Reconstruction of Paleobehavior of Ozonosphere Based on Response to UV-B Radiation Effect in Dendrochronologic Signal

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Introduction

The ozonosphere state appreciably influences the general circulation of the atmosphere. The stratospheric ozone content determines the stratospheric temperature field, whose contrasts form the stratospheric circulation. In addition, the thickness of stratospheric ozone layer modulates the level of UV-B radiation reaching the surface. The Ultraviolet-B (UV-B) radiation substantially influences the photochemical processes in the troposphere, determining the abundance of greenhouse gases in it. For instance, the radiative field in the troposphere at wavelengths shortward of 300 nm controls the content of hydroxyl OH in it, a powerful oxidant of methane and other hydrocarbons.

As is well known, the UV-B radiation exerts a considerable influence on the biosphere. The high level of UV-B radiation causes a stress of vegetation, including trees. In addition, the increase of UV-B radiation may favor an additional generation of tropospheric ozone. The tropospheric ozone is a strong toxicant. Penetrating through respiration stomata, it makes the vegetation stress even stronger. The stress-induced changes in physiologic processes are naturally, reflected in tree ring characteristics. Thus, the multi-secular history of ozonosphere behavior is contained in annual tree rings on the basis of response to UV-B radiation effect [1]. The problem now is just to properly separate this information against response to the other factors, especially temperature and precipitation.

The modern dendrochronologic time series are usually, statistically representative, cover time intervals of over 200-300 years, and are represented by different parameters of annual ring width and tree density for different tree species. As is well known, annual ring growth is widely used for paleoclimatic temperature and precipitation reconstruction [2]. It was found that, for stress effect of UV-B radiation on coniferous (especially cedar) trees, the wood density is a more sensitive parameter. It, on the contrary, is less sensitive to temperature and precipitation variations. Therefore, it is this parameter that we chose as a predictor of total ozone (TO) in reconstruction of behavior of ozone layer and UV-B radiation in the past [3,4].

For Switzerland in the vicinity of Arosa, the dendrochronologic time series are represented predominately by coniferous tree species. We chose the Norway Spruce, Stone Pine, and European Larch. The growing season for trees in Arosa lasts from April to September; therefore, the TO time series was compiled from TO values averaged over April to September. It is usually assumed that the biologic response of coniferous tree species to UV-B radiation is delayed by 1-2 years [5]; therefore, the analysis was made for dendrochronologic time series smoothed over 2 years. In all used dendrochronologic time series, there are no autocorrelation (dependence on tree age) and trend. The results of correlation analysis are presented in Table 1. As seen, the total ozone content is most strongly correlated with mean wood density (MD) for Stone Pine, with a correlation coefficient of -0.6; whereas, the correlation of this parameter for this tree with temperature and precipitation appears less significant.

Table 1. Correlation analysis results.

Correlation Coefficient Between Total Ozone (TO) and Mean Wood Density (MD), Temperature (T), and Precipitation (P)						
File Name in Databank [6]	**Time Frame of Chronology**	**Species**	**Geographic Coordinates (N, E)**	**Correlation Coefficient**		
				MD/TO	**MD/T**	**MD/P**
Swit107	1690-1975	Norway Spruce	46°48, 9°41	-0.4	0.13	0.14
Swit109	1788-1974	Stone Pine	46°24, 8°01	-0.6	<0.1	0.12
Swit111	1792-1974	European Larch	46°24, 8°01	-0.15	0.3	<0.1

In data preparation for reconstruction, we detrended the TO time series (instrumented observation data obtained in Arosa between 1926 and 1974) by the method of linear regression, and converted absolute values to dimensionless indices i(t) by the formula:

$$i(t) = (X(t) - MEAN) / STD \qquad (1)$$

where X(t) is the value from time series, MEAN is the mean value from time series, and STD is standard deviation from time series.

Figure 1 shows the relationship of time series (smoothed using 2*2-year running mean) between TO indices for growing season from April to September and indices of dendrochronologic signal for Stone Pine. As seen, for years with decreased TO level (hence, with increased level of UV-B radiation) there is a marked increase of wood density in tree rings, which corresponds to the characteristic response of coniferous trees to an increased level of UV-B radiation [7].

To reconstruct the behavior of the ozone layer in context of the problem formulation above, it is next necessary to separate from the dendrochronologic signal a component responding most fully to long period TO variations. To decompose the time series of wood density into simpler components, we used the Singular Spectrum Analysis (SSA) method. When time series of MD is decomposed into components, a statistically representative reconstruction of total ozone can be obtained using the sum of first, third, and fifth components (decomposition of series into 21 components), which account for 43% of initial dendrochronologic signal (determination coefficient $R^2 = 0.43$).

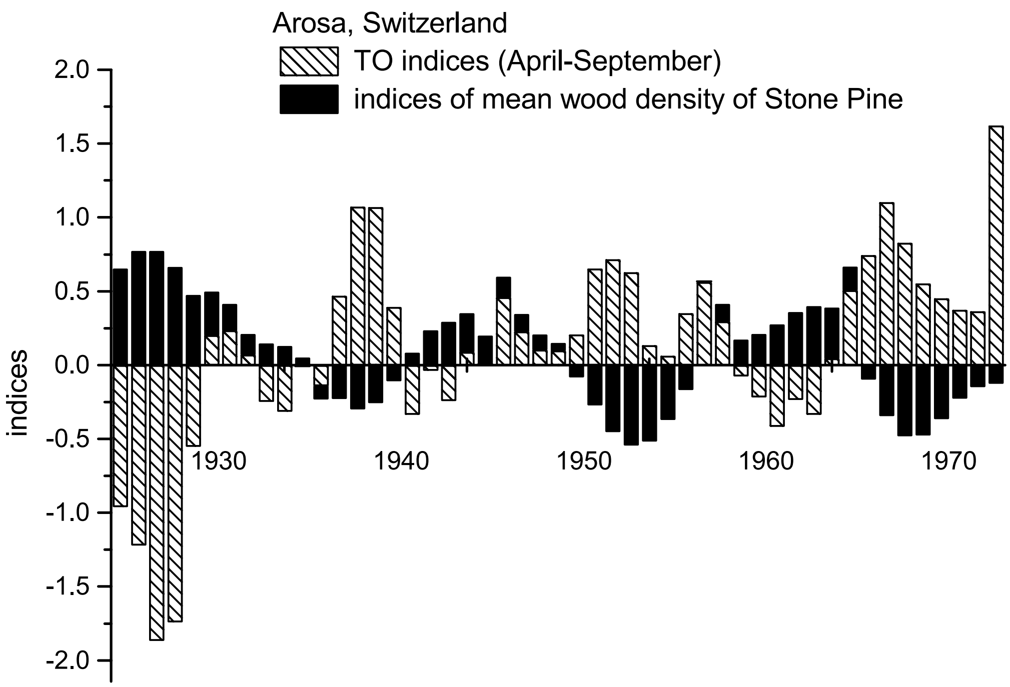

Figure 1. Relationship between time series of TO indices for the growing season from April to September and those of the indices from the dendrochronologic signal: the correlation is -0.6.

The next step was to derive an analytical dependence between TO indices and wood ring density. The obtained expression has the form:

$$j(t)= 0.126-0.785*i(t) \quad (2)$$

where j(t) is time series of TO indices, and i(t) is time series of mean density of Stone Pine. The statistical representativeness of the obtained TO reconstruction is characterized by parameters: $R^2 = 0.56$ and F =0.53 (Fisher criterion). The time series of TO indices, calculated from this formula, is presented in Figure 2. It is clearly seen that the behavior of ozonosphere, smoothed over 22 years (double solar cycle), is characterized by long-period, quasi-cyclic variations of approximately secular on-off time ratio. Overall, the modern TO decline stays within natural limits, a characteristic of entire time series. Moreover, the TO content at the frontier of 18 and 19 centuries was found to be almost half the present value.

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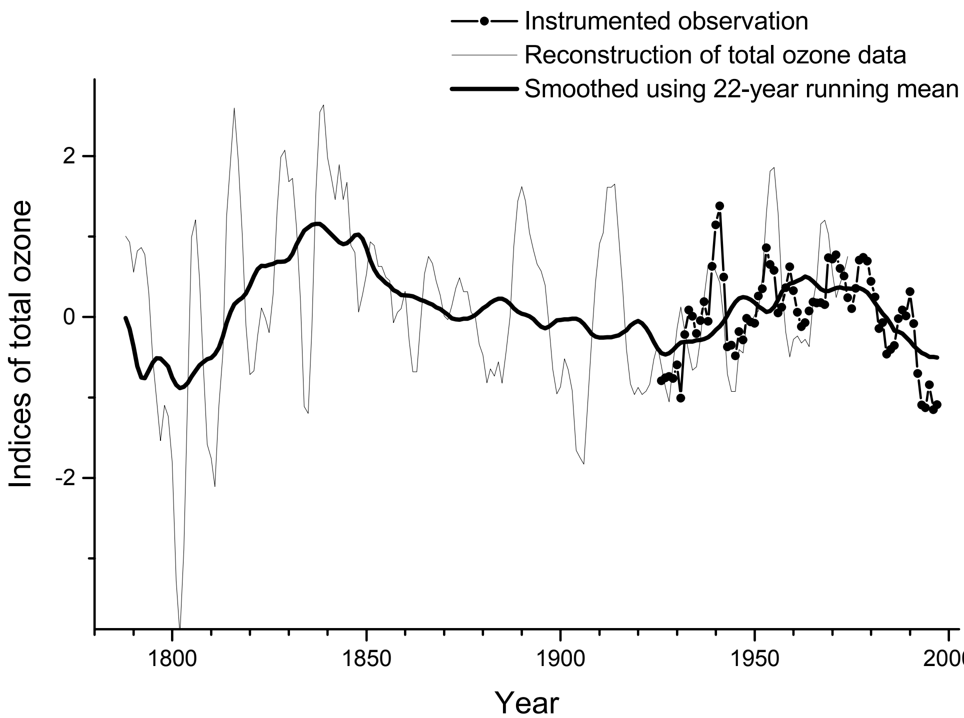

Figure 2. Reconstruction of total ozone, Arosa, Switzerland.

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