The ozone variations during the solar eclipse of 20 May 1966

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ABSTRACT

During the annular (87.6 %) solar eclipse of May 20, 1966, more than 60 measurements of total ozone were taken with the Dobson ozonespectrophotometer at the University of Sofia, Bulgaria. An analysis of data obtained shows an ozone increase of 25–30 m atm-cm ($\Delta\Omega > 2\sigma_\Omega$) at the maximum phase of the eclipse. However, according to the photochemical theory, only ~ 1 m atm-cm increase should occur during an eclipse such as this.

The difference between the theoretical and observed increase of the total ozone may be partly due to the limb-darkening effect. The importance of this effect increases progressively to the maximum phase of the eclipse. When dark-limb correction is applied to observational data, the ozone increase is reduced to 14 m atm-cm (about 4 per cent of the total ozone amount). This increase is as yet unexplained.

1. Introduction

Although nine sets of ozone observations during eclipses have been reported (Bezverkhny *et al.*, 1956; D'Albe & Rasool, 1956; Kawabata, 1937; Khrigian & Kuznezov, 1965; Jerlov *et al.*, 1954; Pariisky & Chao, 1961; Steblova, 1962; Stranz, 1961; Svensson, 1956), results of only three can be compared with confidence. These three (D'Albe & Rasool, 1956; Svensson, 1958; Stranz, 1961) report observations made with Dobson ozonespectrophotometers, which possess the spectral accuracy needed for measurements of this type. The other six sets of observations vary widely and report from a 40 per cent ozone decrease (Jerlov *et al.*, 1954) to a 20–30 per cent increase (Khrigian & Kuznezov, 1965; Steblova, 1962) and even a physically impossible increase of 300–400 per cent (Bezverkhny *et al.*, 1956).

The conclusions drawn from Dobson ozonespectrophotometer observations differ only slightly from each other. Fournier D'Albe & Rasool (1956) used D-wavelength observations only. The sun was very low at the time of their observations, and no significant deviation of ozone was observed. Svensson (1958) after applying a correction for limb-darkening effect, found an ozone surplus of 4–6 m atm-cm after the maximum phase of the eclipse. Stranz (1961) noted a total ozone increase of about four per cent above the mean level (270 m atm-cm) before the eclipse; the rise started about 45 minutes after the first contact and reached its highest value a few minutes after the maximum phase.

Changes in total ozone above Sofia, Bulgaria (42°49′ N, 23°23′ E) were observed with a Dobson ozonespectrophotometer during the annular ($\sim$88 per cent) solar eclipse on 20 May 1966. This eclipse, as seen from Sofia, occurred between 10:14 (first contact) and 13:08 (last contact) East European Time (EET), with maximum solar coverage at 11.38 EET.

2. Observational data

The weather above Bulgaria, though not ideal, permitted satisfactory ozone observations. At Sofia, there was variable cirrostratus to altostratus cloudiness, with a few clear periods. The surface weather map for 20 May shows Bulgaria as an area of increasing pressure between a cyclone centered over the Black Sea and an anticyclone above Italy and Austria.

Changes in the daily ozone mean and in the temperature at 70 and 50 mb at 02 and 08 EET from 18–21 May are shown in Fig. 1. The total ozone decreased from 361 m atm-cm on 17 May to 334 m atm-cm (cloudy sky) on 19 May. It then increased to 381 m atm-cm

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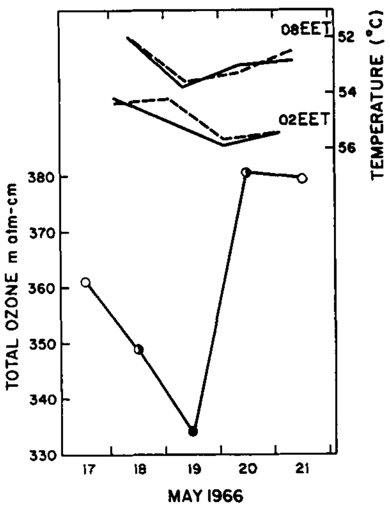

Fig. 1. Total ozone, and the temperatures at 50 mb (———) and 70 mb (- - - - -) at Sofia, 17–21 May 1966.

(AD sun observation) on the day of the eclipse, and remained constant during the following two days. Changes in stratospheric temperatures were approximately analogous to the ozone changes: an increase of 50- and 70-mb temperatures started between 02 and 08 EET on 20 May. A decrease of the tropospheric temperatures (not shown) suggests that a cold front passed above Sofia at least 12–18 hours before the eclipse.

During the eclipse period more than 60 observations were made with the Dobson ozone-spectrophotometer for the standard wavelength settings AD and C (wavelengths λ/λ' are: A—3054/3253; C—3112/3323; and D—3175/3399 Å). The ozonespectrophotometer is designed to determine the total ozone amount from the ground to the top of the atmosphere by measuring the ratio of two wavelength intensities (I/I'). The direct sun measurements (only ten pairs) are unfortunately not sufficient for reliable conclusions. It can only be noted that direct sun C-wavelength observations show one large ozone increase ($\Delta\Omega > 2\sigma$) around the maximum phase of the eclipse, followed by a return to the mean value.

Total ozone values (Ω) calculated from zenith sky observations of C and AD wavelengths are shown in Fig. 2. Routine corrections were made in order to compare observations taken when the zenith was cloudy with those taken when the zenith was clear. Mean total ozone and the corresponding standard deviation for this observational series are AD_z: 352 ± 9, and 334 ± 10 m atm-cm for C_z. Changes in value greater than 2σ can be regarded as significant, with very low probability of chance occurrence. Ozone values for both wavelengths show very similar variations: the ozone decreases by 14–18 m atm-cm (about four to five per cent of the total) after the first contact, after which it remains at a nearly constant level until about ten minutes before the maximum phase is reached; it increases sharply by 25–30 m atm-cm (seven to eight per cent of the total) around the maximum phase of the eclipse; and a few minutes after the maximum phase it starts to decrease to approximately its mean value.

Comparison between the total ozone shortly after the eclipse with that before the eclipse shows a slight decrease (only about two per cent below the mean) for the zenith sky observations.

In the calculation of the total ozone shown in Fig. 2, the intensity of solar radiation outside the earth's atmosphere was assumed to be constant. During an eclipse there is actually a change in solar radiation reaching the earth. We must consider its effect on the calculation of total ozone. The effect of limb darkening on the intensity of the radiation emitted by the sun has been calculated for a few wavelengths by Svensson (1958). Using some of Svensson's data we have computed the changes in the ratio I_0/I_0' during the eclipse, in percentage of its normal value (Table 1). The changes are of the same order of magnitude for the different wavelengths. In the beginning of an eclipse, the ratio I_0/I_0' increases until the eclipsed fraction of the solar diameter is 0.312, and then decreases by nearly eight per cent of initial value close to eclipse totality. If we consider this dark-limb correction, the apparent value of total ozone will be reduced.

Figure 3 shows the ozone calculated by C_z wavelength observations for constant and for variable ratios I_0/I_0'. The change in the ozone values with dark-limb correction (variable ratio I_0/I_0') is similar to the change calculated for constant ratio I_0/I_0', but the magnitude of the changes of the ozone amount is much reduced when the correction is allowed, and in the Sofia observations amounts to only ~ 14 m

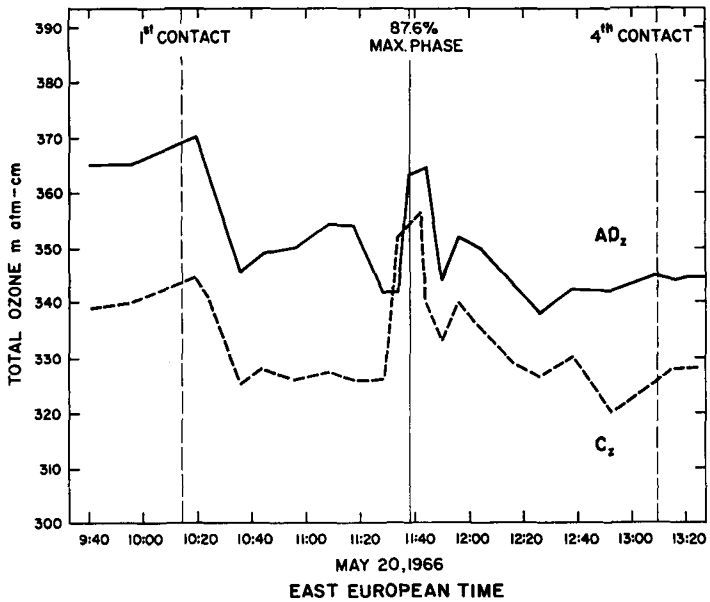

Fig. 2. Changes in total ozone at Sofia during the annular solar eclipse of 20 May 1966.

atm-cm at the maximum phase, about four per cent of the total amount. Even this increase, we will show, is difficult to explain.

3. Discussion

It is known from the photochemical theory of ozone that the equilibrium value for ozone molecular concentration n_3, if there is no solar radiation, will be

$$n_3 = \frac{k_2}{k_3} n_2 M,$$

where $n_2 = O_2$ concentration,
M = the concentration of any third body (molecules), and
k_2, k_3 = recombination coefficients of O_2 and O_3.

During the eclipse, reduction in the intensity of solar radiation reaching the atmosphere markedly reduces the rate of dissociation of both oxygen and ozone, and allows collision reactions between O and O_2, generating O_3, to predominate. Ozone amount will increase until either the n_3 equilibrium value is reached or all the free oxygen atoms are used up. But below 45 km the oxygen atom concentration is about one order of magnitude lower than ozone concentration under normal conditions. Hence, even if all the oxygen atoms below 45 km are converted to ozone, the reflection on total ozone amount will be very small. (At 43° N, only three per cent of the total ozone is found between 37 and 43 km, two per cent between 43 and 48 km, and less than one per cent is found above 48 km (Bojkov, 1965).)

Table 1. *Changes of the ratio I_0/I_0', in per cent from the initial value during an eclipse*

Wave-	Eclipsed fraction of the solar diameter								
length	0.000	0.150	0.3125	0.5375	0.600	0.700	0.800	0.875	0.925
A	100	100.17	100.21	99.72	99.39	98.64	97.41	95.82	92.74
C	100	100.17	100.22	99.71	99.37	98.60	97.37	95.82	92.84
D	100	100.15	100.21	99.70	99.37	98.63	97.41	95.89	92.84

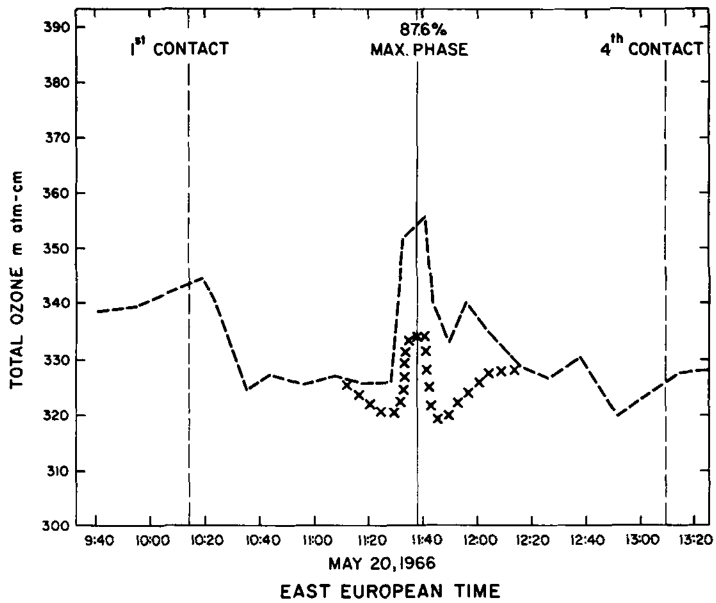

Fig. 3. Changes in total ozone calculated by C_z wavelength measurement (------), and the same after dark-limb correction (× × ×).

Ozone concentration for 5-km layers was calculated on the basis of equilibrium n_3 values reached immediately after darkness occurs (Table 2). Mean upper atmospheric temperatures for May at 42° N latitude are from Kantor & Cole (1965); n_2 and M values for these temperatures were calculated according to the U.S Standard Atmosphere (1962); values of k_2/k_3 are those given by Campbell & Nudelman (1960). The figures of the last column of Table 2 show that there are about 41 m atm-cm ozone above 40 km, or about 25 m atm-cm more than are usually observed at this latitude (Bojkov, 1965). These figures do not represent the actual increase of ozone which will take place during a solar eclipse. However, they enable us to estimate possible changes in ozone if solar radiation is cut off suddenly. Notice that the ozone concentration calculated (Table 2) will be reached if τ, the time needed for the oxygen atom concentration (n) to reach 90 per cent of the photoequilibrium level after a change in intensity of solar radiation, is greater than t, the time during which the change of the intensity takes place.

In the eclipse of 20 May 1966, the time be-

Table 2. *Possible ozone contents (m atm-cm) in 5-km layers after, a sudden decrease in solar radiation, and some parameters used in the calculation*

km	Temp. $k°$	M	n_2	k_2/k_3	$n_3 = \frac{k_2}{k_3} n_2 M$	m atm-cm/5 km
40	258	8.31×10^{16}	1.70×10^{16}	1.3×10^{-18}	1.83×10^{15}	33.927
45	269	4.09×10^{16}	8.45×10^{15}	9.2×10^{-19}	3.18×10^{14}	5.885
50	272	2.14×10^{16}	4.47×10^{15}	8.5×10^{-19}	8.11×10^{13}	1.502
55	266	1.17×10^{16}	2.45×10^{15}	9.5×10^{-19}	2.71×10^{13}	0.503
60	253	6.36×10^{15}	1.35×10^{15}	2.3×10^{-18}	1.98×10^{13}	0.367
65	236	3.47×10^{15}	7.39×10^{14}	4.2×10^{-18}	1.08×10^{13}	0.199
70	217	1.82×10^{15}	3.87×10^{14}	7.5×10^{-18}	5.28×10^{12}	0.098
75	198	9.01×10^{14}	1.92×10^{14}	2.5×10^{-17}	4.33×10^{12}	0.080

tween first contact and the maximum phase was ~5000 seconds. But according to Nicolet (1958) the approximate values of τ will be:

at 50 km: 250 seconds
at 60 km: 2,600 seconds
at 70 km: 35,000 seconds

Thus, on Table 2 the estimated amounts of the possible ozone increase above the 60-km level are too small (< 1 m atm-cm). If the photochemical interpretation is correct, no increase in the total ozone amount could be detected with the measurement methods now in use. Other values for the constants used in the photochemical computations will give us another approximation between theoretical and observed ozone increases, showing again our uncertainty in the values of k_2, k_3, etc., at the present time.

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ИЗМЕНЕНИЕ ОЗОНОСОДЕРЖАНИЯ ВО ВРЕМЯ СОЛНЕЧНОГО ЗАТМЕНИЯ 20 МАЯ 1966 г

Во время кольцеобразного (87,6%) солнечного затмения 20 мая 1966 года в Софийском университете, Болгария, было выполнено более 60 измерений полного озоносодержания с помощью озоноспектрометра. Анализ полученных данных показывает, что содержание озона возрастает до 25–30 м атм-см ($\Delta\Omega > 2\sigma_\Omega$) при максимальной фазе затмения. Различие между теоретическим и наблюдаемым возрастаниями полного озоносодержания, возможно, частично обусловлено эффектом потемнения лимба. Значение этого эффекта существенно возрастает при максимальной фазе затмения. Когда осуществляется поправка к наблюдательным данным на эффект потемнения лимба, возрастание озоносодержания уменьшается до 14 м атм-см (около 4% от полного озоносодержания). Это возрастание до сих пор остается необъясненным.