Long-term variability of the ozonosphere: retrospective and perspective

V.V. Zuev and S.L. Bondarenko

Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

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In this paper we continue discussion on the long-term variability of the ozonosphere. We consider natural factors causing the behavior of the ozonosphere. Reconstruction of paleobehavior of the ozonosphere over Arosa station in Switzerland has made it possible to predict future variations of the ozone layer for a period of several years. According to the prediction the decrease of TOC in the last quarter of the 20th century does not exceed the level of natural variations of the ozonosphere in the past, and the present-day state of the "unperturbed" ozonosphere does not contradict the period of phase change of long-term variations. In support of this statement the time behavior of TOC is given in the form of deviations from the long-term mean over Tomsk from 1996 to 2002, which is characterized by a statistically insignificant near-zero trend.

It is well known that the problem of the ozonosphere variability is being debated for a long time until the present day. The long-standing question in the investigation of stratospheric ozone is the question on the role of anthropogenic factor in the observed variations. There exists a recognized version of technogenic destruction of the Earth's ozone layer. According to this version the behavior of the longest series of measurements of the total ozone content (TOC) in Arosa (Switzerland) is treated as an invariable mean TOC level up to the middle 70s of the twentieth century with its subsequent sharp decrease from the second half of the 1970s (Fig. 1*a*).[1] The present paper describes an alternative version[2] of interpreting the behavior of the same series of TOC in Arosa as an incomplete cycle of long-term variations of the ozonosphere. The series approximation by a sinusoid enabled us to determine the period of variations of the ozonosphere to be about 110 years (Fig. 1*b*). Forecasting of the subsequent variations of the ozonosphere based on the reconstruction of ozone behavior in the past allows one to refine the contribution of a technogenic factor to this process.

It should be noted that normal behavior of the ozonosphere in the last quarter of the twentieth century was distorted due to the increased volcanic activity of explosive type during this period. Figure 2 shows the time dependences of TOC over Tomsk from 1979 to 1999 (*a*) and the behavior of the total backscatter coefficient β_π^a for the stratosphere at mid-latitudes from 1976 to 1999 (*b*). The TOC series was constructed using TOMS satellite data for Tomsk coordinates and data of ground-based observations using an M-124 ozonometer, performed in Tomsk at the Siberian Lidar Station (SLS).[3,4] The series of β_π^a presents the integrated data of laser sounding of the stratosphere in Garmisch-Partenkirchen, obtained at 694.3 nm wavelength[5] as well as the data obtained in Tomsk at SLS at 532 nm wavelength.[6]

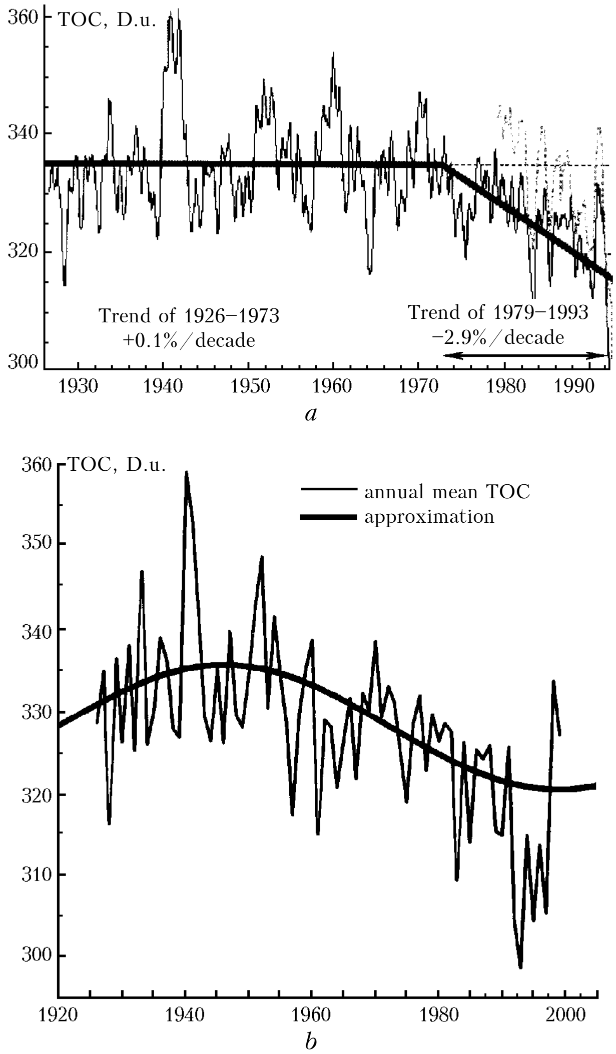

Fig. 1. The behavior of a series of measurements of TOC in Arosa (Switzerland). Version of WMO (*a*); version of long-term cyclic variations of the ozonosphere (*b*).

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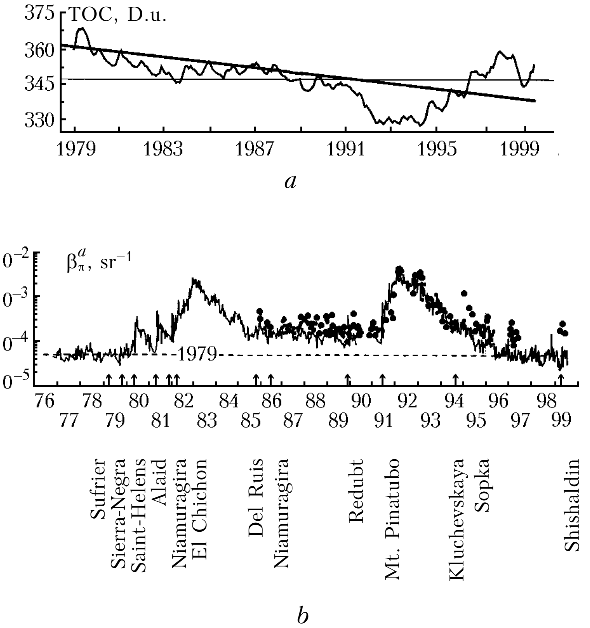


Fig. 2. Time series of TOC over Tomsk from 1979 to 1999 (*a*) and the variation of the net backscattering coefficient β^a_π for the stratosphere of mid-latitudes from 1976 to 1999 (*b*).

From the behavior of TOC and β^a_π variations in Fig. 2 it is clearly seen that the sharp decrease of TOC starting from the late 1970s to the first half of the 1990s is due to the increase of aerosol content in the stratosphere after several eruptions of volcanoes of explosive type. The eruption of Mt. Pinatubo in 1991, the most powerful in the twentieth century, was the last in this series. It caused the largest drop of the TOC level reaching its minimum in 1993. Later on, the TOC values rapidly grew back to the normal level and already in 1998 the TOC values reached the level observed in the 1970s.[7] Thus, the basis for a sharp decrease of TOC value at mid-latitudes of the Northern Hemisphere during the above period is the increased activity of explosive volcanoes, which is natural factor and not the effect of technogenic freons.

But, on the whole, the long-term variations of the ozonosphere are not quite determined by the volcanic activity. The version of long-term cyclic oscillations of the ozonosphere (Fig. 1*b*) was confirmed when investigating the behavior of the ozonosphere in the past, which could be reconstructed from dendrochronological data (for Arosa) over a period of almost 500 years.

Dendrochronological data present a discrete (during the vegetative period) time series of the annual ring parameters characterizing its width and density. All the variations of dendrochronological parameters reflect the physical response of a tree and its ecological system to the impact of the environment. These impacts are always multifactor.[8] Therefore in identifying the specific factors a problem arises of selecting conditions under which a specific factor produces a response that is more pronounced in the dendrochronological signal.

The main factors, affecting the dendrochronological data, are the humidity and temperature. The contribution of their influence on the growth of trees is about 60%.[9] However, at present it is suggested to consider, as a significant factor, the level of UV-B solar radiation controlled by the ozone layer of the Earth's atmosphere.[10]

The association of characteristics of ozone layer and dendrochronological data (TOC and the density of annual ring, respectively) is based on the effect of UV-B radiation on the growth and productivity of plants. It is well known that the ozone layer absorbs the short-wave part of UV-radiation. Thus, the smaller is TOC, the greater is the level of UV-B radiation, and vice versa. Among types of trees, the conifers, especially fir-tree and cedar, are the most sensitive ones to the UV-B radiation.[11] The increase of the UV-B-radiation level, as a rule, results in a stress of the trees. The stress manifests itself in variation of all indices of their development including morphological and structure characteristics of the trees. The stress results in a decrease of the crown, in shortening the lifetime and in the change of pine-needles density, as well as of the rates of increase of the cross section of the trees. The stress action of the UV-B radiation on the trees can manifest itself directly,[12] in particular, because of the violation of mineral feed caused by the variations under the effect of the UV-B radiation of populations of microorganisms in the tree ecosystem providing this feed. The stress is commonly accumulated over a period of many years and can be manifested with a delay of 2 to 3 years.[13]

We have shown previously the existence of high correlation between the chronologies of arithmetic mean of minimum and maximum density (later on called the density) of the annual ring for one of the variety of conifers Stone Pine (cedar pine) and the TOC values averaged over the vegetative period (April–September) for the region of Arosa.[14] A significant correlation – 0.6 at the probability level $p < 0.0001$ is the basis for reconstruction of paleobehavior of the ozone layer.

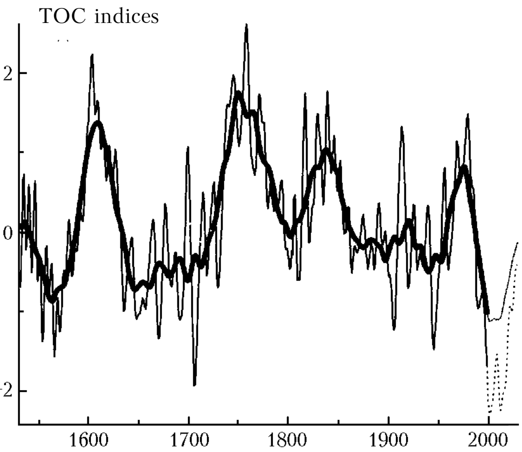
Fortunately, for this region of Switzerland there is a rich base of dendrochronological data and the longest series of observations of TOC as well as the data of meteorological observations that makes it possible to test the validity of the reconstructions performed.

We have used the data of WSL-Birmensdorf (Fritz Schweingruber, Switzerland) recently published in the Internet[15] in the form of standardized (without the age trend) indices of deviations of the annual ring width and its density. The monthly mean TOC values were averaged over the vegetative period (April–September) and transformed to the dimensionless indices $j_x(t)$ by the standard formula $j_x(t) = [X(t) - \text{mean}]/\text{std}$, where $X(t)$ is the value of the variable of TOC series, mean is the mean value, and std is the rms deviation of this series. Time series of TOC indices and densities of annual ring were smoothed by the two-year moving mean that provided not only smoothing of quasi-two year oscillations but taking account of the delay in the tree response to the stress action of the UV-B radiation (altogether with the series shift).

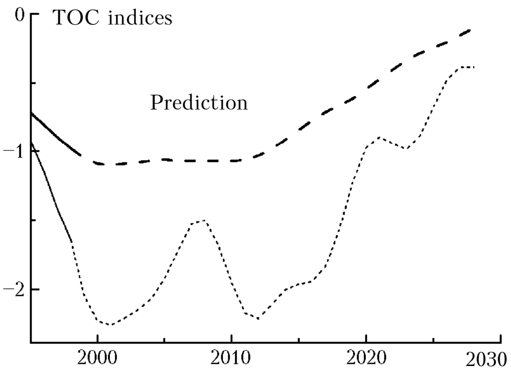
The reconstruction procedure was realized based on the solution of equation of linear regression where the indices of mean density of annual ring of a tree $i(t)$ are the independent variable and the reconstructed indices of TOC $J_x(t)$ are the dependent variable: $J_x(t) = B_0 + B_1\, i(t) + \varepsilon$. In this equation B_0, B_1 are the coefficients calculated in the program package Statistica 5.0 and ε is the error. For predicting the most probable TOC behavior within the next 30 years the method "caterpillar track" was used,[16] which is the analog of the known method SSA (Singular Spectrum Analysis).

Results of reconstruction of TOC indices $J_x(t)$ for Arosa, summarized over three dendrochronologies of the overall duration from 1532 to 1998, are given in Fig. 3*a*.

The behavior of curves illustrate the long-term oscillations of the ozonosphere. The spectral analysis of these oscillations shows the presence of significant cycles with the periods of 11, 22, 47, 77, and 115 years.



a



b

Fig. 3.

The prediction of possible variations of TOC indices over 30 years period is shown by dashed lines in Fig. 3*a*, and, on a shorter time scale, in Fig. 3*b*.

It is evident that already in the first quarter of 21st century the increase of TOC must occur. We also notice that the period of phase variation of long-term variations in the late 20th and early 21st centuries is characterized by small variability of the mean level of TOC. It is just this behavior of "unperturbed" ozonosphere that has been recorded over Tomsk in recent years. The time series of TOC over Tomsk, obtained at SLS from 1996 to 2002 and shown in Fig. 4 as deviations from the long-term mean, is characterized by a statistically insignificant near-zero trend.

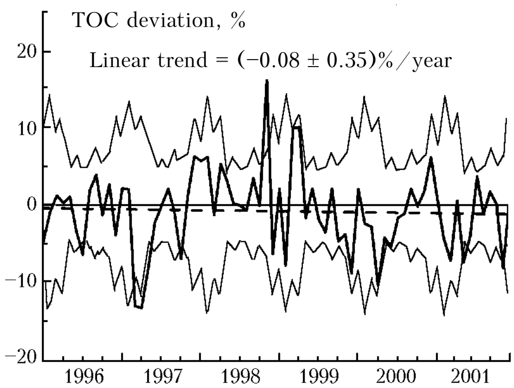


Fig. 4. Deviations of the monthly mean TOC from the norm (1979–1989) over Tomsk (56.48°N, 85.05°E) from 1996 to 2001.

The above considerations and results enable us to draw the following conclusions.

First, the level of technogenic effect on the ozonosphere is highly overestimated. The behavior of the ozonosphere is mainly formed by natural factors.

Second, the TOC decrease in the last quarter of the twentieth century does not exceed the level of natural oscillations of the ozonosphere in the past.

Third, the current state of the "unperturbed" ozonosphere is not contradictory to the period of phase change of the long-term oscillations.

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