Climatology and trends of stratospheric ozone over Tomsk during the period from 1996 to 2002

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The data of lidar measurements of vertical ozone distribution and spectrophotometric measurements of the total ozone content obtained in Tomsk (56.5°N, 85.1°E) are analyzed for the 1996–2002 period of the background stratospheric state, unperturbed by volcanic eruption. The intraannual and interannual variations and trends of total ozone content and vertical ozone distribution in the stratosphere are under consideration. It is shown that the state and significant variations of the ozonosphere are mainly formed in its lower part where the dynamical factor plays a decisive role.

Introduction

The state of the stratospheric ozone layer (ozonosphere) is commonly analyzed on the basis of measurements of the total ozone content (TOC) at the points of ozonometric networks or from space. Measurements of the vertical ozone distribution (VOD) in the stratosphere are performed more rarely and at small number of the points by the contact technique (ozonosondes) or, least often, the lidar remote technique. The lidar measurements of VOD use the DIAL technique in the UV spectral range, where the Hartley–Huggins ozone absorption bands are located.[1] Lidar returns, reflected from the stratosphere, are so weak that can be recorded only in the photon counting regime under conditions of minimal background irradiation, i.e., the nighttime cloudless sky. In the late 1980s, regular lidar observations of the ozonosphere began at some observatories, that enabled the researchers already by the middle 1990s to perform the first climatological studies of seasonal variations and to assess the trends of VOD in the stratosphere based on the lidar data.[2,3,4,5] In Tomsk (56.5°N, 85.1°E), regular lidar measurements of VOD in the stratosphere have been performing at the Siberian Lidar Station (SLS) of the Institute of Atmospheric Optics SB RAS since 1989.[1] It is known that during a long period from 1991 to 1995 the global atmosphere, including the ozonosphere, was in the perturbed condition after the high-power eruption of Mt. Pinatubo in June 1991. Therefore, the analysis of climatology and trends of the unperturbed stratospheric ozone must be limited to a series of VOD lidar measurements from 1996.

In 1998, we have improved the UV channel of SLS by mounting a higher-power excimer laser LPX-120i of the Lambda Physik, and later, more sensitive photodetectors of lidar returns based on the computing photomultipliers and amplifiers-discriminators of the Hamamatsu. All this has made the maintenance of routine regime of laser sensing of the ozonosphere much more simple. For the period of 1996–2002 we have collected 299 representative profiles of VOD. Their monthly distribution for every year of the period is given in Fig. 1.

In spite of gaps in lidar observations connected with weather conditions, expedition researches, and holidays, all months over a six-year period of the lidar ozonospheric observations turned out to be covered as it is evident from Table 1.

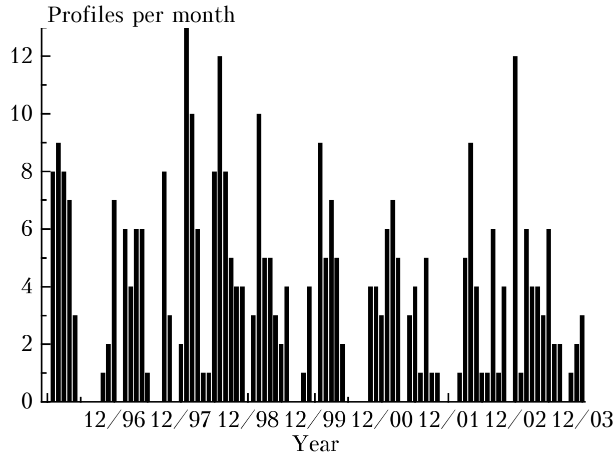

Fig. 1. Monthly distribution of the number of the VOD profiles obtained at SLS from 1996 to 2001.

Table 1

1996–2002	Number of profiles	1996–2002	Number of profiles
January	39	July	18
February	48	August	19
March	40	September	15
April	27	October	18
May	22	November	14
June	16	December	23

Intraannual variability of stratospheric ozone

Figure 2*a* shows the seasonal mean VOD profiles over Tomsk during the observation period, and Figure 2*b* shows the profiles of their root-mean-square deviations (RMSD).

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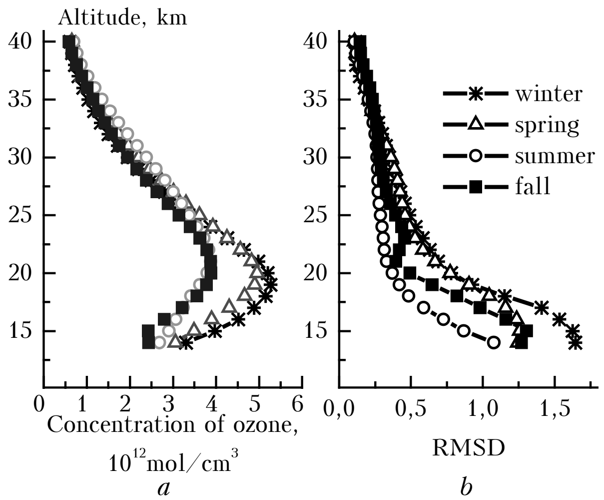

Fig. 2. Seasonal mean VOD profiles over Tomsk (1996–2002) (*a*) and profiles of their root-mean-square deviations (*b*).

It is clear that the maximal variability of VOD is detected in the lower stratosphere where ozone plays a role of a passive tracer of circulation processes. The role of ozone becomes decisive in spring–winter periods when the meridional circulation increases. To demonstrate the VOD climatology in the stratospheric ozone layer in more detail, Figure 3 presents the intraannual behaviors of the ozone concentration at different heights. As a whole, we notice that in the lower stratosphere at the heights below 26 km, the intraannual variations of the ozone concentration are characterized by the maximum in spring and the minimum in the fall, and at the heights higher 26 km the maximum is shifted to the summer period and the minimum – to the winter one. Such a behavior of the ozonosphere over Tomsk, as a whole, follows the results obtained based on the lidar data in Germany[4] and Japan.[5] As it was noted in the literature,[4] at a height of 26 km, where the velopause is located, the ozonosphere is divided into two parts: below its behavior is mainly determined by dynamic processes and in the upper part – by photochemical processes. Closer consideration of intraannual variations of VOD in Fig. 3, allows us to recognize the following factors:

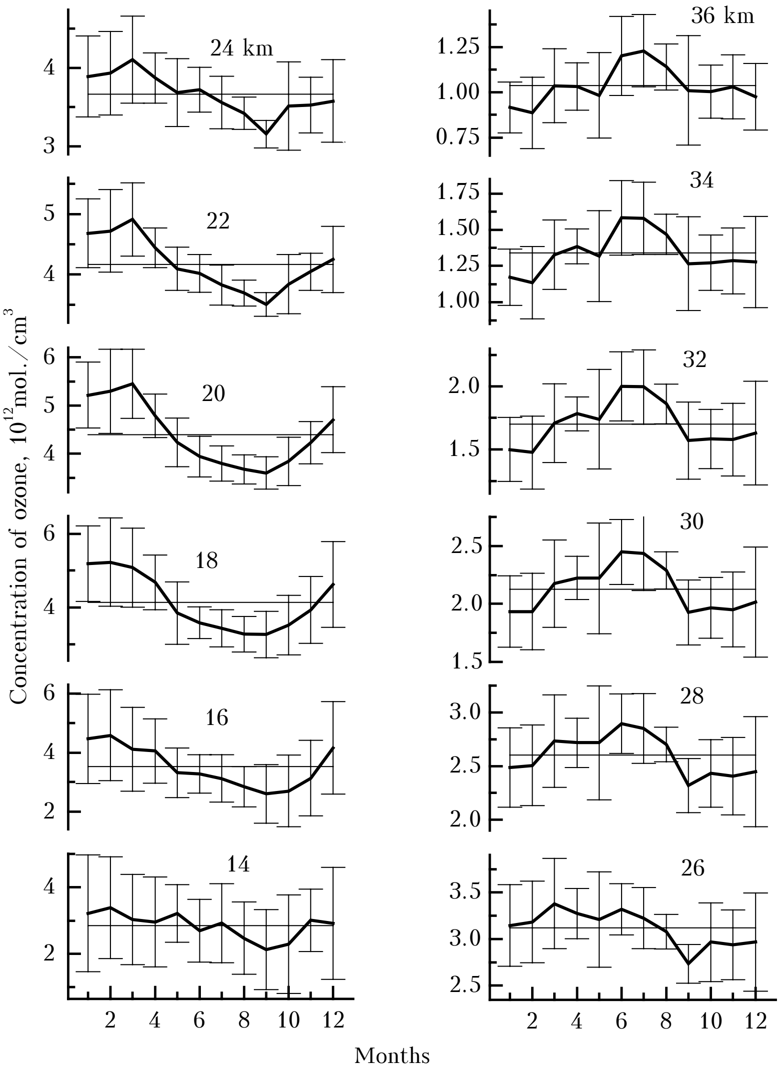

Fig. 3. Intraannual variability of the stratospheric ozone layer at different altitudes. A thin horizontal line denotes the mean value.

a) at a height of 14 km, where, evidently, the effect of altitude variation of the tropopause is significant, no localized maximum is observed.

b) in the range up to 18 km inclusive, the maximum of seasonal variations is observed in February, and in the range from 20 to 26 km – in March.

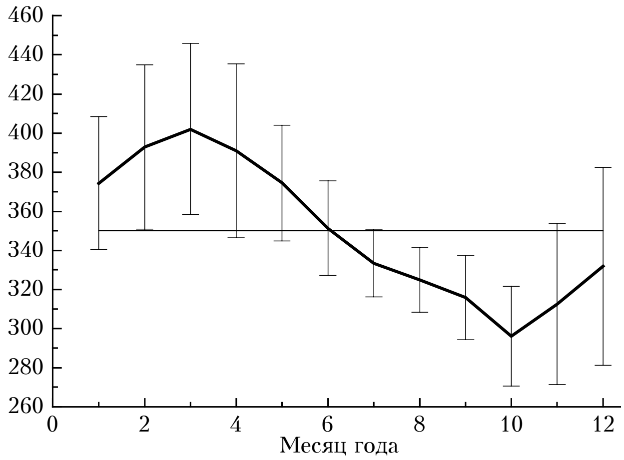

Fig. 4. The annual behavior of TOC based on data of spectrophotometric measurements. A thin horizontal line denotes the mean value.

Figure 4 shows the annual variation of TOC generalized to the results of independent measurements made at SLS from 1996 to 2002 using the ozonometer M-124. From the comparison of Figs. 3 and 4, we notice that the greatest correspondence between intraannual variations of VOD and the annual variation of TOC is observed in the altitude range from 20 to 24 km, especially at the 22 km altitude.

Interannual variability and trends of stratospheric ozone

Figure 5 shows the annually mean VOD profiles in the stratosphere over Tomsk as compared to the annually mean VOD profile obtained by the Krueger model,[6] which serves a reference one. The altitude of the stratospheric ozone maximum over Tomsk is lower than in the Krueger model that is due to the climatic closeness of the Tomsk region to the subarctic regions.[1] Figure 5 shows that the interannual variation of the ozonosphere maximum follows the alternation of the concentration maxima in the even years and the concentration minima in the odd years. This variation reflects the known quasi-biennial cycle (QBC) of the stratospheric circulation. Taking into account the QBC of the stratospheric circulation, to assess the trends of the stratospheric ozone at different altitudes, it is convenient to consider the series of lidar measurements of VOD multiple to the two-year periods.

Figure 6*a* shows the profile of the stratospheric ozone trends over Tomsk calculated by the annually mean values of VOD during the six-year period from March 1996 to February 2002. At all altitudes the trends turned out to be statistically insignificant.

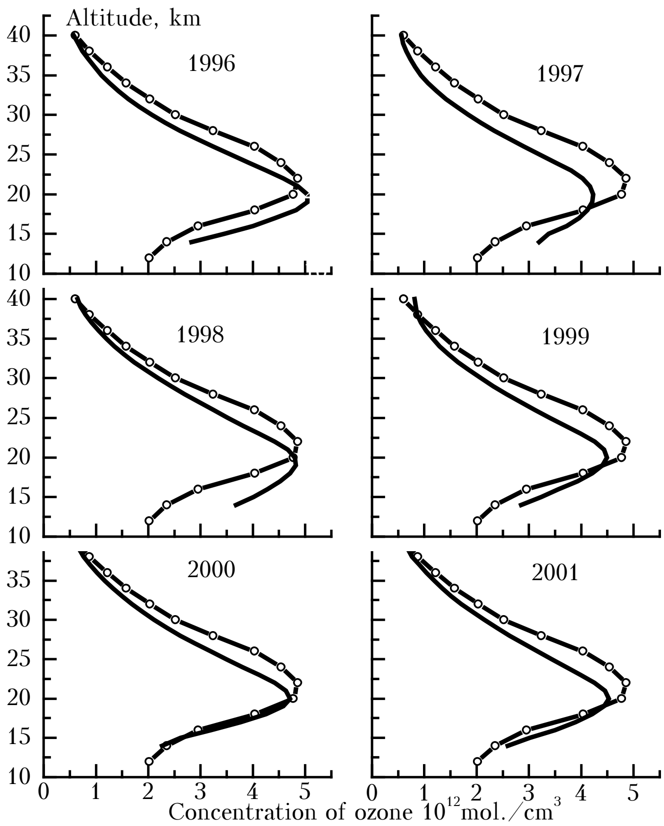

Fig. 5. Annually mean VOD profiles (—) as compared to the Krueger model (–∘–).

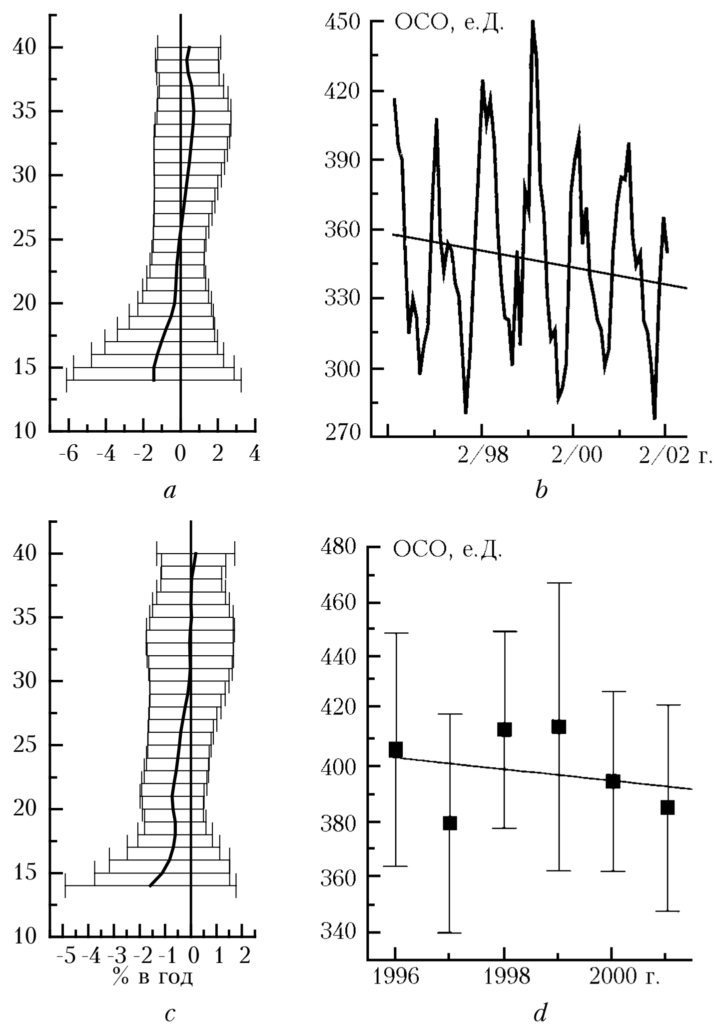

Fig. 6. Trends of vertical and total ozone content.

In the lower part of the ozonosphere they are characterized by negative values, in the upper part – by positive ones. In the region of the stratospheric ozone maximum (~ 20 km) the values of the negative trends are small (~ 0.32% per year). These results are in agreement with the insignificant statistically negligible trend of TOC (0.01 ± 0.026% per year) for the same six-year period (Fig. 6*b*). The main contribution to the trend negative values of the stratospheric ozone in the lower ozonosphere in the period under consideration is due to the spring–winter period in February–March (Fig. 6*c*), which agrees with the more pronounced but also statistically insignificant negative trend of TOC (0.082 ± 0.95% per year) estimated for the same observation period (Fig. 6*d*) (thin line in Figs. 6*b* and *d*).

Conclusion

The results of long-term lidar observations of the ozonosphere over Tomsk have shown that its state and behavior are mainly formed in the lower part of the ozonosphere where the dynamic factor plays a decisive role. The meridian circulation, which increases in the winter–spring period, is there most influencing.

Table 2 shows the quantity of invasions into the mid-latitude stratosphere above Tomsk of polar and tropical air masses determined by the typical distortions of the forms of mid-latitude profiles of VOD (detection of the lowered polar ozone maximum or raised tropical one) from the general number of detected profiles in February–March of the corresponding year (values in the denominator).

It is seen that at the beginning of the analyzed series of lidar observations, the invasions of polar air masses enriched by ozone dominated. At the end of this series, on the contrary, the invasions of tropical air masses with low ozone content were dominant. These processes are decisive in the obtained VOD trends in the lower ozonosphere above Tomsk for the period from 1996 to 2002. It should be noted that in 2000 the solar activity peak was observed. The short-wave radiation enhancement in the peak of solar activity stimulates the photochemical ozone generation in the upper ozonosphere. Most likely, just this fact is connected with the positive values of VOD trends at heights higher than 26 km (Fig. 6*a*).

Table 2

Year		1996	1997	1998	1999	2000	2001	2002
Air masses	Polar	5/17	2/10	3/16	4/15	0/12	0/12	0/1
	Tropical	1/17	2/10	0/16	6/15	4/12	1/12	0/1

Acknowledgments

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