The influence of the ozonospheric variations and the associated solar UV-B radiation on the growth and productivity of coniferous forests

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Received November 12, 2004

The stress effect of the solar UV-B radiation on the growth and productivity of trees is proposed to be taken into account during deforestation and plantation activities. The effect is estimated based on the prediction of natural variability of ozonosphere. The prediction is based on long-period trends of stratospheric ozone paleobehavior for the last 150–200 years. As a result, it became possible to reveal favorable and unfavorable periods for growth and productivity of coniferous trees in the region under study. In the framework of the problem, the information content of satellite monitoring data on the vegetation cover activity (series of the normalized difference vegetation index NDVI) has been treated. The results of the correlation analysis of time series of the total ozone content (TOC) and NDVI for coniferous forests are presented.

Introduction

Changes in the short-wave solar ultraviolet (UV-B) radiation level affect the functioning of forest ecosystems. In large doses the UV-B radiation causes a change in the processes of metabolism, photosynthesis, and damages the genetic apparatus of plants. In its turn, variations of the UV-B radiation level are mainly determined by oscillations of ozonosphere, which absorbs its most part. Thus, there appears some relation between the growth and productivity of forests and the ozonospheric variations.

It is possible to assess the variations occurring in forest ecosystems under the action of the UV-B radiation based on the growth of tree trunks and their phytomass using the characteristics of wood-ring chronologies of the growth of conifers, as well as by means of the normalized difference vegetation index NDVI, which correlates well with the forest productivity.

Specific differences in relations between the total ozone content and dendrochronological characteristics of conifers

It follows from the literature data that not all species of plants are equally sensitive to the UV-B radiation. Among the species of trees the conifers are the most sensitive, especially the fir-tree and the cedar.[1] In dendroclimatic investigations the number of collected chronologies, based on the form of conifer rings with a clearly defined structure is different. This is connected not only with their physical-chemical characteristics, but also with the susceptibility of the trees to destruction. Earlier we have shown that the greatest sensitivity to the UV-B radiation effect is typical of conifers with a low wood density: a spruce, a fir, and a cedar.[2–4] But these species are exposed to destruction to a greater extent, in particular, because of trunk rot. Chronologies on the pine-tree and the larch are presented more often in the dendrochronological data banks. The pine-tree rings are wide and clearly defined, but the larch chronologies are more long-term. The synchronism of dendrochronological series of the larch is also higher than that of the spruce and cedar. Therefore, of specific interest are investigations of the total ozone content (TOC) relations with dendrochronological characteristics of the larch.

In the literature,[5–7] the differences in the sensitivity and synchronism of the dendrochronological series are shown depending on the growth conditions and species of specimens. For example, the variability of wood-ring chronologies of the spruce and larch growing at one dendroclimatic area can be not synchronous (the correlation coefficient $r = -0.04$) for some zones of taiga and Altai, and, on the contrary, it can be synchronous for lowland floodplains of the river Ob ($r = -0.55$). This points to the fact that the growth of spruce and larches depends differently on climatological characteristics. The larch as compared to the spruce and the pine-tree, shows a closer relation between the cell size (the indicator of reaction to the stress) and other characteristics of the annual ring. The results presented in these papers support the conclusion that a detailed estimation of regional and even local peculiarities of a chosen dendrochronological material is necessary for the TOC reconstruction.

In the methods for reconstruction of time series of climatic parameter (the temperature and the precipitation quantity), the data on residual (with removing the

0235-6880/05/01–02 111-04 $02.00

autocorrelation resulted from conditions of preceding years) wood-ring chronologies are often used.[6,7] We consider dendrochronological data for a mountain site with the complex landscape and climatic peculiarities (Aroza, Switzerland), for which the longest representative series of TOC observations is available. We have analyzed the autocorrelograms (Fig. 1) of standard chronologies of the density and annual ring width for different tree types.

Figure 1 shows that in the chronologies of the maximal density of the cedar annual rings the autocorrelation is practically lacking, and for the larch, on the contrary, it is significant. The autocorrelograms of chronologies of the annual ring width are characterized by the opposite pattern. The spruce in this regard occupies an intermediate position.

Tables 1–3 show the results of the correlation analysis of TOC time variations based on data of

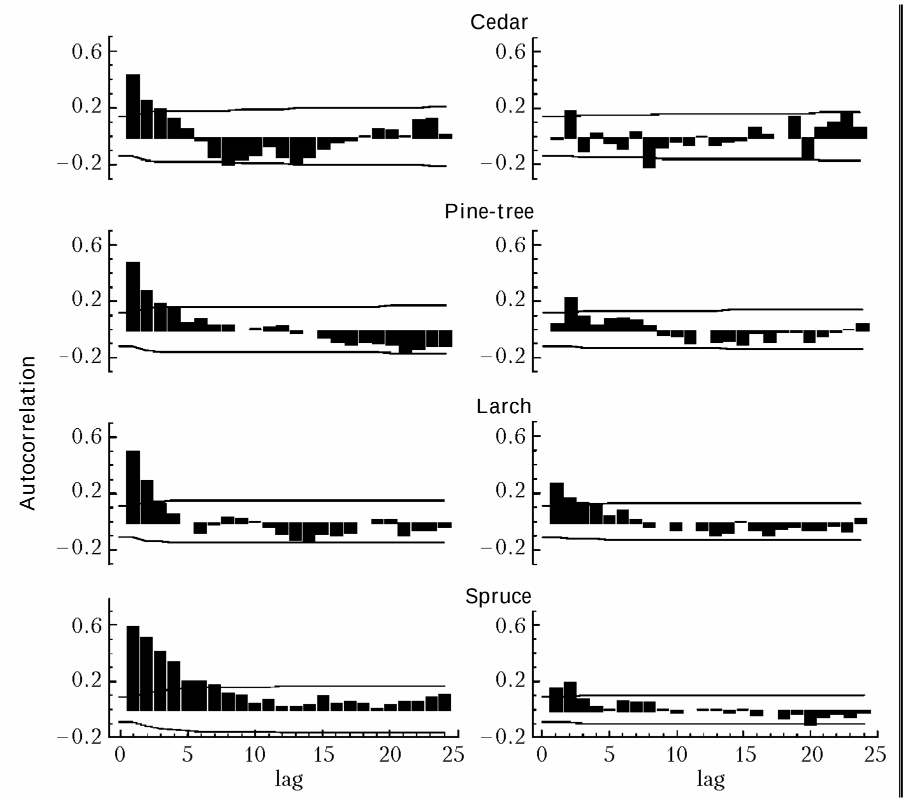

Fig. 1.

Table 1

Parameters	Correlation coefficient of TOC and chronologies near Aroza		
	Pine-tree 58 points	Spruce 58 points	Cedar 49 points
TOC / annual ring width	0.18 ± 0.24	<0.01	0.33 ± 0.25
TOC / maximal annual ring density	−0.34 ± 0.22	−0.56 ± 0.29	−0.6 ± 0.2

Table 2

Larch parameters	Correlation coefficient of TOC and residual chronologies near Aroza (58 points)		
	1	2	3
Maximal annual ring density / annual ring width	0.48	0.16	−0.135
TOC / annual ring width	−0.54	−0.2	−0.25
TOC / maximal annual ring density	−0.45	−0.4	−0.52

Table 3

File	Latitude	Longitude	Correlation coefficient (14–20 points)	
			TOC / larch annual ring density	TOC / larch annual ring width
Yakutia	62°2′	126°7′	−0.17	−0.65
Tyva	50°8′	94°3′	−0.23	−0.7
Ural	57°10′	60°35′	There are no data	−0.6
Nadym	66°1′	71°7′	−0.84	−0.85

ground-based observations near Aroza and residual chronologies of dendrochronological characteristics of the pine-tree, spruce, cedar (Table 1), and the larch (Table 2). Table 3 presents the coefficients of correlation between the satellite data and the data of residual chronologies of the larch for Siberia and the Ural. Significant values of the correlation coefficients are denoted by bold. It is evident that variations of the annual ring density rather than variations of the annual ring width represent the variations of the ozonosphere.

But the annual ring width is a readily determinable dendrochronological parameter, which is present in all databases as opposite to the annual ring density. Therefore, a special attention was given to the analysis of TOC relation with the annual ring width in the larch residual chronologies. Results of the analysis have shown that we can reconstruct the TOC behavior based on this parameter for the larch growing in the lowland conditions. In most cases a significant correlation with TOC for the larch is observed in the presence of synchronism between the chronologies of the annual ring width and the density. The presence of such a relation is almost always true for the North areas, but is unpredictable for Europe.

The relation between TOC and NDVI

It is known that the data on the NDVI agree well with the indices of the forest productivity. The NOAA/AVHRR satellite performs the monitoring of the vegetation cover based on the distinction in spectral chlorophyll characteristics in the visible and near-infrared regions. The oppressed vegetation contains less chlorophyll and has a lower reflectivity in the near-infrared region than the standard one. The difference between reflective powers in two channels varies during the vegetative period and depends on many factors; it is maximal in May and minimal in July. In Ref. 8, the NOAA/AVHRR data on NDVI for forests of Western Siberia are analyzed, from which it follows that an active variation of NDVI takes place in May; the least variation of NDVI is observed during the summer period, when the maximal accumulation of phytomass happens, and in September when the natural destruction of chlorophyll (yellowing leaves) is observed. Since the seasonal dynamics of NDVI for coniferous and birch forests is practically the same, then, based on the birch forest data, we have considered the relation between mean values of NDVI during May–July (the period of intense accumulation of phytomass) and mean TOC variations (TOMS data) from April to July over the territory of Western Siberia (Tyumen' Region, 57°37′N – 72°45′E). Figure 2 shows the smoothed over 2 years curves of the NDVI behavior and TOC variations. It is seen that with increasing variability of TOC the NDVI decreases. Most likely, this is due to slowing down the tree's adaptation mechanisms resulting in the decrease of the forest productivity. The correlation coefficient of series of TOC and NDVI was −0.64 at the probability level $p < 0.025$.

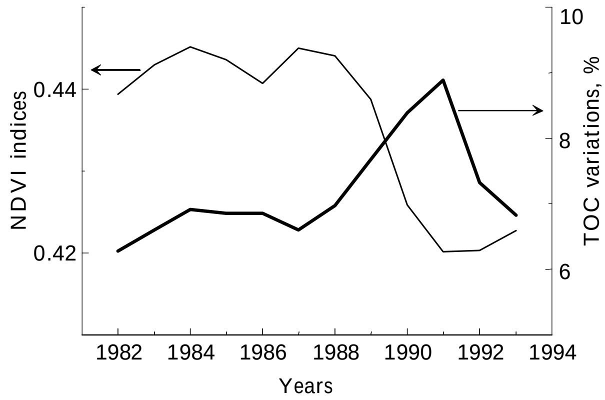

Fig. 2.

Prediction of tendencies in behavior of the ozonosphere and the forest functioning

The tree life length sometimes exceeds the length of series of instrumental physical observations by hundreds of years. The obtained dendrochronologic information makes it possible to analyze and to reconstruct the series for the periods up to several centuries. The knowledge of long-term climatologic tendencies, favorable and unfavorable for the forest functioning, can give a positive result, for example, when developing measures of rational forest use (tree cutting and planting). A series of experiments is known with positive effects of UV-B radiation on seedlings of conifers.[9] The increase of UV-B radiation level has an adverse effect on the grown-up trees, their growth slows down. Therefore, the cutting and planting of forests should be carried out in periods of minimal values of long-term TOC oscillations.

The effect of the ozonosphere variations and related solar UV-B radiation on the growth and productivity of conifers can be estimated from the results of reconstruction and prediction of natural variability of the ozonosphere based on the significant relation of TOC and density of annual rings of the spruce, fir and cedar as well as the width of larch annual rings.[3,4]

Figure 3 shows the results of the 30-year TOC prediction for regions of the North Ural, 61°3′N – 59°3′E (Fig. 3*a*) and the Lowland Ob, 65°35′N –69°5′E (Fig. 3*b*) based on reconstructions of many-century TOC behavior from the spruce annual ring density. The prediction was performed by the "caterpillar" method.[10] The evident antiphase character of tendencies of the TOC indices variation, as well as of tendencies of the growth and productivity of conifers is seen in these two regions located at a distance about 700 km apart. In the North Ural region, the phase of oppression of coniferous forest growth is enhanced, therefore, the optimal period for forest cutting begins here; and the time of the planting of new seedlings becomes optimal in the Lowland Ob region.

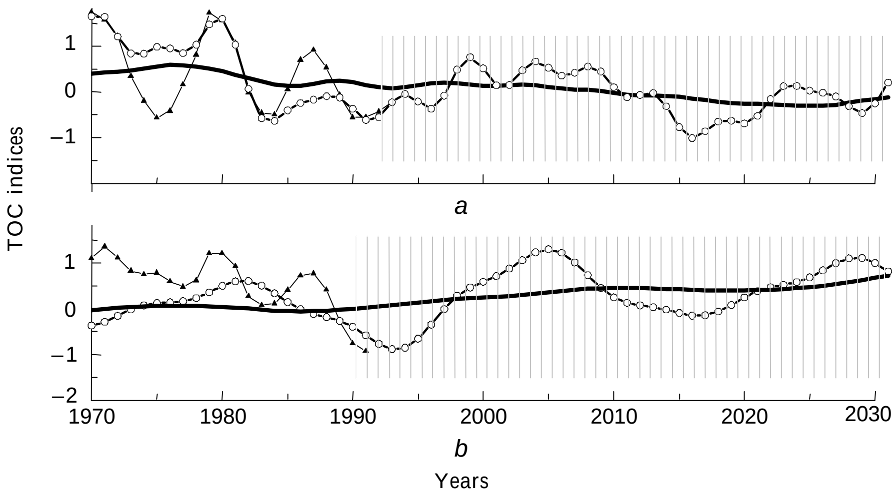

Fig. 3. The results of the 30-year prediction of TOC for the North Ural and Lowland Ob: reconstructed TOC values (triangles), prediction of TOC (circles), the 22-year moving average of TOC (bold line). The prediction range is shaded.

Conclusion

The analysis conducted allows the following conclusions to be drawn:

1. A set of dendrochronological characteristics, used in the reconstruction of the TOC paleobehavior in northern regions, can be extended through the annual ring width of larch chronologies, but in this case it is necessary to take into account more closely the regional and even local peculiarities of the dendrochronological signal.

2. A significant relation was shown for the first time between time series of seasonal variations of TOC and NDVI for forests in the northern part of Western Siberia. This relation occurs, most probably, because of the attenuation of adaptation characteristics of forest ecosystems with increasing TOC variability.

Acknowledgments

In this work, the data given by the scientists of laboratories of dendrochronology of Institute of Forest SB RAS, Krasnoyarsk, and Institute for Ecology of Flora and Fauna UB RAS, Ekaterinburg, were used, as well as data from servers http://www.ngdsnoaa.gov/paleo/treering-wsl.html, http:// jwocky.gs/c.nasa.gov.

This work was supported by the Russian Foundation for Basic Research (grant No. 03–05–65105), Russian Foundation for Basic Research–Ural (grant No. 04–04–96016–p2004 Ural-a), and the Integration Project of SB RAS No. 95.

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