LIDAR AND SPECTROPHOTOMETRIC MEASUREMENTS OF VERTICAL DISTRIBUTION OF OZONE, NITROGEN DIOXIDE, AND TEMPERATURE IN THE STRATOSPHERE OVER TOMSK (WESTERN SIBERIA)

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At present lidar and spectrophotometric measurements of stratospheric ozone, nitrogen dioxide, and temperature at the Siberian Lidar Station (SLS) in Tomsk are directed to study dominating atmospheric processes determining the variability of the vertical distribution and total content of ozone. The results of these integrated measurements and synoptic analysis show that a high positive correlation between temperature and ozone and a variable correlation between ozone and nitrogen dioxide are observed in the lower and middle stratosphere for synoptic periods with strong dynamic activity of the stratospheric circulation processes. Sufficiently high negative correlation between ozone and nitrogen dioxide is observed in the periods with homogeneous stable circulation and weak dynamic activity. The highest negative correlation between ozone and nitrogen dioxide in winter–spring may be observed for a seasonal change of the stratospheric circulation transfer.

1. INTRODUCTION

It is well known that the ozone variability is caused by a combination of three main factors, namely, atmospheric dynamics and chemistry and solar radiation. Petzoldt et al.[1] carried out investigations and revealed a correlation of stratospheric temperature, total ozone content, and baric formations in the troposphere. McKenzie et al.[2] carried out spectrophotometric measurements of vertical distribution of minor gas components in the stratosphere and investigations of their correlation.

Lidar observations of the behavior of the stratospheric ozone layer over Tomsk (56.5°N, 85°E) have been carried out at the Siberian Lidar Station since 1988 (Ref. 3). Measurements of the vertical distribution of nitrogen dioxide (NO_2) with a twilight spectrophotometer by the technique described in Ref. 2 have been performed since November 1995 (Ref. 4).

The aim of this paper is to show the roles and the corresponding contributions of atmospheric chemistry and dynamics to the atmospheric ozone variability.

2. MEASUREMENT RESULTS

Figure 1 shows one of a number of situations observed, which illustrates the correlation between the ozone vertical distribution (OVD) and the temperature vertical distribution (TVD) in the stratosphere over Tomsk in February 1996. It is well seen that the temperature profile obtained on February 5 fits the model TVD[5] and the ozone profile fits the Kruger model OVD. The enhanced temperature of the layer within the 15–25 km altitude range observed on February 12 (approximately by 10 K) correlated with the presence of a large ozone amount in this layer. Later, on February 20, the temperature decrease correlated with the decrease of the ozone content at altitudes 15–25 km, which led to a good fit of the lidar profiles to the model distribution. Very high ozone content in the layer 15–30 km was observed on February 22. The significant increase of the temperature by 10–30 K corresponded to this event. The OVD and TVD observed on February 28 approached their model values.

Figure 2 shows the typical vertical distribution of NO_2 in the morning and in the evening. As a rule, the altitudes of the morning and evening maxima coincided or the morning maximum was slightly higher. In the majority of cases, the amplitude of the evening maximum exceeded the morning one. That is in agreement with running of photochemical reactions in the stratospheric cycle of NO_x family.

3. DISCUSSION OF THE MEASUREMENT RESULTS AND SYNOPTIC ANALYSIS

As is well known, the behavior of NO_2 in the stratosphere is in antiphase with the ozone behavior (the nitrogen catalytic cycle of ozone destruction). However, under real conditions it is difficult to observe this correlation and to estimate the distribution of ozone and NO_2 due to the prevalence of the dynamic factors of transfer in the lower and middle stratosphere.

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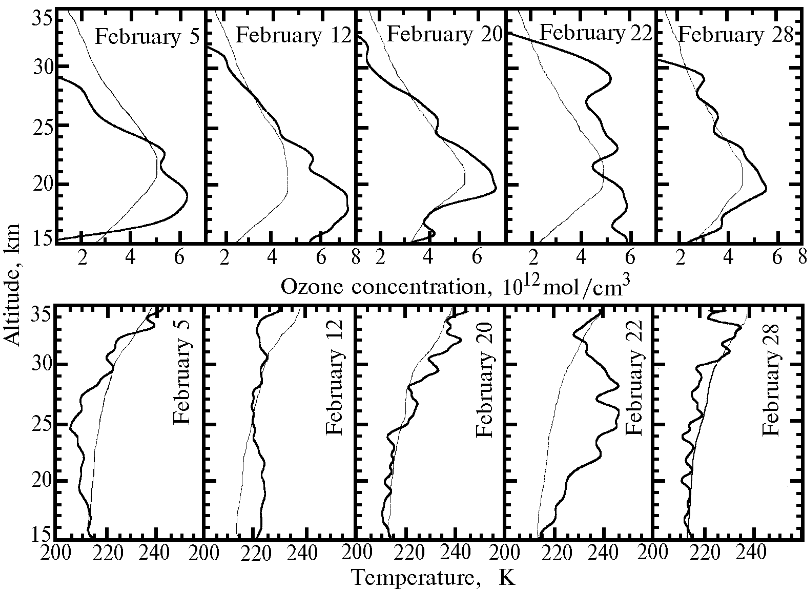

FIG. 1.

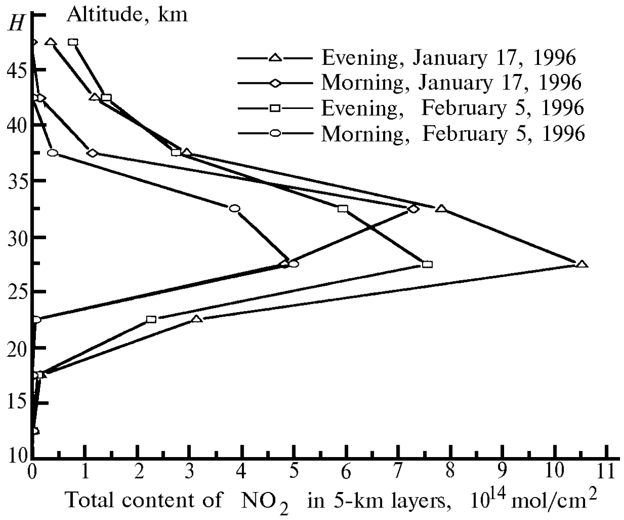

FIG. 2.

The synoptic situations in the stratosphere with stable homogeneous circulation processes and low dynamic activity, when the temporal oscillations of the meteorological parameters have the minimum variance and the normal law of their distribution is not violated, are principally observed during the warm period. However, situations during the periods with unstable atmospheric circulation and high dynamic activity observed in winter and spring are of the greatest interest for investigation of the photochemical relations of ozone with other minor gas components of the atmosphere.

The wind velocity and turbulent transfer, i.e., the dynamic factors, decrease down to their minima in the middle and lower stratosphere during the periods of a seasonal change of the stratospheric circulation transfer. Then the effect of photochemical processes on the content and distribution of the photochemically active atmospheric components in these layers should be maximum.

An analysis of the synoptic data for February and March 1996 showed the following state and evolution of thermodynamic processes in the stratosphere over Tomsk.

The stratospheric circulation in the latter part of February had well expressed zonal character with strong west-to-east wind throughout the stratosphere; the warm blocking anticyclone and high cold tropopause were observed in the troposphere. The heating of the stratosphere was observed in the last ten days of February followed by the circulation change to the summer regime in the first and second ten days of March. The heating and the increase of the geopotential of isobaric levels in the middle and lower stratosphere caused the break of zonal circulation and the intensification of its meridional component, which resulted in the formation of the elevated baric ridge in the lower stratosphere (below a level of 50 hPa) with a change of the circulation transfer to the east-to-west one.

The period with the calm stratosphere corresponding to the period of a change of circulation transfer over Tomsk in spring 1996 reflected in the behavior of the ozone and NO_2 content retrieved from the data of lidar and spectrophotometric measurements. It is well seen from Fig. 3 in the period between the 55th and 73d days, which shows the temporal variability of the total ozone content in the layer 25–30 km, NO_2 in the layer 20–35 km, and temperature at a level of 50 hPa.

It is seen from the curves that weakening of the ozone transfer caused by the decrease of the dynamic activity of stratospheric circulation down to the minimum at the instant of the circulation change caused, on the one hand, the decrease of the ozone content due to its catalytic destruction in the nitrogen cycle, on the other hand, this ozone decrease resulted in the increase of NO_2, because photochemical production of NO_2 continued, whereas its sink on ozone decreased. As a whole, as is seen from Fig 3, although the total ozone content decreased, it remained rather high due to the intense ozone formation in the stratosphere during this period.

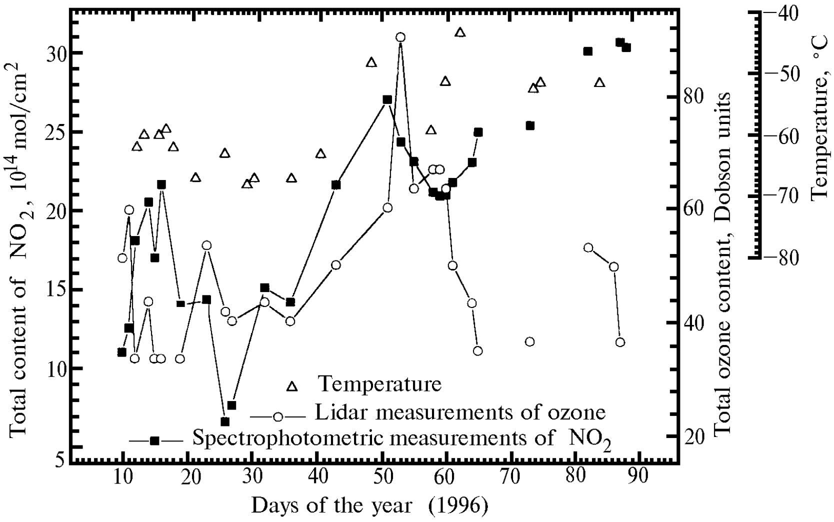

FIG. 3.

4. CONCLUSION

Simultaneous analysis of lidar and spectrophotometric measurements and synoptic data showed that a high positive correlation between temperature and ozone and a variable correlation between ozone and nitrogen dioxide are observed in the middle and lower stratosphere during the synoptic periods with strong dynamic activity of stratospheric circulation processes. Rather high negative correlation between ozone and nitrogen dioxide is observed during the periods with homogeneous stable circulation and low dynamic activity. The highest negative correlation between ozone and nitrogen dioxide in winter and spring can be observed for a seasonal change of the stratospheric circulation transfer.

In this case, it is rather difficult to observe the well-pronounced periods of the stratospheric circulation in winter and spring, when the effect of dynamic factors is minimum.

Thus, the fact is confirmed that the dynamics of the atmosphere is the predominating factor of the variability of minor gas components in the lower and middle atmosphere.

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