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THE IMPORTANCE OF GROUND-BASED AND SATELLITE OBSERVATIONS FOR MONITORING AND ESTIMATION OF UV RADIATION IN NOVI SAD (SERBIA)

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Abstract: Solar ultraviolet (UV) radiation is a significant health hazard in the warm part of the year. In order to assess the level of hazard and the effects of UV radiation on the living world, long-term measured or estimated data are needed. In Novi Sad, the measurement of UV radiation has been performed since 2003, while ozone measurements have been made since 2007. However, those data sets are too short for assessing long-term biological effects. Therefore, several techniques for reconstruction of UV radiation doses have been developed. Reconstruction techniques are based on using available ground-based measurements of the meteorological data and satellite measurements of the total ozone column. It is shown that techniques that use ozone data show better performance than those that use only ground-based meteorological measurements. However, the difference between the performances of the methods is smaller when it comes to the monthly values, indicating that the techniques which use only ground-based meteorological measurements are roughly as good as the ozone-based techniques for assessing long-term changes in the surface UV radiation. The statistically significant increasing long term-trend of annual mean erythemal UV doses (*ERY*) and the decreasing trend in the total ozone column in Novi Sad since 1981 have been noticed. An increase in *ERY* has been noticed in all the seasons except in autumn and it is the highest in winter. The analysis showed that the increase in the *ERY* in the period 1981–1996 was mainly caused by the total ozone column, while the increase after 1996 is largely caused by cloudiness.

Keywords: UV radiation; ozone; measurements; estimation

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Introduction

Besides heat-related hazards, solar ultraviolet (UV) radiation is one of the most significant health hazards to people in the warm part of the year. The exposure of people to solar UV radiation has significant and well-known implications for health, such as degenerative changes in skin cells, photodermatoses, inflammatory reactions of the eye, cataracts, and various skin cancers (Gallagher & Lee, 2006; World Health Organization [WHO], 1995). In addition to being harmful to the human body, UV radiation affects other living organisms. In particular, UV radiation impairs photosynthesis in many species, reduces the size, productivity, and quality in many crop plants, and impairs the productivity of phytoplankton in aquatic ecosystems (Anton, Serrano, Cancillo, & Garcia, 2008). Prolonged exposure to solar UV radiation during outdoor activities contributes to a rapid rise in harmful effects. Additionally, the harmful effects of UV radiation can be accumulated so require studies over prolonged periods of time. Therefore, measurements, prediction, and the reconstruction of UV radiation are essential for the estimation of its long-term biological effects and have a high priority in scientific research (Reuder & Koepke, 2005).

Solar UV radiation has received considerable attention during the last two decades of the 20th century when its significant increase was observed due to stratospheric ozone layer depletion, along with an increase in the number of cases of skin cancer. Networks of ground-based UV radiation measurement stations were first established in Australia and the USA in the late 1970s (Webb, 2000), while shortly thereafter measurements also began in other countries. Today, in all the developed countries, the intensity of UV radiation is constantly measured. A world-wide UV network has been formed, and data are easily accessed mainly via the Internet. However, measurements are not part of the globally organized monitoring program, but they are a random mixture of national measurement schemes and individual stations unevenly distributed over the Earth's surface (Webb, 2000). So far, no international rule has been established that would standardize a measuring instrument, so different instruments and measurement protocols are in use. In most networks, broadband detectors (e.g., Solar Light 501, Yankee UVB-1, Kipp & Zonen) are used to measure the erythemally weighted UV irradiance which is usually expressed as the UV index (UVI). The UVI was proposed by World Meteorological Organization (WMO) and WHO (WMO, 1997) and represents the integration of spectral UV irradiances in the range of 290 nm and 400 nm which is weighted with CIE erythemal action spectrum (McKinley & Diffey, 1987). The action spectrum emphasizes the importance of the UV-B component by increasing the proportion of UV-B radiation from only 6% in the global UV radiation to 83% in erythemal UV-B radiation (Jégou et al., 2011). The World Ozone and Ultraviolet Radiation Data Centre (WOUDC), which is part of the Global Atmosphere Watch program of the WMO, is a major center where UV data are gathered. The WOUDC originally collected only ozone data, while data on UV radiation have been collected since 1992. Although ground-based sensors provide in situ measurements, they are insufficient for a comprehensive study of UV issues because of non-uniform spatial coverage and short observation periods. Ground-based measurements of UV radiation have been complemented by satellite estimations. It is important to note that sensors on satellites cannot directly measure UV radiation, but evaluate it based on the reflected radiation by taking into account factors that influence it such as ozone, cloudiness, aerosols, and albedo. Thus, in order to provide long term UV data with satisfying spatial coverage, besides the combination of ground-based and satellite observations of UV radiation and factors that influence it, it is necessary to develop good estimation techniques. The purpose of estimation techniques is not only to reconstruct past UV data but also to offer the possibility to fill the gaps in databases (Mateos Villán, de Miguel Castrillo, & Bilbao Santos, 2010).

The aim of this study is to present various activities that were performed at the University of Novi Sad in the field of monitoring and estimation of UV radiation in order to improve our understanding of its present and past variations. In the following chapters, a short summary of UV index and ozone monitoring in Novi Sad is given and there are different estimation techniques presented which utilize the available input parameters.

Monitoring details

In Europe, 160 UV monitoring sites in 25 countries can be found. However, there are significant differences in spatial coverage. The least covered areas are eastern and southeastern Europe. In 2017, approximately 57% of the population in Europe had access to information about the UV index level (Schmalwieser et al., 2017). The main goal of these networks and sites is to collect the data about solar UV radiation intensities with the aims to analyze them for scientific purposes but also for public information. The instruments used for UV monitoring are different. Some of them are spectral instruments, like Brewers, but most used are broadband UV radiometers, or biometers. Besides measurements, intercomparisons, calibration of the instruments used for monitoring and collaboration with foreign institutions for interchanging data and national and international comparisons are significant activities in UV monitoring. Intercomparisons are organized periodically at different places over Europe. For intercomparisons with broadband instruments, Brewer spectral instruments are used as the reference. Intercomparisons, which are time, and usually cost consuming, can be replaced with the laboratory check of long-time stability. The presentation of the level of UVI is very important for the promotion of sun protection. It is usually done in three ways: numerically, graphically, and through the colors. Numerically, the values of UVI are presented as a numerical value of UVI as daily maximum or current value for the specific time of the day. The graphical presentation illustrates the diurnal changes of UVI. In both cases, the values are renewed in regular time intervals (for example 10, 20, or 30 min). The color presentation uses standard colors to present the level of UVI (green—low risk, yellow—medium risk, orange—high risk, red—very high risk, violet—extremely high risk). At a number of sites, these three manners of presentation are incorporated.

UV index

Regular UV monitoring in Novi Sad, Serbia started in 2003. The site formed at that time was the first one, not only in Serbia but also in the region. The measuring equipment is placed at the campus of the University of Novi Sad. Geographical data are: 45.33°N, 19.85°E, and 84 m a.s.l. and these data are used in data processing. The site is formed according to the recommendations of WOUDC (WMO, 1998).

For Solar UV radiation monitoring, the Yankee Environmental Systems (YES) UVB-1 piranometer is used. This is a broadband instrument (WMO, 2008) that is often used to build up national Solar UV radiation monitoring networks. The estimated error, combining uncertainty stated by manufacturer and the error introduced by A/D conversion, is less than 7%. The relative spectral response (Dichter, Beaubien, & Beaubien, 1993) of the instrument is close to the erythemal action spectrum (McKinley & Diffey, 1987). The instrument is connected to a computer for data acquisition via data logger. Measurements are done every 30 seconds. The results are averaged over 10-minute time intervals and together with minimal and maximal data values, are recorded in the daily database. The measured values are available for public use through web page (UV index, n.d.) as part of the University of Novi Sad, Faculty of Science, Department of Physics website. They are presented numerically, graphically as well as by colors, by means of diurnal course of the UV index.

Once a year, the procedure of long stability check using three UV sources (WMO, 1998) of the measuring instrument is applied. For this purpose, three halogen lamps of 240 W are used. They are supplied from the current stabilized electrical source with 0.3 % stability. The current is controlled with precision Agilent 34405A multimeter. During the years, the used instrument has not shown significant changes in its response.

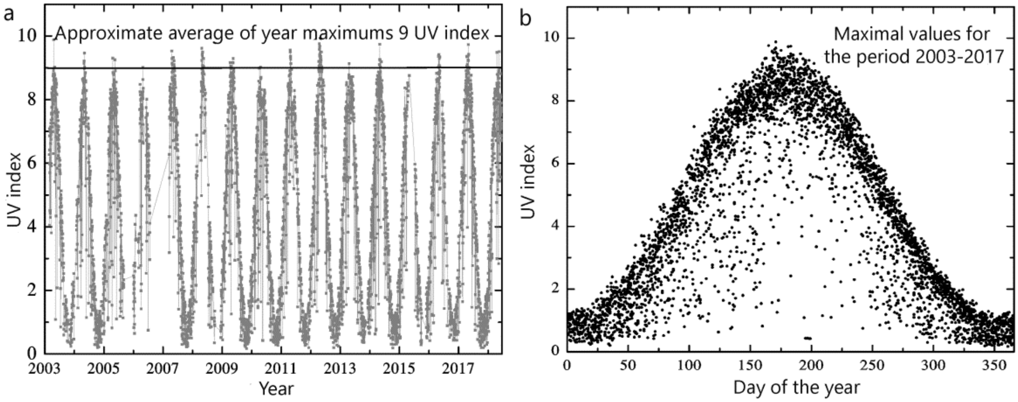

Figure 1. Measured values of UV index in Novi Sad.

The measured values of UV index over the period of fifteen years are presented in Figure 1a. This figure shows that maximal values of the UV index are reached during the end of June and the beginning of July, while minimal values are in the winter months. From Figure 1a it can be seen that UV index values have periodical changes in accordance with year seasons. The critical period, concerning public health, is the period when the UVI is of a high level or higher. This is the period between the middle of April and the end of August. In that period, the protection against harmful effects, UV radiation on eyes and skin must be appointed. Better presentation of UV index during the long period is if it is presented as UV index values as the function of the day of the year. This is presented in Figure 1b. This figure suggests that a very high level of UV index (8 or more) is reached during the summer days between the middle of May and the beginning of August. The average maximal values are reached at the end of June. From Figure 1b it can be seen that this value is around 9±0.5 UVI. The maximal registered value is around 10.

Total ozone column

The ground-based measurements of the total ozone column (TOC) in the atmosphere have been conducted in Novi Sad since September 2007. The measurements have been carried out by MICROTOPS II instrument. The MICROTOPS II instrument has 5 channels at 305.5, 312.5, 320, 936, and 1020 nm and uses measurements of solar irradiance at 3 wavelengths in the UV region to derive the TOC (Morys et al., 2001). The instrument is placed at the Faculty of Sciences, the University of Novi Sad (45.33°N, 19.85°E, and the altitude 84 m) and the measurements are obtained once a day during completely cloudless conditions. The daily TOC values are the average of 5 consecutive measurements conducted at about local noon.

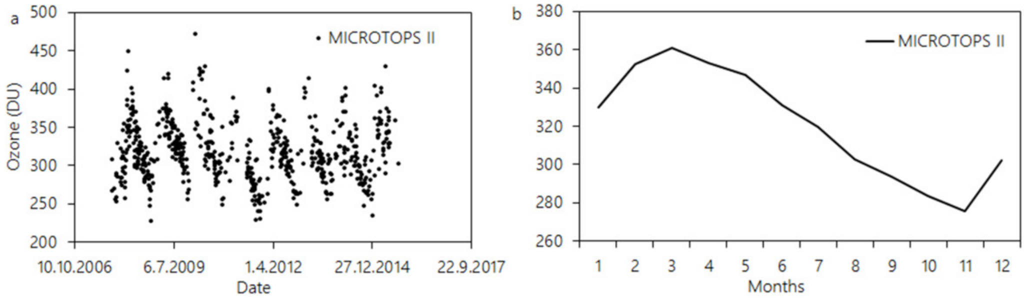

Figure 2. MICROTOPS II (a) daily and (b) monthly TOC values. Adapted from "A Comparison of MICROTOPS II and OMI Satellite Ozone Measurements in Novi Sad from 2007 to 2015," by Z. Podrascanin, I. Balog, A. Jankovic, Z. Mijatovic, and Z. Nadj, 2017, *Pure and Applied Geophysics, 174*(12), p. 4493. Copyright 2017 by Springer Nature. Adapted with permission.

The daily and monthly TOC values from 2007 to 2015 are presented in Figure 2. In Figure 2b the annual cycle in TOC data is notable. The highest monthly TOC value (360 DU) is observed in March while the lowest monthly value is observed in November 270 DU. The mean daily value in this period is 319.8 DU. The observed maximum daily TOC value is 472.6 DU while the minimum daily value is 228.2 DU.

Estimation details

The estimation of UV radiation is necessary because of the low spatial coverage of measuring places, and short-time series of the measured data. One of the most widely used techniques is the estimation by models, either parametric or empirical. The first ones use physical laws to show an interaction between UV radiation and atmospheric components that affect it, while the others compute the UV radiation based on fits of several years of UV observations. In general, parametric models are more accurate, although its accuracy depends on the availability and reliability of input parameters, such as stratospheric ozone column, cloud cover and type and amount of aerosols. The advantage of empirical techniques is that they link UV radiation with easily available variables that control it, like global radiation and/or other commonly available weather data. Therefore, they are not focused only on forecasting but offer the possibility of reconstructing data in the past and filling in gaps in the measured time series for a particular location.

Model NEOPLANTA

The NEOPLANTA UV radiation parametric numerical model at the Center for Meteorology and Environmental Modeling, University of Novi Sad (Serbia) designed by Malinović (2003) estimates solar direct and diffuse UV irradiances under cloud-free conditions in the range 280–400 nm and UVI. The UV irradiances can be computed at any location at different altitudes and times of the day. The values of the direct and diffuse irradiances can be calculated separately and can be integrated over any wavelength range with a resolution of 1 nm. The model takes into account the effect of O_3, SO_2, NO_2, aerosols, and different ground surface types on UV radiation. The model calculates instantaneous spectral irradiance at the given date and time (or solar zenith angle [SZA]) with a possibility of calculating the UVI for a full day at half-hour intervals from sunrise to sunset. In the model, the atmosphere is divided into up to 40 parallel layers, and it is assumed that each layer is a homogeneous medium with corresponding constant meteorological values. The model contains data on vertical profiles of atmospheric pressure, specific humidity and air temperature for a standard atmosphere and it is possible to use the values predicted by the numerical model for the weather forecast. The vertical resolution of the model is 1 km for altitudes below 25 km and 5 km above this height to 100 km, while direct and diffuse UV irradiances are calculated on the lower boundary of each layer. The input parameters of the model are geographical coordinates and time (or SZA), altitude, ground surface type, and the amount of gases. The output values from the model are spectral direct, diffuse, and global irradiance divided into the UV-A (320–400 nm) and UV-B (280–320 nm) part of the spectrum, the erythemally weighted UV irradiance calculated by using the erythemal action spectrum by McKinley and Diffey (1987), the UVI, the spectral optical depth, and the spectral transmittance for each atmospheric component.

Reconstruction techniques

To investigate the long-term UV radiation trend in the Vojvodina region, estimation techniques are necessary, because the measurements are performed for a relatively short period of time only in Novi Sad. Such techniques utilize ground-based measurements of commonly available meteorological data, while the important contributor in reconstructions is the measurement of the TOC made on satellites. However, ozone satellite measurements have been available since 1978, so if we want to explore changes further into the past, reconstruction techniques without ozone have to be used. So far, the estimation of UV radiation in Novi Sad has been done in three ways (i) by an empirical estimation which uses ground-based meteorological measurements; (ii) by an empirical estimation which uses ground-based measurements, satellite measurements, and NEOPLANTA model; and (iii) by using neural network technique that uses available input parameters, or only ground-based measurements or both ground-based and satellite measurements.

Malinović-Milićević (2012) proposed the empirical formula for the estimation of daily doses of UV-B radiation reaching the Earth's surface. It is based on the relationship between daily UV-B doses reaching the Earth's surface (UVB_d) derived from UVI measurements and daily global radiation doses (G_d) in Novi Sad.

$$UVB_d = 0.002507G_d - 5.9850 \quad (1)$$

Malinovic-Milicevic, Mihailovic, and Radovanovic (2015) developed the technique for the reconstruction of daily erythemal UV doses reaching the Earth's surface (*ERY*) under all sky conditions, which implies developing the empirical equation using the ground-based measurement of sunshine duration and satellite measurements of TOC. The daily *ERY* under clear sky conditions (ERY_{max}) was estimated by the NEOPLANTA model, by using daily values of TOC as input data, while the effect of clouds was estimated from the measurement of the sunshine duration (S_{allsky}). The empirical equation (2), based on a relationship between relative sunshine duration ($S_r = S_{allsky}/S_{max}$) and relative *ERY* ($ERY_r = ERY_{allsky}/ERY_{max}$) was found and used to calculate ERY under all sky conditions (ERY_{allsky}) for the period 1981–2003, and also to fill the gaps in the measurement.

$$ERY_{allsky} = ERY_{max}\,(0.5343S_r + 0.3589) \quad (2)$$

Malinovic-Milicevic, Vyklyuk, Radovanovic, and Petrovic (2018) proposed a neural network technique for estimating *ERY* that implies the use of one of the two models, depending on the availability of the input parameters. NN1 model as a predictor uses global radiation (*G*), clearness index (*k*), cloudiness (*C*) and air mass (*m*), while NN2 model adds TOC to the NN1 inputs. The data on *G*, *k*, *m* and *C* data are mostly available through the entire 1949–2012 period. The data on the daily values of the TOC for the period 1978–2012 were taken from the database of National Aeronautics and Space Administration (NASA) and European Space Agency. The availability of the predictors determined the use of the NN1 model to be used for reconstruction in the period 1949–1977. Depending on the available data, a combination of NN1 and NN2 models was used for the reconstruction for the period 1978–2012, and to fill the gaps in the measurements.

Results

It is very important to have a good agreement between satellite and ground-based ozone measurements because of the possibility of use of the satellite data when ground-based measurements are not available. For that reason, the measured MICROTOPS II TOC values were compared with the satellite TOC values. For comparison, the measurements from OMI, an ultraviolet/visible (UV/VIS) nadir solar backscatter spectrometer was used. This instrument was launched onboard the NASA EOS-AURA satellite in July 2004 and it has been providing nearly global TOC coverage in one day with a spatial resolution of 13 x 24 km since then (Levelt et al., 2006). The OMI data using DOAS retrieval algorithms (Veefkind, Haan, Brinksma, Kroon, & Levelt, 2006) was used for comparison (Figure 3). The data was downloaded from Giovanni web application developed by NASA Goddard Earth Sciences Data and Information Services Center (2017). A good correlation between OMI and MICROTOPS II data for Novi Sad with a correlation coefficient of 0.88 and a mean bias of 1.02% were found. Since the measurements with MICROTOPS II are only possible in cloudless conditions these good results allow us to use satellite measurements of ozone during cloudy weather conditions.

The characteristics of the NEOPLANTA model were tested by comparing the value of the calculated UVI and the values measured by the Yankee UVB1 biometer (Malinović, 2003; Malinovic, Mihailovic, Kapor, Mijatovic, & Arsenic, 2006; Malinovic-Milicevic & Mihailovic, 2011; Mijatović et al., 2010). Ozone data used in the NEOPLANTA model runs were taken from satellite measurements (2003–2008) and measurement of ozone layer thickness performed at noon carried out by Mijatović et al. (2010) after 2008. The results showed an agreement within ±0.5 UVI in all the measured measurements in conditions of cloudless sky (Malinović, 2003) and in 95% of the tested measurements for cloudiness up to 2 tenths (Malinovic et al., 2006). It was shown that using the predicted profiles of meteorological elements in the calculation of UVI results is better matched with the measured than when it is calculated using standard atmosphere profiles (Malinović, 2003). Mijatović et al. (2010) found that the predicted values in the conditions of a cloudless sky and almost cloudless sky are slightly higher than the measured ones, with

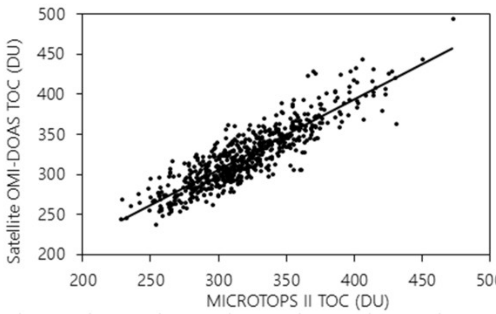

Figure 3. The scatterplot Microtops-II vs OMI-DOAS data. Adapted from “A Comparison of MICROTOPS II and OMI Satellite Ozone Measurements in Novi Sad from 2007 to 2015,” by Z. Podrascanin, I. Balog, A. Jankovic, Z. Mijatovic, and Z. Nadj, 2017, *Pure and Applied Geophysics, 174*(12), p. 4494. Copyright 2017 by Springer Nature. Adapted with permission.

differences between 1% and 6% for the maximal daily values (6% for a day that was not perfectly cloudless) (Figure 4). Malinovic-Milicevic and Mihailovic (2011) compared the measured and calculated values in a one-hour time resolution in Novi Sad from April to September 2006 under different cloud conditions. They introduced the influence of clouds by multiplying the UVI for the cloud-free conditions with a cloud modification factor (CMF) recommended by COST 713 "UV-B forecasting" action (Vanicek, Frei, Litynska, & Schmalwieser, 2000). The study restricted the UVI values on those for which the human body requires sun protection (higher than 3, according to WHO (2002)) and the amount of cloudiness is 6 tenths and less and showed a strong correlation (0.815) and small absolute value of the difference of standard deviations in the simulations and the observations (0.102).

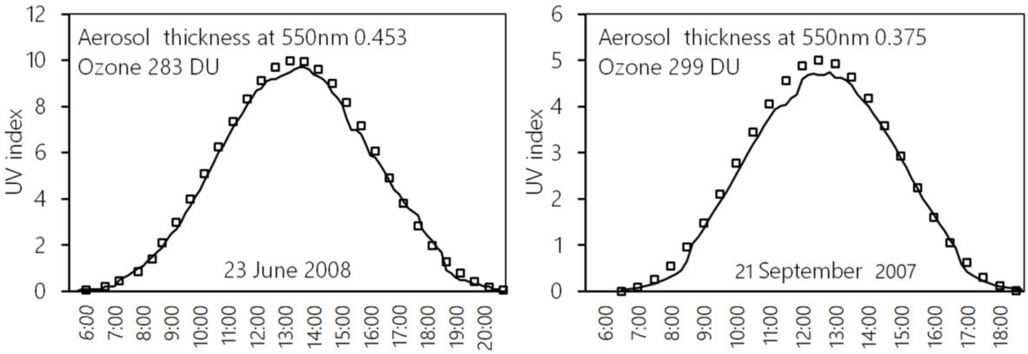

Figure 4. Comparisons between values predicted by the NEOPLANTA model and the measured ones for two different dates (left and right panel, respectively). Open squares (□) represent predicted values, while the solid line (—) represents the measurements. Adapted from "Solar UV radiation: monitoring and new approach in modeling - pioneering work in Serbia" by Z. Mijatović, S. Milićević, D. Kapor, D. Mihailović, I. Arsenić, and Z. Podraščanin, in D. T. Mihailović and B. Lalić (Eds.), *Advances in environmental modeling and measurements* (p. 116), 2010, New York, NY: Nova Science. Adapted with permission.

The first proposed equation (1) developed by Malinović-Milićević (2012) is used for the reconstruction of UV-B doses for seven places in Vojvodina region for the period 1981–2008 (Malinovic-Milicevic, Mihailovic, Lalic, & Dreskovic, 2013) and for the projection of the UV-B doses for the period 2021–2100 (Malinovic-Milicevic, Mihailovic, Drešković, et al., 2015). The reliability of the formula for estimating of the proposed daily doses of UV-B radiation reaching the Earth's surface is proved by a very strong Pearson correlation (0.96) and a small difference between standard deviations (3.7%) between the calculated and measured values. However, the results based on the formula should be treated with caution because they do not take into account past and future ozone changes, so the reconstruction and projection are based on the present relationship between the global and UV-B radiation. In Figure 5 spatial distribution of the estimated UVB_d averaged for the hot period of the year (April–September) and the annual trend per decade (%) of UVB_d in the Vojvodina region for the period 1981–2008 has been shown. Figure 5a shows the existence of small differences between sites in the daily UVB_d values (~3%), and the highest values in the eastern part of the region. Figure 5b shows that the highest trends of daily UVB_d for the hot period are in the central part of the region (up to 5.6%).

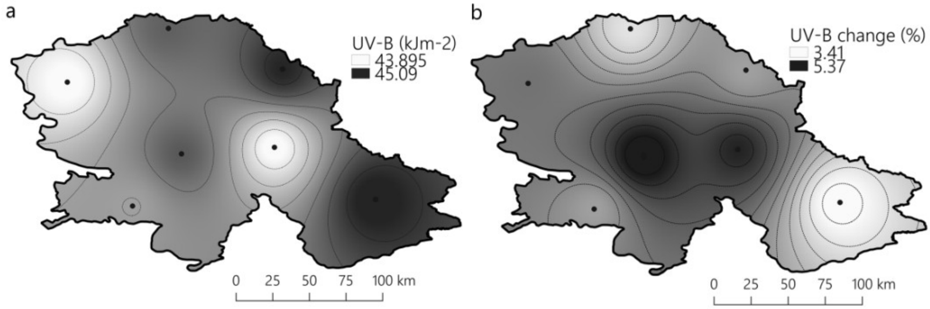

Figure 5. Spatial distribution of annual the estimated daily UV-B doses reaching the Earth's surface for the hot period (Apr–Sep) (a) and the trend per decade (%) (b) of these doses in the Vojvodina region for the period 1981–2008. Adapted from "Thermal environment and UV-B radiation indices in the Vojvodina region (Serbia)," by S. Malinovic-Milicevic, D. T. Mihailovic, B. Lalic, & N. Dreskovic, 2013, *Climate Research, 57*(2), p. 118. Copyright 2013 by Inter-Research Science Publisher. Adapted with permission.

The projection of the UV-B doses in the Vojvodina region for the period 2021–2100 was done using the data on the expected climate conditions which were obtained by applying a dynamic downscaling technique using the EBU-POM model and pessimistic scenario for the greenhouse gas emissions, SRES-A2. The model simulations show that the annual mean UVB_d will recover by 5.2%, in the Vojvodina region by the end of this century, at the higher rate in the first half of this century and slower later on. The recovery of UVB_d is expected to be the highest in autumn and spring. The performance of the proposed formula was evaluated using the root mean square error (RMSE), mean bias error (*MBE*) expressed as a percentage of the mean measured value, and correlation coefficient (*R*) for the development period (2003–2008) and testing period (2009).

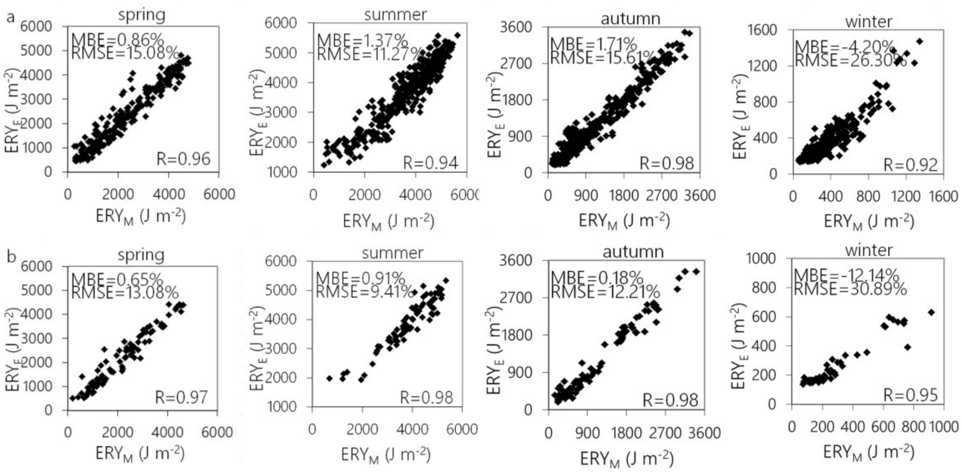

Figure 6. Measured (ERY_M) versus estimated (ERY_E) daily erythemal UV doses reaching the Earth's surface for the development period (2003–2008) (a) and testing period (2009) (b) in Novi Sad for spring, summer, autumn, and winter seasons. Adapted from "Reconstruction of the erythemal UV radiation data in Novi Sad (Serbia) using the NEOPLANTA parametric model," by S. Malinovic-Milicevic, D. T. Mihailovic, and M. M. Radovanovic, 2015, *Theoretical and Applied Climatology, 121*(1–2), p. 136. Copyright 2015 by Springer Nature. Adapted with permission.

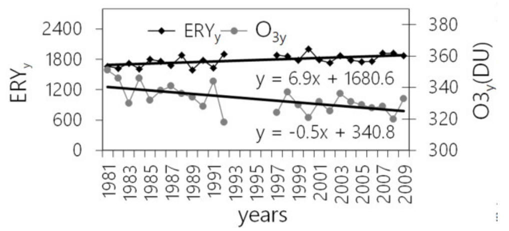

Figure 7. The annual average of daily erythemal UV dose reaching the Earth's surface (ERY_y) and total ozone (O_{3y}) trends in Novi Sad for the period 1981–2009. Adapted from "Reconstruction of the erythemal UV radiation data in Novi Sad (Serbia) using the NEOPLANTA parametric model," by S. Malinovic-Milićevic, D. T. Mihailovic, and M. M. Radovanovic, 2015, *Theoretical and Applied Climatology*, *121*(1–2), p. 136. Copyright [2015] by Springer Nature. Adapted with permission.

The obtained results showed good agreement between the estimated and measured data during spring, summer, and autumn, while the reconstructed values have lower quality during the winter season, in both development (Figure 6a) and testing (Figure 6b) periods. The MBE of this method was also compared to the MBE of two other methods (Lindfors & Vuilleumier, 2005; Rieder et al., 2008), and better results have been found for all seasons, except for winter. The new formula proposed by Malinovic-Milicevic, Mihailovic, and Radovanovic (2015) improved the reconstruction of UV radiation because it takes into account the ratio of UV radiation and the duration of sunshine in the past, which is made possible by using satellite measurements of ozone layer thickness. The TOC data (1981–2009) for Novi Sad, used in the reconstruction model runs, were taken by Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI) on satellites (NASA, 2010).

The long-term trend of *ERY* calculated by the empirical equation (2) and TOC in Novi Sad is shown in Figure 7. A decreasing trend can be noticed in the TOC since 1981 (0.5 DU per year and p = .001) and (ii) an increasing trend in daily *ERY* (6.9 J m^{-2} per year and p = .007). In order to precisely establish differences during the year and examine the cause of changes in UV radiation, the comparison of *ERY* and factors that affect it for the period 1981–1989 with those in two later periods (1990–1999 and 2000–2009) was also done. The analysis showed an increase in yearly *ERY* in both periods. The increase of yearly doses was larger in the period 2000–2009 primarily due to the increased sunshine duration. The analysis also indicates an increase in *ERY* in all seasons in both of the examined periods except in autumn in comparison to the reference period. The highest increase was during the winter season and it is caused by the largest decrease in TOC in combination with the highest increase in sunshine duration. The decline in the *ERY* during autumn is the result of the reduction of the duration of sunshine and the smallest loss of ozone.

Table 1
The statistical parameters for neural network models based on two combinations of input parameters for the testing period 2009-2012

	January-December				April-September			
	R	MBE (%)	MAPE (%)	RMSE (%)	R	MBE (%)	MAPE (%)	RMSE (%)
Daily data								
NN1 (*G*, *k*, *m*, *C*)	0.975	–0.61	12.58	17.72	0.936	–1.23	10.98	13.89
NN2 (*G*, *k*, *m*, *C*, TOC)	0.982	–0.73	10.16	14.51	0.954	–0.85	8.96	11.71
Monthly data								
NN1 (*G*, *k*, *m*, *C*)	0.989	–0.42	8.00	10.65	0.965	–1.20	7.66	8.88
NN2 (*G*, *k*, *m*, *C*, TOC)	0.998	–0.84	3.41	4.74	0.996	–0.84	3.45	4.24

Note. Adapted from "Long-term erythemal ultraviolet radiation in Novi Sad (Serbia) reconstructed by neural network modeling," by S. Malinovic-Milicevic, Y. Vyklyuk, M. M. Radovanovic, and M. D. Petrovic, 2018, *International Journal of Climatology, 38*(8), p. 3269. Copyright [2018] by Springer Nature. Adapted with permission.

The longest series of reconstructed UV radiation, from 1949 to 2012, was obtained using two neural network techniques depending on the availability of the predictors (Malinovic-Milicevic et al., 2018). Table 1 presents statistical parameters for the testing data set (2009–2012) for both used models, separately for the whole year and in the warm part of the year (April–September). It can be noticed that both of the models provide better predictions in the warm part of the year which can be explained by the largest uncertainties of *ERY* estimation due to the cloudiness, which is generally lower in the warm part of the year. The table also shows that although NN1 model is capable to provide acceptable predictions, considerable improvement occurs when highly influential parameter TOC is added. It might be concluded that the NN1 model can lead to lower representativeness of the reconstructed daily *ERY*. However, if we consider the values during a longer period of time, such as monthly quantities, the correlation of the measured and modeled data is much higher, resulting in more representative reconstructed monthly and annual doses of UV radiation.

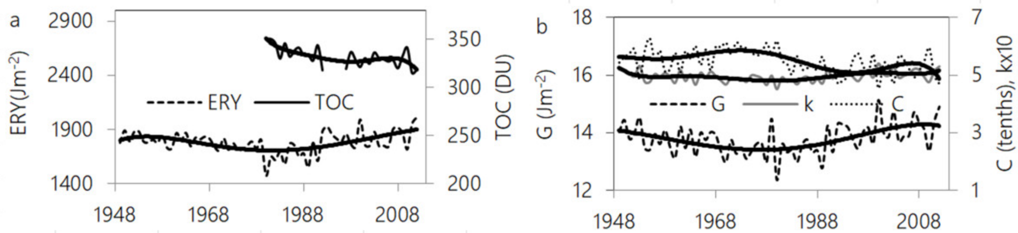

Figure 8. Annual time-series of erythemal UV radiation (UV_{ery}), total ozone column (TOC) (a), and global solar radiation (*G*), clearness index (*k*) and cloudiness (*C*) (b) and their polynomial trends in Novi Sad for the period 1949–2012. Adapted from "Long-term erythemal ultraviolet radiation in Novi Sad (Serbia) reconstructed by neural network modeling," by S. Malinovic-Milicevic, Y. Vyklyuk, M. M. Radovanovic, and M. D. Petrovic, 2018, *International Journal of Climatology*, *38*(8), p. 3269. Copyright [2018] by Springer Nature. Adapted with permission.

Figure 8 presents the reconstructed UV radiation (Figure 8a) along with the measured predictors (Figure 8a and 8b) in Novi Sad in the period 1949–2012. In order to demonstrate the long-term trend of yearly average of daily values of all parameters, the polynomial trends were presented too. It can be seen that variations in annual averages of daily doses are in accordance with appropriate variations of the input parameters and reflect global dimming from the middle 1950s to the beginning of 1990s and following brightening, the eruption of Mt. Pinatubo volcano few years after 1991, and the changes of TOC. It is also found that derived trends in erythemal UV radiation in several different subperiods between 1949 and 2012 are in accordance with findings in other studies. The analysis showed that the increase in the *ERY* in the period 1981–1996 is mainly caused by TOC, while the increase after 1996 is largely caused by cloudiness.

Conclusion and recommendations

In this study, we present various activities that were performed at the University of Novi Sad in the field of monitoring and estimation of UV radiation. The first step was the measurement of the UVI which started in 2003. Shortly after the start of the measurement, the parametric numerical model for the UV radiation forecasting, NEOPLANTA, was developed, which is the first and only model of its kind to originate in Serbia. In October 2007, consecutive daily ground-based measurements of the total ozone column started at the same location. Because of the short time series of measured data, the estimation of UV radiation in Novi Sad has been done by several reconstruction techniques using ground-based meteorological measurements and satellite measurements. It is shown that the estimated UV doses are in good agreement with measurements, and all the developed reconstruction techniques are considered reliable and trustworthy. The techniques that use satellite measured ozone data show better performance than those that use only ground-based meteorological measurements, especially for daily values. For monthly values, the difference between the performances of the methods is smaller, indicating that the techniques which use only ground-based meteorological measurements are roughly as good as the ozone-based techniques for assessing long-term changes in the surface UV radiation.

The time series of the reconstructed UV radiation produced using developed techniques extending back to 1949 provide valuable information on how the UV radiation has varied throughout the years. The data in the reconstructed series are mainly calculated by using ozone data after 1978, and by using only ground-based meteorological data in the period further in the past. However, the time series of satellite measurements of one of the most important predictors, ozone, also has gaps. Thus, in the future, in order to improve the knowledge of UV trends and variations, we plan to use reanalyzed ozone data to estimate UV radiation and get series without gaps. In the field of monitoring, the future activities will be the continuation of UV monitoring, connecting with, primarily, European centers for UV monitoring with the purpose of an international intercomparison of the instruments used for UV monitoring.

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References

Anton, M., Serrano, A., Cancillo, M. L., & Garcia, J. A. (2008). Relationship between erythemal irradiance and total solar irradiance in South Western Spain. *Journal of Geophysical Research: Atmospheres, 113*, D14208. https://doi.org/10.1029/2007JD009627

Dichter, B. K., Beaubien, A. F., & Beaubien, D. J. (1993). Development and characterization of a new solar ultraviolet-B irradiance detector. *Journal of Atmospheric and Oceanic Technology, 10*(3), 337–344. https://doi.org/10.1175/1520-0426(1993)010<0337:DACOAN>2.0.CO;2

Gallagher, R. P., & Lee, T. K. (2006). Adverse effects of ultraviolet radiation: a brief review. *Progress in Biophysics and Molecular Biology, 92*(1), 119–131. https://doi.org/10.1016/j.pbiomolbio.2006.02.011

Jégou, F., Godin-Beekman, G., Corrêa. M. P., Brogniez, C., Auriol, F., Peuch, V. H., . . . Mahé, E. (2011). Validity of satellite measurements used for the monitoring of UV radiation risk on health. *Atmospheric Chemistry and Physics, 11*, 13377–13394. https://doi.org/10.5194/acp-11-13377-2011

Levelt, P. F., van den Oord, G. H., Dobber, M. R., Malkki, A., Visser, H., de Vries, J., . . . Saari, H. (2006). The ozone monitoring instrument. *IEEE Transactions on geoscience and remote sensing, 44*(5), 1093–1101. https://doi.org/10.1109/TGRS.2006.872333

Lindfors, A., & Vuilleumier, L. (2005). Erythemal UVat Davos (Switzerland), 1926–2003, estimated using total ozone, sunshine duration, and snow depth. *Journal of Geophysical Research: Atmospheres, 110*, D02104. https://doi.org/10.1029/2004JD005231

Malinović, S. (2003). A model for the prognosis of the intensity of UV radiation using the numerical weather prediction model (Unpublished master's thesis). University of Novi Sad, Novi Sad, Serbia.

Malinovic, S., Mihailovic, D. T., Kapor, D., Mijatovic, Z., & Arsenic, I. D. (2006). NEOPLANTA: a short description of the first Serbian UV index model. *Journal of Applied Meteorology and Climatology, 45*(8), 1171–1177. https://doi.org/10.1175/JAM2400.1

Malinović-Milićević, S. (2012). Monitoring of the non-ionizing radiation, air pollution and heat indexes in Vojvodina region (Unpublished doctoral dissertation). University of Novi Sad, Novi Sad, Serbia.

Malinovic-Milicevic, S., & Mihailovic, D. T. (2011). The use of NEOPLANTA model for evaluating the UV index in the Vojvodina region (Serbia). *Atmospheric Research*, *101*(3), 621–630. https://doi.org/10.1016/j.atmosres.2011.04.008

Malinovic-Milicevic, S., Mihailovic, D. T., Drešković, N., Đurđević, V., Mimić, G., & Arsenić, I. (2015). Climate Change effects and UV-B radiation in the Vojvodina region (Serbia) under the SRES-A2. *Thermal Science*, *19*(2), S289–S298. http://dx.doi.org/10.2298/TSCI141207031M

Malinovic-Milicevic, S., Mihailovic, D. T., Lalic, B., & Dreskovic, N. (2013). Thermal environment and UV-B radiation indices in the Vojvodina region (Serbia). *Climate Research*, *57*(2), 111–121. https://doi.org/10.3354/cr01163

Malinovic-Milicevic, S., Mihailovic, D. T., & Radovanovic, M. M. (2015). Reconstruction of the erythemal UV radiation data in Novi Sad (Serbia) using the NEOPLANTA parametric model. *Theoretical and Applied Climatology*, *121*(1–2), 131–138. https://doi.org/10.1007/s00704-014-1223-y

Malinovic-Milicevic, S., Vyklyuk, Y., Radovanovic, M. M., & Petrovic, M. D. (2018). Long-term erythemal ultraviolet radiation in Novi Sad (Serbia) reconstructed by neural network modeling. *International Journal of Climatology*, *38*(8), 3264–3272. https://doi.org/10.1002/joc.5499

Mateos Villán, D., de Miguel Castrillo, A., & Bilbao Santos, J. (2010). Empirical models of UV total radiation and cloud effect study. *International Journal of Climatology*, *30*(9), 1407–1415. https://doi.org/10.1002/joc.1983

McKinley, A. F., & Diffey, B. L. (1987). A reference action spectrum for ultraviolet induced erythema in human skin. *CIE-Journal, 6*, 17–22.

Mijatović, Z., Milićević, S., Kapor, D., Mihailović, D., Arsenić, I., & Podrašćanin, Z. (2010). Solar UV radiation: monitoring and new approach in modelling - pioneering work in Serbia. In D. T. Mihailović & B. Lalić (Eds.), *Advances in environmental modeling and measurements* (pp. 113–119). New York, NY: Nova Science.

Morys, M., Mims III, F. M., Hagerup, S., Anderson, S. E., Baker, A., Kia, J., & Walkup, T. (2001). Design, calibration, and performance of MICROTOPS II handheld ozone monitor and Sun photometer. *Journal of Geophysical Research: Atmospheres*, *106*(D13), 14573–14582. https://doi.org/10.1029/2001JD900103

NASA. (2010) *Total Ozone Mapping Spectroradiometer*. Retrieved December 15, 2010, from http://toms.gsfc.nasa.gov/

NASA Goddard Earth Sciences Data and Information Services Center. (2017). Giovanni: The Bridge Between Data and Science (version 4.22) [Web application]. Retrieved from https://giovanni.gsfc.nasa.gov/giovanni/

Podrascanin, Z., Balog, I., Jankovic, A., Mijatovic, Z., & Nadj, Z. (2017). A Comparison of MICROTOPS II and OMI Satellite Ozone Measurements in Novi Sad from 2007 to 2015. *Pure and Applied Geophysics*, *174*(12), 4489–4499. https://doi.org/10.1007/s00024-017-1665-0

Reuder, J., & Koepke, P. (2005). Reconstruction of UV radiation over Southern Germany for the past decades. *Meteorologische Zeitschrift*, *14*(2), 237–246. https://doi.org/10.1127/0941-2948/2005/0027

Rieder, H. E., Holawe, F., Simic, S., Blumthaler, M., Krzyścin, J. W., Wagner, J. E., . . . Weihs, P. (2008). Reconstruction of erythemal UV-doses for two stations in Austria: a comparison between alpine and urban regions. *Atmospheric Chemistry and Physics*, *8*(20), 6309–6323. https://doi.org/10.5194/acp-8-6309-2008

Schmalwieser, A. W., Gröbner, J., Blumthaler, M., Klotz, B., De Backer, H., Bolsée, D., . . . O'Hagan, J. (2017). UV Index monitoring in Europe. *Photochemical & Photobiological Sciences*, *16*(9), 1349–1370. https://doi.org/10.1039/C7PP00178A

UV index. (n.d.). https://www.df.uns.ac.rs/uvindex/UV_index_eng.php

Vanicek, K., Frei, T., Litynska, Z., & Schmalwieser, A. (2000). *UV-Index for the Public. A guide for publication and interpretation of solar UV Index forecasts for the public Working Group 4 of the COST-713 Action "UVB Forecasting". COST-713 Action*. Luxembourg: Office for Official Publications of the European Communities.

Veefkind, J. P., de Haan, J. F., Brinksma, E. J., Kroon, M., & Levelt, P. F. (2006). Total ozone from the Ozone Monitoring Instrument (OMI) using the DOAS technique. *IEEE Transactions on Geoscience and Remote Sensing*, *44*(5), 1239–1244. https://doi.org/10.1109/TGRS.2006.871204

Webb, A. R. (2000). Ozone Depletion and Changes in Environmental UV-B Radiation. In R. E. Hester & R. M. Harrison (Eds.), *Causes and Environmental Implications of Increased UV-B Radiation* (pp. 17–36). https://doi.org/10.1039/9781847550354-00017

World Health Organization. (1995). *Protection against exposure to ultraviolet radiation* (Tech. Rep. WHO/EHG 17). Retrieved from https://apps.who.int/iris/bitstream/handle/10665/58521/WHO_EHG_95.17.pdf

World Health Organization. (2002). *Global Solar UV Index: A Practical Guide*. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/42459/9241590076.pdf

World Meteorological Organization. (1997). *Report of the WMO–WHO meeting of experts on standardization of UV Indices and their dissemination to the public* (WMO/TD-No. 921). Retrieved from https://library.wmo.int/doc_num.php?explnum_id=9714

Word Meteorological Organization. (1998). *Guidelines for Site Quality Control of UV Monitoring* (WMO/TD-No. 884, GAW Report- No. 126). Retrieved from https://library.wmo.int/doc_num.php?explnum_id=9699

Word Meteorological Organization. (2008). Instruments to measure solar ultraviolet radiation - Part 2, Broadband Instruments Measuring Erythemally Weighted Solar Irradiance (WMO/TD- No. 1289; GAW Report- No. 164). Retrieved from https://library.wmo.int/doc_num.php?explnum_id=9302