index and corresponding measurements for both regions for 2003. A comparative study has been carried out between experimental and modelled values using multiple scattering radiative transfer models. This analysis

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*To whom correspondence should be addressed: Solar Radiation Group, University of Valencia, Dr. Moliner, 50. 46100 Burjassot (Valencia), Spain. Fax: 34-96-3543385; e-mail: jmartine@uv.es
*Abbreviations:* DISORT, DIScreet Ordinate Radiative Transfer; ICNIRP, International Commission on Non-Ionizing Radiation Protection; MED, Minimum Erythemal Dose; RB, Robertson–Berger; SBDART, Santa Barbara DISORT Atmospheric Radiative Transfer; SED, Standard Erythemal Dose; TOMS, Total Ozone Mapping Spectrometer; UNEP, United Nations Environmental Program; UVER, ultraviolet erythemal solar radiation; WHO, World Health Organization; WMO, World Meteorological Organization.

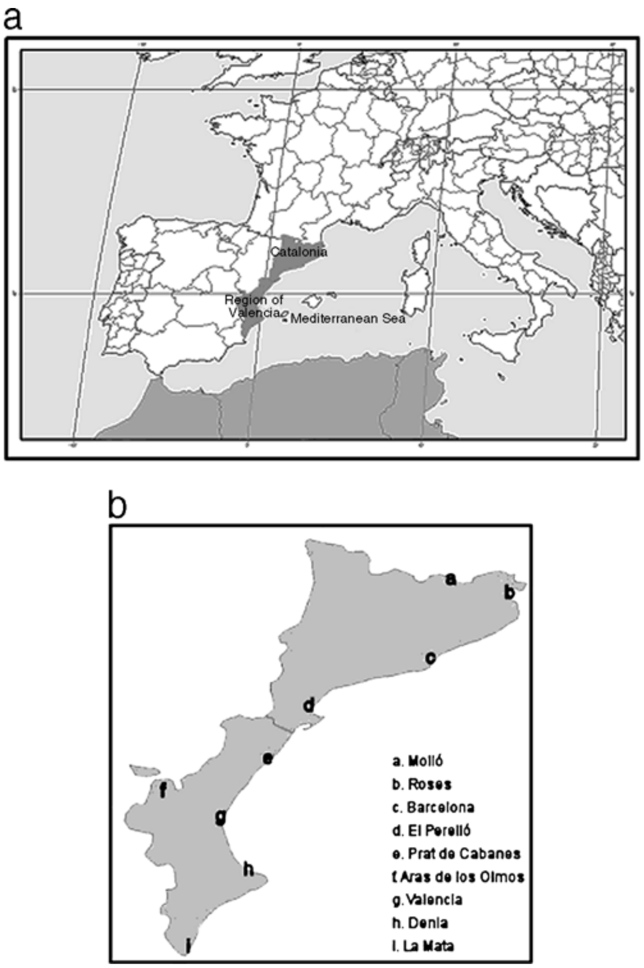


**Figure 1.** Autonomous regions of Catalonia and Valencia in the framework of the Iberian Peninsula and the stations of the measurement networks in both regions.

**Table 1.** Coordinates of the stations of the Catalonian and Valencian networks

| Station | Latitude | Altitude (m above sea level) |
|---|---|---|
| (a) Molló | 42°21′36″N | 1406 |
| (b) Roses | 42°16′16″N | 24 |
| (c) Barcelona | 41°23′08″N | 98 |
| (d) El Perelló | 41°15′25″N | 179 |
| (e) Prat de Cabanes | 40°08′13″N | 14 |
| (f) Aras de los Olmos | 39°57′01″N | 1277 |
| (g) Valencia | 39°27′49″N | 10 |
| (h) Denia | 38°49′19″N | 44 |
| (i) La Mata | 38°00′30″N | 12 |

follows up on a previous paper focussing on the two main cities of these regions, Barcelona and Valencia (12).

## MATERIAL AND METHODS

*Measurement networks.* The UV Index measurement network in Catalonia was established in the middle of 2000. It was designed by the Department of Astronomy and Meteorology of the University of Barcelona. The network consists of four stations, three located on the coast and the other inland at an altitude of 1400 m above sea level. The locations of these stations are shown in Fig. 1. Similarly, the Environment Department of the regional government of Valencia established a UVB-radiation measurement network with five stations. Designed by the Solar Radiation Group of the University of Valencia the network consists of four stations on the coast and another inland at 1300 m altitude. The locations of these stations are also shown in Fig. 1. Table 1 gives the stations' locations and elevations above mean sea level. The higher density of stations in coastal locations is justified as much by the high stable population as by the importance of the coast as a tourist destination. The inland stations are useful for studying continental and altitude effects.

The sensors installed in the Valencian network are UVB-1 pyranometers (Yankee Environmental Systems, Turners Falls, MA). The national UV network of Spain uses the same type of instruments (10). The sensors installed in Catalonia are 501A UV biometers (Solar Light Company, Glenside, PA). All these radiometers are broad-band (280–320 nm) Robertson–Berger-type (RB) radiometers. The RB meter was designed to measure the erythemal dose of solar radiation by means of a fluorescent phosphor that converts the UVB light to visible light, which is then measured by a solid-state photodetector. The response of these instruments is similar to the spectral response of human skin to UV radiation, although these broad-band instruments do not exactly match the weighting function. A methodology to determine how to correct the outputted values with respect to total ozone and solar zenith angle is given by Lantz *et al.* (13).

These sensors are designed to be stable for long periods of time and for field experiments and do not require continuous attention. In each measurement station, the instrument has been installed with an uninterrupted and stabilized battery, a pole with platform on which to mount the sensor and a communication antenna and a protected enclosure with an electrical installation. The data acquisition and transmission involve communications software and protocols and a Global System for Mobile Communications (GSM) communication system.

Although the radiometers are initially calibrated by the manufacturer, they are re-calibrated periodically, approximately once a year. The calibration is carried out using one of two different procedures: in the first method the radiometer is compared with a high-resolution spectroradiometer; the other procedure involves comparing it with a standard radiometer with similar characteristics. In the first procedure two spectroradiometers, Bentham DM 300 (Reading, UK) and Optronic OL-754 (Orlando, FL), are used for Catalonia and Valencia, respectively. The second method, known as intercomparison, is usually used in UVB networks (14–16). The network radiometers are calibrated by comparing their responses with a similar radiometer, called the standard, which has been calibrated previously by a reference lamp or a precision spectroradiometer. For the intercomparison, all of the instruments are placed on a horizontal surface 1.5 m above the ground and separated 40 cm from each other in order to avoid shadows. The measurements are made simultaneously during 2 or 3 days, with fixed specifications such as sample time, scale factor, temperature stabilization, *etc.*

The radiometers, in standard operating mode, measure UVER ($W{\cdot}m^{-2}$) every second. From these values the integrated irradiance values are obtained for the desired time interval, in this case 1 min. These data constitute the primary database for determining the experimental UV Index following the joint recommendations of WHO, WMO, ICNIRP and UNEP (2,8) and those of COST-713 Action (17). After this primary database has been screened, the 10-min means are determined, so that the secondary database consists of 10-min UVER measurements, which are used to calculate the UV Index and its daily evolution. Generally the maximum corresponds with the solar noon.

*UV Index forecast.* The UV Index forecast is calculated by multiple scattering radiative transfer models that usually provide this value directly as an output product (7). The essential input data are date and time, geographical coordinate system, altitude above sea level and vertical ozone column. Results from various models were analyzed and compared, then the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) algorithms (2.0 and 2.3 versions), developed by Richiazzi *et al.* (18), were implemented. The SBDART program, written in FORTRAN, is designed for the analysis of a wide variety of radiative-transfer problems across the atmosphere considering satellite data and energy-balance studies in the atmosphere. It is available for free from various web sites (19,20).

In the SBDART model, the radiative-transfer equation is solved numerically integrating with the DIScreet Ordinate Radiative Transfer (DISORT) method. This provides a stable algorithm to solve the radiative-transfer equations in a vertically nonhomogeneous plane–parallel atmo-

**Table 2.** Cloud Modification Factor for different cloud types and amounts of cloud cover (17)

| Cloudiness (octas) | Clear (0–2) | Partial (3–4) | Extensive (5–6) | Overcast (7–8) |
|---|---|---|---|---|
| High | 1.0 | 1.0 | 1.0 | 0.9 |
| Middle | 1.0 | 1.0 | 0.8 | 0.5 |
| Low | 1.0 | 0.8 | 0.5 | 0.2 |

sphere, using as many as 40 layers and 16 zenital and azimutal angles. Once SBDART has been executed, the UV Index is calculated. This calculus has been automated by a FORTRAN program which calculates the index in various stages: (1) spectral erythemal irradiance; (2) integrated erythemal irradiance; and (3) UV Index.

The model is implemented for clear days forecast for sea level, using as ozone column input the values supplied by the Total Ozone Mapping Spectrometer (TOMS) (21). The clouds and altitude corrections in the UV Index are made at a later stage, once the prediction for clear days has been made, according to the methodology suggested by COST-713 (17):

$$\mathrm{UVI} = \mathrm{UVI_0} \cdot \mathrm{CMF} \cdot (1 + 0.08 \cdot \Delta \mathrm{H})$$

where $UVI_0$ is cloud-free-sky UV Index, CMF is cloud modification factor (a nondimensional number between 0 and 1, see Table 2) and $\Delta H$ is the elevation of the surface above sea level in km.

Every day the radiation groups of the Universities of Barcelona and Valencia make 36-h UV Index forecasts corresponding to solar noon. This forecast is broadcast on the Catalan Weather Service web site (http://www.meteocat.com) and the Valencian Environment Office site (http://www.cma.gva.es/cidam/emedio/uv/).

## RESULTS AND DISCUSSION

### Experimental values of the UV Index

In Fig. 2 (a–i) the 2003 annual evolution of the daily UVER values corresponding to solar noon is shown for each station of the measurement networks. Likewise, Table 3 shows monthly means of cloud-free daily values of UVER for each station.

In view of these tables, some observations about the influence of height and latitude on the UVER can be made. As for latitudinal effect, the analysis of the values at stations that are 2° distant but at the same altitude above sea level—Roses (lat 42° 16′ 16″N), Prat de Cabanes (40° 08′ 13″N) and La Mata (38° 00′ 30″N)—shows an average decrease of 6% per degree north. The altitude effect has been deduced by the comparison of data from Molló and Roses (at similar latitudes) and Aras de Olmos and Valencia (0.5° distant in latitude). The first pair of stations shows an increase of 16% per km; for the second pair the increment is 21% per km. These results are considerably higher than that estimated by the COST-713 Action (17).

The data have been recalculated employing only values of UVER corresponding to a UV Index equal to or higher than 3 (UVER higher than 0.075 $W{\cdot}m^{-2}$). This criterion was chosen because this is the threshold of moderate UV Index; above this value protection from UV radiation is necessary (3). This level was reached in the months from March through September in Catalonia and from March to October in Valencia. The latitudinal effect in this case is 4%. After recalculation, the altitude effect for Molló and Roses is 10% per km and for Aras de Olmos and Valencia the increment is 11% per km. This slight difference could be assumed to be a product of the latitudinal effect, which is not negligible in this case. This percentage fits with the value at noon estimated by the COST-713 Action (17).

In this analysis the differences and similarities in site conditions may be because of conditions such as albedo (snow or grass *vs* bare ground) or pollution (high-aerosol *vs* low-aerosol conditions) that could present an additional influence between the high and low elevation sites. This is particularly important if there is snow in the mountain stations because the increase in the albedo could explain the big differences in UV Index obtained in the winter season.

The COST-713 Action proposed a UV Index increase of about 8% per km. Frederick (1993, personal communication) found an increase of 6% per km through modelling whereas Blumthaler *et al*. (22) found about 14–18% per km from measurements on a horizontal surface. The 10% per km found in this study is close to the 8% per km suggested in the equation shown previously to determine the UV Index.

Although under current recommendations the UV Index represents the maximum daily value of the UVER, the experimental UV Index was determined by the UVER values corresponding to solar noon. In a previous paper (10) the authors analyzed data from 11 stations on the Iberian Peninsula and found a good agreement with both solar noon and daily maximum. In fact, differences between the two criteria to determine UV Index were 1 unit or less in 90–96% of cases, depending on the station. Moreover the highest percentage of agreement corresponded to stations close to the Mediterranean coast. It was therefore considered reasonable to estimate the UV Index based on the noon values. Table 4 shows the UV Index at each measurement station, and its recurrence (in %) over the period under consideration. It can be observed that the maximum UV Index is 10 at the stations of Molló and La Mata because of the altitude and the latitudinal effects, respectively.

**Table 3.** Monthly mean of cloud-free daily values of UVER ($W{\cdot}m^{-2}$) at solar noon for each station

| Erythemal UV ($W{\cdot}m^{-2}$) | (a) Molló | (b) Roses | (c) Barcelona | (d) El Perelló | (e) P. Cabanes | (f) A. Olmos | (g) Valencia | (h) Denia | (i) La Mata |
|---|---|---|---|---|---|---|---|---|---|
| January | 0.040 | 0.030 | 0.032 | 0.035 | 0.035 | 0.037 | 0.034 | 0.039 | 0.041 |
| February | 0.056 | 0.045 | 0.045 | 0.041 | 0.051 | 0.066 | 0.054 | 0.057 | 0.067 |
| March | 0.121 | 0.102 | 0.090 | 0.098 | 0.096 | 0.117 | 0.103 | 0.107 | 0.118 |
| April | 0.157 | 0.142 | 0.140 | 0.147 | 0.156 | 0.178 | 0.149 | 0.162 | 0.172 |
| May | 0.192 | 0.181 | 0.175 | 0.187 | 0.195 | 0.231 | 0.196 | 0.218 | 0.220 |
| June | 0.225 | 0.194 | 0.199 | 0.196 | 0.240 | 0.263 | 0.242 | 0.245 | 0.262 |
| July | 0.214 | 0.184 | 0.187 | 0.187 | 0.232 | 0.259 | 0.224 | 0.230 | 0.248 |
| August | 0.188 | 0.157 | 0.167 | 0.166 | 0.197 | 0.203 | 0.192 | 0.183 | 0.197 |
| September | 0.145 | 0.127 | 0.132 | 0.129 | 0.152 | 0.167 | 0.144 | 0.148 | 0.149 |
| October | 0.107 | 0.087 | 0.073 | 0.055 | 0.086 | 0.098 | 0.091 | 0.099 | 0.095 |
| November | 0.043 | 0.032 | 0.041 | 0.037 | 0.051 | 0.057 | 0.046 | 0.050 | 0.049 |
| December | 0.032 | 0.020 | 0.028 | 0.030 | 0.033 | 0.038 | 0.033 | 0.037 | 0.038 |

**Table 4.** Total days and recurrence percentage (in parentheses) that the indicated UV Index value is reached in each station

| | UV Index | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| (a) Molló | 16 (5) | 52 (16) | 66 (20) | 43 (13) | 23 (7) | 38 (12) | 14 (4) | 21 (6) | 26 (8) | 22 (7) | 5 (2) |
| (b) Roses | 19 (5) | 94 (26) | 39 (11) | 20 (5) | 37 (10) | 45 (12) | 33 (9) | 41 (11) | 33 (9) | 4 (1) | |
| (c) Barcelona | 17 (5) | 79 (22) | 56 (16) | 36 (10) | 25 (7) | 32 (9) | 29 (8) | 45 (13) | 35 (10) | 2 (1) | |
| (d) El Perelló | 25 (7) | 70 (20) | 60 (17) | 22 (6) | 25 (7) | 28 (8) | 32 (9) | 48 (14) | 34 (10) | 4 (1) | |
| (e) Prat Cabanes | 15 (4) | 90 (26) | 52 (15) | 39 (12) | 21 (6) | 25 (7) | 35 (10) | 36 (11) | 27 (8) | 2 (1) | |
| (f) Aras Olmos | 14 (4) | 85 (26) | 55 (17) | 30 (9) | 30 (9) | 27 (8) | 25 (8) | 25 (8) | 25 (8) | 9 (3) | |
| (g) Valencia | 10 (3) | 99 (29) | 47 (13) | 29 (8) | 42 (12) | 28 (8) | 31 (9) | 34 (10) | 24 (7) | 2 (1) | |
| (h) Denia | 18 (6) | 73 (22) | 60 (18) | 29 (9) | 34 (10) | 30 (9) | 25 (8) | 22 (7) | 33 (10) | 2 (1) | |
| (i) La Mata | 6 (2) | 65 (19) | 65 (19) | 27 (8) | 39 (11) | 30 (9) | 19 (6) | 36 (10) | 19 (6) | 30 (9) | 5 (1) |

Based on the previous data a daily UVER irradiation database ($J{\cdot}m^{-2}$) was created. These daily data were used to calculate cumulative doses over the year 2003. The cumulative curves (beginning on 1 January) were obtained by dividing these doses by the Standard Erythemal Dose (SED) (5) and the Minimum Erythemal Dose (MED) of each phototype. In Fig. 3, the results corresponding to the stations of Roses and La Mata are presented. These results represent the irradiances that would be accumulated by an uninterrupted exposure to the sun throughout the course of the year in a horizontal plane. A change of slope is observed on the plots during summer months. Under these exposure conditions, a Type I skin receives approximately 3000 MEDs in a year and about three-quarters of this would come from the summer season. The accumulated doses between Days 90 and 270 (in $J{\cdot}m^{-2}$) for a Phototype I skin are 2350 for Roses and 2970 for La Mata. For the rest of the year they are 862 and 910 respectively.

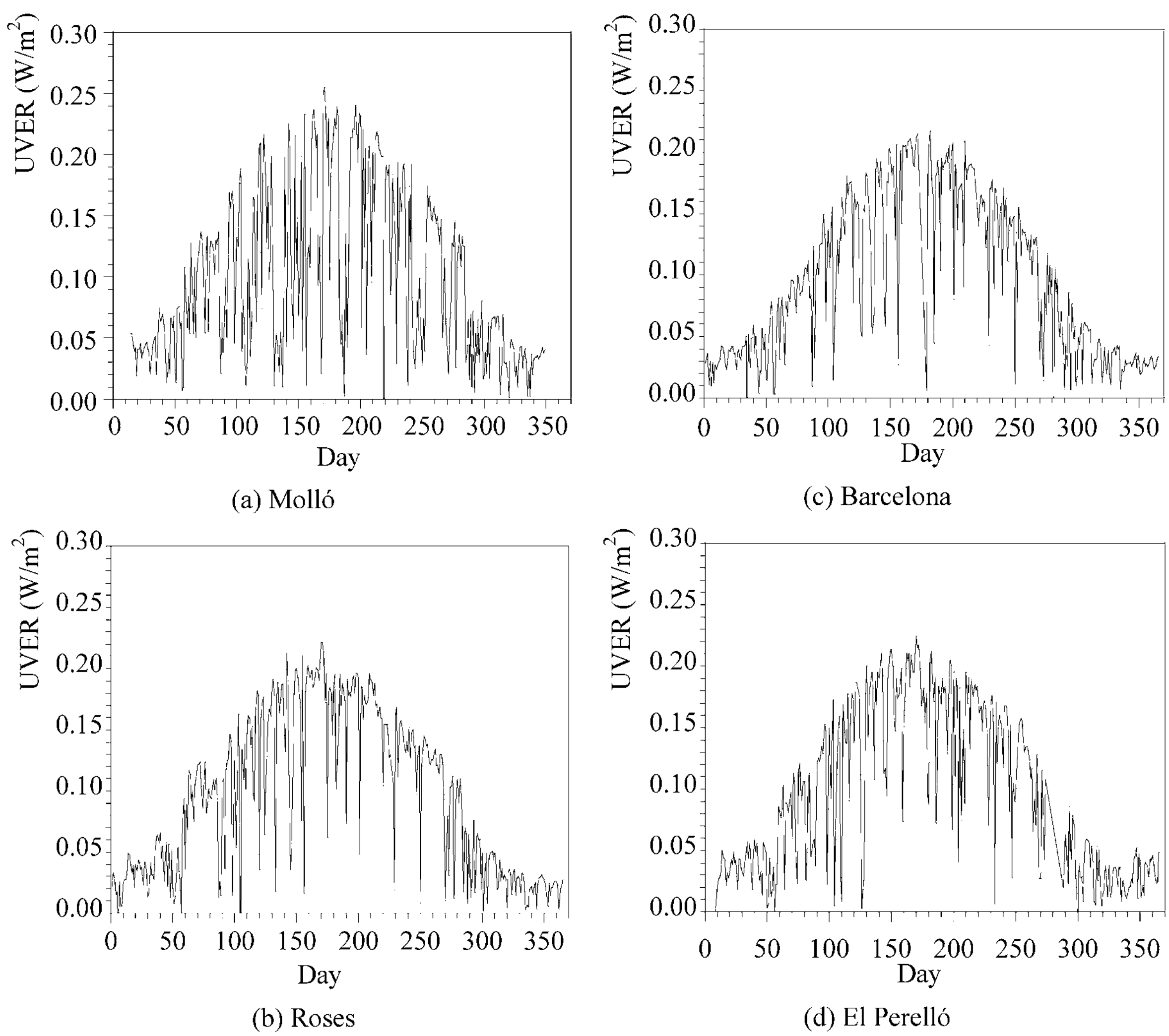


**Figure 2.** 2003 annual evolution of the UVER values at solar noon. (a) Molló; (b) Roses; (c) Barcelona; (d) El Perelló; (e) Prat de Cabanes; (f) Aras de los Olmos; (g) Valencia; (h) Denia; (i) La Mata.

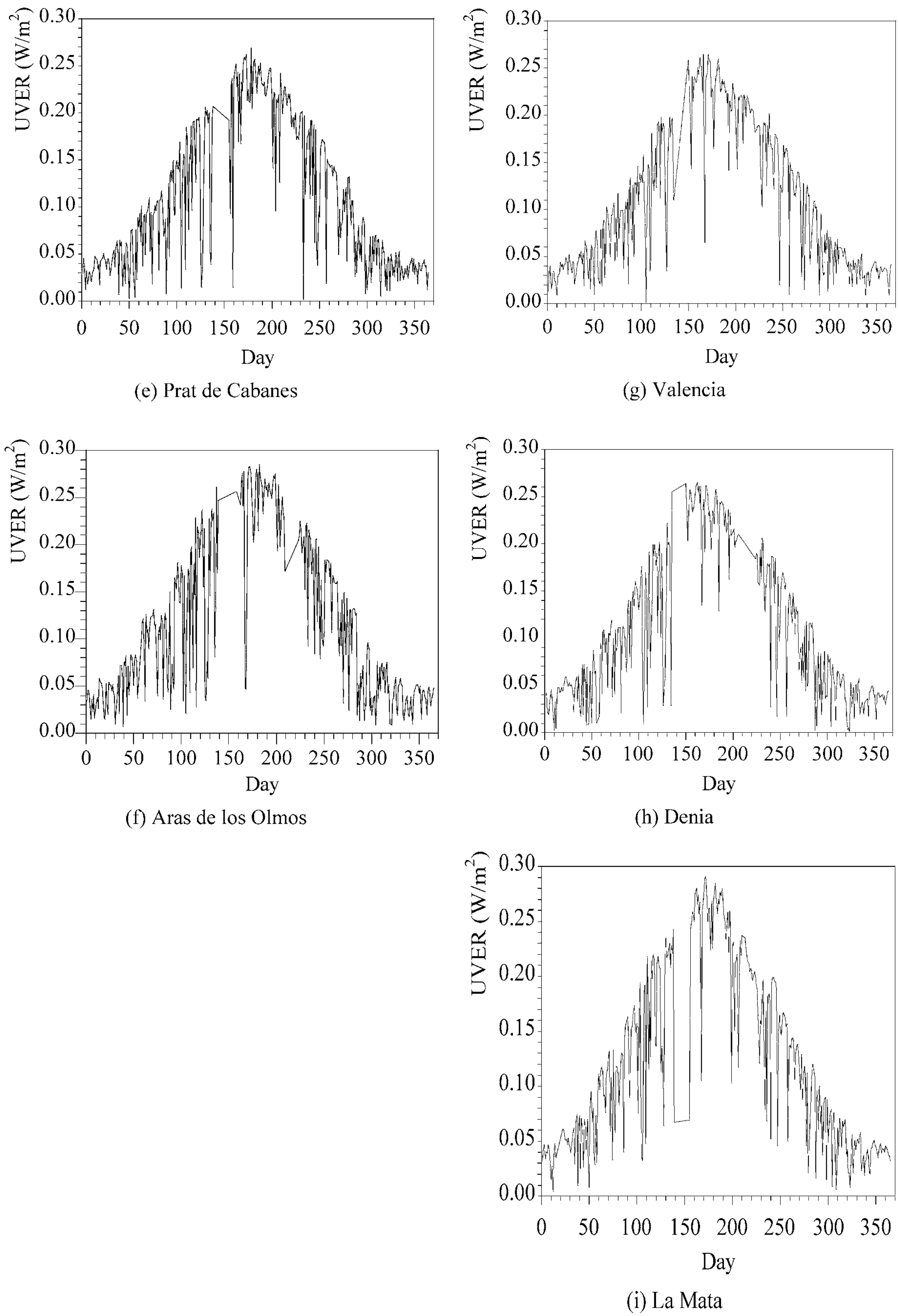


**Figure 2.** Continued.

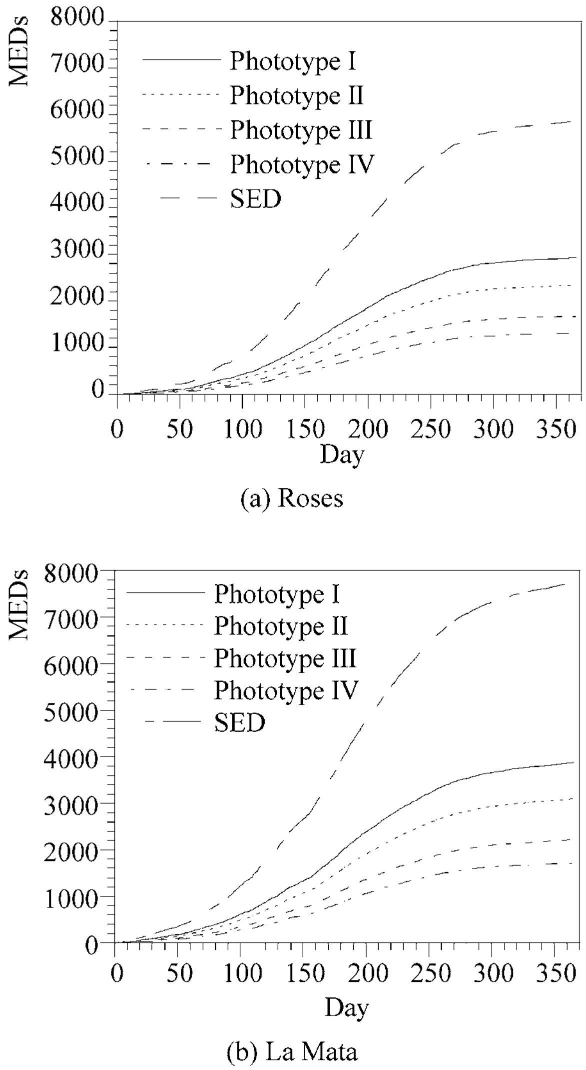


**Figure 3.** Irradiation accumulated over the year, expressed in SED (-•-) and in MED for different skin phototypes: (—) Phototype I; (- - -) Phototype II; (– – –) Phototype III; (– - - - ) Phototype IV. (a) Roses; (b) La Mata.

**Modelled UV Index**

Estimates of the UV Index at solar noon have been calculated using the SBDART model for the nine stations given in Table 1 every day in the period under consideration. As indicated previously, the model has been applied for cloud-free skies, and has been corrected for altitude but not cloudiness. The estimated values have been compared with each station's experimental UV Index. Figure 4 shows, as an example, the annual evolution of the daily measured and modelled UV Index for the Valencia station during 2003. The annual evolution of the UVER values, forecast and measured, is shown in Fig. 5. In this figure the curves show better agreement than they do in Fig. 4 because here the values for the UV Index evaluation are not truncated.

The plots are almost coincident and there are substantial disagreements only on days when the experimental UV Index is abnormally low for that season because of cloudy or overcast conditions (high clouds scarcely affect UV irradiance). Considering that the output of the model does not take into account clouds, the result is quite good. For all stations, both index values (measured and modelled) are in agreement or differ by only 1 unit in more than 81% of cases. This is an acceptable result because the rounding of the index to a whole number alone can mean that a 1 unit difference in UV Index could be the results of a real difference of less than 0.025 W•m$^{-2}$ in UVER. By using cloudiness data provided by the National Institute of Meteorology and the Catalan Weather Service, days on which low clouds were present could be screened. For the remaining days, measured and modelled index values were in agreement to within 1 unit for more than 90% of the cases for all the stations in the period of measurements. Results are summarized in Table 5, finding a total agreement or only 1 unit of difference between measured and modelled values in the 94% of cases.

The analysis of the deviations shows that the SBDART model overestimates the experimental values by about 10%. So the differences between the experimental and estimated values are higher when the incident radiation is higher, which is shown in Table 5, where the bottom three sites are more likely to have a 1 UV Index difference, than are the top four sites, which are more likely to have no difference between the experimental and mod-

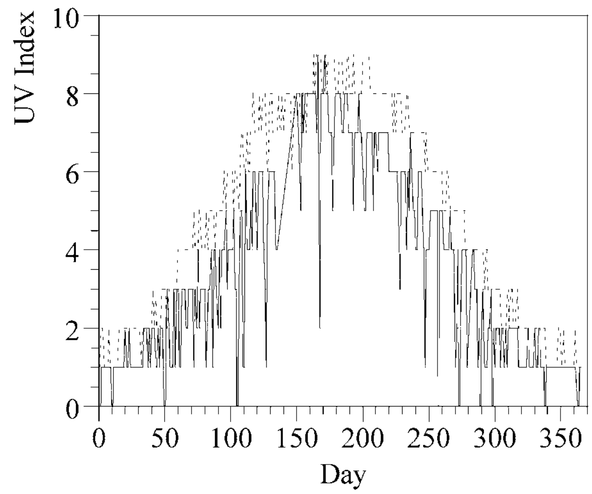


**Figure 4.** Annual evolution of the experimental (solid line) and modelled (dashed line) UV Index values. Station of Valencia.

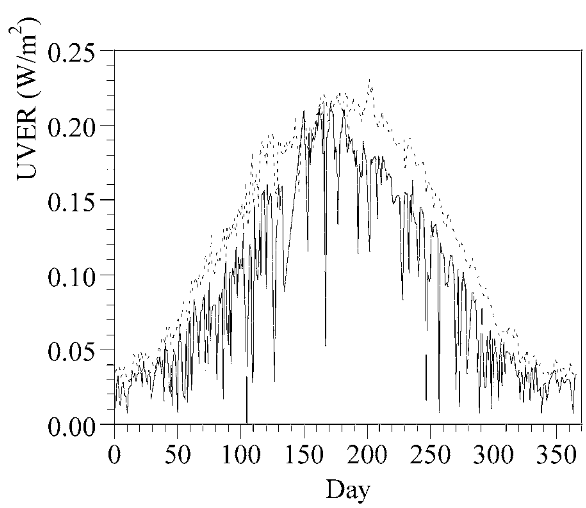


**Figure 5.** Annual evolution of the experimental (solid line) and modelled (dashed line) UVER values. Station of Valencia.

**Table 5.** Percentage of days in which the experimental and modelled indices differ

| Station | Difference | | |
|---|---|---|---|
| | 0 | 1 | 2 |
| (a) Molló | 47.5 | 45.0 | 7.4 |
| (b) Roses | 61.9 | 36.8 | 1.4 |
| (c) Barcelona | 57.1 | 41.0 | 1.7 |
| (d) El Perelló | 54.9 | 43.9 | 1.2 |
| (e) Prat de Cabanes | 42.8 | 53.4 | 3.8 |
| (f) Aras de los Olmos | 52.5 | 47.1 | 0.4 |
| (g) Valencia | 31.8 | 58.5 | 9.7 |
| (h) Denia | 40.6 | 54.3 | 5.1 |
| (i) La Mata | 40.9 | 55.5 | 3.6 |

elled values. This circumstance is being considered in order to introduce modifications in the prediction model.

## CONCLUSIONS

UVER values recorded by the networks of Catalonia and Valencia during 2003 have been analyzed. Considering only values that lead to moderate, high or very high UV Index (3 or more), these values show a latitudinal dependence (at sea level) of 3–4% per degree. In the same way, they present an altitude dependence of 10% per km. There are enough analyzed values to validate these results.

From these measurements, the respective daily UV Indices have been calculated for each location. Most stations show a maximum UV Index of 9 (very high), except for Molló station (the highest altitude) and La Mata station (with the lowest latitude) where values of 10 were reached.

The measured values are useful to test the accuracy of the UV Indices that are forecast independently by the Catalan Weather Service and the Environment Department of Valencia, which in both cases use the SBDART model. In 94% of cases, differences between measured and forecast values, in cloud-free sky conditions, are 1 or less.

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