# Peculiarities of composing generalized chronologies of the total ozone content based on tree-ring reconstruction

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We discuss the criteria and some results on the total ozone chronology generalization. The chronology discussed has been reconstructed from 200-year dendrochronological data for Eurasian subarctic regions. The algorithm of minimizing temperature sensitivity of the dendrochronological signal is proposed in separately analyzing its main components using «Caterpillar» software package. This paper presents data of dendroclimatic monitoring and some results on reconstructed total ozone content in the atmosphere near Tomsk city.

## Introduction

The relation between the global warming in the XX century and a long-term decrease in the total ozone content (TOC) in the atmosphere over vast Eurasian region was for the first time considered in Ref. 1. Long-term TOC chronologies were reconstructed from the dendrochronological data, namely, by analyzing the ring density of coniferous trees using the method based on detection of the tree response to variations in the UV-B radiation caused by TOC changes.[2–4] Since the dendrochronological signals have been collected at the points situated quite far from each other, we need to generalize the reconstructed TOC chronologies on large spatial scales taking into account known spatiotemporal TOC field inhomogeneity[5] in order to analyze paleoenvironmental records.

Reference 6 reports on the first attempt of generalizing the reconstructed TOC data for Eurasian Subarctics using cluster analysis. We selected about 30 chronologies with the maximum recorded density of the annual rings of Siberian spruce and pine-tree growing in lowland of 25–300 m above sea level. Statistical analysis of dendrochronology and TOC data for the period from May to September has revealed a strong correlation for a sample of 13–16 locations. The largest coefficients of correlation of TOC with the annual ring density were obtained for Siberian spruce (0.8–0.96) and lower but still important values for pine-tree (0.5–0.66). We have isolated three groups of chronologies characterizing three different tendencies of the long-term TOC evolution for the past 250 years with the negative, positive, and a nearly zero trends. However, the third group overlapped with the other two not always agreed with the TOC inhomogeneity scales, at least within several hundreds of kilometers. Most probably, this was the result of ignorance of the climate component of a dendrochronological signal, first of all, the near-surface temperature. Thus, there arises the problem of minimization of the temperature sensitivity of a dendrochronological signal.

## 1. The way to minimize the temperature sensitivity of chronology of the annual rings of conifer trees

In order to minimize the temperature sensitivity of a dendrochronological signal, we used the main components method of the "Caterpillar" package (an analog of the SSA, the Singular Spectrum Analysis, method). To check it, we used the annual ring density data of Siberian stone pine samples collected near Tomsk.

The measurements of ring density in Siberian stone pine were taken with the densitometer of the V.N. Sukhachev Institute of Forest SB RAS. By the annual ring peaks, we built a rough chronology. The indices of strongest density variations with subtraction of trend are given in the Table. The behavior of this dendrochronological signal is illustrated in Fig. 1*a*. Figure 1*b* shows the main nine components of this signal discerned using the "Caterpillar" package. The specific weight of each component after double centering is as follows: 1 is 12%; 2 is 11%; 3 is 11%; 4 is 11%; 5 is 10%; 6 is 9%; 7 is 9%; 8 is 8%, and 9 is close to zero.

On the Internet, (www.meteo.ru), one can find a long series of measurement data for Tomsk surface temperature until 1995. Figure 2*a* shows a series of instrumental TOC and the surface temperature measurements in Tomsk for the period from 1979 to 1995. There is no correlation in the behavior of these series (the correlation coefficient $R = -0.27$). However, the chronology of Siberian stone pine ring density for this time interval (Fig. 2*b*) shows distinct response both to variations of the surface temperature ($R = 0.63$) and those of TOC ($R = -0.51$). However, isolating the main components, we have found out that for Tomsk, the first component (Fig. 2*b*) shows significant anticorrelation with TOC ($R = -0.7$), but does not correlate with the surface temperature ($R = 0.22$). Upon prolongation of the considered time interval to 1999, the correlation coefficient of the first component of the dendrochronological signal

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**Table. Siberian stone pine ring density, Tomsk (56°N, 85°E)**

| Year | Index | Year | Index | Year | Index | Year | Index | Year | Index |
|---|---|---|---|---|---|---|---|---|---|
| 1827 | −2.57 | 1863 | 1.05 | 1899 | 2.15 | 1935 | −0.5 | 1971 | −0.2 |
| 1828 | −0.61 | 1864 | −0.02 | 1900 | 1.49 | 1936 | −0.2 | 1972 | −0.45 |
| 1829 | −0.56 | 1865 | −0.03 | 1901 | 0.43 | 1937 | −0.31 | 1973 | −0.28 |
| 1830 | −1.06 | 1866 | −2.12 | 1902 | 0.05 | 1938 | 0.29 | 1974 | −0.2 |
| 1831 | −1.03 | 1867 | 0.82 | 1903 | −1.45 | 1939 | 0.72 | 1975 | 0.43 |
| 1832 | 1.72 | 1868 | 0.12 | 1904 | 1.77 | 1940 | 0.27 | 1976 | 0.52 |
| 1833 | −0.29 | 1869 | 0.63 | 1905 | −0.08 | 1941 | 0.62 | 1977 | 0.73 |
| 1834 | −0.57 | 1870 | −1.32 | 1906 | −0.07 | 1942 | −0.38 | 1978 | −0.91 |
| 1835 | −0.09 | 1871 | −0.4 | 1907 | 0.68 | 1943 | 1.37 | 1979 | −0.52 |
| 1836 | −0.32 | 1872 | −2.66 | 1908 | 1.1 | 1944 | 1.31 | 1980 | −0.45 |
| 1837 | 0.12 | 1873 | 1.11 | 1909 | −0.48 | 1945 | 1.38 | 1981 | −0.09 |
| 1838 | 0.55 | 1874 | −0.4 | 1910 | 0.8 | 1946 | −0.87 | 1982 | 0.77 |
| 1839 | 0.72 | 1875 | −1.47 | 1911 | 0.06 | 1947 | −0.08 | 1983 | −1.6 |
| 1840 | −0.6 | 1876 | −1.74 | 1912 | −1.71 | 1948 | 0.25 | 1984 | −1.6 |
| 1841 | 2.42 | 1877 | −0.26 | 1913 | −0.74 | 1949 | 0.54 | 1985 | −0.86 |
| 1842 | −0.96 | 1878 | 0.48 | 1914 | −0.7 | 1950 | 1.05 | 1986 | −0.87 |
| 1843 | −0.4 | 1879 | −1.04 | 1915 | 1.32 | 1951 | 1.8 | 1987 | 0.22 |
| 1844 | 0.34 | 1880 | −0.7 | 1916 | 0.21 | 1952 | 1.12 | 1988 | 0.31 |
| 1845 | 0.05 | 1881 | 0 | 1917 | −0.16 | 1953 | 0.46 | 1989 | −0.03 |
| 1846 | −1.7 | 1882 | −0.07 | 1918 | 1.07 | 1954 | 0.14 | 1990 | 0.02 |
| 1847 | −2.14 | 1883 | −1.05 | 1919 | −0.36 | 1955 | 0.91 | 1991 | −0.58 |
| 1848 | 0.34 | 1884 | −1.1 | 1920 | 0.49 | 1956 | −0.6 | 1992 | −0.21 |
| 1849 | 1.62 | 1885 | −0.26 | 1921 | 0.1 | 1957 | −0.77 | 1993 | 0.23 |
| 1850 | −1.88 | 1886 | −0.23 | 1922 | 0.94 | 1958 | −1.18 | 1994 | 0.8 |
| 1851 | 0.97 | 1887 | 0.33 | 1923 | 1.24 | 1959 | 0.29 | 1995 | −0.46 |
| 1852 | 0.51 | 1888 | 0.88 | 1924 | 0.91 | 1960 | −0.62 | 1996 | −1.17 |
| 1853 | −1.28 | 1889 | −1.05 | 1925 | 0.47 | 1961 | −0.17 | 1997 | −0.3 |
| 1854 | 4.19 | 1890 | −1.4 | 1926 | 0.24 | 1962 | −0.05 | 1998 | 0.76 |
| 1855 | 0.66 | 1891 | 0.06 | 1927 | 0.57 | 1963 | −1 | 1999 | 0.68 |
| 1856 | −0.21 | 1892 | 1.33 | 1928 | 0.33 | 1964 | 0.8 | 2000 | 0.06 |
| 1857 | −1.47 | 1893 | 0.25 | 1929 | 0.14 | 1965 | −0.82 | 2001 | −0.58 |
| 1858 | 1.34 | 1894 | −0.78 | 1930 | −0.63 | 1966 | 0.65 | 2002 | −0.49 |
| 1859 | −0.73 | 1895 | 2.32 | 1931 | 0.95 | 1967 | 0.18 | | |
| 1860 | 0.26 | 1896 | 1.28 | 1932 | −0.49 | 1968 | −0.15 | | |
| 1861 | 0.86 | 1897 | 1.81 | 1933 | 0.37 | 1969 | −1.43 | | |
| 1862 | 0.33 | 1898 | 0.56 | 1934 | −0.32 | 1970 | −1.83 | | |

with TOC has reached $R = -0.83$, while the correlation of ring density with TOC has not changed essentially ($R = -0.55$). High values of the correlation coefficients provide reliable reconstruction of long-term TOC variations over Tomsk (Fig. 3).

Regardless of the generally consistent behavior of the reconstructed TOC chronologies ($R = 0.45$), in Fig. 3 there are regions of distinctly inconsistent behavior that is indicative of temperature sensitivity of the tree-ring signal.

Earlier, we have demonstrated that during the vegetation period, for the nearest coordinates within a 5–7° grid of the global TOC monitoring, variations have a more general behavior.[7] Variations of climate parameters, first of all, temperature, are more local. Therefore, if chronologies disagree in dendroparameters in these limits, they are likely to be connected with the temperature regime, rather than ozone. For example, in Fig. 4 we have isolated intervals of strong disagreement in the behavior of tree-ring density index chronologies chosen to help in reconstructing TOC at 44°N/63°E and 54°N/64°E. Here, TOC behavior for these geographical points by the TOMS satellite data correlates with a coefficient 0.98.

For the point located at 54°N/64°E, the coefficient of correlation between TOC and tree rings is negative and above the level of significance (−0.63). For the second coordinate, this relation is slightly positive, which generally contradicts our method,[2–4] the latter being based on physiological response of conifers to UV-B radiation conditioning negative correlation between TOC and the annual ring density.

We have made the series expansion up to the ninth term, without traditional smoothing of the series of highest density of conifer annual rings using the "Caterpillar" method. Based on the correlation analysis, we have determined the sums of the same components for both chronologies (the 1st and the 9th), which were almost synchronous in behavior and exhibited a significant negative correlation with TOC (−0.63).

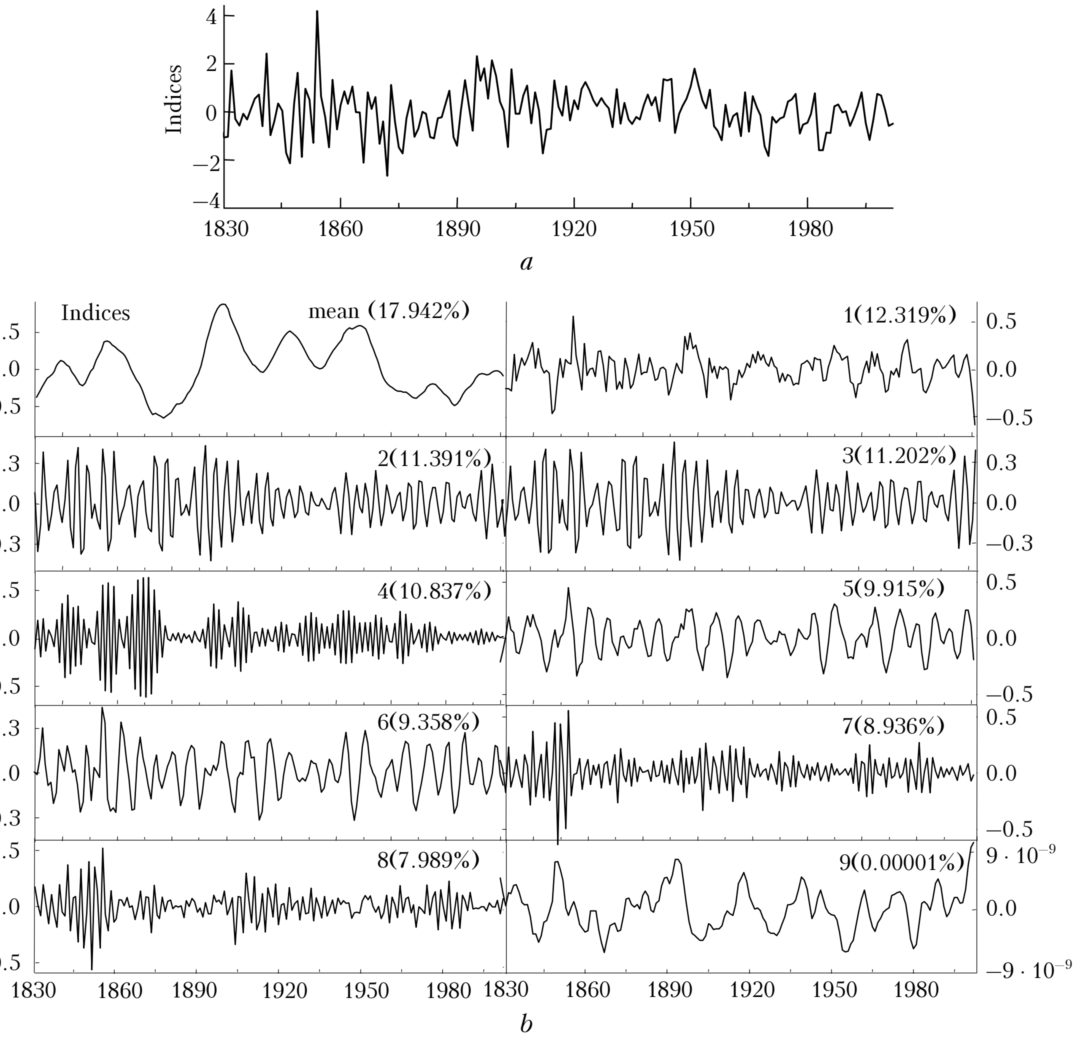



**Fig. 1.** The behavior of the total dendrochronological signal from the Siberian stone pine ring analysis, Tomsk (*a*) and its 9 main components (*b*).

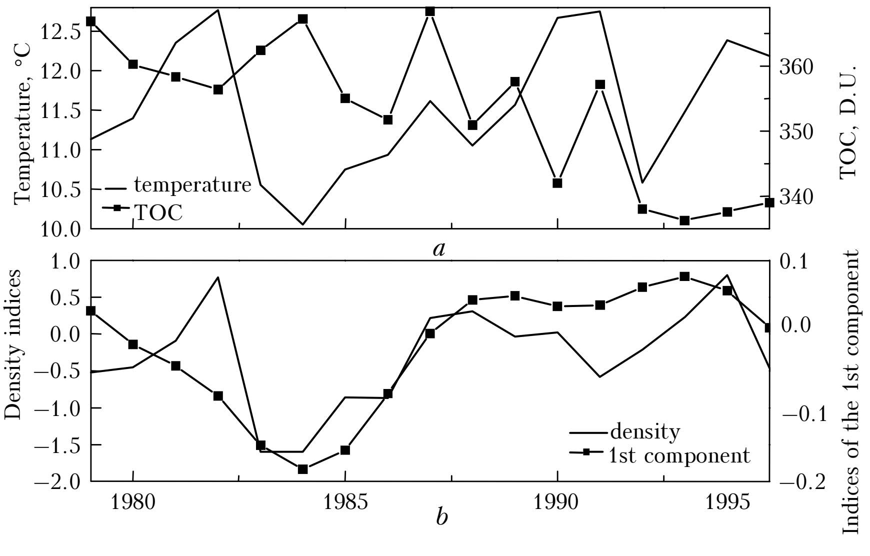



**Fig. 2.** Data of TOC and surface temperature measurements in Tomsk for the period of 1979–1995 (*a*) and behavior of the total dendrochronological signal and its 1st component for the same period (*b*).

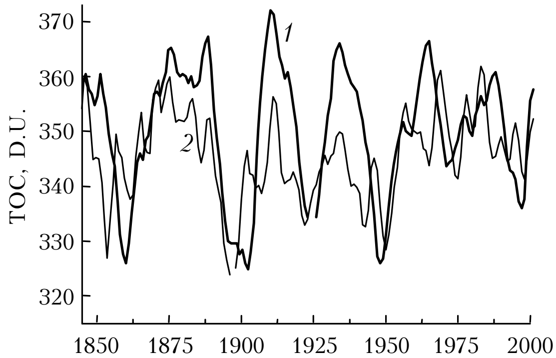



**Fig. 3.** Reconstruction of the total ozone content from the total dendrochronological signal (by analyzing the density of annual rings) and from the first component of this signal: the first component (*1*), density (*2*).

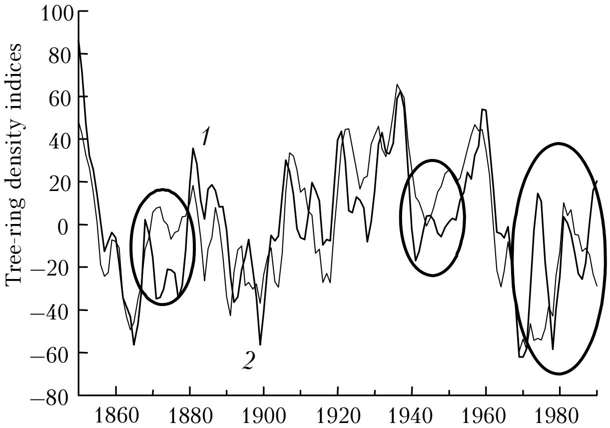
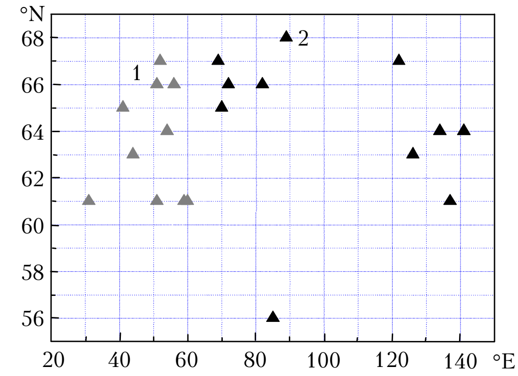



**Fig. 4.** Behavior of the tree-ring density indices by two dendrochronological signals obtained within the TOC field homogeneity: 44°N, 63°E (*1*); 54°N, 64°E (*2*).

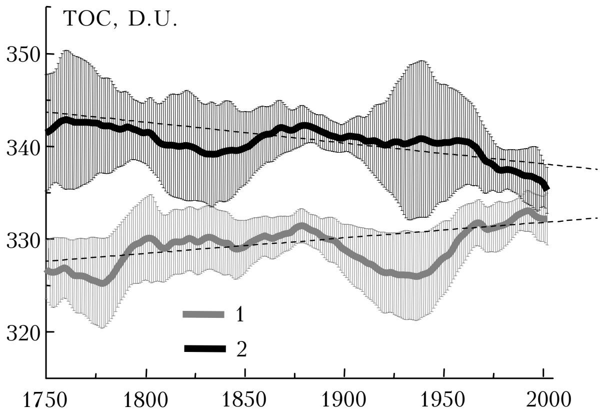
## 2. Generalized chronologies of the total ozone content for subarctic regions

Having reanalyzed the reconstructed data given in Ref. 6 we have found that the third group mostly comprises the results on TOC reconstruction from the data with a strong climatic component of a dendrochronological signal. This data group required additional work taking into account temperature sensitivity using the method of main components. After the cluster reanalysis, TOC field distribution for subarctic regions is represented by two data arrays (Fig. 5*a*), and the generalized TOC chronologies corresponding to these groups are shown in Fig. 5*b*.

One can see that the longitudes of the first group are located to the west from the Urals, i.e., it belongs to the European part of Eurasian Subarctics, and the second one belongs to the Asian part. They are characterized by the opposite trends of the generalized TOC chronologies. These trends seem to belong to an arm of lower TOC frequencies. Since the behavior of the stratospheric ozone in Subarctic regions and, respectively, TOC is entirely formed by the stratospheric circulation of air masses, we suppose that low-frequency TOC fluctuations in the European group are modulated by the thermohaline circulation of the North Atlantic, while the Asian group is modulated by the eastern part of the Arctic Ocean.




*a*




*b*

**Fig. 5.** Distribution of the reconstructed TOC data for Eurasian Subarctics (*a*) and their corresponding generalized TOC chronologies (*b*).

## Summary

Based on the above-presented data, we can formulate the criteria for generalizing the data for investigating the long-term fluctuations of the total ozone content in Subarctic latitudes.

1. Dendrochronological data for certain geographical points must be selected by the peak sensitivity to TOC variations (the correlation coefficient $R$).

2. Expansion of time series by annual ring density to the main components allows us to isolate, in one component (or in a sum of components), the fluctuations of dendrochronological signal, almost independent of temperature variations, but strongly correlating with TOC level.

3. The requirement to selecting the components is their negative correlation with TOC.
4. The correctness criterion for a chosen selection can be the agreement between the TOC chronologies reconstructed from different dendrochronological signals, at least within 5–7° on a coordinate grid.

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