Influence of long-term variations of the ozonosphere of the century on the variability of the global CO_2 content in the atmosphere

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In the paper it is shown that CO_2 sink from the atmosphere due to photosynthesis in vegetation biota exhibit significant correlation with the variations of ozonosphere during the vegetation season because of the sensitivity of chlorophyll to variations of the level of UV-B radiation. We present the reconstruction results on centuries-old variations of the total ozone (TO) indices from dendrochronological data collected in different regions of the Eurasian continent. The analysis of long-period variations of TO indices has shown that the depressions of the stratospheric ozone on large spatial scales in 1930s (of natural origin) and in the last quarter of the twentieth century (with the effect of anthropogenic factor) had no analogs in the preceding history for at least 400 years. The increase of the level of UV-B radiation in these periods depressed photosynthesis in vegetation biota, with ensuing considerable increase of global CO_2 content in the atmosphere. These periods coincide with periods of global warming in the twentieth century.

Introduction

Over a period of the past millennium the global content of carbon dioxide (CO_2) in the atmosphere had been retained at the level of 280 ppm, but in the age of industrial revolution the global CO_2 content greatly increased and by now it practically reached the level of 360 ppm.[1] Similar behavior of global temperatures on the Earth's surface provided the basis for models of global changes of the climate due to "greenhouse" effect.[2–4]

It is interesting to note that in the twentieth century the behavior of global temperatures was very dissimilar though the industrial factor has been permanently increasing. In this connection, we should recall the discussion of the climate warming in the 1930s. Note that the rates of the CO_2 concentration rise in the atmosphere in different periods of the industrial age were also different. For example, since 1956 and until 1988, the CO_2 concentration increased from 315.6 to 351.2 ppm, i.e., at the rate of 1.1 ppm/year, while in the period from 1980 to 1990, the rate was already 1.6 ppm/year.[1]

If we shall consider a series of data on the total CO_2 content in the atmosphere in the 20th century,[5] shown in Fig. 1*a* and subtract from it the polynomial (parabolic) trend, given in Fig. 1*a*, then, as a result, two basic maxima of variability of the total CO_2 content are revealed in the atmosphere in the 20th century during 1930s and the end of century. Taking into account progressively increasing contribution to the global cycle of CO_2 of industrial factor a natural question arises: what is the cause of this variability? Which significant factor more is not taken into account by the models of global climate change?

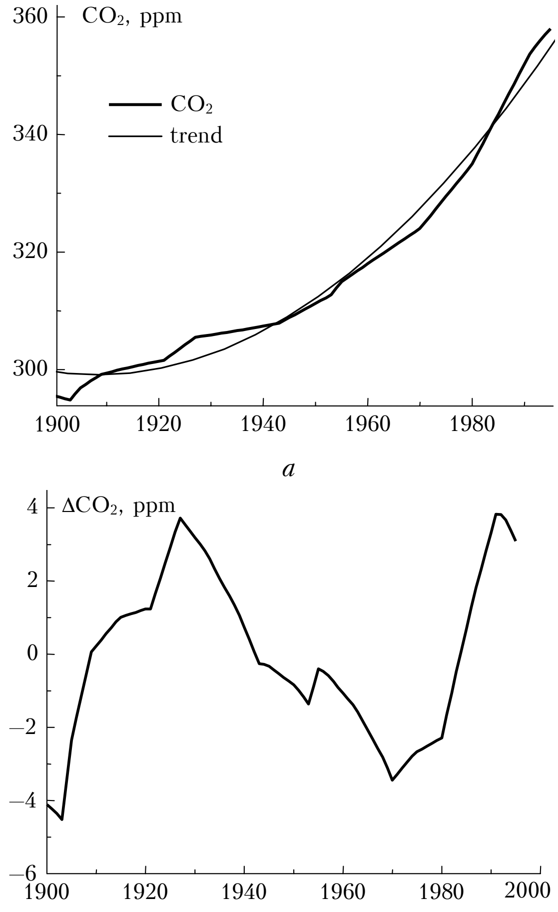

Fig. 1. Time behavior of the global CO_2 content in the atmosphere in the 20th century and its parabolic trend (*a*), and deviations from this trend of global CO_2 content (*b*).

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Statement of the problem

If we look at the balance of the carbon global cycle, given in Table 1 based on data from Ref. 6, a conclusion can be drawn that natural contributions to the carbon cycle exceed many times the anthropogenic contributions. However, the natural contributions are practically completely compensated for in the carbon cycle that makes it possible for the industrial contribution to be distinguished against the natural background.

Table 1. Balance of global carbon cycle in Gt of carbon per year

Sink from the atmosphere		Emission to the atmosphere	
Photosynthesis	120	Ocean	93
Ocean	100	Soil	60
Calcium precipitation	2	Vegetation respiration	60
		Industrial emission	6
		Forest cutting	3
Total	222	*Total*	222

Table 1 shows that the main CO_2 sink from the atmosphere is performed at the cost of photosynthesis in the vegetation biota. In this case, the photosynthesis suppression by a few percent can result in the supplementary increase of CO_2 content in the atmosphere in the amounts, which can be compared with or even exceed the contributions from the industry.

It has been known that the suppressing impact on the vegetation photosynthesis is produced by the UV-B radiation.[1] The level of UV-B radiation, at least, for a clean atmosphere, is controlled by the total ozone content (TOC) because of its absorption especially in the stratospheric ozone layer – ozonosphere.[7] Thus the relation follows between the variations of the ozonosphere and the photosynthetic CO_2 sink from the atmosphere.

This relation has been observed, for example, in the data of instrumental measurements of TOC and CO_2 concentrations over Siberian taiga in summer period.[8]

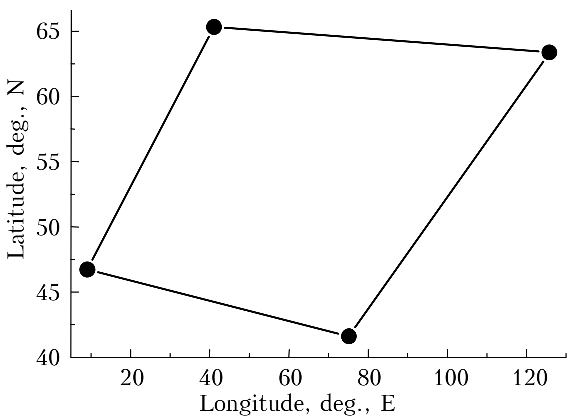

Fig. 2. Diagram in the coordinate plane of analyzed quadrangle, covering a great part of Eurasian continent from Switzerland on the West to Yakutia on the East, from Kyrgyz Republic on the south to Yamal on the North.

The TOC distribution is inhomogeneous in space and time.[9] Usually even in one latitude zone of middle and subpolar latitudes there are regions with low TOC that alternate with zones with high TOC under the effect of polar-frontal jet streams.[10] In integrating these zones on a global scale the averaging of the effect of UV-B radiation on the photosynthetic processes should occur determining the level of the global CO_2 sink varying slightly from year to year. However, for example, in the last quarter of the twentieth century in the middle and especially polar latitudes of both hemispheres the TOC decrease universally occurred at the mean rate of 2.5% during 10 years.[11] This could result in "global depression of photosynthesis" in the vegetation biota favoring a faster growth of the total CO_2 content in the atmosphere.

As indicated above, the CO_2 content in the age preceding the industrial revolution during almost 1000 years did not vary significantly. This raises the question whether the event of global depression of ozone layer in the last quarter of the twentieth century was unique for large spatial scales or it had analogs in the past at this time base. For this purpose we consider a quadrangle (Fig. 2) encompassing a considerable part of the surface of the Eurasian continent. The vertices of this quadrangle are presented by coordinates, for which dendrochronological data are available.

Results of the analysis of the paleobehavior of the ozonosphere based on the dendrochronological data

The influence of UV-B radiation on the photosynthesis of vegetation makes it possible to relate the TOC variations to the dendrochronological parameters using the following chain: solar radiation – ozonosphere (TOC) – UV-B radiation – photosynthesis – growth of plant (dendrochronological parameters). The response to UV-B-radiation effect in the evergreen vegetation can be accumulated with time and can strongly be manifested due to a cumulative effect.[12] Dark coniferous trees (fir, spruce, cedar pine), which are a considerable part of boreal forests, have the strongest radiation sensitivity to the UV-B effect.

Analysis of correlations of TOC indices and dendrochronological parameters, methods, and results of reconstructions of the ozonosphere paleobehavior from the wood-ring chronologies of coniferous trees have been published by the authors in the papers.[13–15]

The TOC values and dendrochronological parameters for the correlation analysis of TOC series and wood-ring chronologies for points of a chosen quadrangle, as before, are taken from Refs. 16 and 17, respectively. Results of this correlation analysis are shown in Table 2.

High values of the correlation coefficients R_{xy} allow us to realize a stable reconstruction of the TOC behavior (Y_i) in the past based on dendrochronological data (X_i) by the linear regression method:

$$Y_i = K_0 + K_1 X_i. \quad (1)$$

The regression coefficients K_0 and K_1 were calculated by the formulae of generalized regression[18]:

$$K_1 = \frac{\sigma_y}{\sigma_x}\frac{B}{A}\frac{1}{2R_{xy}}\left\{\left(\frac{A}{B}-\frac{B}{A}\right)+\sqrt{\left(\frac{A}{B}-\frac{B}{A}\right)^2+4R_{xy}{}^2}\right\}, \quad (2)$$

where

$$A = \sqrt{1-\left|R_{xy}\right|\left(\frac{1-\delta_x^2/\sigma_x^2}{1-\delta_y^2/\sigma_y^2}\right)}, \quad B = \sqrt{1-\left|R_{xy}\right|\left(\frac{1-\delta_y^2/\sigma_y^2}{1-\delta_x^2/\sigma_x^2}\right)},$$

$$K_0 = \bar{Y} - K_1\bar{X}. \quad (3)$$

In the formulae (2) and (3), σ_x and σ_y are the root-mean-square deviations; δ_x and δ_y are the root-mean-square errors of the observation series; $\bar{Y}$ and $\bar{X}$ are the mean values of the series Y_i and X_i. These formulae, taking into account errors of instrumental measurements of TOC and dendrochronological parameters (determined in our case at the level of 2%) enable us to obtain more stable results.

Results of reconstruction of TOC paleodata in the indices for coordinates at the points of a selected quadrangle are shown in Fig. 3*a*. Figure 3*b* shows the periodograms of TOC variations for these coordinates.

In all variations general periods are uniquely manifested associated with a solar cycle of 11 years (11 years and 22 years). Low-frequency oscillations of TOC at each point connected with long-term oscillations of atmospheric circulation, which are characterized by the stratospheric ozone in middle and high latitudes as a passive tracer, have different periods.

We have smoothed the results of TOC reconstruction using the sliding average over a 22 years interval and reduce the smoothed series to one figure (Fig. 4*a*). Figure 4*a* shows that the oscillations of smoothed series are asynchronous practically over the entire 400-year period. This is associated with a characteristic spatiotemporal inhomogeneity of the TOC field on such extended scales. A synchronized decrease in the long-term oscillations of TOC over the entire 400-year interval analyzed is observed only at two parts of the twentieth century: in the 1930s and, especially, in the last quarter of the 20th century. In these periods of the twentieth century the maxima of variations of the global CO_2 in the atmosphere and the maxima of surface temperatures were observed.

Table 2. Evaluation of TOC indices correlations and annual ring density of conifers

Region	Coordinates, N/E	Period, years	Correlation coefficient
Kyrgyz Republic	41°6′/75°15′	1626–1995	–0.65 ± 0.06
Switzerland	46°7′/9°1′	1537–1995	–0.76 ± 0.04
Russia:			
River Vilyui	63°4′/125°8′	1568–1991	–0.61 ± 0.06
River Polui	65°3′/69°5′	1601–1991	–0.94 ± 0.01

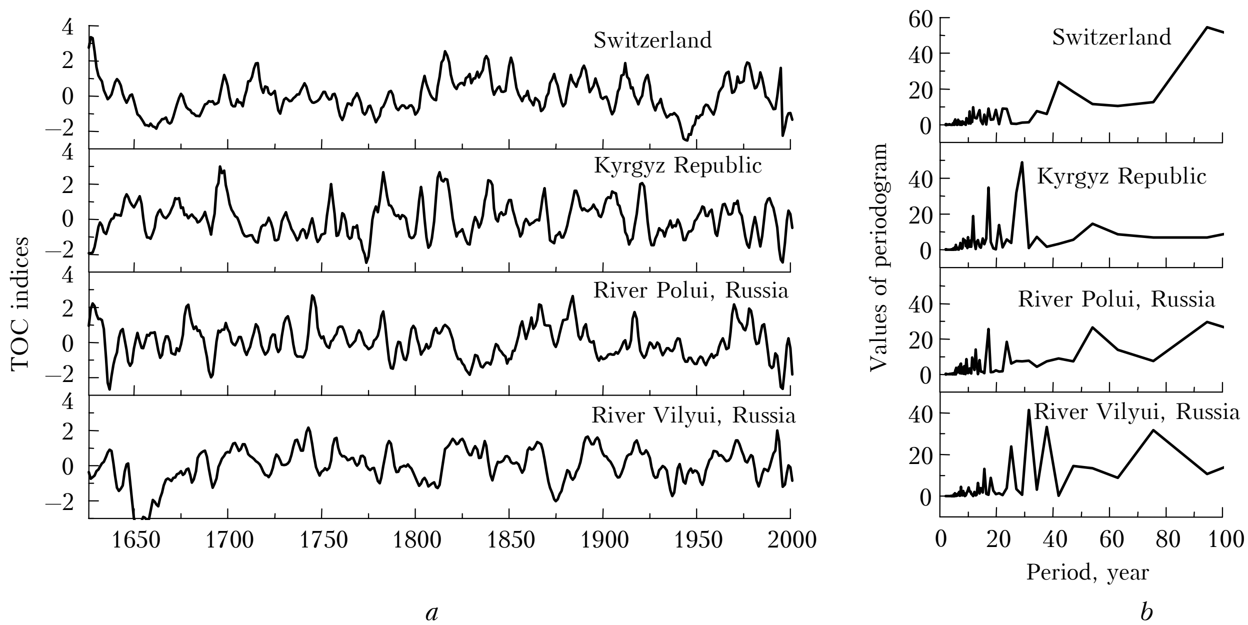

Fig. 3. Results of reconstruction of TOC indices from dendrochronological data (*a*) and periodograms (*b*) of their long-period oscillations.

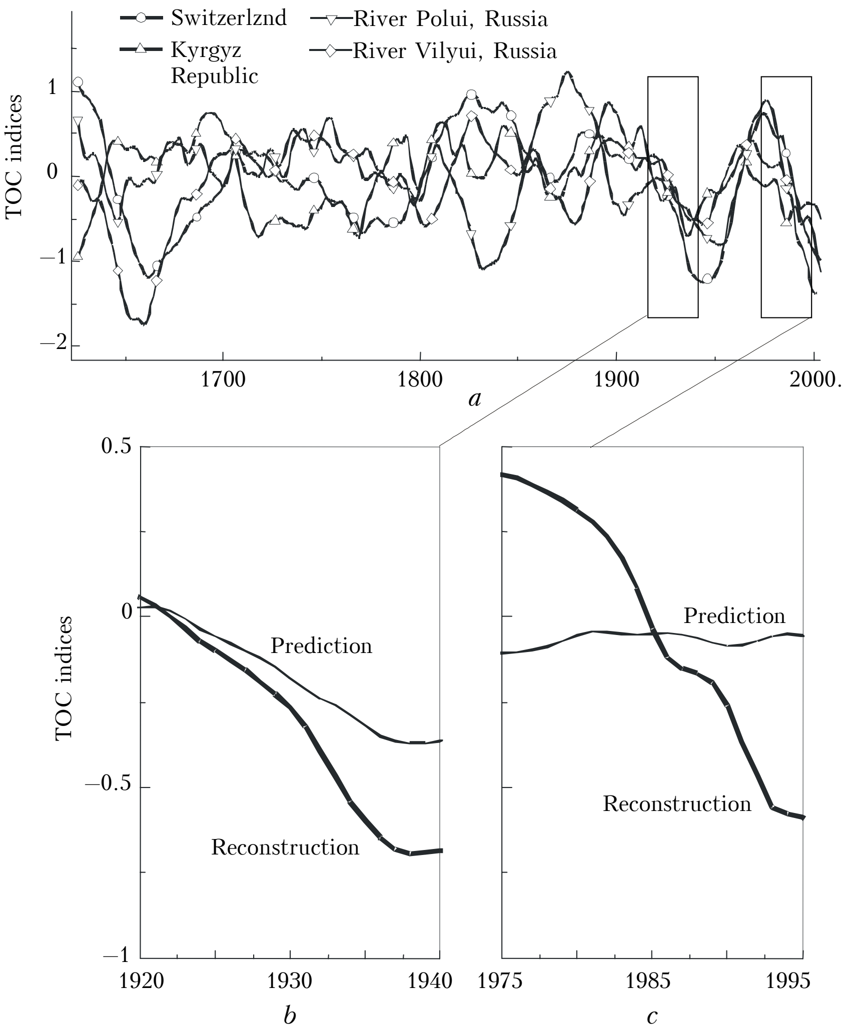

Fig. 4. Time dependences (*a*) of TOC indices reconstructed using dendrochronological data for four coordinates, smoothed by moving average over 22-year interval, and parts of comparison of reconstructed and predicted for 50 years TOC indices averaged at four coordinates over the intervals from 1920 to 1940 (*b*) and from 1975 to 1995 (*c*).

Discussion of results

The results depicted in Fig. 4*a* show that the long-period TOC oscillations in different regions occur, as a rule, asynchronously. The events of the 1930s and the last quarter of the twentieth century had no analogs in a significant part of the northern hemisphere, at least during the past 400 years. It seems reasonable to say that the synchronized decrease of long-period TOC oscillations on global scales is rare. It can be assumed that the event of the 1930s is conditioned by an accidental coincidence of phases of the low-frequency TOC oscillations of natural character with different periods, and the event of the last quarter of the twentieth century happened because of technogenic factor (Freon emissions) enhanced by a long perturbation of the global stratosphere by a volcanic aerosol after a series of volcanic eruptions.[19]

This assumption is confirmed by the results of 50 years predictions of long-term TOC variations performed using the caterpillar method[20] based on long series of reconstructed data. Figure 4*b* shows the results of 50 years prediction of the TOC behavior after 1900 presented for the 1920–1940 interval (the event of 1930s) as compared with the reconstructed TOC values, and Fig. 4*c* shows similar data after 1950 for the 1975–1995 interval (the event of the last quarter of the twentieth century). As an illustration Figs. 4*b* and *c* show only the averaged curves of time dependences of reconstructed and predicted values of TOC indices for four coordinates at the points of the quadrangle being studied. It is evident that the event of 1930s was well predicted based on the preceding history of long-period oscillations, and the event of the last quarter of the 20th century was of anomalous character.

A markedly synchronized decrease of long-period TOC oscillations on global scale must result in “global depression of photosynthesis.” Note that these processes cover not only the vegetation of dry land, but the water vegetative biota, first of all, phytoplankton. The increase of the UV-B radiation destructs the organic solutes (OS) in water that normally absorb residual UV-B radiation thus screening phytoplankton from the UV-B impact.[1] The unprotected phytoplankton is destructed too. The phytoplankton destruction, which stands in the beginning of the trophic chain, affects the population of all water organisms.

Table 3 shows the results of the correlation analysis of volume of catch of smelt and whitefish in Ladozhskoe Lake and monthly mean TOC oscillations in this region.

Table 3. Correlation coefficient (*R*) for the sample from 1946 to 1995 of monthly mean TOC indices smoothed by moving average over two-year wide interval and fish catch in the Ladozhskoe Lake

Month	*R*
Smelt catch and TOC	
April	0.60 ± 0.18
May	0.62 ± 0.17
June	0.94 ± 0.03
July	0.41 ± 0.23
August	0.60 ± 0.18
Whitefish catch and TOC	
March	0.85 ± 0.07
April	0.86 ± 0.07
May	0.51 ± 0.21
June	0.67 ± 0.15
July	0.33 ± 0.25
August	0.83 ± 0.09
September	0.86 ± 0.07

It is evident that TOC oscillations governing the level of UV-B radiation greatly affect the variations in the population of these fishes. Thus, the decrease of TOC on the global scale must lead to reduction of photosynthesis and phytoplankton activity.

In summary, the following conclusions can be drawn.

1. Global low-pressure areas of stratospheric ozone in 1930s and in the last quarter of the twentieth century are rare, having no analogs in the past, at least, in the years from 1600 to 2000. Periods of these ozone depressions coincide with the periods of global warming in the twentieth century.

2. Global decrease of the TOC level accompanied by an increase of the UV-B radiation in these periods resulted in the global suppression of photosynthesis in the vegetative biota. As a result, the balance was disturbed in the global carbon cycle because of the decrease of CO_2 sink and, as a consequence, a considerable increase of global CO_2 content in the atmosphere occurred.

3. In all the climatic models for correct prediction of global variations it is necessary to take into account a possible factor of global increase of UV-B radiation.

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