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VERIFICATION OF THE LONG-TERM STABILITY OF OZONE MEASUREMENTS WITH THE GUV 2511 INSTRUMENT IN STARA ZAGORA

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Abstract: *After the installation of the GUV-2511 instrument in February 2015 at Stara Zagora, the instrument is operating continuously and measures the sky Solar irradiance at different wavelengths in the spectral range from 305 nm to 395 nm. In the past years the total ozone content (TOC) was determined by Stamnes look up tables (LUT), in which were modelled the ratios of irradiances for the 313 nm and 340 nm spectral bands for the Stara Zagora location as function of the zenith angle, the cloud optical depths and a mean albedo of 0.03 for different TOC, using the Tropospheric Ultraviolet and Visible (TUV) model version 4.1. developed by Madronich (1993). The instrument was calibrated versus satellite OMI-Aura ozone values by a shift of the GUV 2511 313 nm filter central wavelength to 313.7 nm. For the calibration ozone time series from 2015/2016 was used minimizing the standard ozone deviation in comparison to the OMI-AURA ozone values. The main goal of the present study is to check the long-time stability of the original calibration based on the examination of the mean biases, their ratios and the regression coefficients in two control groups. One group from 2015 to 2018 and the other one from 2019 to 2022. It was found that the absolute bias increases slightly by 1.8 DU. The increase is significant at the level of 0.05. However, the parameters of the linear regressions are not statistically different. The results let us conclude that the stability in time is acceptable.*

ПРОВЕРКА НА ДЪЛГОСРОЧНАТА СТАБИЛНОСТ НА ИЗМЕРВАНИЯТА НА ОЗОНА С УРЕДА GUV 2511 В СТАРА ЗАГОРА

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Ключови думи: *Общо съдържание на озон, стабилност на измерванията, средно отместване, отношение на интензивности, линейна регресия*

Резюме: *След инсталирането на уреда GUV-2511 през февруари 2015 г. в Стара Загора уредът работи непрекъснато и измерва слънчевата радиация на небето при различни дължини на вълните в спектралния диапазон от 305 nm до 395 nm. През изминалите години общото съдържание на озон (ОСО) се определяше чрез Look up tables (LUT) на Stamnes, при които се моделираха съотношенията на интензивностите на спектралните ивици при 313 nm и 340 nm за местоположението на Стара Загора като функция на зенитния ъгъл, оптичната дълбочина на облаците и средно албедо 0.03 за различни ОСО, като се използва моделът Tropospheric Ultraviolet and Visible (TUV) версия 4.1., разработен от Madronich (1993). Инструментът е калибриран спрямо сателитните стойности на озона от OMI-AURA чрез отместване на централната дължина на вълната на филтъра GUV 2511 313 nm на 313,7 nm. За калибрирането е използван времевия ред на озона от 2015/2016 г., свеждащ до минимум стандартното отклонение на озона в сравнение със стойностите на озона на OMI-AURA. Основната цел на настоящото изследване е да се провери дългосрочната стабилност на първоначалната калибровка въз основа на изследване на средните отмествания, техните отношения и коефициентите на регресия в* *две контролни групи. Едната група обхваща периода 2015-2018 г., а другата - периода 2019-2022 г. Установено е, че абсолютното отклонение се увеличава с 1,8 DU. Увеличението е значимо на ниво от 0,05. Параметрите на линейните регресии обаче не се различават статистически. Резултатите ни позволяват да заключим, че стабилността във времето е приемлива.*

Introduction

GUV type instruments were designed for measurements of the UV global sky downwelling irradiances. It consists of a cylindrical body. On its upper side, there is a light entrance window consisting of a teflon diffusor on a quartz base with a cosine characteristic. The interior of the instrument is a hollow white chamber with built-in photodiodes, one for each receiving channel in six spectral wavebands with filters centered at 305, 313, 320, 340, 380 and 395 nm. The filter in every band has a filter half width of about 10 nm. The main advantage of the GUV instrument series is that they have not moving components. This, together with stabilization of the photodiodes, filters and amplifiers to a working temperature of 50°C, guarantees long life and high stability [1]. For more details of the GUV 2511 instrument see the publication of Level et al. [2]. The GUV instrument was installed in February 2015 on the roof of the Stara Zagora observatory and measures the UV global sky irradiances continuously up to now. The main goal of this paper is to report the results about our investigation of the time stability of TOC amounts obtained by the GUV 2511 measurements.

Short description of the algorithm to calculate TOC amounts

Based on the measurements, the daily total ozone column (TOC) amount was determined using previously calculated Stamnes Look-up tables (LUT) [3]. They relate TOC to the ratios of the irradiance at 313 nm, a wavelength with significant ozone absorption, to a second irradiance at 340 nm, which is insensitive against ozone absorption in dependence of the zenith angle, the cloud optical depth for the Stara Zagora location and for a mean albedo of 0.03. The Stara Zagora GUV TOC was verified by comparison with the OMI-TOMS TOC from the AURA satellite. To obtain acceptable GUV TOC for the LUT calculation the central wavelength value of the filter at 313 nm was shifted to 313.7 nm. For the verification ozone time series from 2015/2016 was used. The TOC amount was retrieved by interpolation of the LUT's for real measured ratios of the irradiances at 313nm/340 nm. In addition, a LUT was previously calculated to obtain the actual optical depth in dependence of the irradiance at 380 nm depending on the zenith angle [4]. The obtained irradiance at 380nm was used for the determination of almost cloudless days. For more algorithm details see the papers [5,6].

Data used

To study the stability of the GUV 2511 measurements we used coincident TOC values from the OMI-TOMS of the AURA satellite. The OMI TOC values are one of the most intensive studied satellite series. The comparison of OMI data with these from references, mostly Brewer or Dobson instruments, shows typically a correlation of 0.96 to 0.98, a bias of some DU and a standard deviation of about 10 DU [7-12]. We use the OMI TOC data retrieved by an algorithm like the TOMS version 8, level 3 (OMTO3d). The data are available at https://ozonewatch.gsfc.nasa.gov/data/omi. They are gridded in steps of 1°x1°. The TOC OMI values for Stara Zagora are obtained by bilinear interpolation via four immediate grid neighbour points.

Method to verify the time stability

For the calibration the ozone time series observed from 2015/2016 was used. To check the stability of the GUV calibration the observations of the two TOC time series of GUV and of OMI from 2015 to 2022 have been divided in two control groups: from 2015 to 2018 and from 2019 to 2022 (see Fig.1). The true values are mostly not known. Usually, as reference values, accepted as true, TOC from ground based Brewer or Dobson instruments are used. These, in turn, are calibrated with the help of standard lamps. The reason of bias changes may be due to changes in the channel sensitivity (caused by aging of filters, inner reflective surfaces or of electronic elements). We will check the regression of the TOC of GUV 2511 against that of OMI AURA, as well.

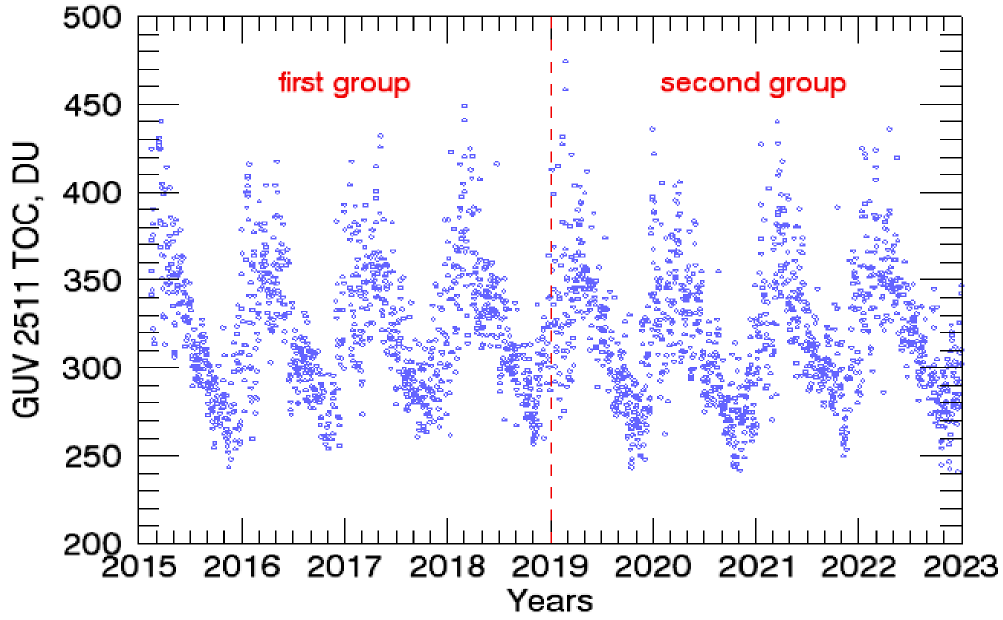

Fig. 1. The observed TOC Stara Zagora time series for the interval 2015-2022. The vertical red dashed line marks the separation line between the two control groups for the study of temporal stability.

The mean bias is defined as:

(1) $$mean\ bias = \frac{1}{n}\sum(x_i - x_i^{true}),$$

The relative mean bias in percent:

(2) $$relative\ mean\ bias = \frac{1}{n}\sum\left(\frac{x_i - x_i^{true}}{x_i^{true}}\right) * 100\%,$$

the standard (mean) bias error:

(3) $$standard\ bias\ error = \frac{1}{n}\sqrt{\sum(x_i - x_i^{true})^2},$$

and its relative value in percent:

(4) $$relative\ standard\ bias\ error = \frac{1}{n}\sqrt{\sum\left(\frac{x_i - x_i^{true}}{x_i^{true}}\right)^2} * 100\%$$

The OMI TOC show biases of only some Dobson units in different locations and at different times. Here we use the TOC OMI values as reference values. Very often, the relative deviations are given instead of relative bias:

(5) $$relative\ deviations = \left(\frac{x_i}{x_i^{true}}\right)$$

It is important that the equations for the relative biases and ratios are related to the true values.
The linear regression is used in the form

(6) $$TOC_{GUV} = \alpha + \beta * TOC_{OMI},$$

where α is the regression constant and β the slope.

Results

The upper panels in Fig. 2 show the obtained biases of the two control groups. In the bottom panels the ratios of the GUV and OMI TOC are presented which are graphically displayed in order to compare easier with graphics in the literature. The biases and ratios do not show dependence from the seasons. The mean bias of the first group is -1.6 DU, the one of the second group is -3.4 DU. Both means are significant at the significance level of 0.05 (see Table 1). The relative deviations are obtained by ratios – 1. Absolute values of biases greater than the 2-sigma level (that means values outside of the confidence band) are related mostly to conditions of high cloudiness.

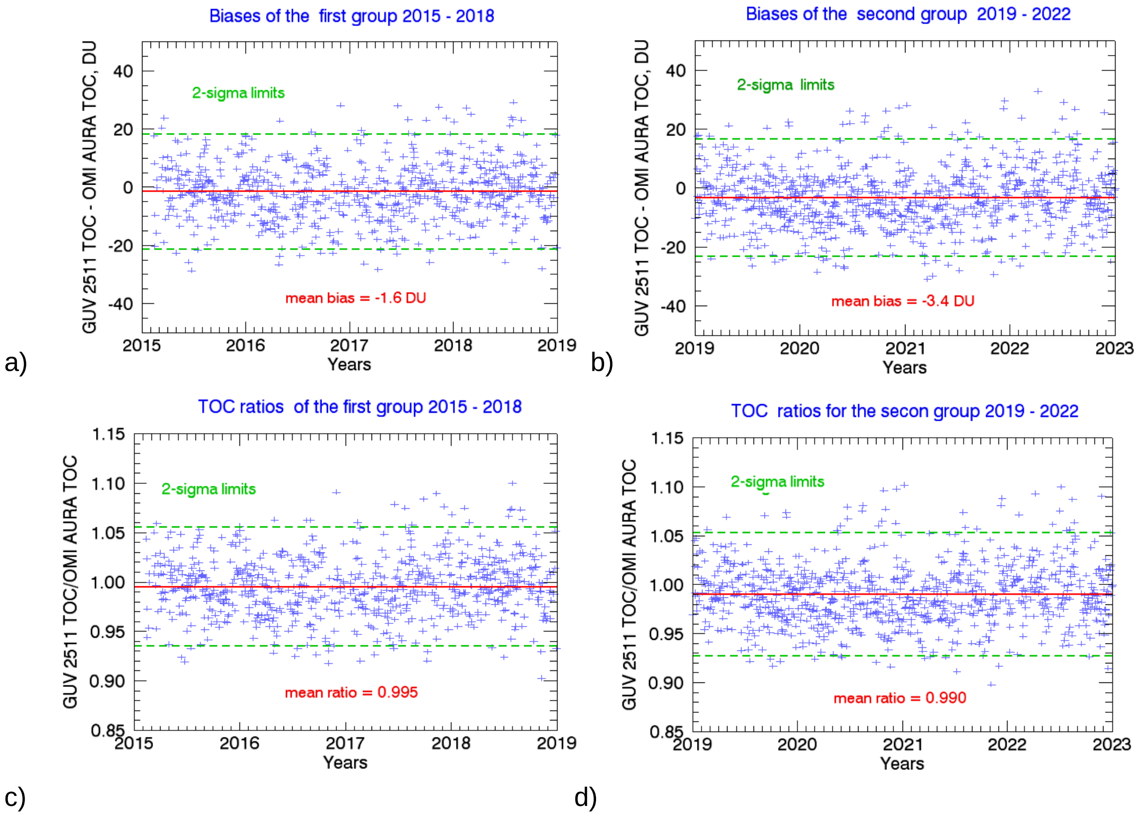

Fig. 2. a) The biases of the GUV TOC related to the OMI TOC for the first control group. b) The same as a) but for the second group. c) The ratios GUV TOC to OMO TOC fort he first control group. d) The same as c) but for the second group.

The absolute value of mean bias of the second group is by 1.8 DU greater in comparison with the one of the first group. The significance of mean bias difference can be tested using the test size

(7)
$$z = (\overline{x_2} - \overline{x_1}) \Big/ \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}.$$

With $\overline{x_1} = 1.56$, $\overline{x_2} = 3.35$, $n_1 = 757, n_2 = 894$, $\sigma_1 = 9.91$, $\sigma_2 = 10.7$ we get a z value of 3.5. The quantil of the Normal distribution at the significance level of α = 0.05 is $u_{1-\alpha} = -u_\alpha = -1.64$. Because $z > u_{1-\alpha}$ the hypotheses H_0: $\overline{x_2} - \overline{x_1} \leq 0$ will be rejected and the alternative hypotheses H_1: $\overline{x_2} - \overline{x_1} > 0$ will be accepted. We found a p-value < 0.001. So the significance is very high. Statistic test can be performed for the ratios as well. The significance tests will give the same result as the one discussed for the biases. Fig. 3 displays the GUV TOC values versus the TOC values from OMI for the two control groups and additionally for the pooled data. The TOC values for cloudless days are marked by red symbols and show a much narrow prognosis interval with a standard deviation of 6.2 DU (not shown here). It is seen in Tab.1 the regression constants α of the two groups don't differ statistically. (Their 2-sigma errors are greater than the constants themselves.) The slope differences are of the same order than their double standard deviations. Furthermore, it can be stated that their prognosis bands (their 2-sigma limits are drawn by dashed green lines) almost completely overlap.

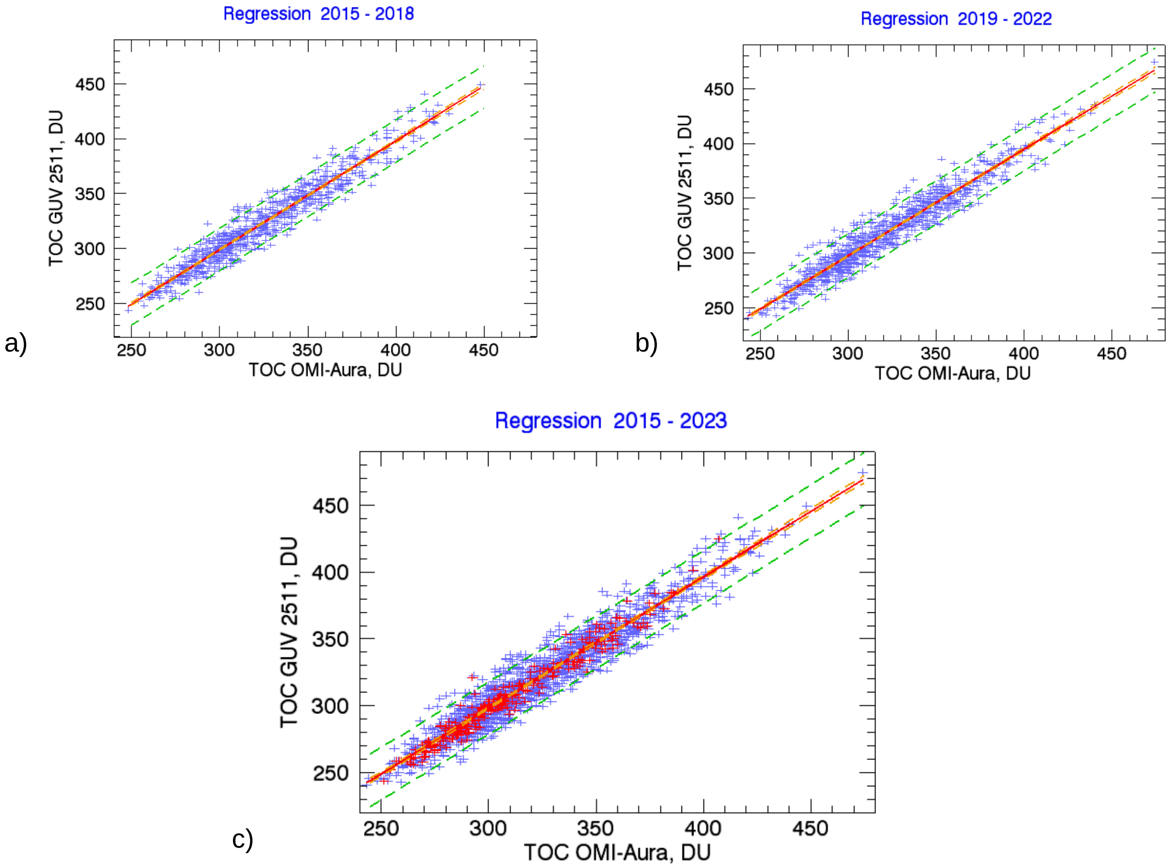

Fig. 3. a) Scatterplot of the TOC GUV versus TOC OMI for the first control group. b) The same as a) but for the second group and c) the same as a) but for the pooled data. In all plots the dashed green lines presented the limits of the prognosis interval at a confidence of p=0.95. By red symbols measurements of TOC GUV under almost cloudless conditions are presented. The dashed yellow lines presented the confidence interval for the expected value of TOC GUV for a certain value of TOC OMI for p=0.95.

Tab. 1. Results of the stability study, related to the bias, TOC ratios and regression equations of the data of the first and second control group and of the pooled data.

		First group 2015-2018	Second group 2019-2022	Pooled data 2015-2022
Bias	**mean bias**	**-1.56 DU**	**-3.34 DU**	**-2.53 DU**
	1-sigma	0.36 DU	0.36 DU	**0.38 DU**
	stddev.	**9.9 DU**	**10.7 DU**	**10.3 DU**
Ratio	**Mean ratio**	**0.9952**	**0.9900**	**0.9923**
	1-sigma	0.0011	0.0011	0.0007
	stddev.	**0.030**	**0.032**	**0.031**
Regr.	**const. -**	**1.2 DU**	**5.5 DU**	**3.5 DU**
	1-sigma$_{\alpha}$	3.3 DU	3.0 DU	2.2 DU
	slope	**0.9914**	**0.9724**	**0.9814**
	1sigma$_{\beta}$	0.0093	0.0093	0.0068
	stddev.	**9.8 DU**	**10.1 DU**	**10.0 DU**
	R	**0.9639**	**0.96182**	**0.9624**

So it is evident that data from the first and the second group are members of one and the same statistical population. (Here we did not adopt stability test of the regression equations, because the data samples are very large.) The parameters resulting of our study are summarized in Table 1.

Summary and conclusion

The results of the study of the bias and ratio on one hand and the regression results of the other hand let us conclude that the stability in time is acceptable. The standard deviations obtained by the regression are of order of 10 DU, the biases are some Dobson units and the standard deviations of TOC ratios are about 0.06. All parameters are in good agreement with observations of other authors (see e.g. Svendby et al. [13]). The absolute bias value of the observed GUV TOC increases slightly during the successive intervals of 4 years - by 1.8 DU corresponding to 0.5%, using the OMI-AURA TOC as reference. The increase is significant at the level of 0.05. However, the parameters of the linear regressions of both time series are not statistically different.

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