Seasonal dynamics of the tropospheric ozone vertical distribution above West Siberia

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Seasonal behavior of vertical distribution of the ozone concentration within the layer from 0 to 7000 m is analyzed by the data of aircraft measurements for the period 1998–2000. It is shown that tropospheric ozone is mainly formed *in situ* inside the inner mixing layer in the spring period. Variation of the ozone concentration at different heights is sufficiently synchronous, that is indicative of weak income of ozone from the stratosphere. Data on the absolute maxima of ozone concentrations at all heights inside the layer under study are presented.

Tropospheric ozone formed *in situ* is the substance related by the State Standard Specifications to the first class of danger, that determines the ecological urgency of its investigation.[1,2] Having long lifetime in the troposphere (from several days to several months) and intense absorption lines, ozone can play significant role in the greenhouse effect. According to estimates,[3,4] its contribution into additional heating of air can be 8–20% of the heating caused by the solar radiation absorption by principal greenhouse gases.

Hence, in order to control the ecological situation in some area and to predict climatic changes, it is necessary to have information on spatiotemporal distribution and variability of tropospheric ozone.

Three methods are used to measure the ozone vertical distribution in the troposphere: balloon-borne, airborne, and laser sensing. For a variety of reasons, regular measurements of the ozone vertical profiles by these methods are not conducted in Russia at the present time. As a result, such a great territory can not be taken into account when estimating the global budget of tropospheric ozone.

Since July 1997, the Institute of Atmospheric Optics SB RAS (Tomsk) together with the National Institute of Environmental Studies (Tsukuba, Japan) conduct regular airborne sensing of the atmosphere, including ozone, over one of the southern regions of West Siberia. Aircraft flights are conducted every month over forest area near village Zavialovo of Novosibirsk region. The flight time is chosen close to noon (~ 1 p.m. of local time), when maximum photochemical generation of tropospheric ozone occurs.[5] Flight duration is 3 hours, during which measurements of vertical distribution of ozone, aerosol, meteorological parameters, and intensity of the total solar radiation are carried out. Simultaneously, samples of air and aerosol are collected during horizontal flights at the heights of 500, 1000, 1500, 2000, 3000, 4000, 5500, and 7000 m for subsequent laboratory analysis of components of the ozone cycle and chemical composition of particles.

The 3–02P hemiluminescent ozonometer developed and constructed by the OPTEK enterprise (St. Petersburg) was installed onboard the AN–30 "Optik–E" aircraft-laboratory for measuring the ozone concentration. It is regularly calibrated by means of the GS–2 ozone generator designed by the same enterprise. The ozonometer and generator are tested in D.I. Mendeleev Scientific Research Institute of Metrology as needed. The relative error of the ozonometer does not exceed 15% in the range from 5 to 1000 $\mu g/m^3$. The time constant of the device makes it possible to take readings with the frequency of 1 Hz, that provides for the vertical resolution of 3–15 m.

The purpose of this paper is to analyze seasonal variations of vertical distribution of the tropospheric ozone concentration within the layer from the ground surface to 7000 m.

Temporal behavior (normalized to the minimum value) of the relative ozone concentration at three heights: 300 m – inside the internal mixing layer[6]; 3000 m – near the upper boundary of the mixing layer[6]; and 6600 m – in the free atmosphere – is presented in Fig. 1. The ozone measurements obtained during all flights from November 1998 to December 2000 were used for calculation. It is seen in Fig. 1 that sufficiently synchronous change of the ozone concentration occurs at all heights. Annual behavior with summer or spring maximum depending on a year is well pronounced. The amplitudes of annual variations at different heights are close. This argues for the fact that the nature of the ozone concentration change is the same through the whole layer under consideration. Such a conclusion is based not only on synchronicity of the ozone concentration change at different heights, but also on the analysis of the vertical distribution of other components of air, such as aerosol and water vapor, which enter into the air from the underlying surface. For confirmation, vertical profiles of the aforementioned characteristics measured on June 26, 2000 are shown in Fig. 2.

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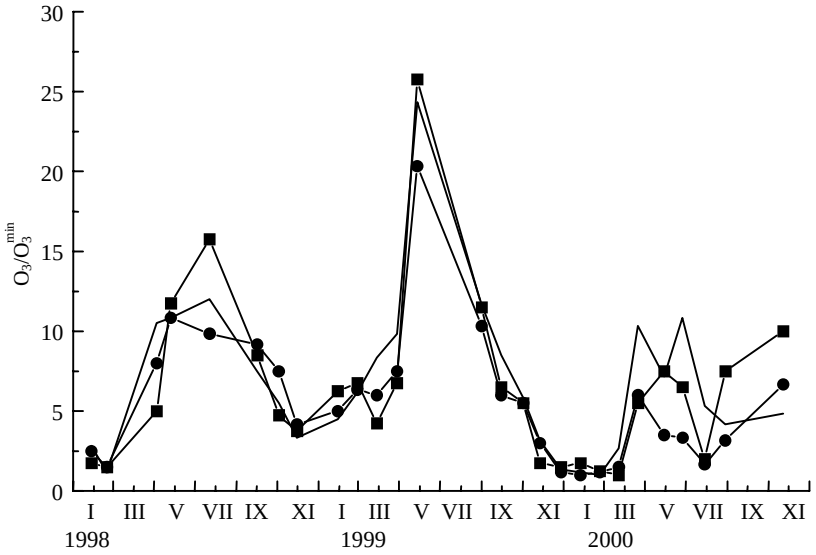

Fig. 1. Ozone concentration at the heights of 300 (—), 3000 (—•—), and 6600 m (—■—) over south of West Siberia from January 1998 to December 2000.

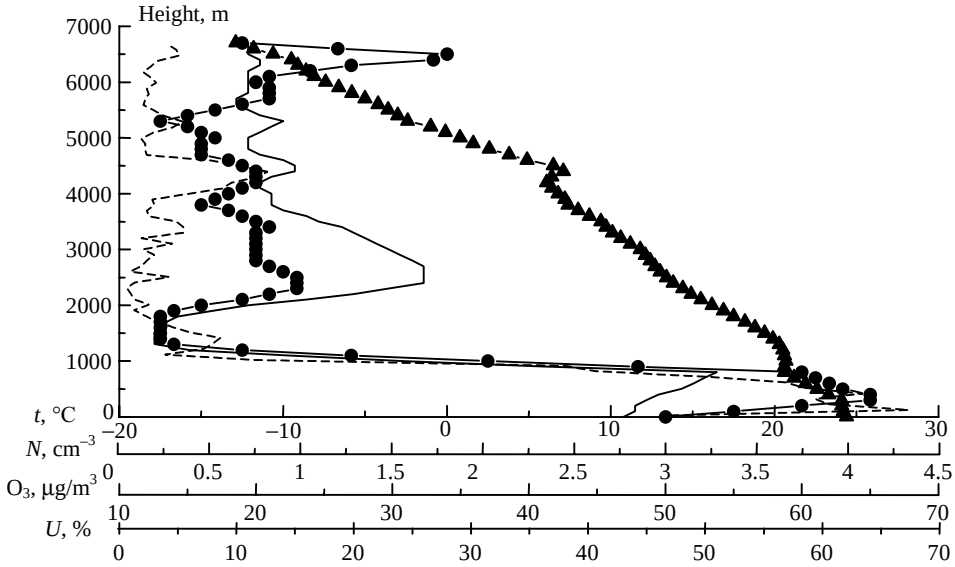

Fig. 2. Vertical distributions of air temperature (▲▲▲), aerosol number density ($d \geq 0.4$ μm) (– – – –), ozone (•—•), and relative humidity of air (——) observed on June 26, 2000.

It is seen in Fig. 2 that the maximum concentrations of ozone, aerosol, and water vapor are observed in the lower part of the boundary layer under the inversion layer. Their content above the inversion layer decreases by several times. Hence, if the source of aerosol and water vapor is evaporation from the underlying surface, then ozone is formed from the same evaporated substances. Moreover, vertical behavior of ozone, aerosol, and water vapor above this inversion also does not differ and well follow temperature stratification, reflecting the effects of accumulation of admixtures under the hampering layers. The exception is the ozone maximum at the height of 6600–6700 m, which is not connected with the hampering layer. Possibly, it is the result of remote transfer or intrusion from the stratosphere.

To estimate qualitatively annual behavior of the ozone concentration, all profiles were divided into five groups according to periods: the period of the winter depression (November, December, and January), period of the beginning of the ozone concentration increase (February and March), period of spring maximum (April and May), period of summer stagnation (June, July, and August), and period of fall rains (September and October). Mean profiles for the aforementioned periods are shown in Fig. 3. Beginning of the spring growth is characterized by the increase of the ozone concentration in the layer up to 1000 m, while in the layer 3000–7000 m some decrease of the ozone concentration is still observed. The vertical profile tilt of ozone strongly changes in the period of spring maximum (April and May). This indicates that its

principal generation takes place in the atmospheric boundary layer. In summer, because of the ozone budget change, the vertical profile levels off. The summer ozone profile tilt alternates its sign in the layer above 5000 m, that favors the possibility of the stratospheric ozone ingress. Against the background of the continued fall of the ozone concentration within the layer from 0 to 1000 m, an increase of the ozone content is observed in the layer from 2000 to 5500 m. Evidently, it is connected with ozone or ozone-forming substances transfer from other territories, where duration of the spring-summer maximum is much longer. Maximum change of the ozone concentration in the layer 0 – 6600 m is observed in the period of spring growth. In average, the ozone concentration within this layer increases from February–March to April–May by 30–50 μg/m^3. The increase is much stronger at low heights than in the free atmosphere.

In some cases the data on absolute variability of the characteristic under study are necessary for minimax estimates. The values of the absolute minimum, maximum, and mean ozone concentrations at each height are shown in Fig. 4 by the results of all flights.

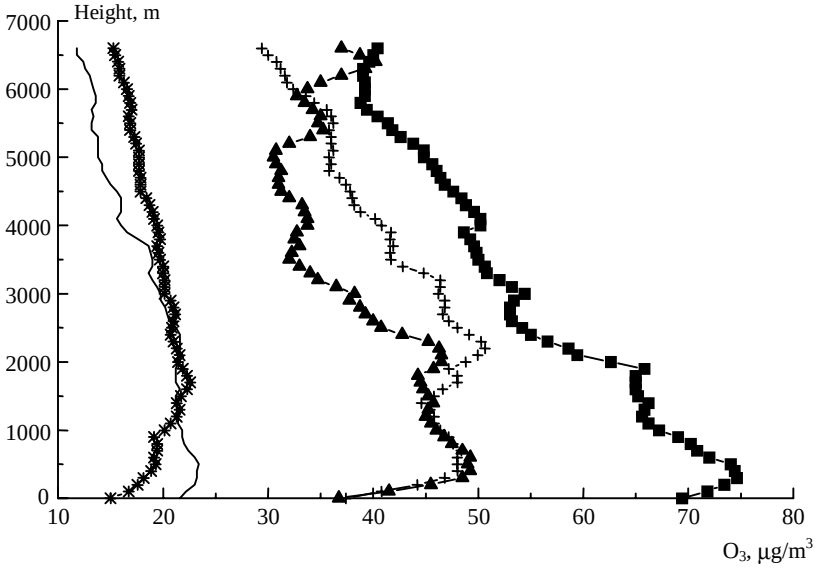

Fig. 3. Mean vertical profiles of the ozone concentration: February, March (—); April, May (—■—); June–August (—▲—); September, October (—+—); November–January (—Σ—) during 1998–2000.

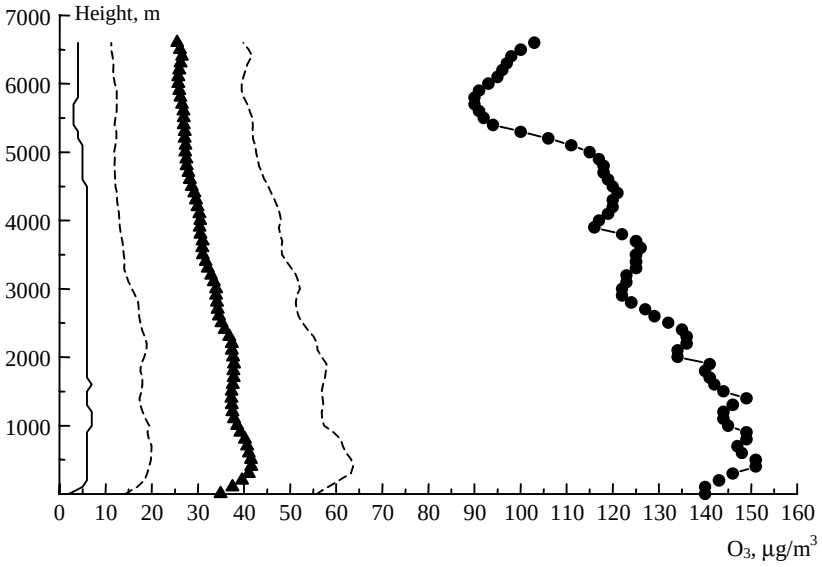

Fig. 4. Absolute maximum (●●●), minimum (—), and mean ozone concentration (▲▲▲) ± rms error (– – – –) on the south of West Siberia in the period 1998–2000.

It is seen in Fig. 4 that the minimum ozone concentrations of 3–6 μg/m^3 can be observed at any height. They have not the pronounced vertical behavior. The maximum concentrations are more variable, though on the whole show some decrease of the magnitude with height. They are the greatest in the boundary layer and the smallest in the middle stratosphere. An increase of the absolute maxima is observed starting from the height of 5600 m. This is possible for two reasons. The first is the ozone transfer from the stratosphere. The second is caused by peculiarities of air circulation over West Siberia. Very low tropopause up to 7 km can be observed over this territory in cold seasons at ultrapolar ingresses. In this case the upper part of the profile can be more attributed to the stratospheric ozone.

The mean ozone profile (±rms error) lies in the limits between absolute minima and maxima. Due to averaging over more than 30 measurements, its behavior is less variable. Maximum concentration is observed in the inner mixing layer. Then the decrease of concentration falls from 42 to 26 μg/m^3. No concentration growth similar to the absolute maxima is observed in the upper part of the profile. This once again supports the above idea that the ozone income from the stratosphere is not a perpetual process.

Summarizing the aforesaid, we can draw the following conclusions.

Photochemical generation of the tropospheric ozone occurs in the inner mixing layer.

Ozone income from the stratosphere is significantly less that its photochemical generation *in situ*.

Maximum content of the tropospheric ozone is observed in spring, minimum – in September and October.

Acknowledgments

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