ON THE SHORT-PERIOD VARIATIONS OF THE OZONE CONTENT AND OF THE INTENSITY OF SOLAR RADIATION IN THE ATMOSPHERE NEAR THE GROUND

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Received March 20, 1990

Two external factors, which determine the short-period variations of the ozone content — the quasi-five-minute variations in the intensity of the solar radiation at the ground and the terminator internal gravity waves (IGWs) — are studied. A hypothesis explaining the mechanism of the appearance of short-period variations of ozone content is proposed.

The study of processes determining the ozone regime as a sum of regular and random variations of O_3 in time makes it possible to model in greater detail the mechanisms responsible for the formation, destruction, and transport of this very important component of the atmosphere. The problem of separating regular variations of the ozone content and the factors giving rise to them is of definite methodological interest.

According to Ref. 1 the factors determining the ozone regime can be conditionally divided into two groups:

a) internal or geographic factors, which determine the formation and regime of ozone by processes that are inherent to the atmosphere itself;

b) external factors, primarily heliogeo-physical factors.

In this paper we study the factors belonging to the second group.

1. In the summer of 1988 observations of the variations of the total ozone content (TOC) were conducted in the town of Daimishche. The measurements were performed with the help of an automatic spectral system (ASS), developed based on the "KSVU-6" system (produced by Leningrad Optical-Mechanical Union). This system is highly sensitive and stable.[2] The system is aimed at the sun with the help of a photoelectric tracking system with an accuracy of 1′. The viewing angle of the apparatus was equal to about 20′ and the spectral resolution was equal to about 2 Å.

The work was performed at four wavelengths: $\lambda_1 = 3199$, $\lambda_2 = 3212$, $\lambda_3 = 3225$, and $\lambda_4 = 3238$ Å (these wavelengths fall on the neighboring maxima and minima of the absorption coefficient of ozone). The choice of a comparatively narrow spectral interval makes it possible to shorten the time required to scan it, which in this case is equal to about 4 s. In addition, in such a narrow spectral interval the aerosol and molecular components of the spectral optical thickness can be approximated to a very good approximation by linear functions of λ.

Taking the logarithms of the spectral readings (L_{ij}) and using Bouguer's law we write

$$L_{ij} = L_{0i} - m_a\tau_{aij} - m_m\tau_{mij} - m_3 X_j \alpha_i ,$$
$$i = \overline{1,4}; \qquad j = \overline{1,N}, \tag{1}$$

where i enumerates the four wavelengths; enumerates the measured spectra; L_{0j} is the exoatmospheric value; m, m_M, and m_3 are the spectral optical masses of the aerosol, molecular, and ozone components, respectively; X_j is the total ozone content; and, α_1 is the absorption coefficient of ozone.

We shall take the first derivative of λ_{ij} in Eq. (1) with respect to λ. Because $\tau_{aij}(\lambda)$ and $\tau_{Mij}(\lambda)$ are linear functions in the wavelength interval studied, the second and third terms on the right side of the derivative become negligibly small. Therefore the second and third derivatives of Eq. (1) with respect to λ should include on the right side only two terms: the "ozone" and "exoatmospheric" terms, respectively,

$$\left.\begin{aligned} L^{(2)}_{ij} &= (L_{01} - 2L_{02} + L_{03}) - m_3 X_j(\alpha_1 - 2\alpha_2 + \alpha_3) \\ L^{(3)}_{ij} &= (L_{01} - 3L_{02} + 3L_{03}) - L_{04} - \\ & m_3 X_j(\alpha_1 - 3\alpha_2 + 3\alpha_3 - \alpha_4) \end{aligned}\right\} \tag{2}$$

As one can see from what was said above, the variability of the derivatives $L^{(2)}_{ij}$ and $L^{(3)}_{ij}$ is a linear function of the variability of the TOC (X_j). We shall employ this fact below to analyze the short-period variations of the ozone content.

2. Every observation is a time series of 1–2 h readings of the TOC. According to the method described in Ref. 3 the observations were processed for the purpose of determining the regular variations in the ozone content. Table I gives as an example the results of analysis of the TOC series starting on June 17, 1988,

0235-6880/90/07 687-04 $02.00

where T_1 and T_2 are the periods and A_1 and A_2 are the amplitudes of the first and second harmonics, respectively.

TABLE I.

Time (h, min)	T_1 (min)	A_1 (rel. units)	T_2 (min)	A_2 (rel. units)
09.21	15.5	60.0	10.0	28.0
10.49	19.0	40.0	11.0	20.0
12.18	20.0	15.0	12.0	5.0
16.24	35.0	25.0	13.0	3.0

It is obvious from Table I that during the day the wave of TOC becomes flatter and fades away. This is indicated by the increase in the periods of the harmonics and the decrease in their amplitudes. Figure 1 shows that during the day the periods T_1 and T_2 increase almost linearly and the amplitudes A_1 and A_2 decrease monotonically.

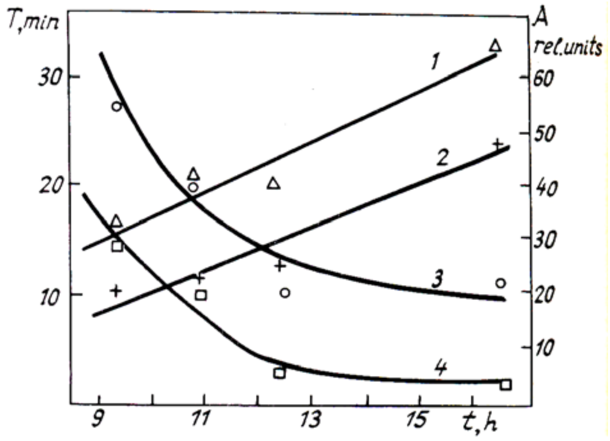

FIG. 1. The results of analysis of a TOC series from June 17, 1988: period T_1(1), period T_2 (2), amplitude A_1(3), and amplitude A_2(4).

This shows that the oscillations under study must be caused by some one-time lowering mechanism. This mechanism could be the solar terminator. The following facts point to this mechanism. According to Refs. 4–7, when the solar terminator passes through the atmosphere a packet of pressure waves (internal gravity waves, (IGWs)) is generated in the atmosphere. The period of the fundamental harmonic of these IGWs is equal to several minutes. The amplitude of this harmonic can be an order of magnitude higher than the amplitude of other waves in the packet. The period and amplitude of the fundamental harmonic depend on the ratio of the velocity of the terminator and the velocity of sound in the atmosphere. The IGWs, caused by the passage of the terminator, generate oscillations of the TOC. These terminator waves (IGWs and the wave of TOC, generated by the IGWs) should fade away by the end of the day because there is no energy influx.

Precisely such a pattern (see Table I and Fig. 1) is observed in the real atmosphere. In this case ozone plays the role of the atmospheric marker, which traces the development of the terminator IGWs. However such a wave can be observed primarily in a plain location. In the mountains these observations are strongly hampered, since the IGWs, generated by the orography of the location, blur and suppress the terminator IGWs.

3. Observations of the short-period variations in the concentration of ozone at the ground (SOG) and the intensity of solar radiation (ISR) at the underlying surface were analyzed in Refs. 2, 3, and 8–10. A photochemical hypothesis of the origin of variations of SOG was put forth. We believe that it is possible to integrate the photochemical hypothesis and the hypothesis of a terminator IGW in order to explain short-period variations of the SOG.

At the moment a terminator IGW arises its period $T_0 \approx 2 \ldots 3$ min (according to Refs. 4 and 5). The intensity of solar radiation at the ground at the moment the terminator passes is insignificant, and for this reason the period of the oscillations arising in the SOG is equal to T_0 and the amplitude of the oscillations is small (the smallness of the amplitude is caused by the low content of ozone in the atmosphere near the ground at night and in the period right before dawnNext the photochemical mechanism of formation and destruction of ozone comes into play. The SOG increases, and at the same time the amplitude of the oscillations of the SOG increases. The period of the terminator wave is equal to $T_0 \approx 5 \ldots 7$ min. At the same time one of the main "peaks" of the oscillations of the solar photospheric radiation in the short-period region lies in the range 2 ... 4.5 MHz, which corresponds to periods in the range 3.7 ... 8.3 min.[11]

As shown in Refs. 2, 8, and 10 the oscillations of the ISR give rise to oscillations of the SOG with periods equal to the periods of the oscillations of the ISR. As a result the following picture is obtained. The oscillations caused by the terminator IGW and the oscillations induced by the ISR add. Because of the randomness of the phase difference and of the change in it, and the changes in the periods of the added oscillations these oscillations interact in a manner such that they form two significant bands with periods ranging from 3.7 to 8.3 min and from 1.7 to 3.7 min,[2] the so-called "five-minute" and "three-minute" bands.[11] The random character of the interaction of the oscillations, caused by ISR and IGWs, can also explain the fact that the observed SOG form wave packets ranging from 0.4 to 1.8 h wide. In addition, it has been found that regularity of the influx of photo chemical reagents, which participate in the formation of in ozone in atmosphere near ground(for example, NO_x, CH_4, OH, etc.), has an enormous effect on the width of the wave packets.

The fact that the amplitudes of the observed variations in the ISR range from 0.5 to 6% of the average value while the amplitudes of the variations of the SOG range from 7 to 40% of the average value can be explained as follows. First, depending on the content of nitrogen oxides in the atmosphere up to four ozone molecules can form when one methane molecule is oxidated.[12] Second, the quantum yield of photolysis of ozone can increase in the presence of some impurity gases.[13] Third, the possible resonance effects appearing when the oscillations of the SOG, caused by the terminator and the ISR, are added must be taken into account.

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