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Original Scientific Paper

ESTIMATION OF UV EXPOSURE IN CROATIA OVER THE SUMMER USING A SIMPLE APPROXIMATE FORMULA

Gordana PEHNEC[1], Nenad KEZELE[2], and Glenda ŠORGO[2]
Institute for Medical Research and Occupational Health[1], Ruđer Bošković Institute[2], Zagreb, Croatia

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The Tropospheric Ultraviolet-Visible (TUV) model, version 4.2 developed by Madronich (2003) was used to estimate the extent of ultraviolet (UV) exposure of general population in Croatia over the summer. Solar noon values (13 h local time, CEST) of the ultraviolet index (UVI) for the period April to October 2004 were calculated for 61 cities in Croatia. The results showed that the risk of sunburn at 13 h local time in clear weather was high between April and September (UVI >7) and very high in July (UVI >10). In July, the UVI exceeded 8 between 11 h and 15 h local time. In this study, we developed a simple approximate formula to estimate UVI. The formula includes data on the time, date, altitude and clouds. The difference between our estimate and the TUV model for the summer months of June, July and August at 10 h to 16 h local time was less than 10 %.

KEY WORDS: *Adriatic coast, altitude, geographic position, Tropospheric Ultraviolet Visible model, UV index*

Ultraviolet (UV) radiation is a part of the Sun's electromagnetic spectrum. With respect to its biological effects, the UV band of solar radiation is often divided into UV-C (100-280 nm), UV-B (280-320 nm), and UV-A (320-400 nm) radiation. The atmosphere absorbs all UV-C and most of the UV-B radiation. In summer days, UV-B is about 5 % of terrestrial UV and the rest is UV-A. However, solar UV-B causes a much greater biological damage than UV-A, contributing to about 80 % of all harmful effects we associate with sun exposure. Although UV-B radiation is necessary for biological processes such as vitamin D_3 synthesis, it also causes many acute and chronic conditions (1). Damages may be on the cell level (DNA damages), tissue (induction of sunburn-erythema, ageing of skin) and the whole body (skin cancers, other cancers, eye disorders, immunosuppression) (2, 3).

The effect of UV radiation on a biological specimen is determined by spectral irradiance, I_λ (W m^{-2} nm^{-1}) delivered to the surface of a biological body and the duration of exposure, T. Total exposure E (J m^{-2}) is calculated as a time integral of the spectral irradiance according to the equation

$$E = \int_0^T \int_{280}^{400} I_\lambda \, d\lambda dt \quad [1]$$

Total exposure provides information about the total photon energy in the UV waveband falling on a unit area of the body's surface. However, the response of the biological body varies with radiation wavelength. For a given photobiological process, the wavelength dependence of the relative spectral effectiveness S_λ is the action spectrum (3). To express biological effectiveness of UV radiation at various wavelengths for a particular biological process it is necessary to weight spectral irradiance with the action spectrum. For a selected biological process, biologically effective UV irradiance, I_{eff} (W m^{-2}) is

$$I_{eff} = \sum_{280}^{400} S_{\lambda} I_{\lambda} \Delta_{\lambda} \qquad [2]$$

The time integral of the irradiance is called radiant exposure or radiant dose E_{eff} (J m^{-2}) (3).

The action spectrum of McKinley and Diffey was adopted by the Commission Internationale de l'Eclairage (CIE) as the standard of average skin response over both UV-B and UV-A regions of the spectrum. The CIE (4) erythemal action spectrum for humans has been employed widely since 1987 for assessing the UV effect on human skin. Anders re-evaluated the erythemal action spectrum in 1993 (3). There are also action spectra for photoconjuctivitis and photokeratitis of the human eye (3). Human skin can adapt to UV radiation by melanin production, but eyes do not have this ability. No action spectrum for melanoma in humans is available; however Setlow et al. (5) have measured the action spectrum for melanoma in fish while De Fabo et al. (6) derived a transgenic mouse model for UV-induced melanoma. In mice overexpressing hepatocyte growth factor (HGF), exposure to UVB at neonatal age led to invasive melanomas (7). UV radiation initiates an immunosuppression which appears to be a critical event in the successful outgrowth of non-melanoma skin cancer. The photoreceptor urocanic acid, UCA, was identified through an *in vivo* action spectrum for immunosuppression (8).

The UV index (UVI) was proposed as a measure of the risk from UV radiation. For UVI calculation, the CIE erythemal action spectrum is suggested, because sunburn is the most common harmful effect on human skin. The UV index is defined as the integral over wavelengths of the solar spectral irradiance reaching the earth's surface, weighted by the erythema action spectrum. It usually refers to the solar noon value of the dose rate for cloudless days. According to the US EPA, UVI (9) is divided in the following categories:

0-2	minimal
3-4	low
5-6	moderate
7-9	high
10 and more	very high

Spectral irradiance is usually measured using spectroradiometers. Total irradiance can be measured with a broadband radiometer over a selected waveband. Passive dosimeters such as polysulphone dosimeter are also in use. Instruments for measuring spectral irradiance are complex and difficult to maintain. Due to high cost and problems with calibration, UV measurements are still relatively rare (2, 3).

Instead, UV exposure is frequently estimated using different mathematical models. Surface UV radiation is a function of the extraterrestrial solar flux, solar zenith angle, ozone amount, cloud characteristic, aerosols and surface albedo. Models for UV-index forecasting usually include in calculation the following parameters: geographic position (longitude, latitude and altitude), date, time of the day, total ozone data and cloud data, and, when available, aerosol data.

Although the harmful effects of UV radiation are well established and described in literature (1, 3, 6), measurements in Croatia are limited. In Zagreb, the measurements of erythemal UV radiation started in 1998 (10). Values of UVI higher than 10 were observed occasionally in the summer (11). UVI forecasts using the Model DM4 are available on the web pages of the Meteorological and Hydrological Service of Croatia (12). There are only a few papers describing solar UV exposure in Croatia (10, 11, 13). The aim of this study was to estimate the extent of UV exposure of Croatian general population using a radiative transfer model known as the Tropospheric Ultraviolet-Visible Model (TUV). It calculates UV indices for different places on different dates and times throughout the year, taking into account their location, atmospheric conditions, and geophysical constants. Because these values are especially interesting over the summer and on the Adriatic coast where people spend a lot of time outdoors at this time of the year, we wanted to develop a simple approximate formula, based on more accurate results obtained by the TUV model, that would make possible a reliable estimate for any location in Croatia, time, and weather condition over the three summer months of June, July and August.

METHODS

To evaluate UV exposure we used the Tropospheric Ultraviolet-Visible Model (TUV), version 4.2 (developed by Sasha Madronich; released in May 2003) (14-17). TUV is a multi-stream radiative transfer model able to quantify the transfer of radiation in a scattering and absorbing atmosphere. Atmospheric curvature (important for low sun conditions) is modelled using a pseudo-spherical approximation. It is a one-dimensional FORTRAN 77 model suitable to compute various radiative quantities over a broad range of environmental conditions. It can be used in the wavelength range 121 nm to 750 nm for calculating the spectral irradiance, the spectral actinic flux, photodissociation coefficients, and biological effective irradiance. Output parameters are presented as functions of wavelength and altitude. Many papers describe good agreement between measured values of UV radiation and values calculated by TUV (18-20).

In our first approximation, the following constants and atmospheric conditions were assumed:

- US standard atmosphere (21)
- surface albedo 0.1 at all wavelengths
- aerosol vertical optical depth τ_{aer}=0.235 at 550 nm from surface to space [for aerosols, vertical profile typical for continental regions from Elterman (22) was assumed]
- total ozone column 300 DU (DU - Dobson Unit, one DU is $2.69x10^{20}$ ozone molecules per square meter)
- to calculate the dose rate, the UV spectrum on the ground was integrated with a 1 nm step over the 280 nm to 420 nm band
- solar noon time

Dose rates and UV indices were calculated for 61 sites in Croatia (Figure 1) with corresponding data on longitude, latitude and altitude. We selected the city of Makarska as a representative location for estimating the effects of elevation, time of the day, cloudiness and total ozone column because it is at the sea level, it is central at the Croatian coast, it is at the feet of Mt Biokovo (1762 m a. s. l.), and it has the clearest sky all over the year. UV indices were calculated for different days at 13 h local time (Central European Summer Time, CEST), which roughly corresponds to solar noon. For 1 July, UVI were calculated for different daytime hours in order to establish their dependence on the time of the day. Clear sky was assumed in most calculations. When considering the effect of clouds on UV indices, we assumed a uniform cloud coverage of the sky. The input parameter was cloud optical depth, τ.

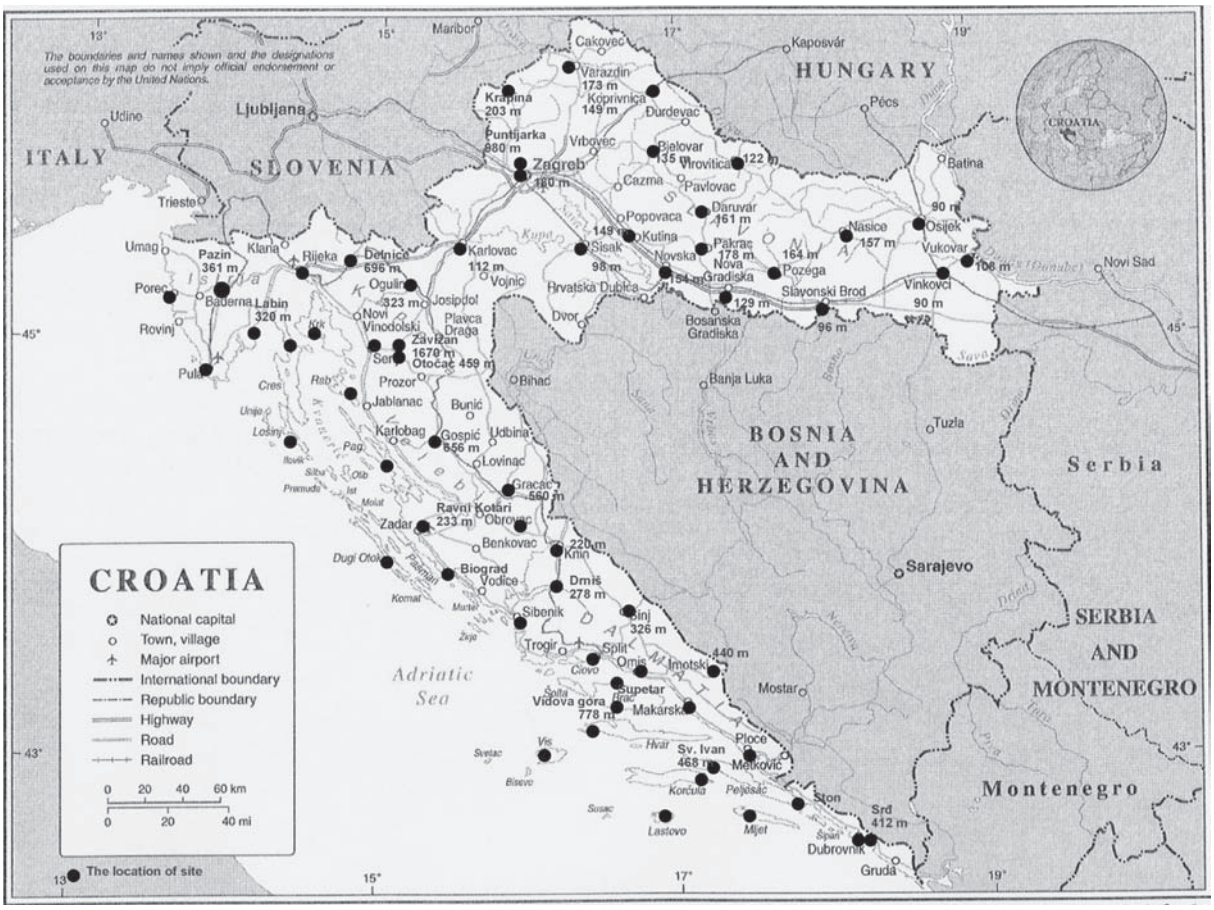

Figure 1 *The location of 61 Croatian sites with UVI calculated using the TUV model*

Table 1 *UVI calculated by TUV for 61 sites in Croatia at 13 h local time (CEST) for three different days*

	Site	April, 1	July, 1	October, 1
1	Biograd	6.6	10.5	4.7
2	Bjelovar	6.2	10.2	4.2
3	Cres	6.4	10.3	4.4
4	Daruvar	6.3	10.2	4.3
5	Delnice	6.5	10.5	4.5
6	Drniš	6.7	10.6	4.7
7	Dubrovnik	6.9	10.7	4.9
8	Gospić	6.7	10.7	4.7
9	Gračac	6.7	10.7	4.7
10	Hvar	6.9	10.7	4.9
11	Imotski	6.9	10.8	4.8
12	Karlovac	6.3	10.2	4.3
13	Knin	6.7	10.6	4.7
14	Komiža	6.9	10.7	4.8
15	Koprivnica	6.1	10.1	4.2
16	Korčula	6.9	10.7	4.8
17	Krapina	6.1	10.2	4.2
18	Krk	6.4	10.3	4.4
19	Kutina	6.3	10.3	4.3
20	Labin	6.4	10.4	4.5
21	Lastovo	6.9	10.7	4.9
22	Lipik	6.3	10.3	4.3
23	M. Lošinj	6.5	10.4	4.5
24	Makarska	6.8	10.6	4.8
25	Našice	6.3	10.2	4.3
26	Nova Gradiška	6.3	10.3	4.3
27	Ogulin	6.4	10.4	4.4
28	Omiš	6.8	10.6	4.7
29	Osijek	6.2	10.2	4.2
30	Otočac	6.3	10.3	4.3
31	Pag	6.5	10.4	4.5
32	Pakrac	6.3	10.3	4.3
33	Pazin	6.4	10.4	4.4
34	Ploče	6.9	10.7	4.8
35	Poreč	6.3	10.2	4.4
36	Požega	6.3	10.3	4.3
37	Pula	6.3	10.3	4.5
38	Puntijarka	6.4	10.6	4.4
39	Rab	6.4	10.3	4.5
40	Ravni Kotari	6.7	10.6	4.7
41	Rijeka	6.3	10.2	4.3
42	Sali	6.6	10.5	4.7
43	Senj	6.4	10.3	4.4
44	Sinj	6.8	10.7	4.8
45	Sisak	6.3	10.2	4.3
46	Slavonski Brod	6.3	10.3	4.3
47	Sobra (Mljet)	6.9	10.7	4.9
48	Split	6.7	10.6	4.7
49	Srđ	7.1	10.9	5.0
50	Ston	6.9	10.7	4.9
51	Supetar	6.8	10.6	4.8
52	Sv. Ivan (Pelješac)	7.0	10.9	5.0
53	Šibenik	6.7	10.5	4.7
54	Varaždin	6.1	10.1	4.1
55	Vidova gora (Brač)	7.0	11.0	5.0
56	Vinkovci	6.3	10.2	4.3
57	Virovitica	6.2	10.2	4.2
58	Vukovar	6.3	10.2	4.3
59	Zadar	6.6	10.5	4.6
60	Zagreb	6.2	10.2	4.3
61	Zavižan	6.9	11.1	4.8

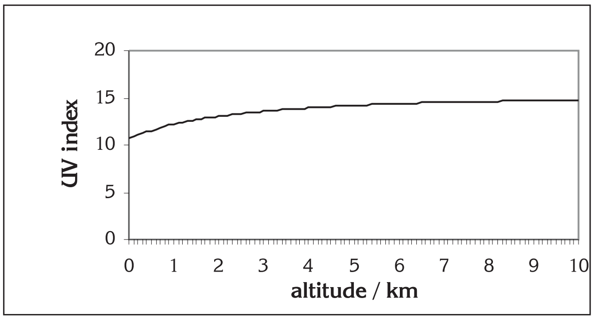

Figure 2 *Annual variations of UVI (calculated for Makarska at 13 h local time, in clear weather*

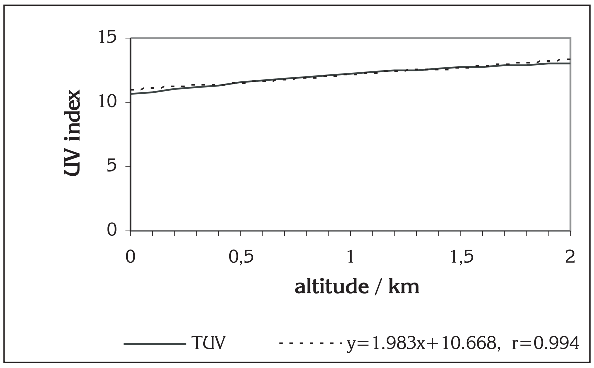

Figure 3 *Changes in UVI with altitude; up to 10 km (upper graph) and up to 2 km (lower graph), calculated for Makarska on 1 July, in clear weather*

For UV index estimation some simplified equations were found and compared with the TUV results. These equations explain the changes in UVI with daytime, elevation, cloudiness, and the time of the year, and will be discussed in the section below.

RESULTS

UV indices were calculated for 61 sites in Croatia (Figure 1). All values were calculated for 13 h local time (daylight saving time, CEST), which corresponds roughly to an actual solar noon time. Table 1 shows UVI under clear sky for three days set three months apart: 1 April, 1 July, and 1 October. They range between 6.1 and 7.1 in April, 10.1 and 11.1 in July, and 4.1 and 5.0 in October. The maximum UVI, 11.13, was calculated for Zavižan (1670 m a.s.l.) in July. However, as the extreme east and west points in Croatia have different solar zenith angles (SZA), actual UVI may differ as well. In order to estimate this error, UVI was calculated for extreme east and west Croatian towns, Vukovar and Poreč, respectively, which are approximately at the same latitude. For better comparison, the same altitude (0 m a.s.l.) was taken

Table 2 *Differences in solar zenith angle (SZA) and UVI for two sites with the same latitude (45.3 °N) and greater difference in longitude (calculated for 1 July; altitude 0 km a.s.l.)*

Local time / h	SZA			UV index		
	Vukovar 19.007 °E	Poreč 13.593 °E	Difference	Vukovar 19.007 °E	Poreč 13.593 °E	Difference
10	40.55	44.21	3.66	6.07	5.22	0.85
13	22.36	22.31	0.05	10.19	10.20	0.01
16	44.66	41.00	3.66	5.12	5.97	0.85

Table 3 *Correlation coefficients between UVI calculated by TUV for different months*

	May	Jun	Jul	Aug	Sept	Oct
April	0.99	0.97	0.97	0.99	0.99	0.99
May		0.99	0.99	0.99	0.99	0.98
Jun			0.99	0.99	0.98	0.95
Jul				0.99	0.98	0.96
Aug					0.99	0.98
Sep						0.99

Table 4 *Linear regression parameters for the dependence of UVI on altitude (up to 2 km a.s.l.).*

Month	Slope	Intercept	R	Difference UVI (2 km)- UVI (0 km)
Jan	0.366	1.383	0.996	0.8
Feb	0.566	2.192	0.996	1.1
Mar	0.960	4.038	0.995	1.9
April	1.446	6.821	0.995	2.8
May	1.797	9.216	0.995	3.6
Jun	1.968	10.531	0.995	4.0
Jul	1.982	10.668	0.995	3.9
Aug	1.853	9.677	0.995	3.7
Sep	1.542	7.483	0.995	3.1
Oct	1.099	4.797	0.995	2.2
Nov	0.648	2.550	0.996	1.3
Dec	0.396	1.500	0.996	0.8

in calculations. Table 2 shows the differences between the two towns calculated for 1 July, 10 h, 13 h, and 16 h local time, indicating that the effect is mostly pronounced in the morning and afternoon hours and is negligible at noon time.

Correlation coefficients were calculated between UVI for different months at every location. Table 3 shows correlation coefficients between UVI calculated for the period April-October.

Annual variations of UVI for Makarska are shown in Figure 2. It also shows a comparison between TUV calculations and calculations according to the simplified equation

$$UVI = 11 - \left| \frac{w - 25}{4} \right| \quad [3]$$

where w is the week of the year. The difference between UVI calculated by TUV and by equation

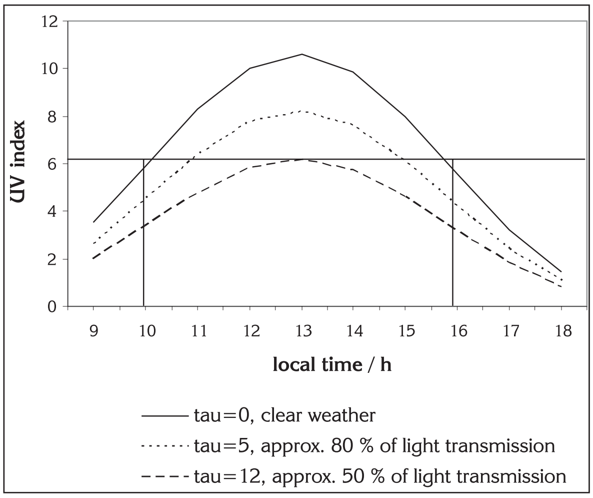

Figure 4 *Diurnal variations of UVI in clear weather (cloud optical depth, τ=0), and cloudy weather (τ=5 and τ=12), calculated for Makarska on 1 July*

Table 5 *Differences between TUV and equation [5]* results in the estimation of UVI changes with altitude*

Month	5			6			7			8		
Week	17			22			26			31		
	UVI			UVI			UVI			UVI		
Altitude / km	TUV	[5]	D / %**	TUV	[5]	D / %	TUV	[5]	D / %	TUV	[5]	D / %
0	9.0	9.0	0.2	10.3	10.3	0.6	10.5	10.8	-2.9	9.5	9.5	-0.3
0.1	9.3	9.2	0.8	10.6	10.4	1.2	10.7	10.9	-2.3	9.7	9.7	0.3
0.2	9.5	9.4	1.2	10.8	10.6	1.7	11.0	11.1	-1.8	9.9	9.9	0.8
0.3	9.7	9.5	1.6	11.1	10.8	2.1	11.2	11.3	-1.3	10.2	10.1	1.2
0.4	9.9	9.7	2.0	11.3	11.0	2.5	11.5	11.5	-0.8	10.4	10.2	1.5
0.5	10.1	9.9	2.4	11.5	11.2	2.8	11.7	11.7	-0.4	10.6	10.4	1.9
0.6	10.4	10.1	2.6	11.8	11.4	3.2	11.9	11.9	-0.1	10.9	10.6	2.2
0.7	10.6	10.3	2.8	12.0	11.6	3.4	12.2	12.1	0.2	11.1	10.8	2.5
0.8	10.8	10.4	3.1	12.2	11.8	3.7	12.4	12.3	0.5	11.3	11.0	2.7
0.9	11.0	10.6	3.3	12.5	12.0	3.8	12.6	12.5	0.7	11.5	11.2	2.9
1	11.2	10.8	3.5	12.7	12.2	4.1	12.8	12.7	0.9	11.7	11.4	3.1
1.1	11.3	11.0	3.2	12.9	12.4	3.8	13.0	12.9	0.7	11.9	11.5	2.7
1.2	11.5	11.2	2.8	13.0	12.6	3.5	13.2	13.1	0.4	12.0	11.7	2.5
1.3	11.6	11.3	2.5	13.2	12.8	3.2	13.3	13.3	0.1	12.2	11.9	2.2
1.4	11.8	11.5	2.2	13.3	12.9	3.0	13.5	13.5	-0.2	12.3	12.1	1.9
1.5	11.9	11.7	1.8	13.5	13.1	2.6	13.7	13.7	-0.5	12.5	12.3	1.6
1.6	12.1	11.9	1.6	13.7	13.3	2.3	13.8	13.9	-0.7	12.6	12.5	1.3
1.7	12.2	12.1	1.2	13.8	13.5	2.1	14.0	14.1	-1.0	12.8	12.6	0.9
1.8	12.4	12.2	0.9	14.0	13.7	1.8	14.1	14.3	-1.2	12.9	12.8	0.6
1.9	12.5	12.4	0.6	14.1	13.9	1.5	14.3	14.5	-1.6	13.1	13.0	0.3
2	12.6	12.6	0.2	14.3	14.1	1.2	14.4	14.7	-1.8	13.2	13.2	0.0

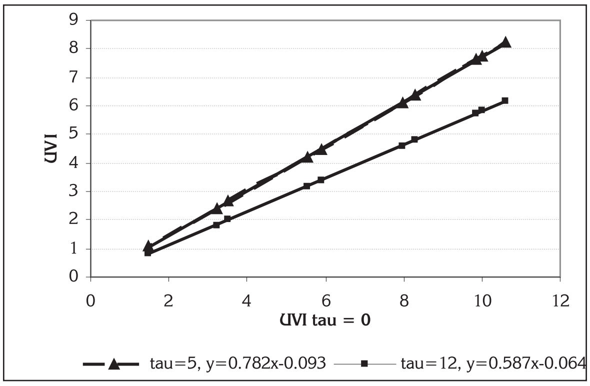

Figure 5 *The comparison of UVI in clear and cloudy weather*

[3] was calculated as an error (%) according to the equation [4], and it ranged between 0.21 % and 2.87 %, except for April and September, when it was 18 %.

$$D = \frac{UVI\,(TUV) - UVI\,(eq)}{UVI\,(TUV)} \times 100 \qquad [4]$$

The influence of elevation on UVI was evaluated for Makarska. Figure 3 shows changes in UVI with altitude

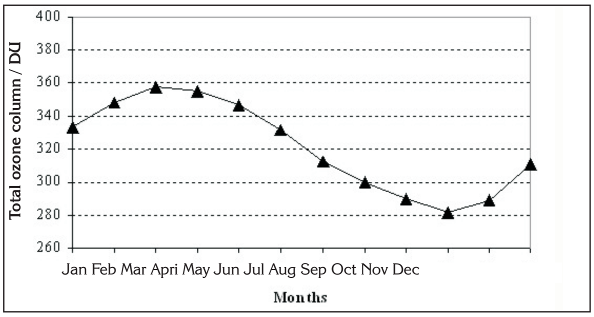

Figure 6 *Annual variations of total ozone column calculated with monthly averages over the period 1996-2005*

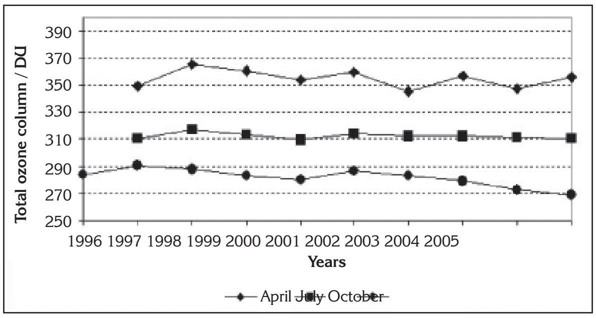

Figure 7 *Variations in total ozone column for the months of April, July and October over the period 1996-2005*

Table 6 *Estimated diurnal UVI variation using the TUV model and equation [6]**

	UVI		Error
Local time / h	TUV	[6]	D / %
9	3.5	4.3	-23.4
10	5.9	6.0	-1.9
11	8.3	7.7	7.4
12	10.0	9.3	6.8
13	10.6	11.0	-3.9
14	9.8	9.3	5.1
15	8.0	7.7	3.8
16	5.5	6.0	-8.1
17	3.2	4.3	-34.9

Table 7 *Correction of UVI with regard to changes in total ozone column (equation [9]*) for Makarska at 13 h local time*

Month	Average total ozone column / DU	UVI (300)	UVI (DU) estimated by equation [9]
April	354.7	6.8	5.7
July	312.2	10.6	10.2
October	281.5	4.8	5.2

on 1 July, under the clear sky. For altitudes below 2000 m the altitude-dependence curve is almost linear, and may be described by linear regression. Table 4 shows parameters of linear regression lines for every month of the year. This makes it possible to expand equation [3] to the estimation of UVI at different altitudes. Equation [5] applies for the months of May through August.

$$UVI=(2-\left|\frac{w-25}{40}\right|\times h+(11-\left|\frac{w-25}{4}\right|) \qquad [5]$$

where w stands for the week of the year and h for altitude expressed in km. Values obtained by equation [5] were compared with corresponding values from the TUV model (Table 5).

Figure 4 shows diurnal variations of UVI on 1 July, calculated by TUV for different cloud conditions in Makarska. Under different cloudiness, UVI indices may be represented as a linear function of UVI under clear-sky conditions (Figure 5).

Diurnal variations of UVI were calculated according to equation [6]:

$$UVI=11-\left|\frac{t-13}{0.6}\right| \qquad [6]$$

where t is local time (h).

The comparison of UVI calculated by TUV and by equation [6] is shown in Table 6.

DISCUSSION

In our study, UVI (Table 1) was calculated for 13 h local time. However, there is a difference between the SZA at the extreme east and west points of the country (Table 2). Differences are significant at 10 h and 16 h local time, as the UVI curve (Figure 4) has the greatest slope at these hours. As the differences are minimal at 13 h (top of the curve), the error between UVI may be neglected.

Calculations of UVI (Table 1) show that even in April there is a moderate risk of sunburn from UV radiation in clear weather (UVI between 6 and 7), which turns to high and very high risk in July (UVI above 10). Figure 2 shows that the risk of sunburn at 13 h local time is high between May and September (UVI >7). In July, the calculated UVI in Makarska was above 8 between 11 h and 15 h local time (Figure 4). Recommendations are (9) to limit outdoor activities at this time of the day, and to use protection against sunburns (a hat and other clothing, sunglasses, or sunscreen).

Correlation coefficients were calculated between solar noon UVI at each location for the period April-October (Table 3). There is a significant linear correlation between UVI calculated for different months. These results show that UVI variations over the year may be estimated using simple linear regression.

We estimated the annual UVI using equation [3], and compared it to the TUV results. For Makarska, we obtained a good agreement between equation [3] and the TUV results for the period May-August, with an error of less than 3 %. For April and September there was a greater difference between the results (up to 18 %).

UVI increases significantly with altitude (Figure 3). Below 2 km a.s.l., and the maximum altitude in Croatia is 1831 m a.s.l. (Mt Dinara), the curve is almost linear and may be described by linear regression. The dependence is linear in all months over the year, but the slope and intercept vary significantly (Table 4). According to the literature, a UVI increase of 6 % per km is expected (10). For more accurate estimation, we used equation [5]. Table 5 shows that there is no significant difference between the TUV results and results obtained by our simplified equation [5]. The error was less than 4 % for May-August and for all altitudes (being below 2 km a.s.l.).

The estimation of diurnal UV variation using equation [6] showed that this equation also gave a good agreement with the TUV model (Table 6). The error was less than 8 % for local time between 10 h and 16 h, when UVI may have been increased (Figure 4).

Clouds significantly reduce UV exposure (Figure 4). Those with a 50 % transmission of light reduce UVI by more than 50 %. There is a linear relationship between UVI calculated in clear weather and UVI in cloudy weather (Figure 5). If the intercept is zero, the UVI can be parameterized by a simple equation:

$$UVI = UVI_0 \times C \quad [7]$$

where UVI_0 is the clear-sky UVI and C is a cloud transmission factor with values 0-1. These results correspond to those found in literature (16, 20).

An estimation of UVI may use a summarised formula which includes data on the week of the year, time, altitude and cloudiness. Therefore we added equations [6] and [7] to equation [5] to make one comprehensive equation:

$$UVI = \left[(11 - \left| \frac{t-13}{0.6} \right|) + (11 - \left| \frac{w-25}{4} \right|) + (2 - \left| \frac{w-25}{40} \right| \times h) \right] \times C \quad [8]$$

This equation was used to estimate UVI for the period between May and August, from 10 h to 16 h local time, and for altitudes up to 2 km a.s.l.

The influence of total ozone column was also studied. In Croatia, annual averages of total ozone column varied from 351.7 DU in 1979 to 316.8 in 1992, and the 25-year average (1979-2004) was 332.5 DU (23). The decrease in total ozone was about 6 % during the same 25-year period, but in the last six years the decrease was only 2 % (23, 24). Total ozone column values were higher in the spring and summer (11). Figure 6 presents annual variations of total ozone column over the last decade. Average monthly ozone amounts were calculated for the period 1996-2005. The ozone data were obtained from the NASA/TOMS web site (25). Figure 7 shows variations of average ozone values for months April, July and October over the same decade.

UVI was calculated by TUV for Makarska on 1 July, with the following ozone column values: 250, 270, 300, 330 and 350 DU. Changes in ozone were found to contribute significantly to UVI (according to our calculations, a 10 % decrease in ozone column corresponded to a 11 % to 13 % increase in UVI). These results correspond to the literature data, where a decrease of 1 % in total ozone column corresponds to a 1.1 % increase in UVI (26). Influence of changes in total ozone column on UV exposure was discussed in detail by Micheletti et al. (26). They calculated radiation amplification factor (RAF) with the TUV model for different action spectra. RAF is a measure of the sensitivity of biologically active irradiadiance, I_{bio}, to changes in ozone vertical column amount. A simple parameterization of the dependence of UVI on ozone is as follows:

$$\frac{UVI\,(DU)}{UVI\,(300)} = \left(\frac{300}{DU} \right)^{RAF} \quad [9]$$

where DU is ozone amount in Dobson Units and RAF is Radiation Amplification Factor, which for erythema action spectrum is about 1.1 (26).

However, unlike other data relevant for UVI calculation, the Internet data on ozone concentrations are available with a delay of a day or two. For that reason we did not include stratospheric ozone data in our approximate formula. The same total ozone column was used in all calculations, because we wanted to separate geographic position and time data (which are easy available to general population) from other influences. Over the summer months, while the highest UVI are obtained (June to August), total ozone values are usually higher than 300 DU which is used in our calculations (Figures 6 and 7). This is why our estimated UVI may be equal or higher than real. The idea is to avoid surprise on days with lower stratospheric ozone values that would lead an increased number of sunburns. However, all our data may be corrected by ozone amount using equation

[9]. Table 7 shows corrections for Makarska in the months of April, July, and October.

CONCLUSION

Our estimation of UV exposure in Croatia over one year has taken into account the influence of geographic position, altitude, time of the day, time of the year, and clouds. We established some linear relations between them and UVI. This made it possible for us to develop a simplified, Croatia-specific formula to quickly estimate UV exposure over the summer. Unlike the TUV model, our formula does not include variations of tropospheric pollutants, stratospheric ozone, aerosols and albedo. Our future research will focus on a detailed estimation of UV exposure and influence of sunlight on photochemical processes.

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Sažetak

PROCJENA IZLOŽENOSTI UV ZRAČENJU TIJEKOM LJETNIH MJESECI U HRVATSKOJ S POMOĆU JEDNOSTAVNE PRIBLIŽNE FORMULE

Tropospheric Ultraviolet-Visible (TUV) model, verzija 4.2 autora S. Madronicha (2003.) upotrijebljen je za procjenu izloženosti ultraljubičastom (UV) zračenju stanovništva u Hrvatskoj. Podnevne vrijednosti (13 h prema lokalnom vremenu) ultraljubičastog indeksa (UVI) izračunane su za 61 mjesto u Hrvatskoj za razdoblje travanj - listopad. Rezultati pokazuju da je u 13 h prema lokalnom vremenu rizik od nastanka opeklina izazvanih sunčevim zračenjem u danima bez naoblake visok između travnja i rujna (UVI > 7) te da je rizik vrlo visok tijekom srpnja (UVI >10). U srpnju tijekom dana UV indeks prelazi vrijednost 8 između 11 h i 15 h prema lokalnom vremenu. U ovom radu za procjenu UV indeksa razvijena je jednostavna približna formula. Formula omogućava procjenu UV indeksa na temelju podataka o datumu, satu, nadmorskoj visini i naoblaci. Prilikom usporedbe rezultata dobivenih formulom i točnih rezultata dobivenih TUV modelom za ljetne mjesece lipanj, srpanj i kolovoz te razdoblje od 10 h do 16 h među rezultatima dobivena je razlika manja od 10 %.

KLJUČNE RIJEČI: *geografski položaj, jadranska obala, nadmorska visina, Tropospheric Ultraviolet Visible model, UV indeks*

CORRESPONDING AUTHOR:

Gordana Pehnec
Institute for Medical Research and Occupational Health
Ksaverska cesta 2, 10000 Zagreb, Croatia
E-mail: *gpehnec@imi.hr*