FORECAST SCHEME OF THE LOCAL UV-INDEX OVER BULGARIA – FIRST TEST RESULTS

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Abstract: *The UV-index (UVI) is a measure of the erythemally effective solar radiation reaching the Earth surface. It was introduced to alert people about the need of sun protection and to help for elaborating recommendations about safety exposure to solar UV radiation. Therefore, the UVI has to be determined with adequate accuracy and its forecast appears to be an essential task. To minimize the risk of too high sunburn levels, the UVI previsions are usually made for clear sky conditions (cloud and aerosol free atmosphere). In such conditions, the solar UV irradiance over a given geographical location depends mainly on the total ozone column (TOC) and thus, the UVI forecast implicates the knowledge of the TOC. Schemes of one-day UVI forecast for Stara Zagora and Bulgaria are presented and discussed in the present report. A detailed analysis has been supported by results of the first tests performed from 19th Sep. to 19th Oct. 2019.*

СХЕМА ЗА ПРОГНОЗА НА ЛОКАЛНИЯ УВ-ИНДЕКС НАД БЪЛГАРИЯ – ПЪРВИ РЕЗУЛТАТИ ОТ ТЕСТОВЕТЕ

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Резюме: *УВ-индексът (УВИ) представлява мярка за еритемално ефективната слънчева радиация, достигаща земната повърхност. Той беше въведен, за да предупреждава хората за необходимостта от защита от слънчевото лъчение и за да помогне за разработване на препоръки за сигурност при експозиция на слънчева УВ радиация. Затова УВИ трябва да се определя с адекватна точност и прогнозирането му представлява много важна задача. За минимизация на риска от силно слънчево изгаряне, прогнозата на УВИ обикновено се прави за условия на ясно време (безоблачна и свободна от аерозоли атмосфера). В такива условия слънчевото УВ лъчение над дадено географско място зависи главно от общото съдържание на озон (ОСО) и така предсказването на УВИ включва сведения за ОСО. В доклада са представени и дискутирани схеми за еднодневна прогноза на УВИ за Стара Загора и за България. Детайлният анализ е съпроводен* от *резултатите от първите тестове, проведени от 19ти Септември до 19 Октомври 2019 г.*

Introduction

The ultraviolet (UV) irradiance reaching the Earth surface has an impact on the human's health. The UV-B irradiance stimulates the production of vitamin D, important for good being. However the overexposure to solar ultraviolet evokes erythema and over long time it represents a risk of DNA damage and of skin cancer [1]. Sun related eye diseases and in acute cases snow blindness are well established. To alert people about the need of sun protection, the UV-index (UVI) was introduced as a measure of the erythemally effective solar radiation reaching the Earth surface. At a given moment *t* it is defined as scaled integral over the wavelength given in nm of the solar irradiance at the Earth surface $F_t(\lambda)$ measured in mW/(m^{2}nm) weighted by the erythema action spectrum $A_e(\lambda)$, where the value of 1/25 mW/m^2 is used as scaling factor [2]. By the scaling the UVI is a dimensionless quantity and it is in the range up to 10 at midlatitudes at noon under cloudless conditions when the risk of harmful sunburn is the highest. The UVI can be determined by highly precise spectrometric measurements, by multichannel filter instruments and by UV photometers of the solar irradiance [3, 4], which are ground based or represent part of satellite instrumentation.

In many countries, UV monitoring networks were established. In Canada there are 13 spectral UV stations. In Austria the network involves 12 stations at different locations, equipped with broadband UVB radiometers [5]. In Europe currently 160 stations in 25 countries deliver online values to the public *via* Internet [6]. In Bulgaria a comparable net of automatic working stations does not exist.

To minimize the risk of too high levels of sunburn the UV-index is determined usually for clear sky conditions (cloudless and aerosol free) at solar noon, when the risk of harmful sunburn is the highest. Under clear weather conditions the UVI depends strongly on the total ozone column (TOC). The UVI varies with the surface albedo and with the sun elevation change.

1. Data used for forecasting the ozone and UVI

1.1. Stara Zagora Observatory ground based station

The total ozone columns over the Stara Zagora Observatory are retrieved from UV irradiance measurements by a GUV 2511 instrument. To determine the TOC and the UVI lookup tables [7, 8] were calculated by help of the radiation transfer model TUV of Madronich [9]. Some instrument parameters were chosen to adjust the TOC to the TOC OMI level 3 data. The data processing procedure is described in detail in Werner et al. [7, 8]. In comparison with the OMI TOC the Stara Zagora TOC over the whole measurement time interval of almost 5 years is biased by about -1 DU and the root mean squared difference is 7.5 DU.

1.2. GOME-2 instrument satellite data

The Gome-2 instrument on Meteorological Operational satellites (MEOTOP) A and B is a scanning spectrometer with a scanning width of 1920 km and a pixel field of view on the ground of 80x40 km^2. Different websites make data and maps available. Level 3 data of the GOME-2 MEOTOP-B are gridded at longitudes by 1.25° and at latitudes by 1.0° and can be found at https://www.ospo.noaa.gov/Products/atmosphere/gome/gome_to3_dat_B.html. To provide the near-real time forecast the observed by GOME-2 ozone data are input in a data assimilation program considering chemical ozone production and loss and dynamical processes as well [10]. The GOME-2 forecast total ozone column and the calculated UVI field data are available as HDF-files with a resolution of 1.5° by 1° for ozone and 0.25° by 0.25° for the UVI. The METOP-B satellite orbits are sun-synchronous and the satellite overpasses Stara Zagora about one and a half hour before solar noon. Ozone overpass data are placed on the same website. UVI and all GOME forecast data for six days in advance are published on the Temis website http://www.temis.nl/protocols/O3global.html for selected locations and for the UVI map on http://www.temis.nl/uvradiation/world_uvi.html.

1.3. OMI instrument satellite data

The OMI instrument on board the AURA satellite is a scanning spectrometer, the same as GOME-2 instrument. The swath width is 2600 km with a pixel area on the ground of 12 by 24 km^2 [11]. Level 3 data of ozone measurements are published at https://ozonewatch.gsfc.nasa.gov/data/omi as ASCII data. The data grid is 1° by 1°. The AURA satellite orbits are also sun-synchronous, and the satellite overflies Stara Zagora about one and a half hour after solar noon.

1.4. Topographical data for downscaling

For downscaling to higher resolution elevation corrections are used. The Shuttle Radar Topography Mission (SRTM) provided global elevation data with 1 and 3 arcsec resolution. Here we have used the 3 arcsec data set to retrieve the elevation map for the geographic region where Bulgaria is located. (The map data were downloaded from the website https://gdex.cr.usgs.gov/gdex/ (now a similar site can be found at http://dwtkns.com/srtm30m/). The elevation map for the Bulgarian Area (8° x 4°) with 3 arcsec resolution originally consists of 8400 by 4800 grid cells.

2. Forecasting Method

2.1. Forecast for the Stara Zagora location

To forecast TOC statistical methods can be used. However, in statistical models which have been developed, for each location a lot of every day additional inputs of meteorological and chemical character like the used ones in the GOME assimilation program are necessary. With the main goal of UVI forecast usually an easier way to do this is preferred, where persistence of the ozone column is assumed for the next day, which guarantees a quality that is convenient with the requirements of UV Index forecast procedures [12]. From the GUV UV radiation measurements TOC and UVI, determined for the actual day by calculated lookup tables are used as forecast for the next day. To validate the ground based TOC and UVI the results were compared with satellite OMI and GOME-2 METOP-B measurements and GOME-2 forecast data. For this purpose TOC over Stara Zagora (25.633 °E, 42.217 °N) was retrieved from the OMI and GOME-2 METOP-B maps by interpolation of the gridded values for the Stara Zagora location. GOME-2 forecast at a location data were used, where the values of the four nearest to Stara Zagora grid point values were downloaded and bilinearly interpolated. The elevation differences of the four grid points of about 250 m are small and an elevation correction (see the next section) was not taken into account. The UVI-LT using the lookup tables were determined for the solar noon and were compared with the UVI-E calculated from the satellite TOC observations based on an empirical model [13].

2.2. Forecast for the Bulgarian region

Because the absence of a Bulgarian ground based monitoring net for forecasting of TOC and UVI the satellite Gome-2 forecast gridded data are used. Bulgaria is extended over the geographic region between about 22 °N and 29 °N longitude and from 41 °E to 45 °E latitude, an area of 8° by 4°. Thus the GOME-2 “forecast ozone at a specific location” and the UVI field data over Bulgaria are determined by a matrix of 33 by 17 ozone values with a resolution of 0.25°. The ozone field has not strong gradients over small geographic regions, which allows to minimize the time expense to retrieve the forecasted values. A rougher grid with steps of 1° is used, with the lower left grid cell centre at 21.125 °E, 41.125 °N and the higher right grid cell centre at 29.125 °E, 45.125 °N (a matrix of 9 x 5 values). The data were further reduced using a grid step of 2° x 2° (a matrix of only 5 x 3 values). The downloaded TOC and UVI 9 by 5 (respectively 5 by 3) values, characterizing the TOC and UVI distribution over the Bulgarian area were downscaled taking into account the topography. The UVI distribution can be extracted directly from the HDF file as well.

In the first step the retrieved forecasted TCO values were recalculated to sea level height by:

(1) $$TOC(h=0)^{low} = TOC(h^{low})/(1-c_{elev}^{ozone} * h^{low}/1000m)$$, with h^{low} in meters

where the value of c_{elev} = 0.01 per km results from the assumption that the tropospheric ozone content is about 10% of the TOC and the mean tropopause is at about 10 km height [14]. Schmalwieser [12] based on UV measurements at the Austrian Sonnenblick high mountain station in comparison with EP TOM satellite observations found an altitude dependce of 1.13% per 1000 m. In eq. (1) h^{low} is the mean elevation over the grid cells of 0.25° x 0.25°.

In a similar way the retrieved forcasted UVI values are recalculated to sea level.

(2) $$UVI(h=0)^{low} = UVI(h^{low})/(1+c_{elev}^{uvi} * h^{low}/1000m)$$, with h^{low} in meters

In the second step the TOC and UVI values for sea level heights are interpolated to a new topographic grid with the higher resolution of about 1km. TOC values are recalculated by:

(3) $$TOC(h^{high}) = TOC(h=0)^{high} * (1-c_{elev}^{ozone} * h^{high}/1000m)$$, with h^{high} in meters

from the sea level heighs to the mean elevations h^{high} given in the Bulgaria elevation map. The UVI values were recalculated by:

(4) $$UVI(h^{high}) = UVI(h=0)^{high} * (1+c_{elev}^{uvi} * h^{high}/1000m) * c_{alb}$$, with h^{high} in meters

where c_{alb} is an albedo correction factor. Using the TUV model we found out that the UVI elevation correction $c_{elev.}$ depends only weakly from the sun elevation and from the sea level TOC. We obtained an UVI increase with increasing elevation of 0.06 per km in very good agreement to the value of 6% to 8% per km given by Vanicek et al. [15] and Dahlback et al. [16]. Other authors have reported higher altitude corrections, e.g. Diffey has established 16% per km [17]. (For more details see Schmalwieser, and the citations herein [18].) The albedo correction has to be introduced because it is substantially higher in winter, when the surface or parts of it is snow covered. For the albedo correction we use the UVI ratio

(5) $$c_{alb} = \frac{UVI(albedo)}{UVI(reference\ \ albedo)} .$$

The effective albedo of soils and vegetation is about 0.03, which is used here as reference albedo. Feister and Grewe found an albedo for surface fully covered by polluted snow of 0.62 to 0.76 [19]. McKenzie et al. established an enhancement in the UVA region of 22 % and in the UVB of 28 % by snow corresponding to an albedo of 0.62 ± 0.08 [20]. It has been established a stronger UV irradiance enhancement for fresh snow and a decrease later when the snow pollution increases and the snow is more packed. By means of the Madronich model we have found an albedo correction of 1.25 for a mean snow albedo of 0.6. An albedo correction of 1.06 was determined for beach sands with an albedo of 0.14 [19].

The elevations h^{high} in equations (3 and 4) are taken from the SRTM elevation map, where the original data were box care smoothed by 11 x 11 points and the grid number in the Bulgaria map was reduced from 8400 by 4800 to 763 by 436 pixels corresponding to a horizontal resolution of approximately 1 km. The obtained elevation map for the Bulgaria region is shown in Fig. 1.

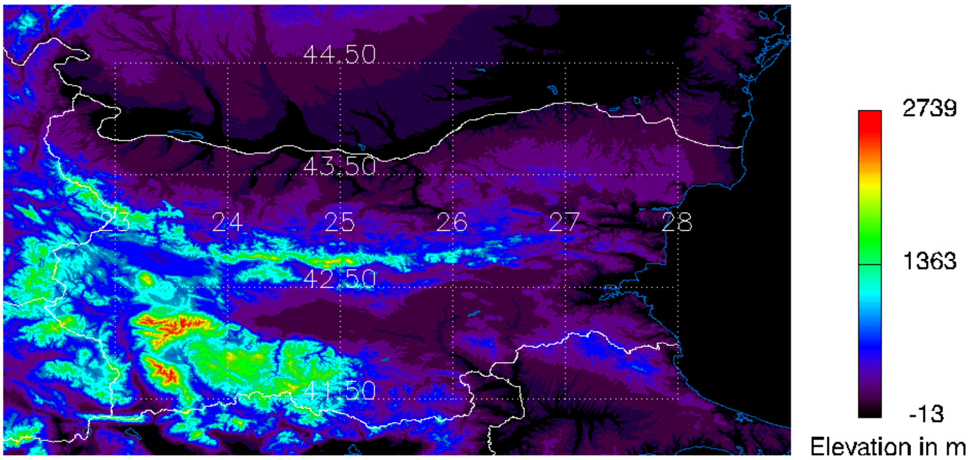


Fig. 1. Elevation map for Bulgaria (in an area of 22°E - 29°E and 41°N - 45°N). The elevations are the means over the grid cells of 0.00917° x 0.00917°. The land frontiers are shown as white lines, the coasts as light blue lines.

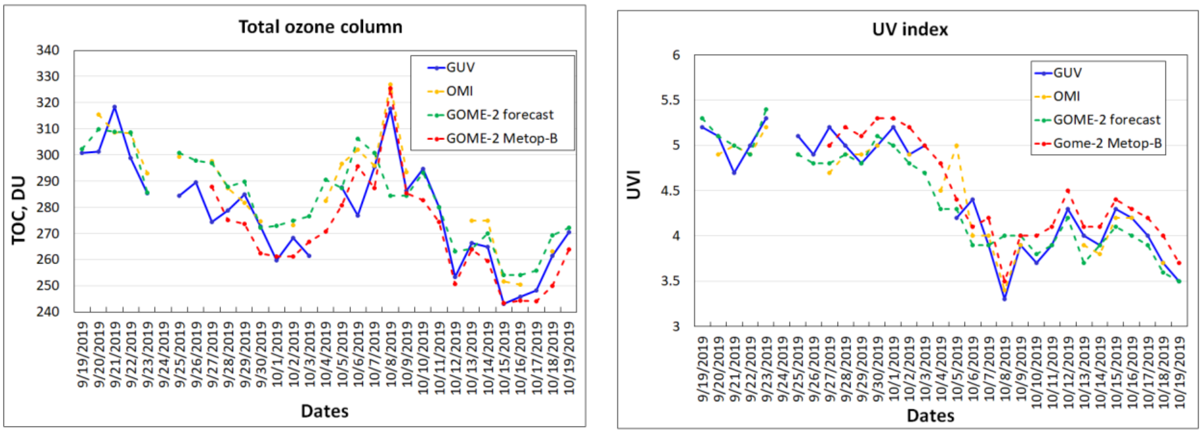
3. Results

3.1. UVI calculation

The UVI are calculated from the obtained ozone values for zenith angle at solar noon 12.17 LT at Stara Zagora. The moment of solar noon at Stara Zagora changes only by ± 2 minutes over the year. The found out UVI at solar noon and for optical depths of zero during the test interval from 19th Sep. to 19th Oct. 2019 are higher than the GOME-2 forecast values by approximately 1 to 1.5 UVI units. In the empirical model [13] the cosine of the zenith angle was corrected and an aerosol optical depth of 0.58 is used to compensate atmosphere scattering effects to calculate the UV irradiance for clear days. The UVI of the Stara Zagora TOC series was calculated by both methods – first the UVI-LT using the lookup tables and the UVI-E using the empirical model. If in the UVI-LT calculations for clear sky conditions an optical depth of 3.5 is adopted then the mean bias (MB) is negligibly small and the root mean squared difference (RMSD) between the UVI-LT and the UVI-E is only 0.08 and the linear correlation coefficient is 0.9996. The maximal deviation of the UVI calculated by both methods is about ± 0.2, a small value compared to the daily forecast UVI errors from 0.1 up to 0.55 given for GOME-2 Sofia overpass UVI data.

3.2. TOC and UVI forecast for Stara Zagora

The results of the Stara Zagora GUV TOC in comparison with the satellite TOC data during the test period are shown in Fig. 2a and for the UVI in Fig 2b. The GUV ozone and UVI follow very well the course of the TOC and UVI observed by satellites. It is interesting that on 08.10.2019 the TOC by ground based and satellite measurements are higher and the UVI are lower, respectively, than the found by GOME-2 forecast data. The RMSD between the ozone forecast and the actual ozone values is about 23 DU and the corresponding UVI RMSD is about 0.4 for the whole time period (2015–2019) including summer periods for which the UVI for Stara Zagora is up to 10.



a) **b)**

Fig. 2. Obtained by ground based and satellite instruments TOC and UVI for Stara Zagora for the test period (19.09.2019 – 19.10.2019)

3.3. TOC and UVI Forecast for the Bulgaria region

In this paper it is possible to present only one forecast example. The results based on “forecast data at specific location” (using 9 by 5 grid values) for 29.09.2019 are shown in Fig. 3. At the left hand side the maps show the recalculated to sea level and interpolated TOC and UVI. The downscaled, elevation corrected TOC and UVI are pictured on the right side. It is clearly seen the decrease of the ozone in mountain regions and vice versa - the increase of the UVI, both not evident on the sea level maps. In the mountains, on 29.09.2019 the UVI is about 1 UVI unit higher than in the surrounding area. In the summer, when the UVI is about 8 in plane regions, in the mountains an 1.5 unit higher UVI is to be expected, which is essential for sun burn protection.

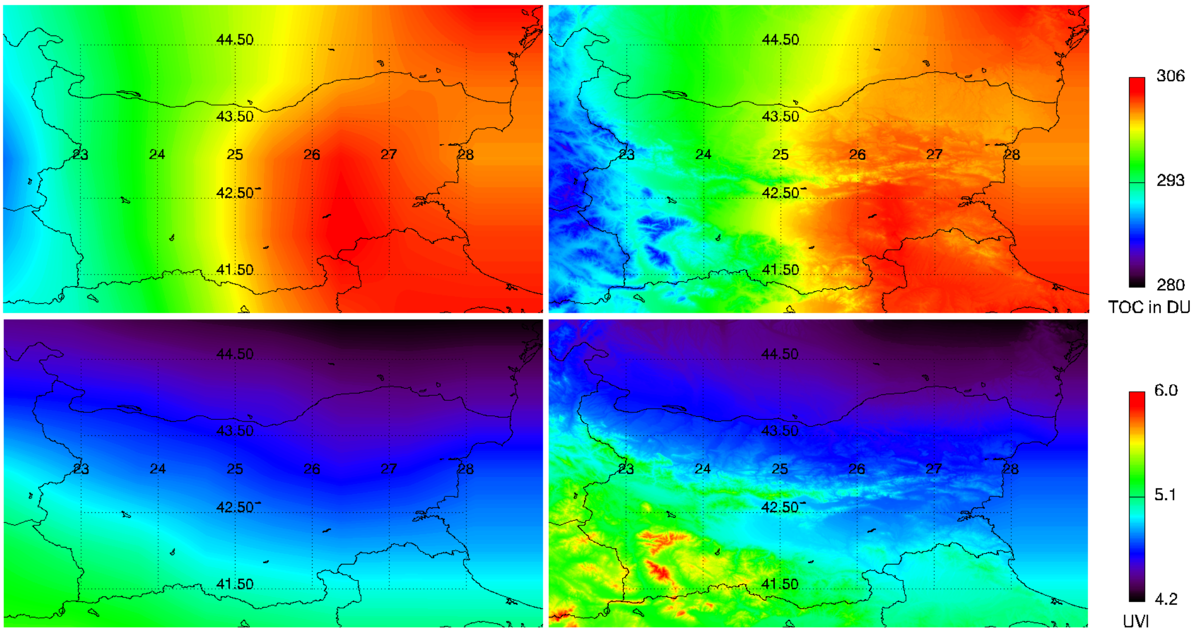


Fig. 3. The top row shows the interpolated on the topographic grid ozone distribution for the Bulgaria region. The bottom row shows the same for UVI. The recalculated quantities for sea level are presented at the left side. At the right side are shown the elevation corrected ozone and UVI distributions.

The UVI forecast map for one day in advance can be downloaded as HDF file in the morning of the actual day from the Temis website with a resolution of 0.25° by 0.25° (see paragraph 1.2.). The part of the Bulgaria area can be extracted. The map of the scaled to sea level UVI (not shown here) displays the same local structure and is very close to the one shown in the bottom left panel of Fig. 3 and the resulting downscaled UVI is almost the same as the downscaled map obtained using the matrix of 9 by 5 UVI elements. The use of the HDF files is simple and the downscaled procedure is very fast.

Summary

A forecast scheme for the TOC and the UVI was worked out based on downscaling of satellite data to a grid with higher resolution. It is foreseen to correct the ozone and UVI values for surface elevations and albedos for snow, soil and vegetation and beach sand by parametrization. The correction factors were determined using the radiation transfer model TUV of Madronich. The analysis of the results obtained during the test period shows that TOC and UVI forecasts were done with sufficient accuracy.

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