Total ozone content and solar activity

B.Mendeva [1] , B.Petkov [2]

1 Space Research and Technology Institute, Bulgarian Academy of Sciences, Stara Zagora Department, Bulgaria, bmendeva@abv.bg

2 Institute of Atmospheric Sciences and Climate, National Research Council, Bologna, Italy

Abstract

The response of the ozone in the atmosphere to the solar activity changes has been studied. Data of the total ozone content (TOC) from the satellite experiments TOMS-EP and SCIAMACHY over Bulgaria during the 23-rd solar cycle (1997-2008) and from OMI during the recent 24-th solar cycle are used.

The annual ozone course in 2003 (maximum of the 23-rd solar cycle) is presented and compared with those in 1997 and 2008 (minima of this cycle). TOC course in 2013 (maximum of the 24-th solar cycle) is compared with the course in 2008 (minimum of this cycle).

The solar activity is characterized by the sunspot daily numbers W, the solar radio flux at 10.7 cm (F10.7) and the MgII wing-to-core ratio solar index. The estimation of the influence of the solar activity on the TOC is made by an analysis of the ozone response to some separate cases of sharp changes in the course of W, F10.7 and Mg II in the examined period.

Introduction

The impact of the solar activity on the atmospheric ozone dynamics is considered a major issue for Earth's science. The mechanism of the ozone-solar activity relationship has been a subject of numerous studies [1,2,3]. It can be assumed that the increase of the UV radiation during the high solar activity periods leads to a corresponding increase of the ozone concentration. Most authors have received a positive ozone-solar activity correlation, while others have obtained a negative one. Chandra and McPetters [3] have shown that about 2 % change in the total ozone content (TOC) and 5-7 % change in the ozone mixing ratio in the upper atmosphere can be attributed to the change in the solar UV flux over a solar cycle. Solar activity effects may be latitude dependent, as in high latitudes high energy particles may play a significant role.

Brasseur [1] reported that the increases in the solar irradiance, within the 208-265 nm wavelength interval, equal to 3% and 5%, cause TOC changes of 1.1% and 1.3% at the equator. These changes enhance with the latitude and reach up to 1.5 and 1.7% in the polar regions. However, Fleming et al. [4] obtained a positive 27-daily total ozone response to the UV flux, independently of the latitude throughout the tropics (30º S – 20º N) with a maximum of +0.35. Tertishnikov [5] and Makarova and Shirochkov [6], receiving a negative ozone-solar activity correlation, concluded that the increased energetic particles flux as a result of enhanced solar activity should both increase the ionization in the atmosphere and change the velocity of the chemical reactions, which lead to production of ozone active combinations. Their increased quantity can provoke a perceptible drop of the ozone.

Instruments and methods

The response of the ozone in the atmosphere to the solar activity changes has been studied. Data of the total ozone content (TOC) from the satellite experiments TOMS-EP and SCIAMACHY over Bulgaria during the 23-rd solar cycle (1997-2008) and from OMI during the recent 24-th solar cycle are used.

Total Ozone Mapping Spectrometer-Earth Probe (TOMS-EP) continues the NASA Program for mapping and research of the global ozone distribution in the Earth's atmosphere from 1996 to 2005. The TOMS measurements cover the near ultraviolet region of the electromagnetic spectrum where the solar radiation is partially absorbed by the ozone. The intensity is registered in 6 wavelengths. TOMS measures the total ozone content in an atmospheric column from the Earth's surface to the upper atmospheric boundary under any geophysical daily conditions.

SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY) on board the ENVISAT satellite (ESA) is an imaging spectrometer, which carries out global measurements of various trace gases in the troposphere and stratosphere. The data are retrieved from the instrument by observation of transmitted, back scattered and reflected radiation from the atmosphere in the wavelength range between 240 nm and 2400 nm. In Nadir Mode, the global distribution (total column values) of the atmospheric trace gases, including ozone, is observed.

Ozone Monitoring Instrument (OMI) flies on the Aura satellite since July 2004. OMI is a nadir-viewing wide-field-imaging spectrometer giving daily global coverage. It employs hyperspectral imaging in a push-broom mode to observe solar backscatter radiation in the visible (350-500 nm) and ultraviolet (270-380 nm). Two algorithms, OMI-TOMS and OMI-DOAS (Differential Optical Absorbtion Spectroscopy) are used to produce OMI daily total ozone datasets. OMI is continuing the TOMS record for total ozone and other atmospheric parameters related to ozone chemistry and climate.

Data analysis and results

The annual ozone courses over Bulgaria in the years of maximum and minimum solar activity of the previous 23-rd and the current 24-th solar cycle are presented and compared.

Fig.1 presents the annual TOC course (monthly mean values) in 1997 (minimum of the 23-rd solar cycle) and in 2003 (maximum of this cycle), using TOMS-EP data.

It is seen that in the year of maximum the ozone values are higher than in the year of minimum. This is clearly expressed in the first half of the year. The biggest differences are in March and May, when the increase is respectively 29 DU and 44 DU (Dobson unit), which is 8.3 % and 13.4%.

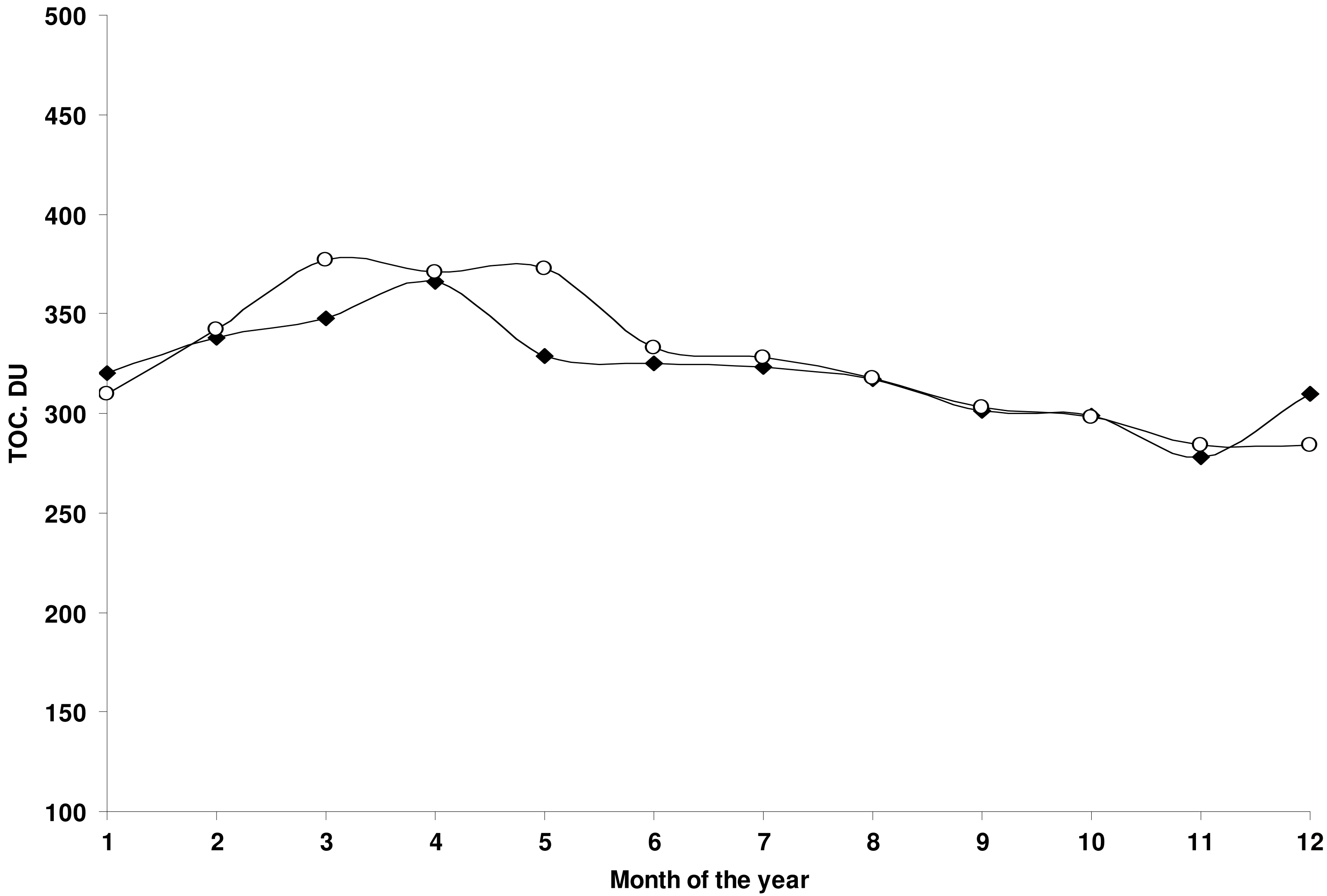

Fig.1. Total ozone content over Bulgaria in the years of minimum (1997 - ♦) and maximum (2003 - ○) of the 23-rd solar cycle by TOMS-EP data

Fig. 2 shows such a comparison for 2003 (maximum of the cycle) and 2008 (minimum) by data of SCIAMACHY. Here the TOC monthly averages throughout the year of maximum definitely are higher than in the year of minimum. The biggest differences are in February - 68 DU, April - 30 DU and August - 32 DU.This is an increase of 20.4 %, 8.5% and 11.3 % respectively.

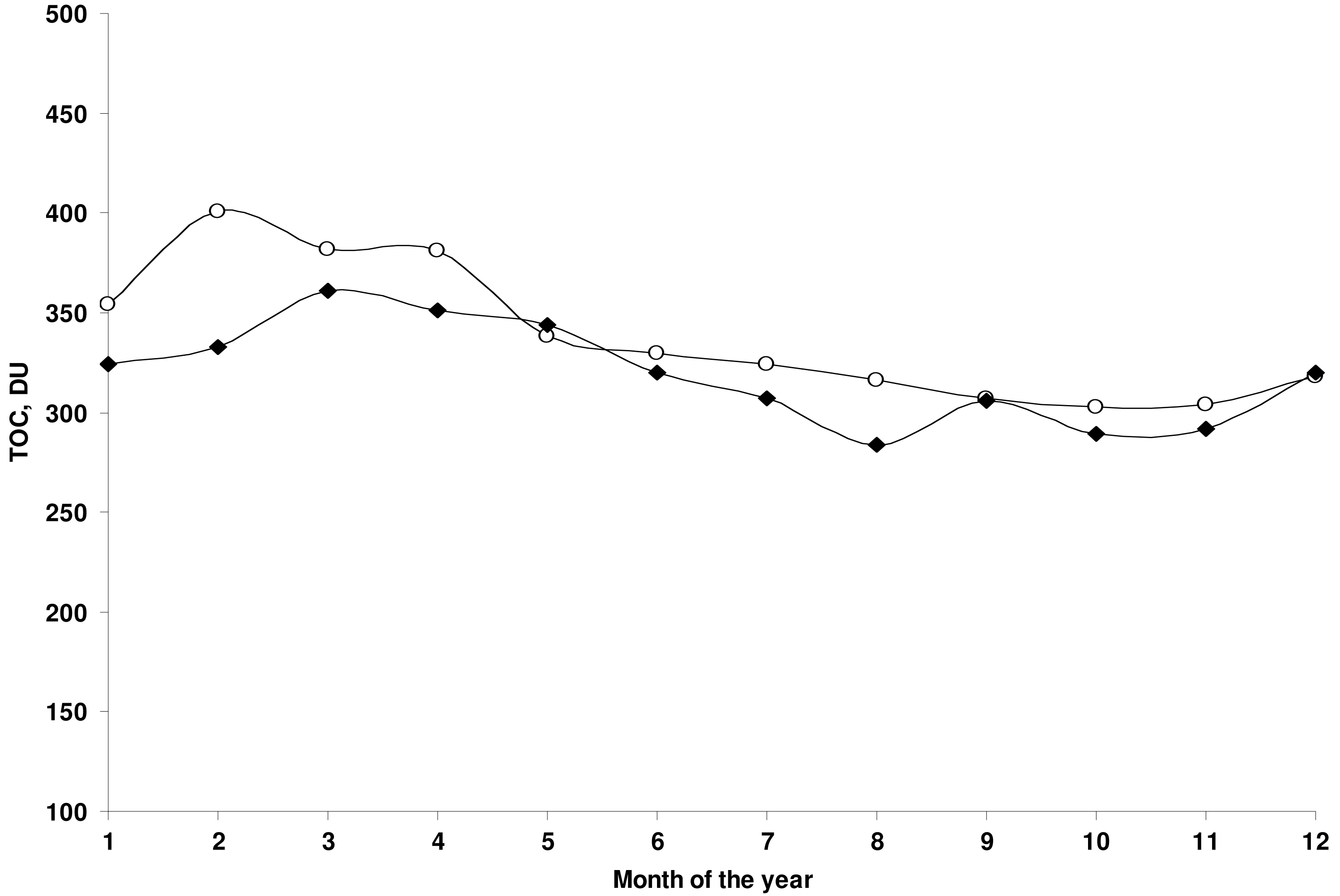

Fig.2. Total ozone content over Bulgaria in the years of maximum (2003 - ○) and minimum (2008 - ♦) of the 23-rd solar cycle by SCIAMACHY data

Fig.3 presents the annual TOC course (monthly mean values) in 2008 (minimum of the 24-th solar cycle) and in 2013 (maximum of this cycle), using OMI data. The TOC values in the year of maximum are higher than in the year of minimum again,butthe differences are smaller. In February the increase is 35 DU (10,8 %) and in April – 19 DU (5.5 %). In almost all other months the increase is about 13-14 DU (4% - 4.8 %)

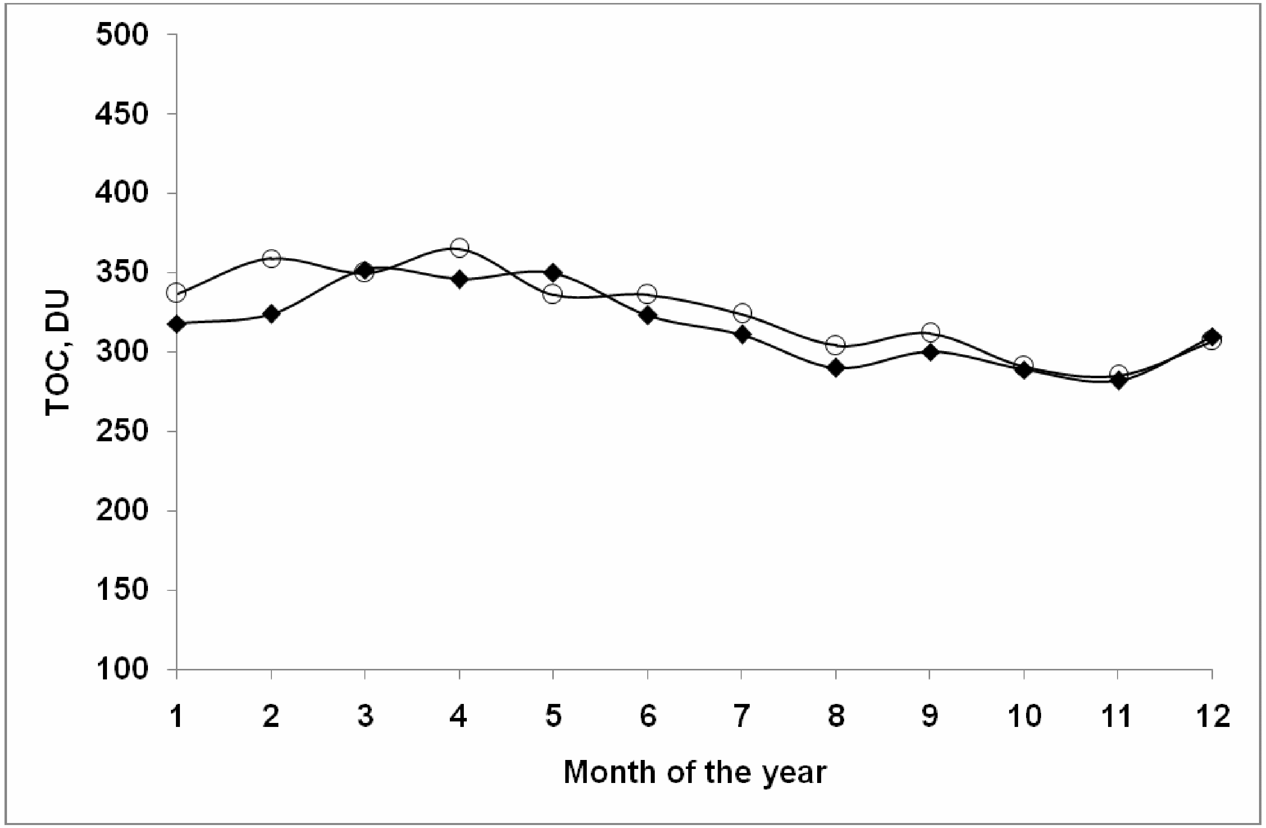

Fig.3. Total ozone content over Bulgaria in the years of minimum (2008 - ♦) and maximum (2013 - ○) of the 24-th solar cycle by OMI data

The influence of the solar activity on TOC has been studied, analyzing the ozone response to sharp changes of parameters, characterizing the solar activity: sunspot daily numbers (W), solar radio flux at 10.7 cm (F10.7) and MgII wing-to-core ratio solar index. The sunspot numbers correlates with the presence of the so-called "UV active regions" on the Sun. The long-term course of MgII index is similar to that of W.

Some of the examined cases showed a positive correlation between TOC, on the one hand, and W, F10.7, MgII on the other. For example,the course of four parameters: TOC, W, F10.7 and MgII, determined by their daily values in the spring of 2001 is shown in Fig.4. After sharp increases of W, F10.7 and MgII a rebuff rise in TOC – from 280 to 420 DU with a phase lag of about 4 days, can be seen. This example demonstrates the positive TOC response to the solar activity. There are some cases when the sharp increases of the solar activity did not provoke any TOC changes.

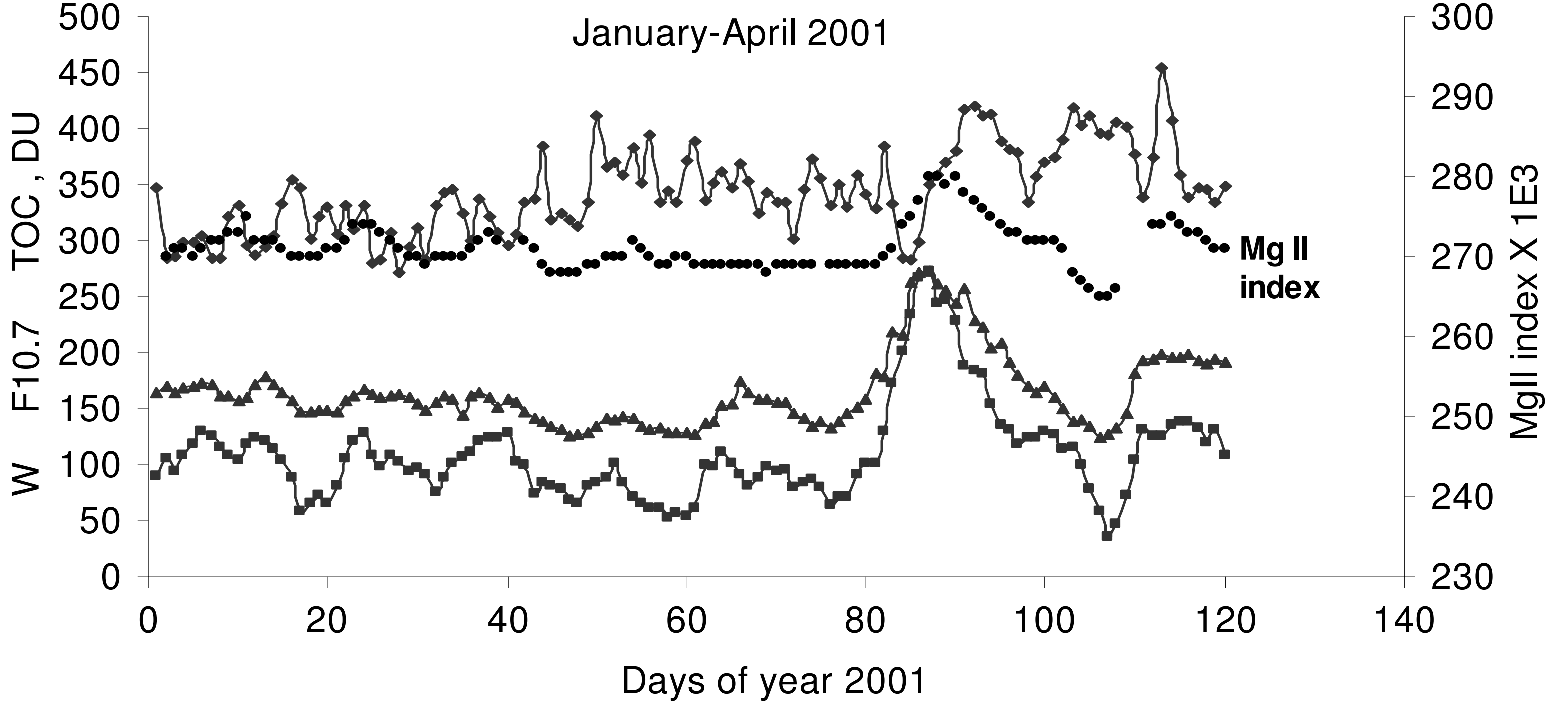

Fig.4. A case of positive correlation between TOC and the solar activity parameters W, F10.7, MgII

Similar ambivalent results (positive and negative) for the relation between the total ozone and the solar activity are presented in the studies of Varotsos [8] and Soukharev [2]. They attributed the ozone response to the solar activity changes to the different phases of quasi-biennial oscillation (QBO) of zonal winds in the equatorial stratosphere. During the West phases of QBO, positive correlations were observed and during the East phases – negative ones. Analyzing connections between the index of stratospheric circulation C1 and the sunspot numbers, on the one hand, and the obtained correlation between the variations of total ozone and C1, on the other, Soukharev [2] has concluded that the solar cycle-QBO-ozone connection occurs through the dynamics of the stratospheric circulation. In compliance with the above we could suppose that the registered TOC variations, connected with the solar activity, had been provoked by changes in the atmospheric circulation, which are caused by the solar dynamics.

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