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DETERMINATION OF THE TOTAL OZONE COLUMN WITH CONSIDERATION OF THE CLOUD OPTICAL DEPTH

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Abstract. Since the installation of a GUV-2511 instrument in February 2015 automatic measurements of the solar irradiances at wavelengths 305, 313, 320, 340, 380, 395 nm in the UV spectral range and the irradiance at the wavelength interval from 400 to 700 nm in the visible range have been carried out. The GUV instrument receives the solar irradiance from the sky. Therefore a simple calculation based on the Beer-Lamber Law is not applicable. So-called Lookup tables are prepared - for a multitude of ozone values irradiance ratios depending on different parameters as zenith angle and cloud optical depth were calculated previously using the Tropospheric Ultraviolet and Visible (TUV) radiation transfer model. The total ozone column amount was retrieved by interpolation of the tables for real measured ratios of the irradiance at 313nm, a wavelength with significant ozone absorption, and a second irradiance at 340 nm, which is insensitive against ozone absorption. For the estimation of the optical depth the ratio of the observed and the estimated for cloudless conditions irradiances at 380 nm is determined depending on the zenith angle. In addition a lookup table was previously calculated to obtain the actual optical depth in dependence from the zenith angle and the irradiance ratios at 380 nm. Ozone column data from OMI-instrument satellite Aura on the Earth Observing System were used for comparisons and to find the exact wavelength centre position for the 313 nm filter to minimise the ozone retrieval error for our algorithms. All observations from February 2015 up to January 2018 were included in the data processing.

Introduction

The calculations of the Total Ozone Column (TOC) for measurements in Sun direction are based on the Beer-Lambert law. To retrieve TOC's from global UV irradiance measurements, so called Lookup tables (LUT) were calculated, by help of radiation transfer models, where the irradiance ratios are modeled as function of the zenith angle for different TOC [*Stamnes*, 1991]. In a previous work 2D LUT were calculated and the TOC were determined from irradiance ratios, which were smoothed and for the ratios an upper envelope was calculated to reduce the influence of clouds on the irradiance ratios [*Werner et al.*, 2017]. Here we use a 3D LUT depending not only from the zenith angle but additionally from the cloud optical depth.

The main goal of the presented here study is the better consideration of the cloudiness in order to enhance the TOC processing procedure.

Estimation of the cloud optical depth

The arbitrary solar irradiance at wavelength λ on an area at zenith angle ϑ (at the top of the atmosphere) is given by:

$$\frac{I_0(\lambda,\vartheta)}{I_{Sun}(\lambda)} = \left(\frac{R}{R_0}\right)^2 * \cos\vartheta \qquad (1)$$

where R is the actual distance to the Sun and R_0 the mean Earth–Sun distance. The measured irradiances at 380 nm at clear days (cld) were regressed against the arbitrary solar irradiance:

$$I_{cld}(\lambda,\vartheta) = -4.74 + 82.09 * \frac{I_0(\lambda,\vartheta)}{I_{Sun}(\lambda)} \qquad (2)$$

The ratio of actual measured irradiances to the irradiances at clear days was determined by:

$$Irr(\lambda,\vartheta)_{ratio} = \frac{I_{meas}(\lambda,\vartheta)}{I_{cld}(\lambda,\vartheta) * corr} \qquad (3)$$

A LUT for the irradiance ratio changing with the zenith angle for different optical depths was calculated. It was established that the irradiance ratio depends only weekly from the zenith angle. So we used the dependence from the ratio only for the zenith angle of 50 deg. regardless of the actual zenith angle for which the measurements were carried out.

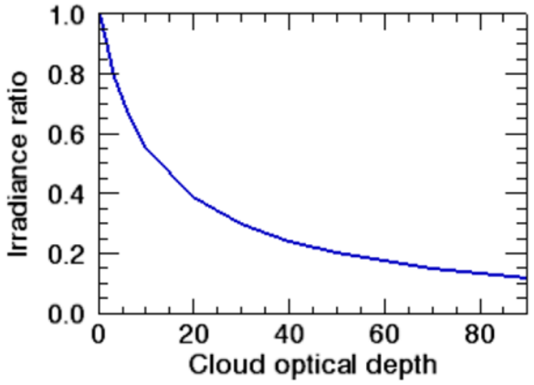

Figure 1. The cloud optical depth (COD) is determined by the Irradiance ratio eq. (3) for the wavelength unaffected from ozone at 380nm.

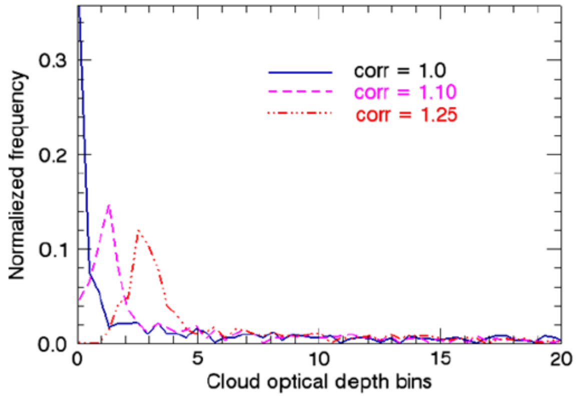

Figure 2. Histogram of the COD corresponding to the distribution of scattered stratocumulus [*Beaulne et al*., 2005].

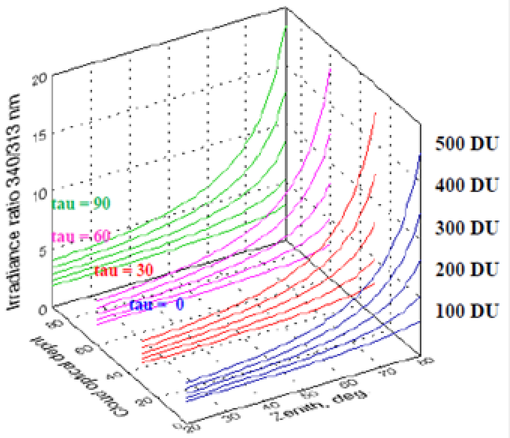

Figure 3. 3D LUT for the determination of TOC.

From the calculated dependences the cloud optical depth is determined using the experimentally found ratio $Irr(\lambda,\vartheta)_{ratio}$. The correction factor *corr* guarants $Irr(\lambda,\vartheta)_{ratio}<1$ and shifts the maximum of the COD histogram to greater values (see Fig. 2).

Determination of TOC

To estimate the TOC a 3D LUT was calculated by help of a the TUV [*Madronich*, 1993] radiation transfer model, where the ratio of an irradiance (340 nm) unaffected of ozone and an irradiance (313 nm) absorbed by ozone in dependence of the zenith angle for different TOC and COD. The TOC is determined for actual values of the irradiance ratio, the COD and the zenith angle from the LUT (see Fig. 3) by spline interpolation.

COD influence on the determination of TOC

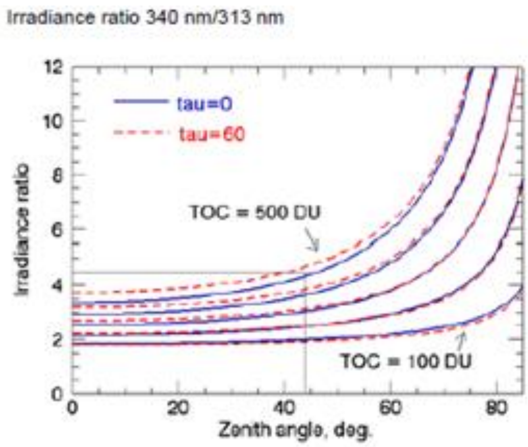

Figure 4. Comparison of the LUT for the COD τ =0 and τ =60. If the COD would be neglected the TOC can be under or overestimated depending of the zenith angle. In the figure for an irradiance ratio of about 4.5 and a zenith angle of 44 deg. for τ = 0 a value of 520 DU is estimated. However, if the real COD is of about 60 then a TOC of 480 DU is found.

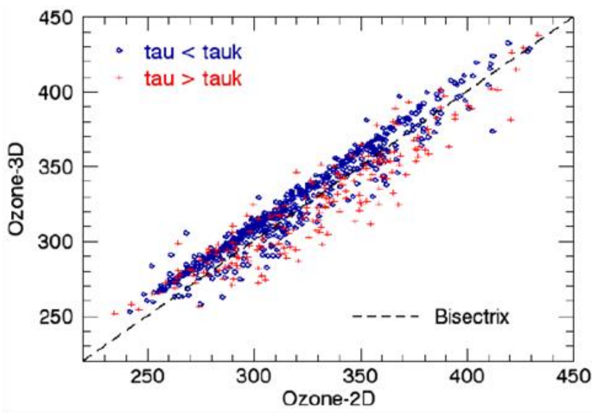

Figure 5. Comparison of the TOC determined by the 2D (Ozone-2D) and the 3D (Ozone-3D) algorithm. The Ozone-3D values are systematically smaller than the Ozone-2D values, especially for greater COD with $\tau \geq \tau_k$ (with τ_k = 11.5). Therefore, the mean ozone values of the 2D and the 3D series are different as well.

Results

TOC results obtained by the 2D and the 3D algorithms were compared with measurements performed by the OMI-AURA satellite. Some of the statistics for days when the results are available for all processing types are summarized in Table 1. The best results are obtained for the 2D algorithm when the COD are smaller than a limit of τ_k =11.5. An improvement can be received by combination of results of the 2D algorithm for $\tau < \tau_k$ with the ones of the 3D-algorithm for $\tau \geq \tau_k$.

Table 1. Results of statistic study of the 2D and 3D algorithm in comparison with TOC obtained by the OMI satellite.

	N_{coinc}	R	R^2	σ_{abs} in DU	σ_{rel} in %
2D	514	0.966	0.933	9.6	3.0
3D	514	0.953	0.908	11.1	3.4
2D $\tau < \tau_k$	385	0.977	0.954	7.7	2.4
3D $\tau < \tau_k$	385	0.971	0.943	8.4	2.6
2D $\tau \geq \tau_k$	129	0.937	0.878	13.7	4.3
3D $\tau \geq \tau_k$	129	0.959	0.919	10.4	3.1
2D-3D comb.	514	0.973	0.947	8.5	2.6

The regression results of the TOC obtained by 2D-3D combination against the OMI TOC are graphically presented in Fig. 6. and Fig. 7.

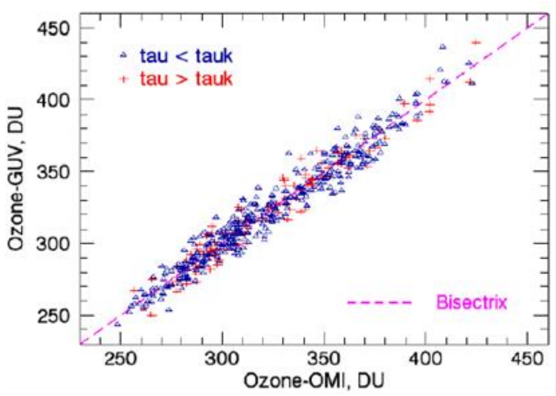

Figure 6. Regression of the TOC-GUV results obtained by the combination of 2D and 3D algorithm against the TOC retrieved from measurements by the OMI-AURA satellite. Systematic differences depending on tau are not visible.

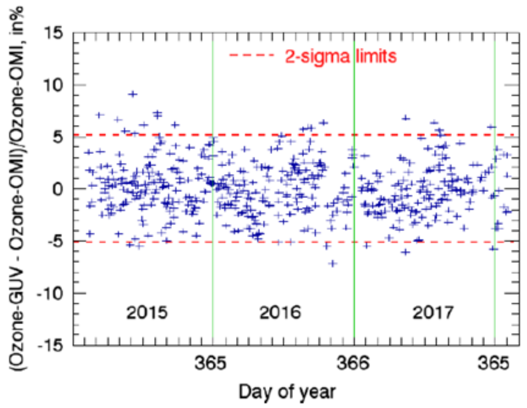

Figure 7. Deviations of the Ozone-GUV related to the satellite OMI TOC.

Conclusions

The statistical analysis shows that the combination of the two developed algorithms for retrieval of the TOC from the measurements performed by a GUV 2511-instrument installed in Stara Zagora allows obtaining TOC with uncertainties of about 8.5 DU, corresponding to 2.6% (1-sigma values). The improvement is only about 10% in relation to the 2D algorithm, but the 3D algorithm, which works also for the TOC retrieval under strong cloudiness, allows obtaining ozone for greater number of days than the 2D algorithm.

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