RESULTS OF A COMPLEX EXPERIMENT ON OPTICAL MONITORING OF THE OZONOSPHERE AT SIBERIAN LIDAR STATION

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Some results of the analysis of measurements carried out at Siberian Lidar Station of the Institute of Atmospheric Optics, SB RAS in Tomsk (56.5°N, 85°E) *in February and December of 1996, are presented. The complex measurements include lidar measurements of the vertical distribution of ozone (VDO) and temperature (VDT) in the stratosphere, spectrophotometric measurements of the total ozone column (TOC), and vertical distribution and total column of nitrogen dioxide (VD/TC* NO_2*). The analysis of anomalous fluctuations in the ozone observed has shown their good connection with the behavior of circular-synoptical processes on the global scale. It is noted, that the unusual VD* NO_2 *is connected with the positive anomalies in TOC; no explicit relation of the ozone behavior to* NO_2 *at negative anomalies in TOC was found. The comparison of the results obtained with the synoptical ones has confirmed the potentiality of such a complex approach to investigation of the ozonosphere from one observational point.*

1. INTRODUCTION

In spite of numerous investigations, the problem of studying the atmospheric processes and mechanisms responsible for the ozone behavior is now urgent as before. To solve this problem, a complex for optical observations of the state of the upper troposphere and stratosphere has been created and is still under development at the Siberian Lidar Station (SLS) of the Institute of Atmospheric Optics SB RAS in Tomsk (56.5°N, 85°E). The instrumentation, measurement techniques and the results of investigations have been described in our previous papers (see the references in Ref. 1 and Refs. 2–7).

This paper is aimed at joint analysis of the results of simultaneous measurements of ozone, nitrogen dioxide and temperature in the stratosphere performed in December 1996 in the frameworks of the complex experiment, as well as an attempt to interpret the dynamical processes in the stratosphere on the basis of this analysis.

2. METHODICAL AND GEOPHYSICAL PRINCIPLES OF THE COMPLEX EXPERIMENT

The methodical basis for the optical observations of the ozonosphere are complex measurements and analysis of some atmospheric parameters and components, namely:

– lidar measurements of the vertical distribution of stratospheric ozone (VDO);

– lidar measurements of the vertical distribution of stratospheric temperature (VDT);

– spectrophotometric measurements of the vertical distribution and total content of the nitrogen dioxide (VD/TC NO_2);

– spectrophotometric measurements of the total ozone content (TOC).

The complex approach based on the methods of analytical and statistical comparison allows one to reveal both general and specific features and processes causing the spatio-temporal behavior of the atmospheric parameters and components under study.

It is well known[8,9] that the stratospheric ozone content correlates with temperature, because it not only affects the rate of photochemical reactions in the stratosphere, but also is an indicator of that or another dynamical stratospheric processes that take part in the redistribution of ozone and other minor gaseous components.

The observations of the nitrogen dioxide in the stratosphere is no less important. This gaseous component plays dominating role in the nitrogen catalytic cycle of the stratospheric ozone destruction, the portion of which is up to 50% of the total catalytic ozone destruction.[8]

It is also known that the ozone and nitrogen dioxide have a well pronounced zonal distribution[8–10] which is characterized by an increase in the content with the latitude increase. Ozone has such a distribution during all year, only the amplitude of the seasonal behavior increases from low latitudes to the polar ones. The distribution of nitrogen dioxide, as a

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more photochemically active component, is different in winter when its total content quickly decreases from the latitudes 40–50° to the pole. It is caused by the fact that practically all nitrogen dioxide is converted into the reservoir compounds $ClONO_2$ and N_2O_5 under the conditions of deficiency or the absence of shortwave solar radiation in high latitudes in winter. The maximum gradients in the zonal distribution of the winter field of the total content of nitrogen dioxide at the latitudes of 40–50° form the so-called cliff-effect, the result of which are significant variations in the content of nitrogen dioxide at a certain large-scale circulation processes during the short time intervals (from a day to a week). So, significant variations in the fields of the total content and vertical distribution of ozone, nitrogen dioxide and temperature in the lower and middle stratosphere occur at significant deformations of the zonal transfer observed at activization of the high pressure centers (Asor, Pacific or Asian anticyclones) during the periods of their motion to high latitudes and stabilization.

Thus, by simultaneously observing the ozone, nitrogen dioxide and temperature in the stratosphere, one can reveal the atmospheric processes that affect the content and variability of the stratospheric ozone, and even to make attempt to predict further development of these processes.

However, a question arises: Is it possible to reliably speak about the atmospheric processes, if the data on the vertical distribution and total content of ozone, nitrogen dioxide and temperature have been obtained at one point? The answer is yes. It is confirmed by the climatic differences in the content and distribution of the fields of atmospheric components and parameters and the instability and variability of the atmospheric processes, as was said above.

3. DISCUSSION OF THE RESULTS OF THE COMPLEX EXPERIMENT

The outcome of the complex experiment on the optical observations of the ozonosphere in 1996 are time series of spectrophotometric observations of the total ozone content (Fig. 1), total content (Fig. 2) and vertical distribution of nitrogen dioxide, and the lidar profiles of the vertical distribution of ozone and temperature in the stratosphere.

The most informative bulks of data were obtained in two winter months, February and December. The highest TOC values in 1996 were observed in these months (490, 455 and 456 D.U. on February 12, 22 and 23, respectively, and 464 D.U. on December 27). The unique short decrease of TOC to 196 D.U. was observed on December 5. These periods occurred to be extremely interesting from the standpoint of the anomaly in the development of the synoptic processes, that will be mentioned in the next section. The periods analyzed are marked in Figs. 1 and 2. The 6 and 20-days average curves are also shown, characterizing the mean natural synoptic period and the mean half-period of the long planetary waves in the general atmospheric circulation, respectively.

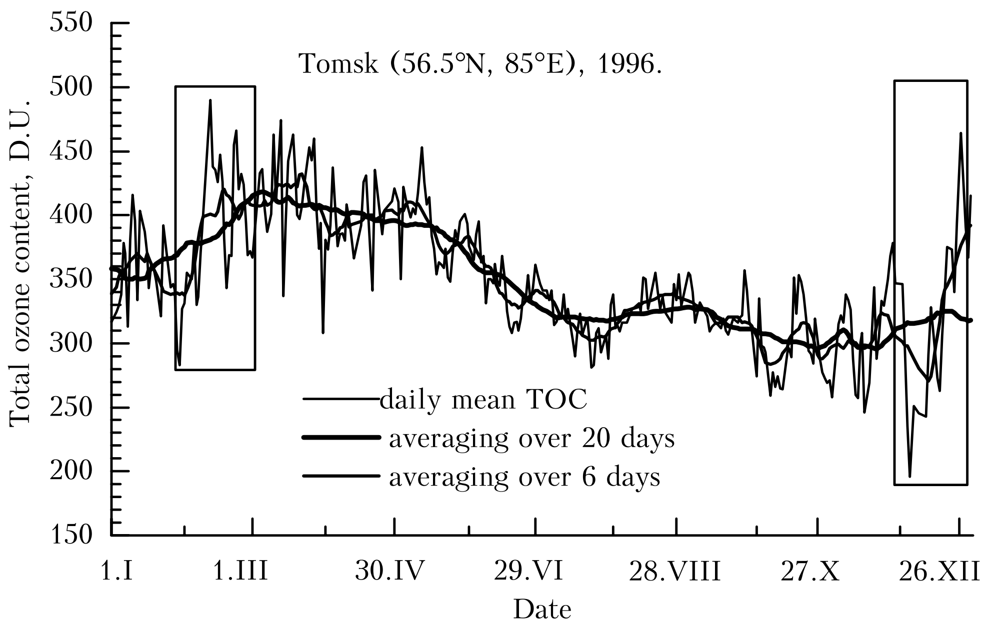

FIG. 1. Temporal behavior of the diurnal mean TOC values over Tomsk in 1996. Averaging over 6 and 20 days is also shown.

The enhanced values of TOC were generally observed in February with the maximum deviation up to +28% of the long-term February average value. The periods with anomalously low TOC (maximum deviation up to –39%) were observed in the first decade of December, and the anomalously high values (up to

+44%) were observed in the last decade of December 1996. No significant deviations in the nitrogen dioxide were observed in these periods. In general, the average behavior of the NO_2 total content repeats the TOC average behavior, the difference is in the amplitude of deviations. Since nitrogen dioxide is more photochemically dependent component of the stratosphere and is less subject to the effect of dynamics than ozone, the variations in the NO_2 total content are less pronounced. But on the other hand, in winter because of the deficiency of the solar radiation the effect of photochemistry on the nitrogen dioxide is also less pronounced in comparison with summer, so in winter the dependence on the atmospheric dynamics is essential.

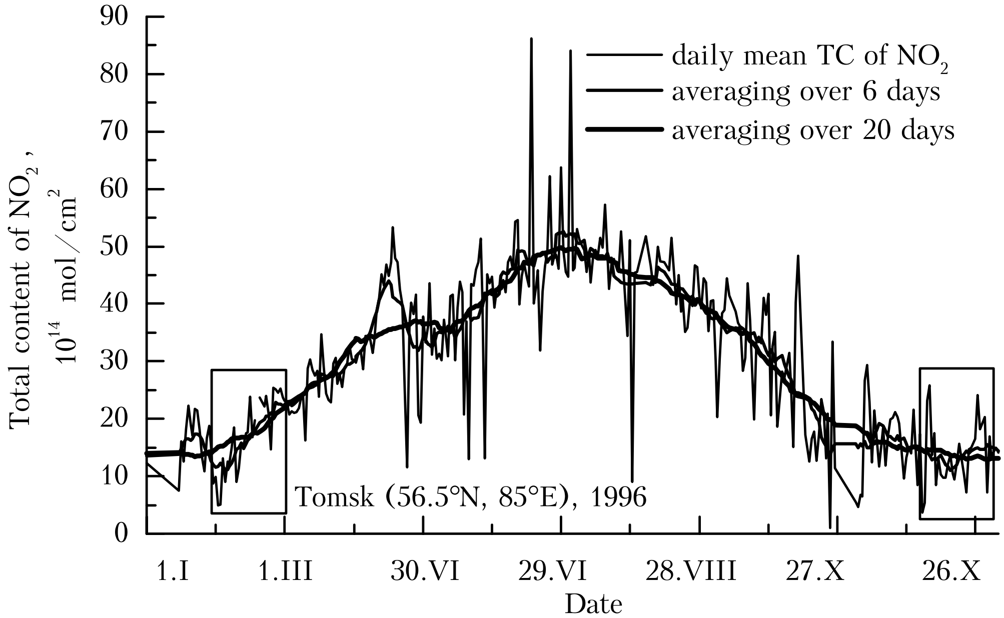

FIG. 2. Temporal behavior of the daily mean values of the NO_2 *total content over Tomsk in 1996. Averaging over 6 and 20 days is also shown.*

The VDO and VDT lidar profiles corresponding to these periods are shown in Fig. 3. As is seen, in the cases when VDO is the most different from the mean model distribution, the most significant difference in the total content is also observed. There can be significant differences in the VDO profiles at approximately the same TOC values, that is well seen from the comparison between the ozone profiles on February, 22 and December, 27. The VDT profiles are also different: there are higher temperature values on February, 12 in the layer with the enhanced ozone content; correlation between temperature and ozone on February, 22 is positive in the middle stratosphere and negative in the lower stratosphere; the anomalously low temperature was observed on December, 27 at the anomalously high ozone content in the lower stratosphere at the altitude of the mean climatic ozone maximum.

Based on the knowledge of the latitude distribution of the fields and vertical structure of ozone and their relations to the pressure fields and circulation processes in the stratosphere,[8–14] one can suppose that the observed differences in VDO are caused by different vertical development of the circulation synoptic processes, namely: the increase of the ozone and temperature in the lower stratosphere on February, 12 was caused by the movement of Arctic air mass to the south and the descending vertical flows in the area of the warm core of the circumpolar cyclone vortex. The indented structure of the ozone profile can characterize the pronounced zonal feature of the stratospheric transfer.[14] Simultaneous increase of the ozone in the lower and middle stratosphere and temperature in the middle stratosphere observed on February, 22 can be unambiguously related to the winter stratospheric warming, and, as a result, to the decrease of zonal component of the transfer. One can assume that significant break of the zonal manner occurred on February, 22, and, as result, the ozone content increased due to the horizontal advection of the Arctic air without a significant change of the temperature regime in the lower stratosphere. The enhanced ozone content observed on December, 27 analogous to that observed on February, 12, and the very low stratospheric temperature are caused, as one can assume, by a significant displacement of the cold part of the circumpolar cyclone vortex to our latitudes. The particular case with the anomalously low TOC was observed on December, 5. The extremely low TOC, 196 D.U., was recorded this day from ozonometric observations. Lidar sounding performed on December, 5 also has shown very low ozone concentrations in the lower and middle stratosphere, though the significant negative temperature deviations were not observed. As is seen in Fig. 1, low TOC was generally observed during the first half of December with the minimum on December, 5.

Similar low values of TOC in winter are characteristic of the tropical zone. As it was noted in Refs. 11 and 13, at the invasion of tropic (or subtropic) air masses into midlatitudes of Arctic resulting from movement to North and stabilization of the high blocking anticyclones (or high ridges) covering the lower stratosphere too, the situations may occur with the low TOC and the characteristically transformed profile of VDO. Analogous VDO was observed on December, 5, when a significant decrease of the ozone occurred above and below the local climatic ozone maximum: below due to the advective replacement of the air mass in the altitude pressure ridge, and above due to the ascending vertical motions in the area of the cold core at the edge of the circumpolar vortex.

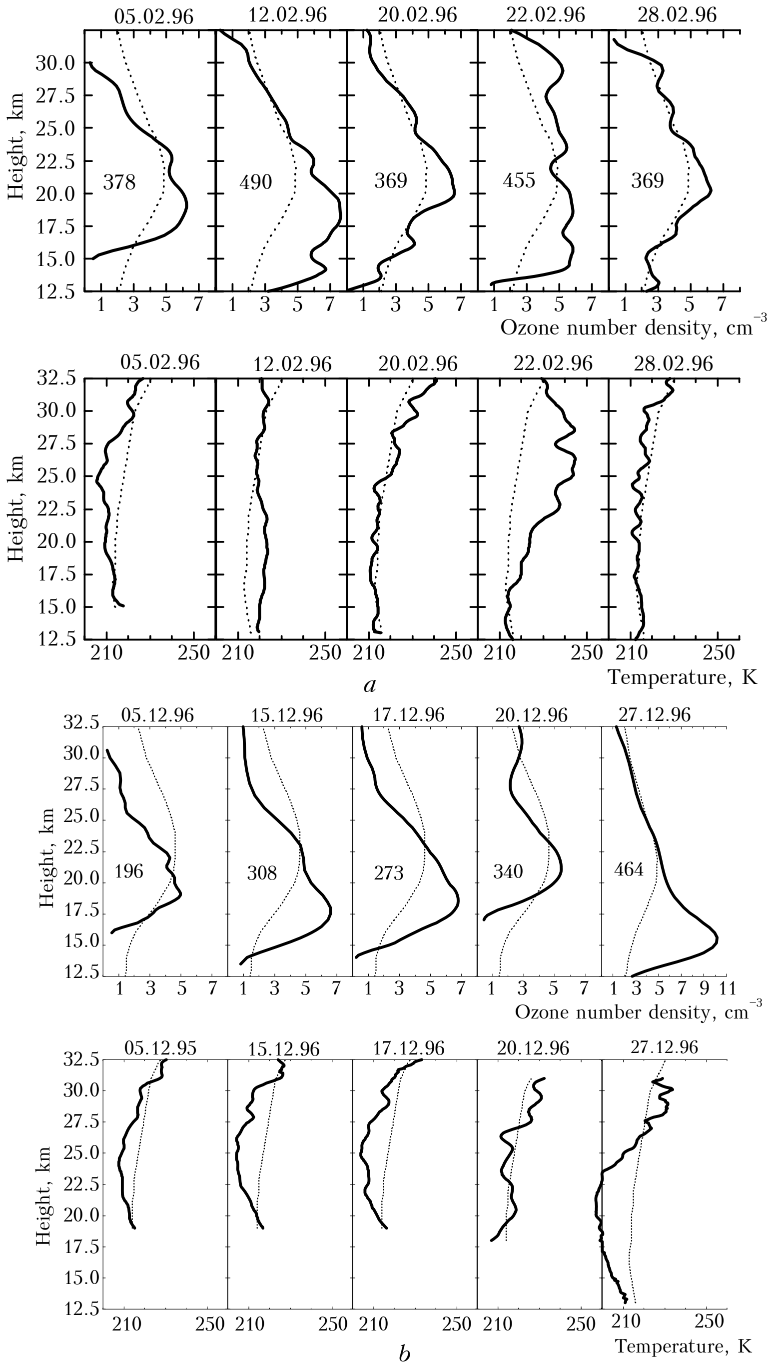

FIG. 3. Vertical distribution of the ozone and temperature in February (a) and December (b) assessed from the data of lidar sounding. Model distributions of the ozone and temperature are also shown and the value TOC in D.U. are presented.

The peculiarity in the vertical distribution of NO_2 is also characteristic of three aforementioned cases with the anomalous positive deviations of TOC and VDO. The spectrophotometric profiles of NO_2 assessed from the data of twilight measurements in the morning and in the evening are shown in Fig. 4. They show the variations of the distribution of nitrogen dioxide in the periods when the positive ozone anomalies were observed. As is seen, the sharp increase in the nitrogen dioxide content, with the maximum at the altitudes of 10–15 km (that is usually situated at the altitudes of 25–30 km), is observed in the lower stratosphere in all three cases 2–4 days before the appearance of the TOC maximum. Then it is seen that the vertical distribution of NO_2 recovers in a day, then it is unstable and becomes stable after the ozone reaches its maximum.

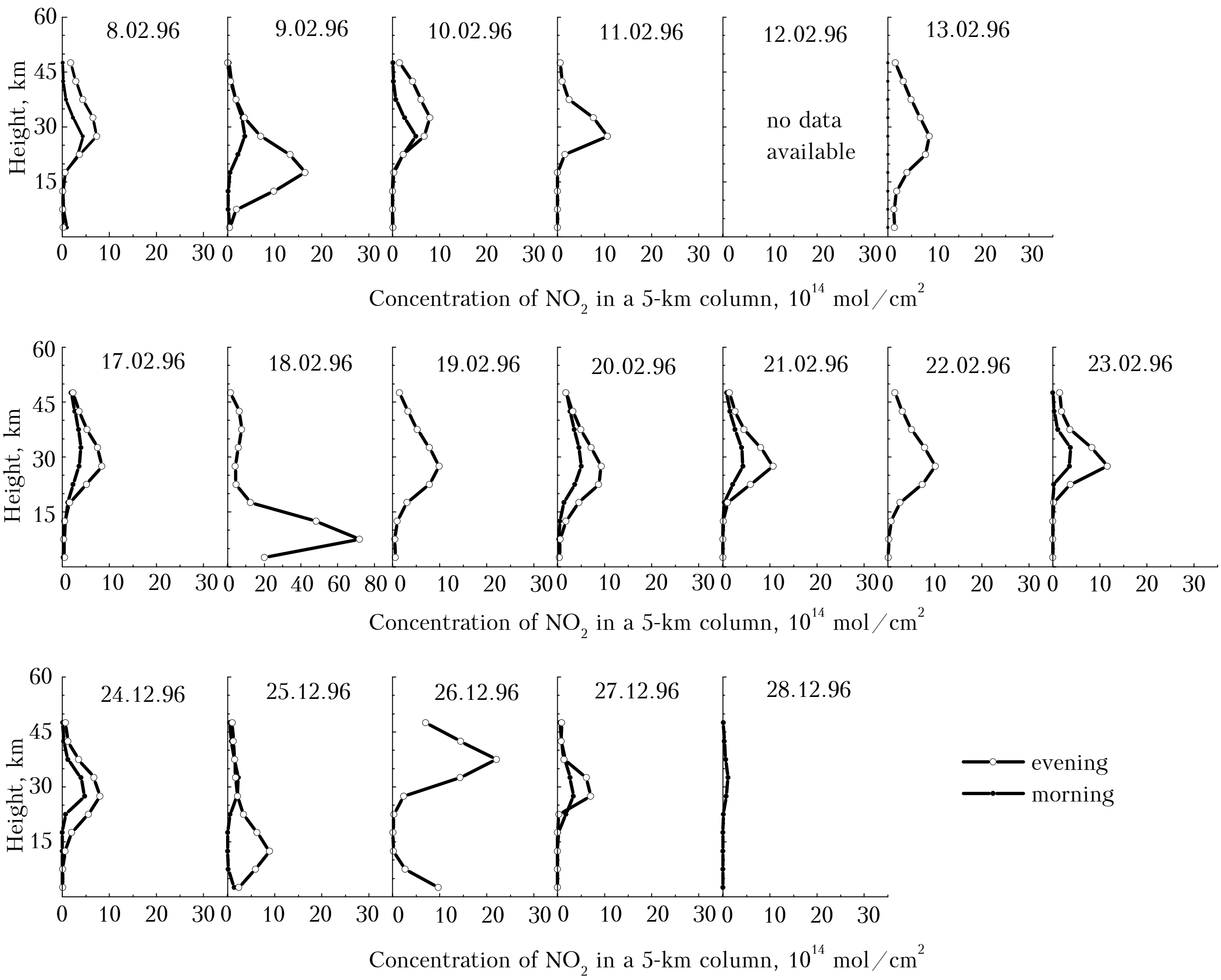

FIG. 4. Vertical distribution of the nitrogen dioxide in the periods of positive anomalies in the ozone observed in February and December 1996 (spectrophotometric data).

We did not observe any significant deviations of the total content of nitrogen dioxide in the first half of December. The instability of the behavior of the vertical distribution of NO_2 was observed: the oscillations of the content maxima and in the day-to-night content ratio.

Possibly, the observed regular behavior of the nitrogen dioxide is caused by the atmospheric dynamics and by the peculiarity in the latitude distribution of nitrogen dioxide in winter, the same as the anomalous deviations of the ozone content. Obviously, a significant displacement of the cold Arctic air mass with the small content of NO_2 but high content of the reservoir compounds ($ClONO_2$, N_2O_5, etc.) from the Arctic night zone to the illuminated midlatitudes leads to an intense photolysis of the reservoir compounds and formation of NO_2 in the first light day after the invasion of the cold Arctic air. Since the mixing ratio of $ClONO_2$ and N_2O_5 in the upper troposphere and lower stratosphere in this air mass is several times greater than at the same altitudes in a midlatitude air mass, the increase of the quantity of regenerated NO_2 initially occurs in the lower stratosphere.

Thus, on the basis of the data of complex experimental measurements carried out at one geographical site, we tried to analyze the atmospheric processes and to show the possibility of such a complex approach to solving the problem of optical observation of the ozonosphere from one site.

4. COMPARISON OF THE RESULTS OF THE COMPLEX EXPERIMENT WITH THE METEOROLOGICAL DATA

To check our conclusions drawn from the discussion of the results of complex experiment, we have carried out synoptic analysis of the situations in the selected periods (February and December 1996), the results of which are presented below. The analysis was carried out using the altitude pressure maps of the absolute topography and the aerological data obtained in Novosibirsk.

In the first half of February stratospheric circulation had a well pronounced zonal character with a strong west wind in all stratosphere. It was caused by the displacement of the circumpolar cyclone vortex to the lower latitudes, that caused the increase of cyclonic behavior and intensification of the high tropospheric cyclone, in the zone of which Tomsk was found.

In the beginning of the second half of February stratospheric circulation over Tomsk also had, in general, well pronounced zonal behavior with a strong west wind. Arm blocking anticyclone with high cold tropopause formed in the troposphere that time.

Stratospheric warming occurred in the last decade of February, which preceded seasonal transformation of the stratospheric circulation to the summer regime which took place in the first half of March. Warming and increase of the geopotential altitudes of isobar levels in the lower and middle stratosphere caused the break in zonal behavior of the circulation and intensification of the meridional transfer, that manifested itself in the formation of high pressure ridge and in the change of the transfer direction in the lower stratosphere (up to the level of 100 hPa) to the east one. The increase of temperature when warming occurred from above to below and was related to the movement of the warm center in the area of the high frontal zone to the high latitudes, which is usually observed at the activization and displacement of the high pressure centers to the higher latitudes in the periods of stratospheric warming.

Two periods were observed in the stratospheric circulation over Tomsk in December: anticyclonic in the first decade and cyclonic in the second half. The altitude pressure fields had very high pressure gradients and strongly deformed zonal transfer in both the first and second periods.

The wide, high, warm blocking anticyclone with the pressure more than 1055 hPa with the center over South Ural and a powerful cold cyclone over the North-East part of Yakutia were observed during the first period in the troposphere and lower stratosphere. The cold core of the Arctic circumpolar vortex was situated in the middle stratosphere above the anticyclone. Then the cyclone expanded, the lower pressure field transformed, but retained.

In the second period the lower pressure field covered practically all territory of Russia and moved to the Middle Asia, the center over European part of Russia became sharper, and was partially filled over Yakutia. The observed deformation of the low pressure field occurred due to the movement and stabilization of the North-Pacific and Asor anticyclones in high latitudes. The North-Pacific anticyclone blocked the zonal flow over Chukotka and Alaska, right up to Scandinavia. In the middle stratosphere there was an altitude trough of the circumpolar vortex displaced to lower latitudes.

Comparing the results of the analysis of data of complex measurements and the synoptic analysis, one can see their good agreement. This means that the complex approach proposed to investigation of the atmospheric processes and ozonosphere from one observation site is correct and viable.

5. CONCLUSION

Complex lidar measurements carried out at SLS in 1996 in the frameworks of optical observations of the ozonosphere and the analysis of the results of February and December measurements showed that:

– three cases of the anomalous increase in TOC were observed during these months (on February 12 and 22–23 with maximum deviation from the monthly average value up to +28% and on December 27 with the deviation up to +44%), and one case of anomalous decrease (on December 5, up to –39%), which were unambiguously connected with the analogous periods in the behavior of TOC and are well pronounced when averaging over 6 and 20 days;

– the observed anomalies of the TOC behavior can be related to the evolution of the circulation-synoptic processes caused by the migrating long planetary waves, braking of which by the high blocking anticyclones causes a significant break of the zonal behavior and intensification of the meridional transfer, that results in an intense advective transfer of air masses and ozone;

– apart from the significant advective change of the ozone content in the lower stratosphere, in the observed anomalies the change of the content can take place in the middle stratosphere due to the developed vertical motions caused by the sharp high pressure formations;

– it was revealed that the unusual vertical distribution of the nitrogen dioxide concentration is connected with the positive anomalies in TOC, when a sharp increase in the nitrogen dioxide content occurs in the lower stratosphere 2–4 days before appearance of the TOC maximum, and at the end of day it occurs in the upper troposphere. We suppose that this effect is a consequence of the motion of Arctic air and regeneration of nitrogen dioxide from the reservoir compounds;

– we did not reveal any explicit relations between the ozone and nitrogen dioxide behaviors at the negative anomalies of TOC;

– it was observed that, in general, in winter the behavior of NO_2 total content coincides with that of TOC, but has lower amplitude, that is an evidence of a great influence of the atmospheric dynamics on the NO_2 total content in winter;

– the analysis of data of complex measurements of ozone, nitrogen dioxide, and temperature, aimed at the interpretation of the atmospheric processes, in comparison with the results of synoptic analysis, confirmed the potential ability of the complex approach to investigation of the ozonosphere from one site.

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