Peculiarities of stratospheric ozone vertical distribution over Tomsk

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Comparative analysis of sets of lidar observations over the ozone vertical distribution (OVD) in the stratosphere over Tomsk in summer and winter 1998 has been conducted. The averaged profiles of OVD obtained from 23 and 26 individual high profiles of the ozone for winter and summer, respectively, as well as the profiles of their variability were under analysis. It was noted that above the altitude of the OVD profiles meet (25 km), summer concentration of the ozone is higher than the winter one and, on the contrary, lower 25 km the winter concentration significantly exceeds the summer one. Maximum variability takes place in the low stratosphere at 14–17 km heights both in summer and winter. In winter the atmospheric dynamics forms a considerable relative variability of the ozone at the heights higher 25 km, whereas in summer the ozone variation in the central and upper stratosphere is stabilized by intense photochemical processes. A correlation analysis between layer-to-layer and total ozone content (TOC) has shown most correlation between the TOC and the ozone concentration to be at the maximum height in both seasons. Thus, the top of the ozone maximum layer is shown to contribute mainly into the TOC variability and the layers located lower the maximum – into OVD variability.

Investigation of the ozone vertical distribution (OVD) in the stratosphere is the necessary stage in the study of the reasons and mechanisms of the variability of the stratospheric ozone layer. The use of lidar methods of sounding allows to study the vertical structure of the stratospheric ozone fields in more details, because it makes it possible to obtain the ozone distribution in the altitude range of its maximum content with the high spatiotemporal resolution.

In this paper we analyze the series of lidar observations of stratospheric ozone at the Siberian Lidar Station[1] in different seasons of 1998 with characteristic high (winter) and low (summer) ozone content.

Twenty six mean night ozone profiles were obtained during three summer months of 1998. The series of 23 mean night ozone profiles were obtained in winter of the same year (January and February). A mean night ozone profile was reconstructed from the total lidar return accumulated in 3–4 cycles of measurements, each of which was determined by the time of the lidar return accumulation in the photon counting mode ~ 25 minutes. In principle, one can reconstruct the statistically provided ozone profile up to 30–35 km with the altitude resolution 0.1–0.4 km from each separate series of measurements. However, obtaining of the more representative data on OVD in the lower half of the stratosphere in the altitude range 13–35 km was reached due to the accumulation of the total signal during 1.5–2 hours.

The generalized results of winter and summer lidar observations of the ozonosphere state over Tomsk in 1998 are shown in Fig. 1 as the seasonal mean ozone profiles. The Kruger model midlatitude annual mean ozone profile and the ozone profile obtained from measurements and averaged over two seasons are also shown here. All profiles are shown with the spatial resolution of 2 km.

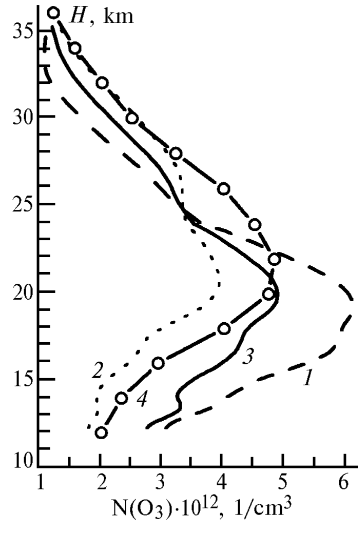

Fig. 1. Comparison of the mean winter (curve *1*), summer (*2*), and averaged over two seasons (*3*) ozone profiles over Tomsk with the Kruger model midlatitude annual mean profile (*4*).

In general, the differences in the OVD behavior in winter and summer are in agreement with the data on the seasonal ozone distribution over midlatitudes.[2] The maximum of the ozone layer in winter is situated at the altitude of ~ 19 km, and in summer it is near 21 km. The ozone concentration values change from winter to summer by 1.5 times, from $6\cdot 10^{12}$

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to $4 \cdot 10^{12}$ 1/cm^3. As is seen in Fig. 1, the lidar ozone profile averaged over the period of observation (curve *3*) has some differences from the model OVD (curve *4*). They are the following: the more powerful and low ozone maximum, the lower ozone content above the maximum and the enhanced ozone content below the maximum. On one hand, the differences indicate the climatic peculiarity of OVD over Tomsk, and on the other hand, the specific peculiarity of circulation processes during the periods of observations, when, according to the data of synoptical analysis, the formation and development of cyclonic circulation were observed more often, and were accompanied by often intrusion of arctic air masses to the midlatitudes both in the troposphere and the lower stratosphere.

The seasonal profiles of rms deviations of the ozone concentration values from the seasonal mean ones are shown in Fig. 2. It is seen that the maximum variability is observed at the altitudes below 17 km both in winter and summer in absolute and relative units. First of all, it is evidence of the aforementioned northern periphery of the observation site at Tomsk. It is characterized by big probability of intrusion to the lower stratosphere of arctic air masses with characteristic high ozone content and low position of the ozone peak.[3] Big ozone variations in winter at the altitudes more than 25 km can be related with the deformation of circumpolar vortex under the effect of the high blocking anticyclones (for example, Asian one) with its frequent displacement to the midlatitudes in winter.[4] Small ozone variability at these altitudes in summer is evidence of the prevalent role of photochemical processes in the ozone formation in the stable field of solar radiation in comparison with the dynamic processes. It is also seen in the good agreement between the summer mean and model values of the ozone concentration at these altitudes.

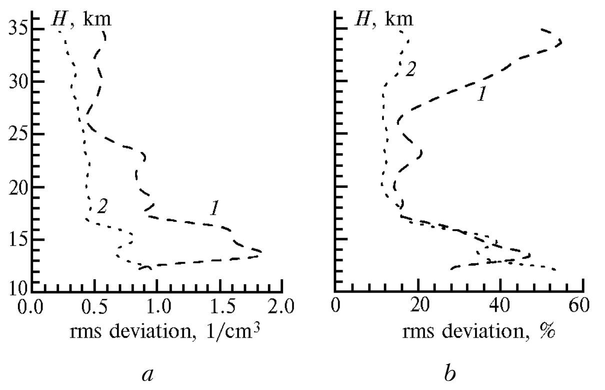

Fig. 2. Winter (curve *1*) and summer (*2*) profiles of rms deviation in absolute (*a*) and relative (*b*) units.

Figure 3 shows the inter-level correlation functions of OVD calculated for the 2-km-thick layers in the altitude range 14 to 32 km. The significance level of the correlation coefficient is ~ 0.4 for the confidence probability 0.95. Vertical distribution of the correlation curves has both common and different attributes. One can select three characteristic altitude ranges in the Fig. 3: 15–19, 19–27, and 27–31 km. Judging from the sharp decrease of the correlation curves in the lower altitude range, especially in winter, one can conclude that the OVD over Tomsk was determined in this period by the well pronounced azonality of circulation in the lower stratosphere up to 19 km. Above this level, one can observe the increase of the inter-level correlation up to 27 km both in winter and summer due to the intensification of zonality. The correlation coefficients at these levels are greater than the level of significance. The correlation coefficients in the third range 27–31 km are the same and even insignificantly increased, that is related with the aforementioned regional peculiarities of the vertical motions of the stratospheric air masses over Tomsk. The sharp decrease of correlation with passing through zero is observed in this altitude range in summer, that is caused by the prevalent effect of photochemical processes in the middle stratosphere in summer.

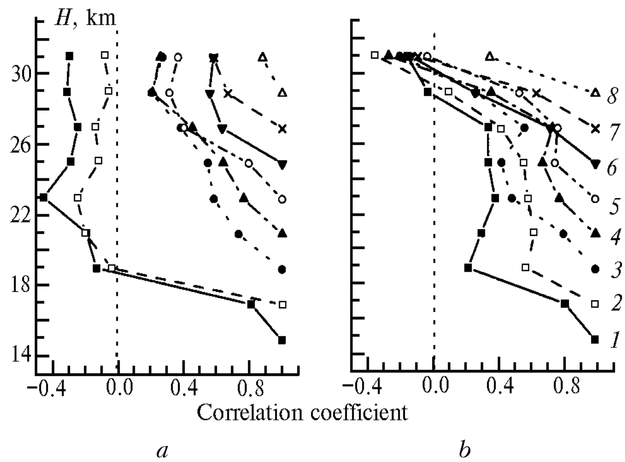

Fig. 3. Inter-level correlation functions of the ozone content in the layers 14–16 (curve *1*), 16–18 (*2*), 18–20 (*3*), 20–22 (*4*), 22–24 (*5*), 24–26 (*6*), 26–28 (*7*), and 28–30 km (*8*) in winter (*a*) and summer (*b*).

The analysis of correlation of the ozone content in each layer with the total ozone content was carried out for the same 2-km-thick layers. The results are shown in Fig. 4 as vertical profiles of the correlation coefficients. We expected the more close positive relation to be revealed in the range of the ozone maximum both below and above it, especially with its more variable lower part. But it occurred that the ranges of positive relation are limited by the altitudes of 18–24 km in winter and 20–28 km in summer at the significance level 0.4. Comparing them with the seasonal ozone maximum positions, one can say that the ozone content in the upper part of the maximum with the specific ozone content 30% better correlates with TOC both in winter and summer.

So unexpected, at first sight, result is in good agreement with the result of analysis of the inter-level ozone relations shown in Fig. 3. The significant inter-level relation in the altitude range 19–27 km is evidence of the fact that the ozone layer in this range behaves as a whole. Approximately 30% of ozone is contained in this layer. Of course, one can suppose that such a relation of TOC and stratospheric ozone is evidence of the specific climatic peculiarities of our region or of observations in 1998. At least, one should pay attention to this fact in further investigations.

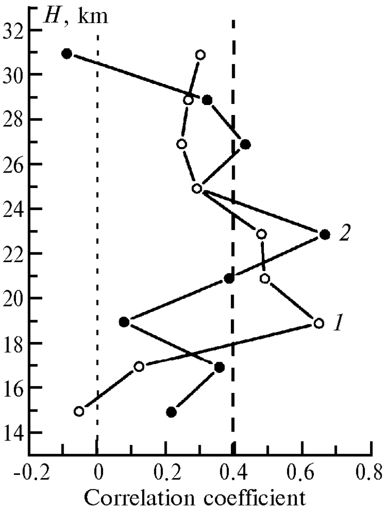

Fig. 4. Correlation between ozone content in each layer with TOC in winter (curve *1*) and summer (curve *2*).

Considering OVD over Tomsk, one should also note the altitude range near 25 km. It is interesting that the winter and summer mean ozone profiles and their variances cross at the same altitude, 25 km. The local minima of correlation of the layer and total ozone content are also related to this altitude.

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