QUASI-BIENNIAL OSCILLATIONS OF VARIATIONS OF TOTAL CONTENT AND VERTICAL DISTRIBUTION OF STRATOSPHERIC OZONE AND AEROSOL ACCORDING TO OBSERVATIONS AT SIBERIAN LIDAR STATION (56.5°N, 85.0°E)

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ABSTRACT

We analyzed quasi-biennial oscillation (QBO) in time behavior of integrated aerosol backscattering (IABS) coefficient in the stratosphere and total ozone (TO) content according to data of observations at midlatitude Siberian lidar station (Tomsk: 56.5°N, 85.0°E) for period 1986-2002. For background state of the stratosphere under conditions of extended volcanically quiet period 1996-2005, data of lidar measurements of vertical distribution of stratospheric aerosol and ozone are analyzed. The presence of quasi-biennial oscillations in variations of integrated content and vertical distribution of stratospheric aerosol and ozone is demonstrated. In westerly QBO phase of variations of average zonal wind velocity in the equatorial stratosphere, for midlatitudes of Tomsk an increase of integrated aerosol scattering and decrease of TO content are observed. Conversely, in the easterly QBO phase a decrease of IABS and increase of TO take place. The vertical distribution of stratospheric aerosol and ozone show an analogous pattern. In addition, we demonstrated the presence of seasonality in variations of aerosol content, with its larger content in winter-spring than in summer-fall period. The presence of seasonality and quasibiennial oscillation, with increase of aerosol content at middle latitudes in periods of intensification of winter-spring meridional transport from tropical belt to midlatitudes and in westerly QBO phases, is evidence in favor of hypothesis on the presence of tropical reservoir of background stratospheric aerosol.

1. INTRODUCTION

Ozone and aerosol are passive tracers of stratospheric transports. Their variations reflect seasonal, quasibiennial, and other cycles of variations of stratospheric circulation, resulting in change of aerosol and ozone transport from reservoir regions to middle and high latitudes.

The stratospheric aerosol content inferred from lidar data can be characterized by integrated aerosol backscattering (IABS) coefficient ΣB_A at height H 15÷30 km. At the Siberian Lidar Station (SLS) in Tomsk, laser sensing of stratospheric aerosol layer (SAL) at wavelength λ=532 nm is performed since 1986. During this time, series of measurement data is accumulated both for conditions of perturbation of the stratosphere by powerful volcanic eruption (Pinatubo, 1991), and conditions of extended volcanically quiet period after 1995. Ozone content in the stratosphere constitutes predominating part of its atmospheric concentration (ΣO_3); therefore, all TO variations are determined primarily by ozone variations in the maximum of ozone layer in the lower stratosphere. Regular TO observations are performed at SLS using spectrophotometric device M-124 since 1993. They show good agreement with ΣO_3 values obtained by satellite instrument TOMS for location of Tomsk [2]. The correlation coefficient of TO time series, measured at SLS in Tomsk and by TOMS is 0.95. This allows us to extend TO time series of observations over Tomsk retrospectively back to 1986 supplementing it with TOMS data. The TO time series over its complete span can be considered stationary, with well-defined seasonal variations with maxima in winter-spring period and minima in summer-fall period. The vertical distribution of stratospheric ozone is measured at sensing wavelengths 308/353 nm using the method of differential absorption and scattering since 1989.

2. QUASI-BIENNIAL OSCILLATIONS IN VARIATIONS OF INTEGRATED CHARACTERISTICS OF STRATOSPHERIC OZONE AND AEROSOL

To smooth the seasonal variations in time series which, especially for TO time series, are dominating, we used the procedure of one-year running mean. As a result, variations with periods somewhat longer than two years (QBO), as well as other long-period variations, became distinctly seen. For instance, in the smoothed TO time behavior we can clearly see a minimum (late 1991 – late 1995), with span coinciding with time interval extending through period during which volcanic aerosol was present in the stratosphere and had depression effect on ozone.

Further preparation of initial data for correlation analysis was to reduce them to time series with zero mean and remove strong perturbations of SAL and ozonosphere in the interval 1991-1995. For instance, the pro-

cedure of removal of TO dip, caused by negative influence of volcanic aerosol, was performed as follows. The ΣO_3 time series was subjected to 26-month fast Fourier transform (FFT) filter Φ_{26}, which subsequently was subtracted from the smoothed ΣO_3 series:

$$\Delta O_3(t) = \Sigma O_3(t) - \Phi_{26}(t), \qquad (1)$$

where t is the time. The absence of stationarity in the series ΣB_A, caused by the presence of volcanic aerosol in the interval 1991-1995, substantially complicates approximation of its long-period variations using a single function with subsequent its subtraction from initial values. Therefore, the time series ΣB_A was divided into three independent time intervals (January1986 - June 1991, January 1992 – December 1995, March 1996 – December 2003). Taking into account that ΣB_A on the interval January 1992 – June 1994 drops exponentially [3], its values were subject to logarithm operation. On each of the three time intervals, own linear trend was determined.

$$\Lambda(t) = A + B\,t, \qquad (2)$$

which then was subtracted on the corresponding intervals:

$$\Delta \ln B_A(t) = \ln \Sigma B_A(t) - \Lambda(t). \qquad (3)$$

The series $\Delta \ln B_A(t)$ and $\Delta O_3(t)$, flattened and reduced to zero mean by the above-mentioned method, are presented in Figs. 1a and 1c, respectively. In addition, Fig. 1b shows time series of zonal wind velocity (ΔD)for the 30 mb level in equatorial stratosphere, based on the data taken from [4].

Letters E and W in Fig. 1 denote the sections of ΔD time series with easterly and westerly directions of zonal wind velocity, determining the corresponding QBO phases. It is clearly seen that the variations of IABS and TO over Tomsk in different QBO phases are 180° out of phase. At the same time, the westerly phase is characterized mainly by increase of IABS and decrease of TO; whereas easterly phase, conversely, by decrease of IABS and increase of TO. Thin lines in Fig. 1 illustrate approximations of the full time series of experimental data based on the least squares method using the functions of the following form:

$$Y(t) = A \sin(\pi \frac{t - t_C}{w}), \qquad (4)$$

where t is time in months; A is amplitude, while w is half-period of oscillations; t_C is phase shift (this same formula was used for approximation of experimental data series on the three chosen time intervals; however, the model series thus obtained are not presented in Fig. 1 in order not to overload it). The correlation analysis has shown that, not only for ΔD but also

$\Delta \ln B_A$ and ΔO_3, the correlation coefficients R considerably exceed the confidence level (0.8; 0.6, and 0.5, respectively).

The results of the studies show that in the time behavior of integrated aerosol backscattering coefficient and total ozone over West Siberia, variations modulated by quasi-biennial oscillations of zonal wind velocity in the equatorial stratosphere are clearly manifested. Noteworthy, in the stratosphere over Tomsk increased (decreased) aerosol and decreased (increased) ozone are mainly observed in westerly (easterly) phase.
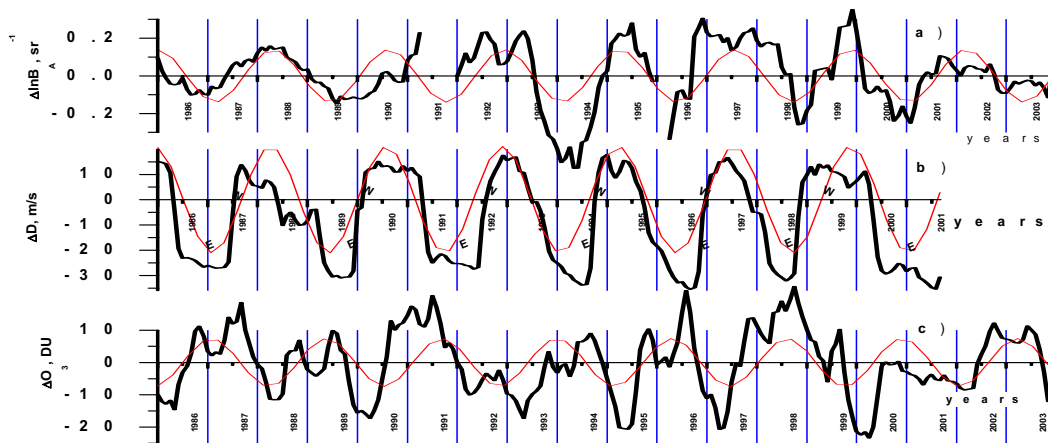

Fig. 1. Time behaviors of $\Delta \ln B_A$ (upper curve), the mean zonal direction of wind velocity ΔD (middle curve), and ΔO_3 (lower curve).Thin lines, superimposed on these time series, are their approximations by *sin* function.

3.QUASI-BIENNIAL OSCILLATIONS IN VERTI-AL DISTRIBUTION OF STRATOSPHERIC AEROSOL AND OZONE

Vertical distribution of stratospheric ozone is determined from laser sensing data as altitude distribution of concentration of ozone molecules. The vertical distribution of stratospheric aerosol is represented in the form of profiles of scattering ratio R, defined as the ratio of the sum of coefficients of aerosol backscattering β_π^A and molecular scattering β_π^μ to β_π^μ. We analyzed the profiles of vertical distribution of stratospheric aerosol and ozone, obtained under background conditions of extended volcanically quiet period 1996-2004. All the profiles were averaged over three months: January, February, and March. Moreover, we separately averaged the profiles pertaining to easterly and westerly QBO phases, which were determined using monthly mean zonal wind components in equatorial stratosphere, based on the data measured in Singapore (1°N, 104°E) [5] for the 30 mb level. For the analyzed months in 1996, 1998, 2001, and 2003, easterly QBO phases were observed; and those in 1997, 1999, 2000, 2002, and 2004 were characterized by westerly phases. The results are presented in Figs. 2 and 3. The horizontal lines show standard deviations for arrays of ozone and aerosol profiles in easterly and westerly QBO phases. Larger aerosol content is observed in westerly QBO phases, and larger ozone content in easterly QBO phases. Noteworthy, the differences are most marked in the lower stratosphere, up to heights approximately 22 km.
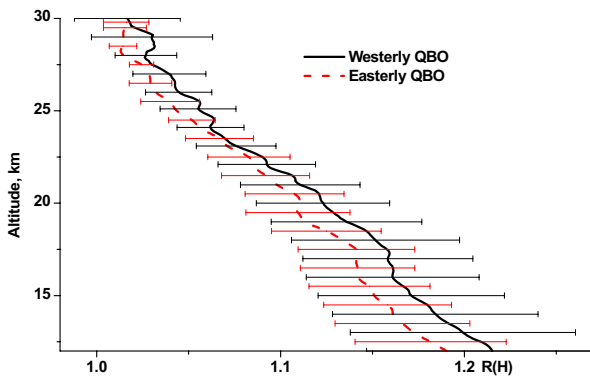

Fig.2. Average (JFM) aerosol backscatter ratio profiles for the westerly and easterly phases of the QBO.

Nonetheless, difference in ozone and aerosol contents in different QBO phases is also observed at higher altitudes. Figure 4 shows altitude behavior of deviations of ozone content (Fig. a) and aerosol (Fig. b) in easterly and westerly QBO phases from average for entire analyzed period. Maximum deviations for aerosol are observed in altitude ranges 18-20 km and above 25 km.

For ozone, the maximum deviations take place in the region 16-22 km; and the second weak peak of increase of deviations is in the region 27-28 km. The presence of two peaks of deviations is also seen in the profiles of modulation coefficient of altitude variations of ozone and aerosol contents under influence of QBO (Fig. 5.), calculated using data of Figs. 2 and 3 as the ratio of difference of maximum and minimum values of ozone (aerosol) content at a certain altitude to the sum of these values.
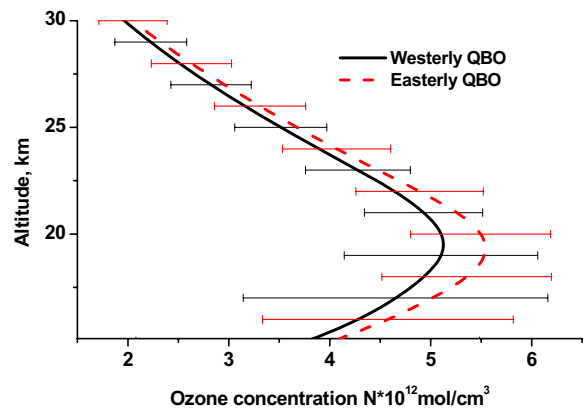

Fig.3. Average (JFM) ozone profiles for the westerly and easterly phases of the QBO.

It is seen that the largest modulation of ozone and aerosol contents under influence of QBO in the equatorial stratosphere is observed in the altitude regions (17-21) km and above 25 km.
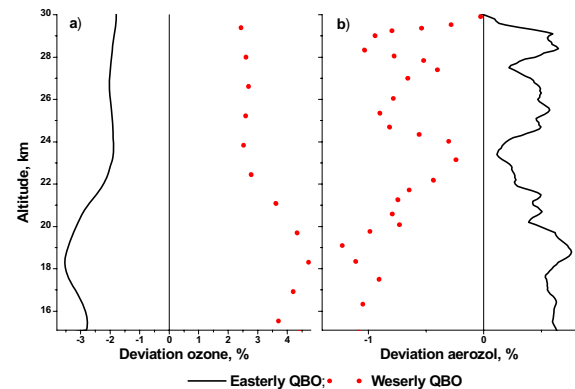

Fig.4. Deviation of aerosol and ozone for the westerly and easterly phases of the QBO from average (JFM) profiles.

The presence of two maxima in the distributions, possibly, is associated with two regimes of transport from tropical reservoir, namely the "upper" and "lower" regimes [1].
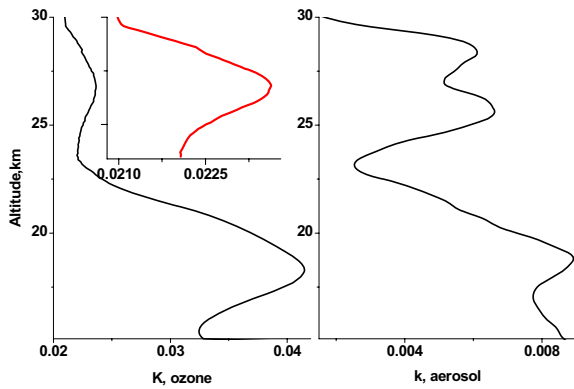
Fig.5. Coefficients of modulation of variations of stratospheric ozone and aerosol contents under influence of quasi-biennial oscillations. Separately, K,ozone is given on a larger scale in the inset in left-upper part.

4. DISCUSSION AND CONCLUSIONS

The increase of ozone content in easterly QBO phase in comparison with westerly phase at midlatitudes corresponds to observations of QBO in variations of ozone content according to data of measurements using Solar backscatter ultraviolet (SBUV) spectrometer on Nimbus 7 [6] in tropical and middle latitudes. In easterly QBO phase, ozone-rich Arctic air masses are transported into middle latitudes of Tomsk. In westerly QBO phase, the meridional transport from tropical belt to high latitudes prohibits this transport.

According to the climatology of stratospheric aerosol [1], increase of aerosol content in the stratosphere of middle latitudes in westerly QBO phase is associated with intensification of meridional aerosol transport from tropical belt to the middle and high latitudes in this time period. Moreover, this process is observed in winter-spring period. Figure 6 presents half-year average profiles of altitude distribution *R(H)* for measurement period November 2000 – May 2005. For averaging, ~ 60 profiles of summer-fall period and ~ 80 profiles of winter-spring period were used. At altitudes below 22 km, insignificantly larger *R(H)* values in winter-spring period in comparison with summer-fall period for background conditions of extended volcanically quiet period remain.

The presence of seasonality and quasibiennial oscillations, with increase of aerosol content at midlatitudes in periods of intensification of winter-spring meridional transport from tropical belt to the midlatitudes and in westerly QBO phases, is an evidence in favor of hypothesis on the presence of tropical reservoir of background stratospheric aerosol. The recent models of background sulfate aerosols, obtained using atmospheric general circulation models with inclusion of chemical processes, also show [7,8] that the formation of new aerosol particles by homogeneous nucleation takes place predominately in the tropical lower stratosphere.
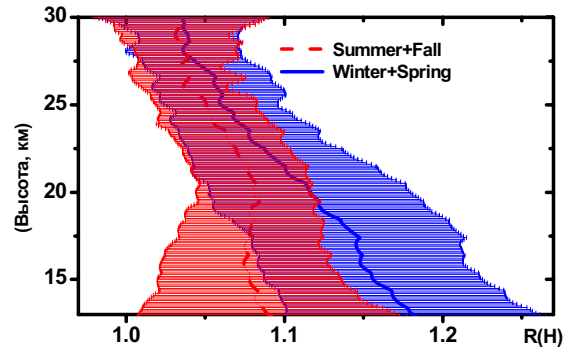

Fig. 6. Seasonally mean profiles of vertical distribution of stratospheric aerosol (dashed line for summer + fall, solid line for winter + spring). Thin lines show corridors of standard deviation.

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