The UV Radiation and Total Ozone during Solar Eclipse

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Abstract. The solar eclipse is an event, which gives the opportunity to receive the important information about the sun itself as well as about the influence of the solar radiation on the processes, defining the atmospheric components dynamics. The measurements of the UV radiation reaching the Earth's surface in time of an eclipse and the total ozone content (TOC), calculated by them give us an idea about this kind of solar dynamics effect on the ozone.
In this paper we present the results from our measurements of the UV radiation and total ozone during the solar eclipses on 11 August 1999 (96% max coverage for Stara Zagora) and 29 March 2006 (76% max coverage). The observations were performed in Stara Zagora, Bulgaria by a ground-based scanning ultraviolet spectrophotometer Photon, which measures the direct solar radiation in the range 255-400 nm, with 1 nm resolution.
The course of some wavelength irradiances, registered by Photon during these eclipses shows that the radiation decrease about the max phase is different for separate wavelengths. The irradiance at shorter wavelengths was reduced more than at longer ones (limb darkening effect).
The total ozone variability during these eclipses shows almost the same time-patterns features during both eclipses. After the first contact TOC began to decrease till the maximum obscuration, reaching values which turned out to be less by about 75 DU for 11 August 1999 and 82 DU for 29 March 2006 with respect to the corresponding ones before the eclipses. In both cases, two maxima on either side of the totality were also found.

Keywords: Solar eclipse, Ultraviolet solar radiation, Spectrophotometric measurements, Total ozone content

Introduction

The solar eclipse is an event, which gives an opportunity to receive important information about the sun itself as well as about the influence of the solar radiation on the processes defining the atmospheric components' dynamics. The measurements of the UV radiation reaching the Earth's surface in time of eclipse and the total ozone content (TOC), calculated by them give us an idea about this kind of solar dynamics effect on the ozone.

The results for the total ozone amount during solar eclipse, obtained so far, sometimes differ significantly.

Using the photochemical theory, Hunt (1965) estimated that the change of the atmospheric ozone during eclipse should be approximately 0.6%. That means that the modern devices should register no variations. But in fact the measured changes are significant, exceeding the expected ones.

Such measurements were made by Bojkov (1966) in Bulgaria during the eclipse on 20 May 1966. He found a 4-5% decrease of the total ozone after the first contact after which it remained almost constant. About 10 minutes before the maximum phase the ozone amount sharply increased by 7-8 % and after several minutes it began to decrease till reaching the normal level.

Bolshakova et al. (1987) measured the ozone during the total eclipse on 31 July 1981. Several minutes before the second contact they found a decrease of the ozone by 20 DU (~6%) and several minutes after the third contact the ozone was 30 DU (~9%) more than the normal value, after which it began to decrease rapidly.

Two minima of the ozone on each side of the total phase were reported by Mims and Mims (1991). In both of them the ozone amount was 7-8% less than the value before the eclipse. The occurrence of two maxima: one - 50 minutes before the second contact and the other - 25 minutes after the third contact, were ascertained. The ozone amount in these maxima was ~3% higher than the value after the fourth contact. Two minima of the ozone were observed by Osherovich et al. (1974), too. They found ozone falls of 5% to 11% compared to the value before the eclipse.

A significant fluctuation in the total ozone amount was reported by Chakrabarty et al.(1997) during the eclipse on 24 October 1997. Approximately 4-5 minutes after the third contact the ozone was ~12% less than the value observed after the fourth contact. 5 minutes after that the ozone amount sharply increased and reached a value, 10% higher than that after the eclipse. Then the ozone returned to normal values but a wavelike fluctuation was still present. Data of TOC measurements during different solar eclipses are summarized by Hrgian (1973). In most of the observations an increase of the ozone has been found and the maximum has usually been reached after the total phase.

These results show that until now there is no certain notion about the ozone behavior during an eclipse. Some researchers explain it as a result of the different devices used in the observations, others – of the different atmospheric conditions. Until now this problem remains open.

Instrument and method

The observations of the total ozone content during the eclipses on 11 August 1999 (96% max coverage for Stara Zagora) and 29 March 2006 (76% max coverage) were performed by a scanning ultraviolet spectrophotometer Photon which measures the direct solar radiation, reaching the Earth's surface (B.Petkov, 2001). The instrument's sensor is a Seya-Namioka monochromator with concave holographic diffraction grating. The spectrophotometer measures the radiation intensity in the range 255 - 400 nm, with 1 nm resolution. The spectral calibration was performed in laboratory conditions using a mercury lamp with narrow emissions bands. In absolute units the instrument was calibrated by comparison to a standard Brewer spectrophotometer in Thessaloniki, Greece (1997) and in Andenes, Norway (2002). A spectrophotometer sensor was mounted on the 20 cm telescope.

The method for determination of the total ozone content is similar to the method, applied in the classical Brewer spectrophotometers. TOC is determined from direct solar spectra by applying the Bouguer-Lambert's law of radiation attenuation during transition through the Earth's atmosphere and different absorption of the separate wavelengths by the ozone molecules. We, however, use the intensity of more wavelength couples (about 20). This way enhanced precision in the determination of TOC is achieved (B.Petkov , 2001).

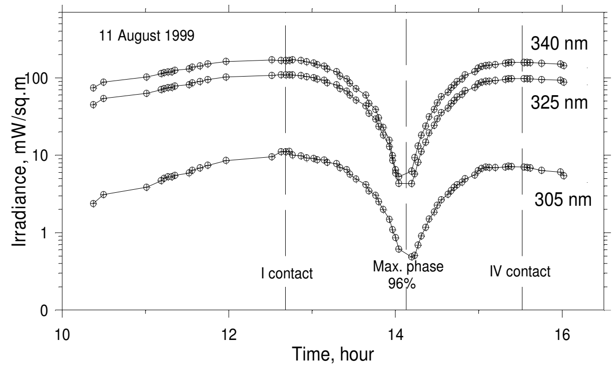

Fig.1. The behaviour of UV solar radiation during the solar eclipse on 11 August 1999 in Stara Zagora

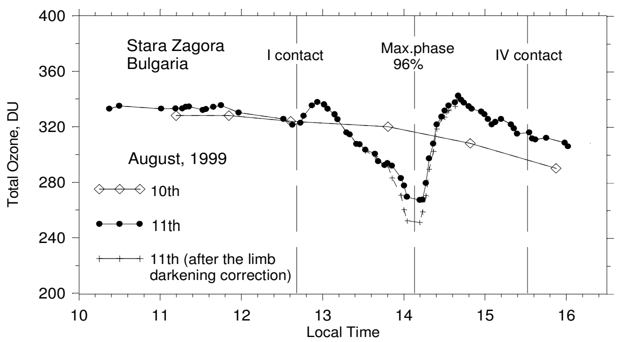

Fig.2. The total ozone behaviour during the eclipse on 11 August 1999.

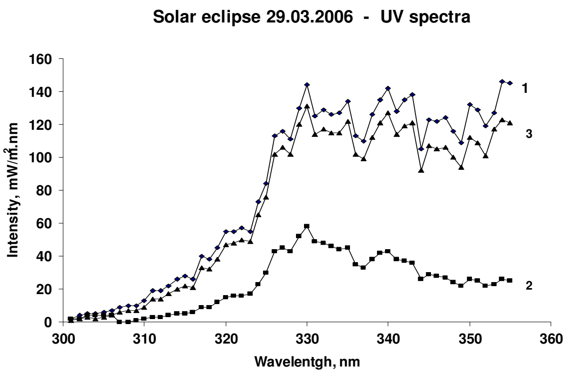

Fig. 3. Direct solar spectra: 1 before the eclipse, 2 in the maximum eclipse phase, 3 after the eclipse (Stara Zagora).

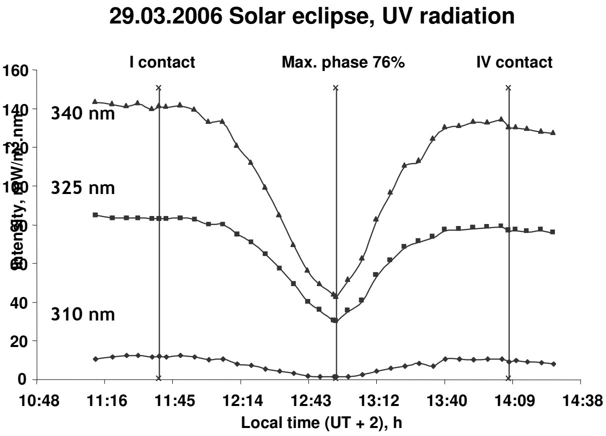

Fig. 4. The behaviour of UV solar radiation during the solar eclipse on 29 March 2006 in Stara Zagora

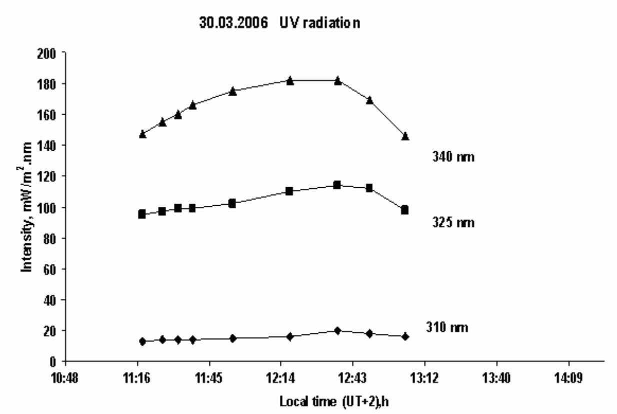

Fig.5. The course of UV solar radiation on 30 March 2006 (control day).

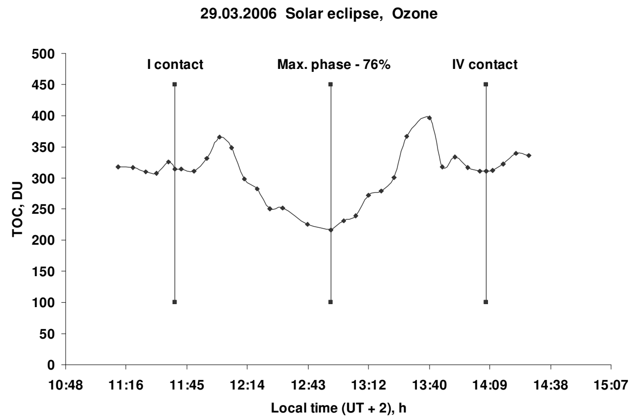

Fig. 6. The total ozone behaviour during the eclipse on 29 March 2006

Data analysis and results

The measurements of the UV radiation reaching the Earth's surface in time of the eclipses and the total ozone content (TOC), calculated by them, was performed in Stara Zagora (42º25'N, 25º38'E). The meteorological situation before, after and on the days of the eclipses was stable and the sky was clear.

The course of some wavelength intensities, registered by the spectrophotometer Photon during the eclipse on 11 August 1999, is presented in Fig.1. The measurements show that the decrease in the different wavelengths is not equal. For example, the intensity of λ = 325 nm decreases 41 times, while λ =340 nm - 31 times at 95% coverage.

The results for the total ozone content during this eclipse are presented in Fig.2. The data from 10 August 1999 (control day) are also presented and the ozone change during the eclipse is

comparedwith them. About 15 minutes after the first contact a comparatively weak increase (~5%) of the ozone was seen. After that it began to decrease till the maximum obscuration. Approximately 5 minutes before the maximum phase the ozone reached a value ~14% lower than that on the control day. Almost 5 minutes after the maximum coverage the total ozone sharply increased and 30 minutes later it became ~10% more than on 10 August. Then the ozone amount decreased, reaching a level 6% higher than that on the control day.

The registered behaviour of the total ozone after the maximum obscuration was similar to that, reported by Chakrabarty et al. (1997). In our case, however, the duration of the ozone increase was longer - ~30 minutes. The appearance of a maximum in the total ozone ~60 minutes before the maximum phase was similar to the results reported by Mims and Mims (1991) when such a maximum was registered 50 minutes before the second contact.

The results for the total ozone, taking into account the limb darkening of the solar disk, are presented in Fig.2. It is seen that as a result the maximum fall of the ozone amount is 4-5 % ~25-30 minutes before and after the maximum coverage. A similar result was reported by Bojkov (1966).

The maximum solar coverage during the eclipse on 29 March 2006 in Stara Zagora was 76%. During the observation 42 direct solar spectra were registered. Fig.3 presents three spectra: (1) – before the eclipse, (2) – in the maximum phase and (3) – after the last contact.

The measurements of UV irradiance show that the radiation decrease about the max phase is different for the separate wavelengths. The irradiance at shorter wavelengths is reduced more than at longer ones (limb darkening effect). The radiation course describes very well the moments characterizing the eclipse: beginning, maximum phase, end (Fig.4). Since the local noon was 33 minutes before the maximum phase, this course is a combination of the eclipse effect and the irradiance changes due to the solar zenith angle changes.

Fig.5 shows the intensities of the same wavelengths on 30 March (control day). The normal course with a maximum in the Sun culmination can be seen.

The ozone variability during this eclipse is illustrated in Fig.6. The first anomaly began immediately after the first contact. A sharp TOC increase of 50 DU was registered. After that TOC began to decrease and its value was 216 DU in the maximum phase, which is 120 DU less than that in the control day. 45 minutes after the maximum phase the ozone reached a value which was 50 DU higher than that in the control day. After that a sharp decrease was observed and the TOC values approached those from the control day.

The comparison of the UV and TOC variability during both eclipses - on 11 August 1999 and 29 March 2006 shows almost the same time-pattern features. The registered TOC variations about and after the maximum obscuration are quite similar to the ones obtained by Mims and Mims (1991) and Chakrabarty et al. (1997).

Conclusion

The observed ozone behaviour over Bulgaria during solar eclipse can not be explained by the contemporary theory of the processes, determining the ozone amount in the atmosphere. According to this theory, the ozone shall have a comparatively long lifetime in order to respond to the changes of the ultraviolet radiation during the eclipse. That is why the presented significant ozone fluctuations during the eclipse, as well as most of the changes reported till now,seem inexplicable.

Some researchers (Gerasopoulos et al., 2008) suggest that the TOC decrease is an artifact in the measured irradiance due to the increased contribution of diffuse radiation against direct irradiance caused by the eclipse.

On the other hand, the eclipse causes temperature gradients in the atmosphere, leading to transport processes which can influence the ozone amount.

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