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ULTRAVIOLET RADIATION LEVELS OVER BULGARIAN HIGH MOUNTAINS

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Abstract

The UV-index (UVI) is a measure of the erythemally effective solar radiation reaching the Earth surface and it was introduced to alert people about the need for Sun protection. This study applies a model that estimates the UVI over the high Bulgarian mountains for clear sky conditions considering the Total Ozone Content (TOC), which was taken from satellite measurements. The results show that during the periods from May to August at altitudes above 2 000 m a.s.l. high UVI's (greater than 8) were observed for more than 18 days per month. The UVI values were high for every day of July at altitudes higher than 1 500 m. Extremely high UVI result from episodes with TOC lower than 290 DU during June and July at the highest mountain parts with elevations greater than 2 500 m. High radiation risks were observed during April, especially when the preceding polar vortex was strong and the mountains were snow covered.

Introduction

The solar ultraviolet (UV) radiation affects the Earth's atmosphere by heating, exciting, dissociating and ionising its main constituents. UV-rays are important for its impact on Earth's surface, atmosphere, ionosphere and exosphere [1]. The ionosphere is created by the most penetrating radiations, which are very sensitive to solar activity. An analysis of the conditions of absorption of solar radiation shows that the UV lines Lyman-Alpha (Ly-α), Lyman-Beta (Ly-β) and UV continuum, along with X-rays and cosmic rays, are factors for the formation of ionosphere of the Earth, planets and their satellites in the solar system [1–4].

Ultraviolet irradiance reaching the Earth surface impacts the human's health (induces erythema, cataract, provokes skin cancer, DNA damages and others). The UV-index (UVI) was developed from Canadian scientists in 1992 as a simple measure of the risk from unprotected sun exposure. It represents a dimensionless measure of the erythemally effective solar radiation reaching the Earth surface, defined as an integral over the radiation reaching the Earth surface at a certain time, expressed in $W/(m^2*nm)$, weighted by the erythemal action spectrum and multiplied with 40 m^2/W (see e.g. WHO [5]).

The UVI can be determined by highly precise spectrometric measurements, by multichannel filter instruments or by UV photometers of solar irradiance both, both ground-based and satellite born [6, 7].

In many countries, local UVI monitoring networks were established. In Europe, currently 160 stations in 25 countries deliver online values to the public *via* the Internet [8]. UVI daily forecast maps for Bulgaria and forecasts for some stations based on multi-yearly averages were constructed and empirical models were developed in National Institute of Geophysics, Geodesy and Geography-BAS [9] (http://data.niggg.bas.bg/uv_index/uv_index_bg.php).

To study the day-to-day variations of the harmful solar irradiance, the UVI is usually determined for clear sky conditions at solar noon, when the risk of harmful sunburn is the highest. Under clear weather the UVI depends strongly on TOC and varies with the surface albedo and with the sun elevation change. The main goal of the presented here paper is to estimate the UVI for a multi-year period in the Bulgarian high mountains.

Data used and description

For estimations of the ozone over the Bulgarian high mountain region, long-time TM3DAM-OMI overpass data for Sofia and Thessaloniki were used (http://temis.nl/protocols/o3field/overpass_omi.html). The data are provided in ASCII format. We have used the ozone data for Sofia and Thessaloniki at noon. The time series are almost gapless, and the data are available for the time interval from 10.01.2004 up to now.

Stratospheric ozone

Stratospheric ozone is produced by solar ultraviolet irradiance reaching the Earth atmosphere mainly in the tropics during summer. However, a significant amount of ozone is generated at mid-latitudes as well [10]. Ozone is transported poleward by the Brewer-Dobson circulation forced by temperature difference over the tropics and the polar atmosphere. The meridional temperature gradients and hence the dynamical processes are the strongest in winter. At mid-latitudes the stratospheric ozone has maximal values during spring. In each winter, the polar vortex is built up with very low temperatures inside it. By heterogenic reaction ozone can be destroyed catalytically in spring. In the Northern Hemisphere, strong planetary waves induced by the orography frequently disturb the polar vortex. In addition, other atmospheric circulations, short-term and mid-term variations up to a few months (e.g., advection and upwelling of the air masses) contribute to the ozone variability.

After strong Vulcan eruptions TOC increases are observed worldwide. However, the causes of the increase are complex [11] and the net effect on UVI must be carefully investigated.

Ultraviolet radiation

The energy emitted by the Sun that arrives at the Earth is about 1361 W/m^2 and is almost constant (the solar constant) slightly varying by about 0.1% during the solar cycles [12, 13]. In the near UV (300–400 nm), the variations are somewhat greater (probably they are of the order of 0.5%–1%). Today, short-term UV variations are the object of intensive research. As the Total Solar Irradiance (TSI), the near UV radiation decreases with the increase in the Sun-Earth distance. Passing through the Earth atmosphere the UV radiation is strongly absorbed by ozone and scattered by air molecules and aerosols. The received UV radiation at a horizontal Earth surface varies with the local zenith angle and hence with the day time, season, and geographic location. For the public, the UVI forecast is usually given as its maximum over the day (at solar noon) for cloudless weather taking in such a way into account only the absorption of UV irradiance by ozone. However, the UVI depends on the albedo of the underlying surface, in particular in the case of ice and snow. At mid-latitudes, the UVI mainly varies between 1 and 10 and the radiation risk of UVI values exceeding 8 is considered as very high, while for values greater than 11 it is extremely high.

Method for investigation

The UVI variations caused by the ozone deviations from the seasonal mean for the Bulgarian high mountains will be the subject of the paper. A part of the Bulgarian mountains higher than 2500 m is located between Sofia (42.817°N, 23.383°E) and Thessaloniki (40.520°N, 22.970°E) stations at latitudes from about 41.6°N to 42.2° N. For describing the ozone series variations over the Bulgarian high mountains the average values from the Sofia and Thessaloniki time series were calculated with a weight of 0.6 for the first station and 0.4 for the second one. These weights correspond to the distances of the mountains from Sofia and Thessaloniki, respectively. The seasonal multi-year means of the resulting series were determined by a Fourier series of second order with the basic period of one year, consisting of 365.25 days [14]. The time series is shown in Fig. 1 together with the sum of its trend and seasonal components in a wide range. The daily ozone values vary in a wide range from about −70 DU up to 100 DU around the seasonal mean with the correspondingly weaker or stronger solar UV absorption. On the assumption, that about 10% of TOC is contained in the troposphere and ozone in this layer is nearly uniformly distributed, the ozone values w ere recalculated to the sea level. Taking the TOC values for clear sky, UVI at noon were determined by applying the fast empirical algorithm developed by Allaart et al. [15], where besides the TOC Two more parameters are necessary: the solar zenith angle (*SZA*) and the Sun-Earth distance (*D*).

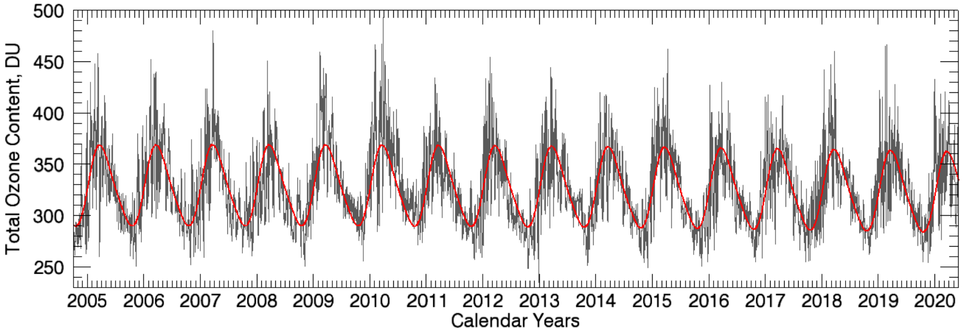


Fig. 1. TOC time series for the Bulgarian High Mountain region recalculated to sea level by using weighted OMI overpass ozone data for Sofia and Thessaloniki. The red line shows the sum of the trend and seasonal components.

$$UVI = \left[\left(\frac{D_0}{D}\right)^2 \cdot S_0 \cdot \mu_x \cdot exp\left(-\frac{\tau}{\mu_x}\right)\right] \cdot \left[F \cdot X^G + \frac{H}{TOC} + J\right]$$

(1) $$S = 1.24\, Wm^{-2}nm^{-1} \quad \tau = 0.58 \quad \mu_x = \mu_0 \cdot (1 - \varepsilon) \cdot \varepsilon$$

$$\mu_0 = \cos(SZA) \qquad \varepsilon = 0.17 \quad F = 2.0 \qquad X = 1000 \cdot \frac{\mu_0}{TOC}$$

$$G = 1.62 \quad H = 280.0 \quad J = 1.4 \quad .$$

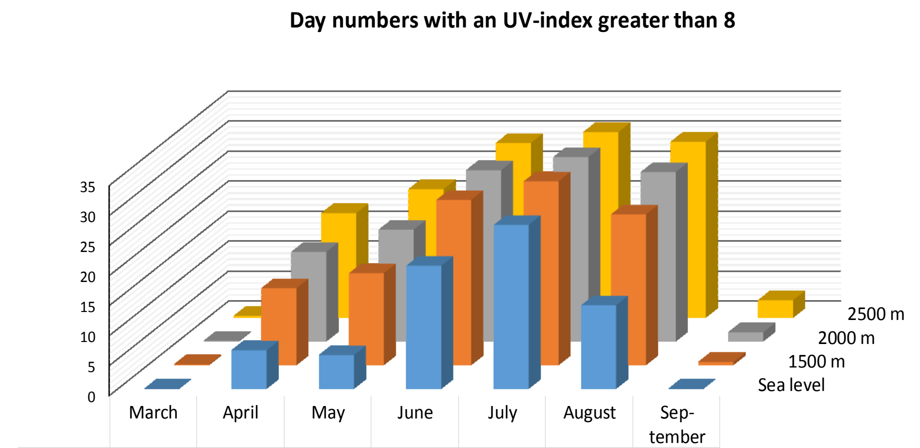
SZA and *D* were calculated from the implementation of an astronomical algorithm [16].

Using the TOC at sea level in the empirical model the UVI for the elevation h=0 m is obtained. By help of the Tropospheric Ultraviolet and Visible (TUV) radiative model [17] we found an UVI increase of 6% per km with elevation increasing, which is in very good agreement with the value of 6%–8% per km given in [18,19].

The UVI behaviour was studied for the March-April and May-September (hereinafter referred to as spring and summer, respectively). During the spring the polar vortex is already developed. At the same time, the *SZA* becomes low and the High Mountains are usually snow covered. The UVI for snow covered surfaces were corrected by a factor of 1.25 corresponding to a mean snow albedo of 0.8. [20, 21]. During the summer the Sun culmination is high that corresponds to elevated irradiation risk. The obtained UVI time series allows estimation of the number of days with very high UVI (greater than 8) in the time intervals under study.

Results Satellite data processing

The UVI values corresponding to the TOC time series determined above were calculated for all days of the time interval under study and the monthly means were determined for four altitudes – sea level, 1500 m, 2 000 m and 2 500 m. The results are presented as column chart and as table in Fig. 2. (For the days of spring the UVI's were snow corrected.) During the period from April to August in the high mountains (above 2 000 m altitude) more than 18 days per month with very high UVI'-s were observed. At altitude higher than 1 500 m in practice all the days of July are characterized by very high values. However, the monthly variations in the number of days with UVI greater than 8 from year to year are of the order of 30% (not shown here), especially in spring. The lowest number of days with UVI > 8 was observed in the winters 2006/2007 and 2008/2009, when the polar vortex was weak and the TOC exceeded the average values in March – April with some exceptions (Fig. 3).



	March	April	May	June	July	August	Sep-tember
Sea level	0	6,4	5,6	20,5	27,3	13,9	0
1500 m	0,1	12,8	15,3	27,5	30,6	25,1	0,5
2000 m	0,1	14,9	18,6	28,5	30,7	28,2	1,5
2500 m	0,3	17,4	21,4	29,1	30,9	29,3	2,9

Fig. 2. Mean monthly number of days with an UVI greater than 8 for some altitudes during the period 2005–2020 in the Bulgarian high mountain region

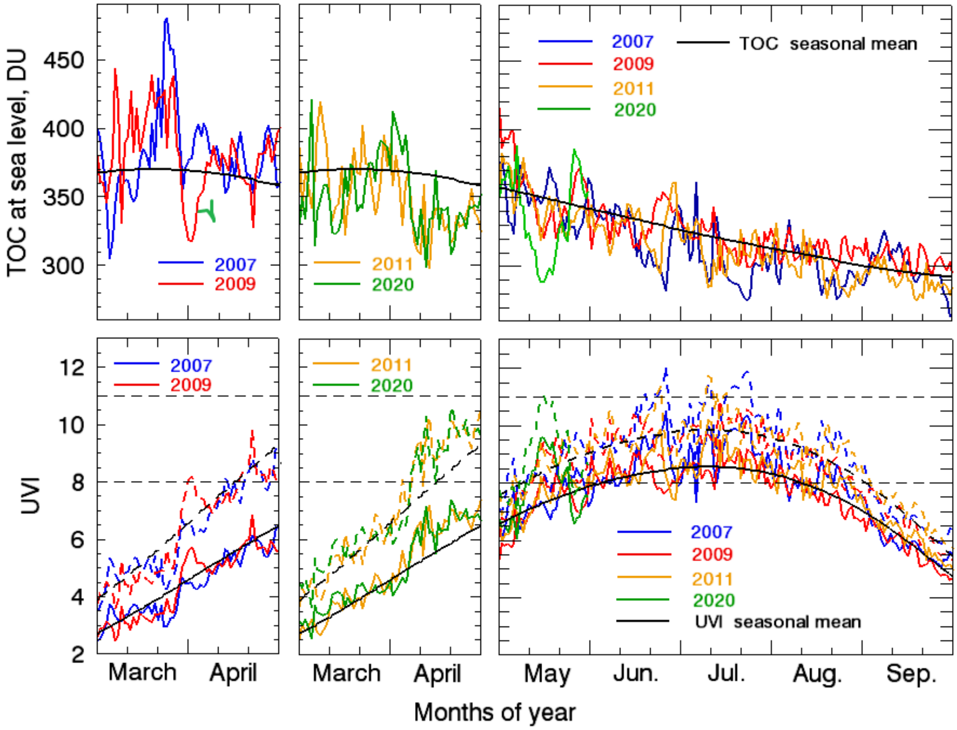


Fig. 3. At the top row TOC series are shown. At the bottom row UVI series are presented calculated from the TOC. The solid lines are for the sea level, and the dashed ones are for the altitude of 2 500 m. The UVI at 2 500 m is snow corrected for the time periods of March – April. The horizontal black dashed lines represent the UVI = 8 and UVI = 11 limits.

The observed lower TOC values in March had not a significant impact on UVI because of the low Sun culmination. However, at the end of March/April 2009 low TOC caused two UVI peaks higher than eight, but only for some days. For 2011 and 2020, when the vortexes were strong, air masses with low TOC values were located over the snow covered Bulgarian high mountains in April, that lead to continuously very high UVI values during the whole period with peak values of more than 10. For the summer period the TOC values did not show annual differences, depending on the vortex strength in winter/spring. An exception was the vortex 2019/2020, which persisted up to the beginning of May – the latest persistence up to now. Low ozone events caused by strong planetary wave activities were observed up to the mid of May. During the same time a part of the tropospheric jet stream transported Sahara dust, which reduced the surface UV radiation importantly.

On the other hand, the highest parts of the mountains with an elevation greater than 2 500 m were snow covered during the mid of May 2020. In period from May to August the UVI was very high. For some days in June and July when the Sun culmination is highest the TOC was relatively low (lower than 290 DU) that lead to extremely high UVI (greater than 11) in the mountains at altitudes higher than 2 500 m. At the same time, the UVI at sea level was very high from June to July, as well.

Summary and conclusions

Using the clear sky UVI as a measure of the harmful UV radiation, in days with high UVI values one could choose appropriate clothes and means with higher protection. Clouds absorb UV radiation and the real UVI is usually lower than that of clear sky. However, in some cases, the UV can be higher due to reflections from clouds. To take into consideration the fast changing cloudiness for the prognosis of UVI, especially in mountains, requires complex weather forecast models. Thus, the easiest way that provides a realistic assessment is the use of a clear sky UVI.

Based on the multiyear ozone values, the clear sky UVI's were estimated and corrected for altitude and snow albedo. The paper reports results about the UVI in the high mountain regions in Bulgaria. It was shown, that in the mountains, due to the altitude and reflections by snow, the UVI increases to very high levels at the end of spring, particularly in years when the polar vortex was very strong. A very high radiation risk in the Bulgarian high mountains was found in summer as well.

The highest UVI were observed during June and July, as it was expected. At 2 500 m elevation in the mountains, the UVI is higher than the UVI at sea level by a factor of about 1.15. In limited cases when the TOC is below 290 DU in summer, extremely high radiation risk (UVI > 11) can be achieved. But very high UVI levels in the high mountains can also be occurred in spring, when the TOC values are below the mean in April and the terrains are snow covered.

We would like to remind, that the World Meteorological Organisation recommends staying indoor during midday hours, when the radiation risk is very high (UVI > 8). Since above 2 500 m, the alpine grasslands dominate, the probability to find shade at these altitudes for minimising the radiation risk is very limited, both at the end of spring and in summer. When there are very high radiation risk levels during the summer and winter seasons in the high mountain regions, people has to be alarmed in their accommodations or online about the risk.

The results obtained in this work will help to improve the environmental and solar-terrestrial models and provide the input for planetary modelling of helio-biological and space weather processes in quiet and disturbed conditions [22].

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НИВА НА УЛТРАВИОЛЕТОВА РАДИАЦИЯ НАД ВИСОКИТЕ ПЛАНИНИ В БЪЛГАРИЯ

Р. Вернер, В. Гинева, А. Атанасов, Д. Вълев, Д. Данов, Б. Петков, А. Кирилов

Резюме

Ултравиолетовият индекс (UV-индекс, UVI) е мярка за еритемално ефективната слънчева, достигаща земната повърхност, и той беше въведен за да предупреждава хората за необходимостта за предпазване от слънцето. В настоящото изследване се прилага модел, който оценява UV-индекса над високите планини в България при условия на чисто небе, като се отчита общото съдържание на озон (TOC), получено от спътникови измервания. Резултатите показват, че през периодите от май до август при височини над 2 000 m са наблюдавани много високи UV-индекси (по-високи от 8) за повече от 18 дни на месец. На практика стойностите на UV-индекса са много високи за всеки ден на юли за височини над 1500 m. Екстремно високите UV-индекси са резултат от случаи на TOC по-ниско от 290 DU през юни и юли, и се отнасят за най-високите части на планините, над 2 500 m. Висок риск от слънчева радиация е наблюдаван през април, особено когато предшестващият полярен вихър е силен и планините са покрити със сняг.