THE TOTAL OZONE OVER BULGARIA DURING THE SOLAR ECLIPSE ON 11 AUGUST 1999

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Abstract

The measurement of the total ozone amount during the solar eclipse on 11th August 1999 was performed by an ultraviolet spectrophotometer. The device measures the direct solar radiation in the range 300-360 nm at 1 nm spectral resolution. It was compared to a standard Brewer spectrophotometer. Approximately 15 minutes after the first contact, the ozone amount began to decrease till the maximum phase when it was 14% less than the value on the control day (10th August). After the maximum phase (96% coverage) the total ozone sharply increased and 35 minutes later it became 10% more than that on the control day. During the next 50 minutes the ozone amount reached a level, 6% higher than that on 10th August.

1. INTRODUCTION

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

Using the photochemical theory, Hunt [1] estimated that the change of the atmospheric ozone during the eclipse would be approximately 0,6%. That means that the modern devices should register no variations. But, in fact, the measured changes have been significant, exceeding the expected ones.

Such measurements were made by Bojkov [2] 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. [3] measured the ozone during the total solar 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 by 30 DU (~9%) more than the normal value, after which it began to decrease rapidly.

Two minima of the ozone on either side of the total phase were reported by Mims and Mims [4]. 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. [5], too. They found ozone falls of 5% to 11% towards the value before the eclipse.

A significant fluctuation in the total ozone amount was reported by Chakrabatry et al. [6] during the eclipse on 24 Oct.1997. Approximately 4-5 minutes after the third contact the ozone was ~12% less than the value observed after the fourth contact and 5 minutes after that the ozone amount sharply increased and reached a value of 10% more than that after the eclipse. Then the ozone returned to normal values but a wavelike fluctuation was still seen. Data of a number of total ozone measurements during different solar eclipses are summarized by Hrgian [7]. In most of the observations an increase of the ozone has been found and the maximum was usually reached after the total phase.

These results show that until now there is not any notion about the ozone behavior during an eclipse. Some researchers explain it as a result of the different devices used in the observations, others - by different atmospheric conditions but till now this problem remains open.

2. INSTRUMENT AND METHOD

The observations of the total ozone amount during the eclipse on 11 Aug. 1999 were performed by a scanning ultraviolet spectrophotometer Photon-2 [8] which measures the direct solar radiation, penetrating to the earth surface. The instrument sensor is a Seya-Namioka monochromator with concave holographic diffraction grating. The spectrophotometer measures the radiation intensity in the range 290 - 360 nm with 1 nm resolution. The spectral calibration was performed in laboratory conditions by a mercury lamp. A comparison to a standard Brewer#86 instrument was made in Thessaloniki, Greece in 1997. For comparison figure 1 shows two spectra, registered simultaneously by Photon-2 and by the standard spectrophotometer. A good agreement of the two instruments' readings can be seen.

A spectrophotometer sensor has been fixed on the 20 cm-telescope by means of which a series of photographs of the solar eclipse phase was performed. These photos

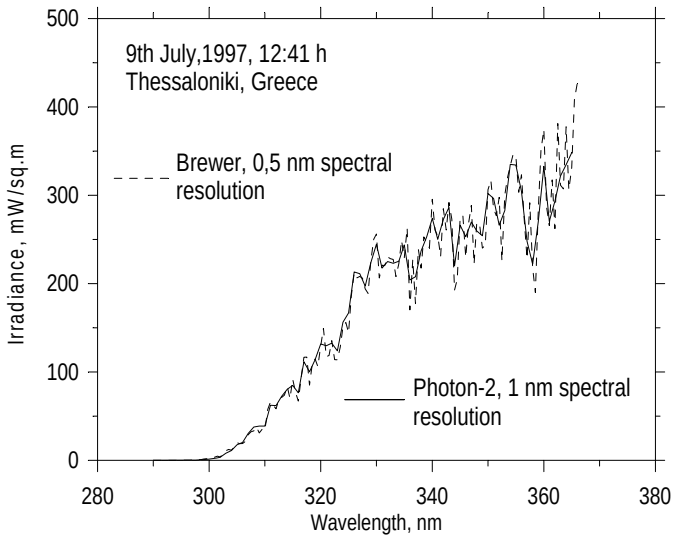

Figure1. Two spectra, registered simultaneously by Photon-2 and Brewer 86.

trace the eclipse progress and the results were used to take into account the limb darkening correction of the ozone estimation. The total ozone computation was made by comparing the intensities of two wavelengths. Using the Bouguer-Lambert's law for each couple (λ_1,λ_2) and (λ_3,λ_4) the following relation can be written:

$$\ln\frac{I(\lambda_1)}{I(\lambda_2)} - \ln\frac{I_0(\lambda_1)}{I_0(\lambda_2)} - \ln\frac{I(\lambda_3)}{I(\lambda_4)} + \ln\frac{I_0(\lambda_3)}{I_0(\lambda_4)} = \\ = \left[-(\Delta\sigma_{12} - \Delta\sigma_{34})\cdot n_o - (\Delta\alpha_{r12} - \Delta\alpha_{r34}) - (\Delta\alpha_{m12} - \Delta\alpha_{m34})\right]\cdot d\cdot\sec(z) \quad (1)$$

where $I(\lambda)$ is the solar radiation intensity with wavelength λ, measured on the earth surface, $I_0(\lambda)$ is the respective extraterrestrial solar spectrum at the top of the atmosphere, $\sigma(\lambda)$ is the ozone absorption section and $\Delta\sigma_{ik}=\sigma(\lambda_i)-\sigma(\lambda_k)$, n_o is the ozone molecules concentration, $\alpha_r(\lambda)$ and $\alpha_m(\lambda)$ are the respective Releigh's attenuation coefficient and the aerosol attenuation coefficient and $\Delta\alpha_{ik}=\alpha(\lambda_i)-\alpha(\lambda_k)$, d is the distance which the solar ray passes through the atmosphere and **z** is the solar zenith angle. If we select the couples so that λ_1 is close to λ_3 and λ_2 - to λ_4, then $\Delta\alpha_{r12}-\Delta\alpha_{r34}\approx 0$ and $\Delta\alpha_{m12}-\Delta\alpha_{m34}\approx 0$, so the influence of the Releigh and aerosol extinction can be neglected [9] and (1) can be written as:

$$F\left[I(\lambda_1), I(\lambda_2), I(\lambda_3), I(\lambda_4), I_0(\lambda_1), I_0(\lambda_2), I_0(\lambda_3), I_0(\lambda_4)\right] = \\ = (\Delta\sigma_{34} - \Delta\sigma_{12}) \cdot N \cdot \sec(z) \tag{2}$$

where F[…] signifies the left part of (1) and $N=n_o \cdot d$ - the column density. The last equation shows that function F depends linearly on $\Delta\sigma_{34}$-$\Delta\sigma_{12}$. Therefore, the column density and hence - the total ozone can be determined for a multitude of fours by the least squares fitting. A similar approach, applied not for fours but for couples, was used in [10]. In order to compute the ozone amount by the described method, about 30 fours in the interval 300-340 nm were selected. Data for $I_0(\lambda)$ were used from [11] and for $\sigma(\lambda)$ - from [12]. For the spectrophotometer - measured spectra the error does not exceed 4-5 % when we determine the total ozone.

The penetrating ultraviolet radiance and the ozone amount have been measured by the described device and method since 1997. The results for the ozone have shown a good agreement with the TOMS/NIMBUS-7 data. Figure 2 shows the comparison between the TOMS data and our spectrophotometer data for the period July-September 1999.

The extraterrestrial ultraviolet radiance changes during a solar eclipse as a result of the limb darkening of the solar disk. This effect should be taken into account when the ozone amount is evaluated during the eclipse by comparing wavelength intensities [2]. Following [13], the correction for $I_0(\lambda)$ is given by functions of λ and θ - the angle between the observation direction and the normal to the solar surface. This angle can be expressed by the distant d_{SM} between the Sun and Moon disk centers on the solar eclipse phase photos. In this way, taking into account the $I_0(\lambda)$ corrections, the influence of the limb darkening on the ozone can be estimated.

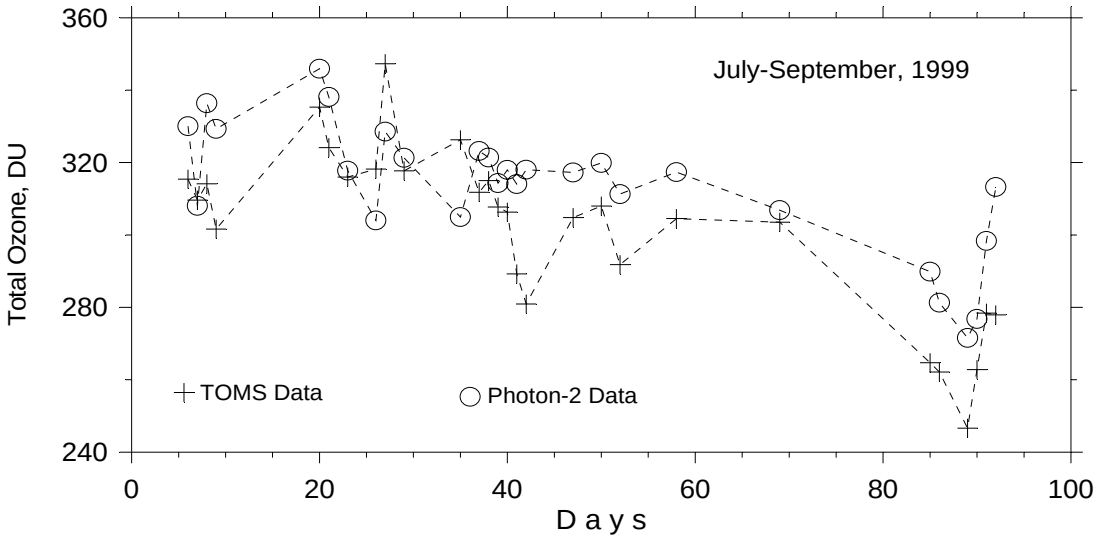

Figure 2. Comparison between TOMS data and Photon-2 spectrophotometer data in the period July-September 1999.

3. RESULTS AND DISCUSSION

The measurement of the total ozone amount during the solar eclipse on 11 August 1999 was performed in Stara Zagora (42°25′N, 25°38′E, Fig.3). The town is located in central Bulgaria approximately 200 km south-west from the path of the total eclipse. The meteorological situation before and on the day of the eclipse was stable and the sky on 10th and 11th August was clear. Unfortunately, the situation on 12 August sharply changed and the clouds prevented further observations.

The solar eclipse was traced by a series of photos. Figure 4 presents the change of the distance Solar-Moon d_{SM}, expressed by the Sun disk radius. Using these results, the moments of the contacts and the maximum obscuration were defined: first contact - 12:41 local time and fourth contact - 15:31. The maximum coverage was 96% and it occurred at 14:08. The moments of the contacts and the maximum obscuration degree are in a good agreement with the theoretical evaluations.

The behaviour of some wavelength intensities measured by spectrophotometer uring the eclipse is presented in figure 5.

The results for the total ozone amount are presented in figure 6. The data for 10 August are also presented and the ozone change during the eclipse was taken into account in comparison with 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 of ~14% less 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 the value on 10th August. Then the ozone amount decreased, reaching a level of 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 Chakrabatry et al. [6]. In our case, however, the duration

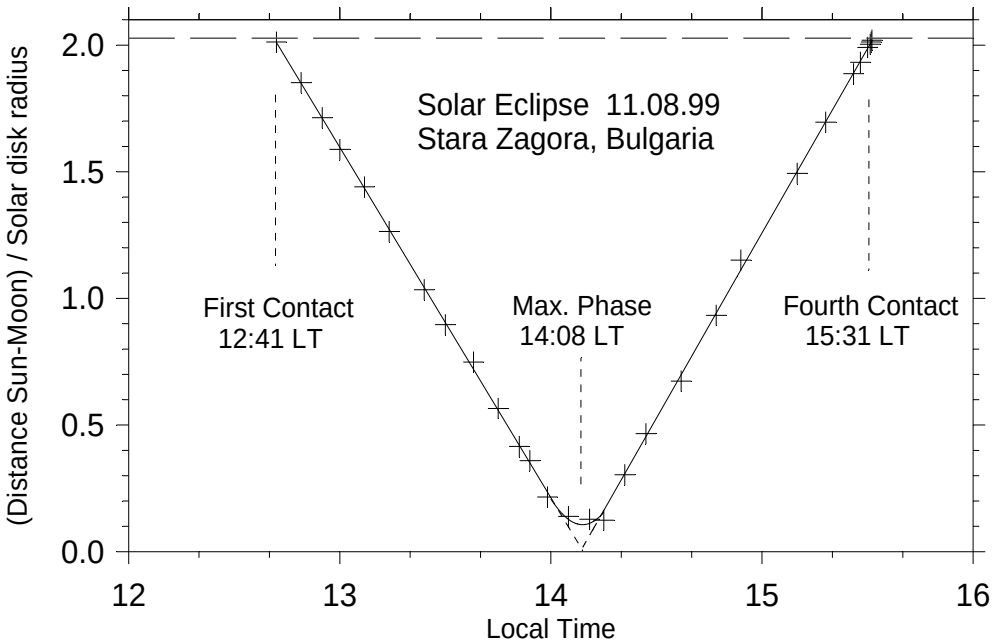

Figure 4. Change of the distance between the Solar and Moon disk centers on the photos expressed by Solar radius. If the Solar disk radius is 1 then the Moon radius will be 1.028. The moment of the first and fourth contact are defined when the distance value is 2.028.

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 [3] when such a maximum was registered 50 minutes before the second contact.

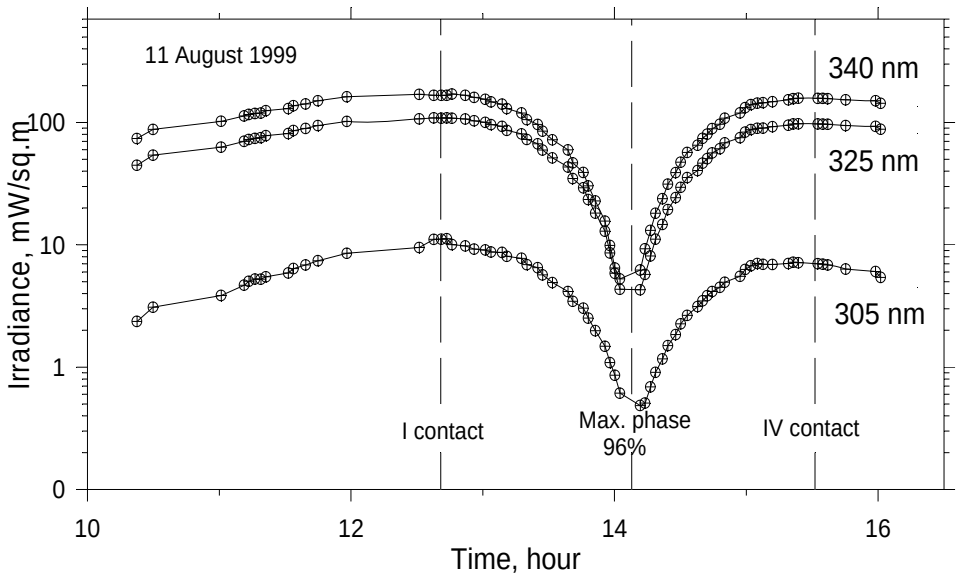

Figure 5. Behaviour at 305 nm, 325 nm and 340 nm wavelengths radiation on 11th August 1999.

The results for the total ozone, taking into account of the limb darkening of the solar disk, are presented in Fig.6. 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 [2].

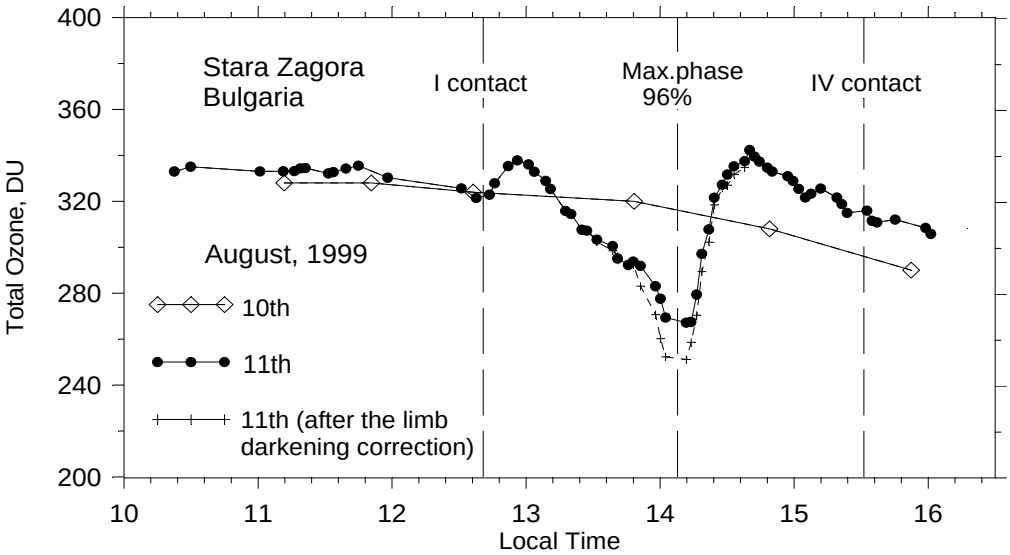

Figure 6. The total ozone amount behaviour during the eclipse.

The observed ozone behaviour over Bulgaria during the solar eclipse as well as most of the results reported till now can not be explained by the contemporary notions for the processes, determining the ozone amount in the atmosphere. As it is known,

the existence of the atmospheric ozone has been described by a large number of forming and destroying reactions [14]. They can be only photochemical ones and reactions in which another atmospheric component participates as well. All these reactions maintain almost constant ozone amount. The current estimations show that the ozone lifetime in the atmosphere is comparatively long (several weeks). That is why the changes of the ozone during the eclipse cannot be explained by the photochemical theory.

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

4. CONCLUSION

The presented results for the atmospheric ozone fluctuations during the solar eclipse on 11th August cannot be explained by the contemporary theory for 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. It is possible these variations to have been caused by transport processes in the atmosphere during the eclipse.

The results of these observations will be an object of future investigations.

ACKNOWLEDGMENTS

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