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ORIGINAL RESEARCH PAPER

Response of conifers to UV-B and climate in mountain areas

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ABSTRACT: The current study was focused to examine the combined effects of climate and ultraviolet-B radiation on conifer tree-ring density. Statistical methods were employed to extract tree responses in annual ring density and to identify functional relationship in trees when the level of ultraviolet-B radiation changes regardless of climate variations. In this study, the consideration was given to the series of total ozone content (instead of ultraviolet-B), tree-ring density, and De Martonne aridity index. After the correlation analysis, all trees were divided into two groups: 1) Trees whose correlation between tree ring density and UV-B values in April is significantly positive; 2) Trees whose correlation between tree-ring density and aridity index values in March-September is significantly negative. Then, tree-ring series for the Swiss Alps in each group were generalized and decomposed into separate components: long period trends, ultraviolet-B and climatic signals. For the ultraviolet-B-responsive tree group in the period 1932-1974, the correlation coefficient between the tree-ring density and ultraviolet-B was 0.55 at $p < 0.05$. For the climate-responsive tree group the correlation coefficient between tree-ring density and aridity index was -0.51 at $p < 0.05$. Data mining diagrams showing the impact of atmospheric factors that affect the anatomic changes in the wood growing in mountain regions reveal that hormone can link the interaction of stem and crown. Generalized tree-ring density series may also be used to reconstruct past changes in ultraviolet-B and climate and to predict the conifer state in other mountain regions in the world.

KEYWORDS: C*limate change; Conifers; Growth hormones; Principal components; Singular Spectrum Analysis; tree-ring density; Ultraviolet-B radiation.*

INTRODUCTION

Assessment of forests under the influence of external factors is an important element of climate simulation in mountain regions. The temperature decreases with increasing altitude of tree growth, while the humidity and the level of solar radiation are higher. Present-day processes are more complicated and less homogeneous (Philipona, 2013). Air temperature and humidity affect the respiration and photosynthesis of trees and may be limiting to the annual ring growth (Wieser, *et al.,* 2010; Saurer, *et al.,* 2012). Ultraviolet-B (UV-B) radiation passing through the stratospheric ozone layer to the Earth's surface penetrates the photoreceptors of plants, affecting thus all their organs and physiological processes. UV-B radiation may alter photosynthesis, respiration, structure, metabolism, and genetics of plants. UV-B radiation reduces the photosynthetic activity and phytomass, which was revealed in the end of the last century (Turtola, 2005, Suchar and Robberecht, 2016, Trošt, 2014). Modern papers review the genetic effects of UV-B exposure in plants, which are more manifested in high-mountain regions (Wang, *et al*., 2014). The UV-B impact on conifers was studied in papers along with other environmental factors (Liu, *et al*., 2004). However, the impact of UV-B and climatic factors on tree-ring density for mountain regions in the past (1932-1974) has never been a separate subject of study. Moreover, there has been little study on the functional relationship between physiological

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processes in needles and annual wood growth. It was noted that the functional relationship between stem respiration, photosynthetic activity of crown, and wood growth are well pronounced under weather conditions, favorable for plant growth (Meinzer, *et al.*, 2011). In addition, empirical regularities of stem growth and crown phytomass were established (Suvorova, 2016). Separate studies are devoted to the influence of nutrients on wood cell growth (Silkin and Ekimova, 2012), using the example of such a construction element as calcium. Some well-known studies describe phytohormone regulation of cell processes in plants and their growth in response to stressor effect. These hormones are thought to perceive the stress signal and help the plant to adapt by triggering defense responses to adverse conditions using well-developed mechanisms (Verma, *et al.*, 2016). However, laboratory and field studies were concentrated only on crops. There was little analysis on conifers, and little is known about the processes in wood density of growing trees with depressed crown. Today it is more difficult for plants to adapt to environmental changes due to accelerating nature climate changes (Suchar and Robberecht, 2016). Present-day changes in climate create unfavorable growing conditions for conifers, especially in Europe (Gobiet, *et al.*, 2014). The decrease in soil and air moisture, enhanced by increased UV-B radiation, which is characteristic for modern warm-dry climate era, is unfavorable for pine and fir forests (Zang, *et al.*, 2014; De Micco, *et al.*, 2016). Since 1980s, the distribution of fine-fir forests, once covering a vast area in Europe, has been decreased (Bigler, *et al.*, 2006). It can be assumed that fine-fir forests lost their competitiveness due to combined effects of various stressors and accelerated climate change. This has led to the disruption of previously successful mechanism for adaptation to changes in growth conditions. Therefore, the effect of growth conditions on conifer wood density is considered as a characteristic of wood quality and tree hardness for an extended period in which climate anomalies were insignificant as compared to recent decades. It is known that the data on maximum tree ring density (MXD) serves as the UV-B indicator during the growing period (Zuev and Bondarenko, 2007). It is assumed that under certain conditions UV-B radiation may be a limiting factor to the tree growth on large territories. Using a set of tree ring density series of different tree species growing at different altitudes in the Swiss Alps will allow reviewing the voluminous statistical material. The purpose of the study is to review the combined effects of climate and UV-B radiation on the annual conifer ring density. The study has responded to the following questions:

1) What is the range of conifers with the ring density responsive to UV-B changes?
2) How does the climate affect (according to De Martonne aridity index) the density of UV-B-responsive trees?
3) Is it possible to extract UV-B-responsive signal from MXD series with the background fluctuations in the level of UV-B radiation?
4) What is the functional relationship between direct impact (on the crown) and indirect impact (on the stem) of UV-B radiation and climate?

The current study of the series of total ozone content TOC (instead of ultraviolet-B), tree-ring density, and De Martonne aridity index is significant and unique as uses statistical methods to extract tree responses to changes in UV-B radiation in annual ring density regardless of climatic variations and on that basis to perform Data Mining in order to establish the functional relationship between separate tree fractions. The study has been carried out on the territory of the Swiss Alps based on online databases for the period of 1932 to 1974.

MATERIALS AND METHODS

Study area

The Swiss Alps are the most appropriate area to study the impact of UV-B radiation on conifer tree-ring density. Both long climatic and dendrochronological datasets as well as the longest series of total ozone content (TOC) were available for this region. The mountain area of the Swiss Alps (Fig. 1) is characterized by complex orography and high insolation. Two temperature anomalies were observed in this area in the period 1940s-1950s and the mid-1950s to the mid-1960s. Temperature anomalies in the study region were accompanied by precipitation anomalies (Beniston, 2006). In general, the soil was sufficiently moisturized for trees. The forest composition was dominated by coniferous tree species.

Data processing

Normalization (standardization) of values

Normalization (standardization) of values was performed using a known statistical Eq. 1.

$$Index(t) = \frac{[X(t) - mean]}{STD} \tag{1}$$

Where, *Index(t)* is an index,*X(t)* is a parameter value in the series, *mean* is the average value; and *STD* is a standard deviation of the parameter in the series.

Smoothing

The Fast Fourier Transform (FFT) Filter by Origin software (smoothing tools for signal processing) is used to remove high-frequency noise from the time series of parameters (Zheng, *et al*, 2015).

Data

Data on maximum density

Time series included various tree species growing at different altitudes. Time series contained data for the period 1875-1974 (Table 1). The number of core sampling sites was 15. No standard time series from the data bank were used because separate series a fortiori contained a strong climatic response. Individual time series of tree ring density (“raw” data)

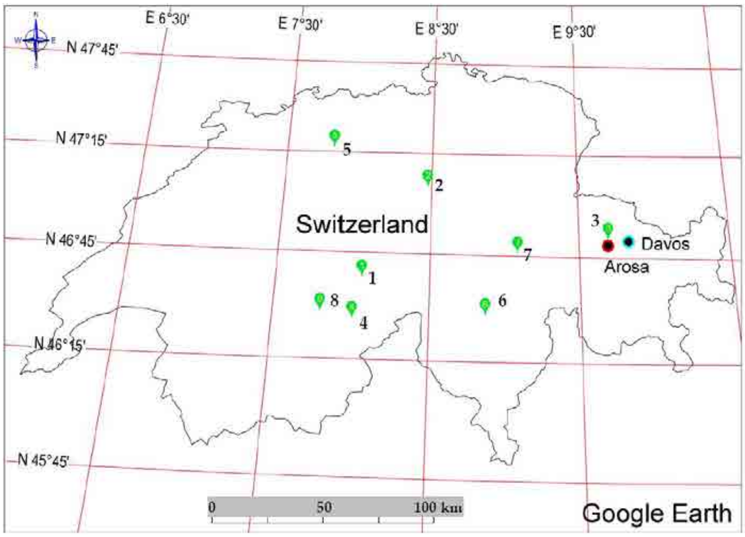

Fig. 1: Study area and tree sampling sites specified in green symbols,
Light climate observatory (red symbol) and weather station (blue symbol)

Table 1: Data on the wood density measurements

N	Site	Tree species	Coordinates		Altitude, m	Raw data	Tree cores
			Lon., E°	Lat., N°			
1	Grindelwald BE	PCAB	8.0	46.6	1370	swit102x	17
	Grindelwald Nord (N3)	PCAB	8.0	46.6	1700	swit174x	13
2	RigiStaffel SZ	PCAB	8.5	47.0	1600	swit103x	9
	RigiKlЎsterli SZ	PCAB	8.5	47.0	1400	swit104x	5
3	Arosa GR Rot Tritt (Nord	PCAB	9.7	46.8	1940	swit107x	7
	ArosaGR Arlenwald (S№d)	PCAB	9.7	46.8	2000	swit108x	5
4	Riederalp VS Aletschwald	PICE	8.0	46.4	2000	swit109x	6
	Riederalp VS Aletschwald	PCAB	8.0	46.4	2000	swit110x	10
	Riederalp VS Aletschwald	LADE	8.0	46.4	2000	swit140x	13
5	Roggwil BE Tanneabsterb	ABAL	7.8	47.2	535	swit141x	15
	Roggwil BE Tannegesund	ABAL	7.8	47.2	535	swit142x	16
	Roggwil BE Fi Vergl.Prob	PCAB	7.8	47.2	535	swit143x	5
6	Suaiza, TI	PCAB	8.87	46.4	1520	swit171x	18
7	Obersaxen, Meierhof, GR	PCAB	9.0	46.7	1520	swit173x	12
8	Loetschental, CH	PCAB	7.8	46.4	1900	swit176x	9

Note: Time series cover the period 1875-1974; PCAB is *Picea abies*, PICE is *Pinus cembra*, LADE is *Larix decidua*; ABAL is *Abies alba*. X is MXD marker.

were used to identify a group of trees responsive to UV-B changes. MXD series for less than 50 years was not included in the sample. The analysis did not consider the data on the cores before the year of 1875. Therefore, an equal number of cores was analyzed (160) for each year. Raw data (marked as "rwl") was provided by the Data Bank of the Swiss Federal Institute for Forest, Snow, and Landscape Research (supplied by Schweingruber F.H.) (Schmatz, *et al*., 2001). MXD time series were smoothed using FFT to remove 2-year fluctuations. Typically, an age-related trend is removed from the time series of tree-ring width. However, tree age has little impact on density variation. Nevertheless, a climatic long-term trend can be observed in MXD time series. These trends were reconstructed from MXD time series using the Singular Spectrum Analysis (SSA) method. MXD data were normalized relative to the average density in the series. Earlywood (low density wood) is formed at the beginning of the growing season. Earlywood formation is dependent on nutrients preserved during the previous year. Latewood reaches its maximum values due to nutrients received during the current year (Cuny *et al*., 2014). Thus, dendrochronological data contain a two-year periodicity. The changes unrelated to UV-B radiation were removed from these data using FFT (a 2-year window). Also, MXD time series have fluctuations that depend on the lifetime of needles. The needle age is 1 year for European larch (*Larix decidua)* and above 3-4 years for Norway spruce *(Picea abies)*, Swiss stone pine (*Pinus cembra)*, and European silver fir (*Abies alba)*. Cumulative effects of UV-B radiation were seen in old needles (Turunen, 2005). MXD fluctuations that depend on the needle age were removed from MXD series using the SSA method. All the tree species in Table 1 dominate in the forest composition in the Swiss Alps (Bebi, *et al*. 2017).

Total ozone column and climatic data

Monthly average characteristics of temperature, precipitation, and UV-B values in homogenous changes of all study area were used from monitoring data in the center of area. These are:

1) TOC, since 1926, Arosa, Switzerland, (E 9° 40', N 46° 46'), Light Climate Observatory (Stübi, *et al*., 2017).
2) Temperature (T) and precipitations (P), since 1867, the Davos weather station (E 9° 49', N 46° 47') (Begert, *et al*., 2005).

Monthly series from March to September were normalized. In 1932-1974, a long-term trend was close to zero for all-time series. Therefore, this period has been selected for the research.

Quasi-biennial variations associated with the climate change were revealed in TOC and weather parameters (Gruzdev and Bezverkhnii, 2006). These fluctuations were removed from the data by smoothing (FFT-filter).

UV-B index (I_{UVB}) data

TOC data can be used for indirect assessment of biological effects of UV-B radiation (Zuev and Bondarenko, 2007; Zuyev, *et al*., 2009). In general, using TOC data is a reliable method to evaluate the impact of UV-B radiation. UV-B and TOC measured at the Uccle station (E 4° 21', N 50° 48', since 1983) showed a strong anti-correlation **(**Boucher, 2010, Krupa, 2000) in live UV index. A high correlation between TOC and UV-B was observed throughout the growing season. Their highest values were observed annually in April (TOC) and June (UV-B). At the same time, the intensive growth of annual rings is characteristic for April; therefore, all the above-mentioned conditions lead to the intensive biological impact of UV-B (TOC) in April (Casale, *et al*., 2000; Rieder, *et al*., 2008). UV-B index (I_{UVB}) was used to describe the monthly dose of UV-B in nondimensional units of monthly TOC variations. Thus, I_{UVB} (March–September) was aligned with normalized seasonal variations of TOC index (I_{TOC}) based on Eq. 2.

$$I_{UVB}(t) = -I_{TOC}(t) \qquad (2)$$

The UV-B index allows estimating impact UV-B changes on trees.

De Martonne aridity index (IDM) data

IDM is calculated by the Eq. 3 **(**Mavrakis and Papavasileiou, 2013**)**:

$$IDM = \frac{\sum P}{T+10} \qquad (3)$$

Where, ΣP is the total monthly precipitation (in mm) and T (°C) is the monthly average air temperature.

The index also allows analyzing climate changes on a small area. IDM classification allows recognizing climatic type whether it is a colder and more humid climate in the north or a warmer and drier climate in the south. If the aridity index increases, the plant obtains more moisture from the soil or air. If the index decreases, the plant will suffer from lack of moisture. Excessive evaporation, temperature increase and (or) insufficient precipitation affect tree growth. Under such conditions, the density of tree rings will increase (Chen, *et al.*, 2015). Thus, IDM and MXD have a negative correlation. Therefore, IDM was calculated for March-September (entire vegetation period) and then normalized and filtered using FFT (a 2-year window). Climatic trend (linear trend) was further extracted from the data.

Time series analysis

TOC, temperature, and precipitation series in the study area

Correlation functions between TOC time series were calculated to identify the homogeneity zone of TOC spatial variations at the center (–2-18°E, 30-60°N) of Arosa observatory. For this purpose, the reanalysis data of satellite ozone sounding for the last 40 years of Tropospheric Emission Monitoring Internet Service (TEMIS) project were used (Van der A, *et al*., 2015a, 2015b). The synchronization of TOC time series was maintained for the study area around Arosa for all sites where dendrochronological data were collected (9°±3° E and 46.5°±7° N), as evidenced by high spatio-temporal correlations (R = 0.99 – 0.96). Based on the analysis of spatio-temporal variations in meteorological parameters (set of 12 homogenized monthly mean temperature and precipitation series in Switzerland for the period 1864–2000), presented in the paper (Begert, *et al.*, 2005), according to climatic trends in the Swiss Alps, the study area can be described as climatically homogeneous. Thus, these metrological data were normalized in order to use temperature and humidity values from Davos Meteorological Station and to smooth the differences in the absolute values.

Cluster analysis

For the period 1932-1974, the number of N measurements is 43. Correlations (correlation coefficient R) are considered to be significant if they exceed the value of R=0.29 with a probability of error $p<0.05$. All sampled trees were grouped according to the correlations between MXD and I_{UVB} (or IDM). Cluster diagram for 160 series based on weighted pair-group average Pearson correlation illustrates 2 different responses in the sites (Fig. 2). It is supposed that, firstly, the MXD data for each selected site can show a strong UV-B signal and, secondly, there are trees in the same site, the MXD series of which can contain a strong climatic signal. Another type of responses of the trees was not studied. Fig. 3 shows distribution of the responses in the sites.

Group I. Trees whose correlation between MXD and I_{UVB} values in April is significantly positive. Increased UV-B leads to an increase in MXD for this group. Therefore, these trees were called UV-B-responsive trees.

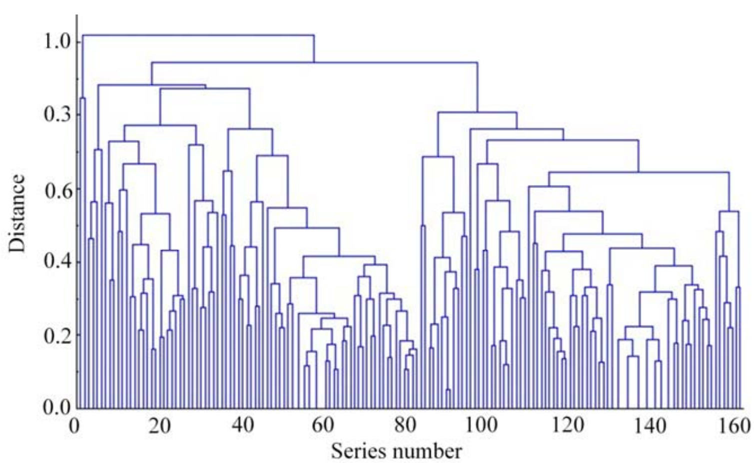

Fig. 2: Clusters of UV-B-responsive trees and of climatic-responsive trees

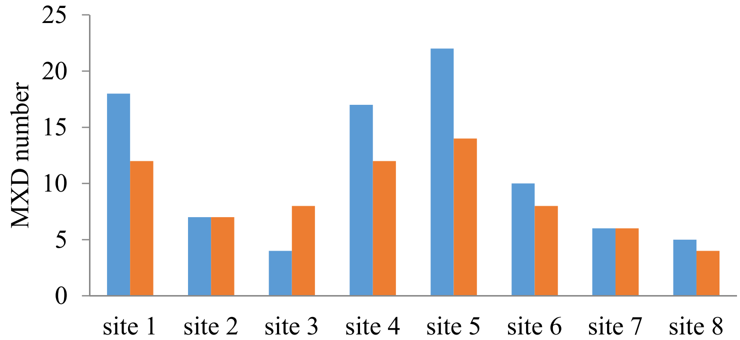

Fig. 3: Tree diagram for 160 series (UV-B responsive trees are marked with red and climatic-responsive trees are marked with blue)

Group II. Trees whose correlation between MXD and IDM values is significantly negative. Increase in IDM leads to a decrease in MXD. Therefore, such trees were called climatic-responsive trees.

The number of series of the group I and group II is different in each sites.

Decomposition of MXD time series into components using the SSA-Caterpillar method

The SSA-Caterpillar method is based on the transformation of one-dimensional time series to the matrix. The matrix is formed by one-step successive shifting of series. The longer the series, the larger the matrix dimension. The longer the series, the higher the number of the components in the decomposition, and the number of comparison variants. Caterpillar program provides visualization of all stages in decision making process for factor analysis, correlation matrices, periodograms of series and components, decomposition and summation of components, and vector and recursive prediction (Golyandina and Zhigljavsky, 2013).The SSA-Caterpillar method allows decomposing MXD time series MXD into climatic and UV-B components (Bondarenko, 2006; Ageev, *et al.*, 2013). Regional MXD time series is analyzed using the Caterpillar software. MXD time series can be represented as a sum of fluctuations with different periodicity and amplitude. The main components of the decomposition were analyzed and re-summed. Reconstructed MXD series comprises components (series), which have responses of trees to UV-B or climate changes. The residual MXD series has tree responses related to species differences and various growth conditions.

Factor analysis of the array of MXD time series. Extraction method: Principal components

The results of the factor analysis (Statistica) of numerous MXD series in groups I and II were used to determine the percentage of explained variance of 3 significant factors for 100 years (1875-1974): temperature (T), precipitation (P), and UV-B radiation. For short periods (1940-1952 and 1953-1964) two significant factors that influence tree-ring density were considered in group I: UV-B radiation and climate (IDM).

Obtaining data on regional MXD changes searching for UV-B signal in MXD data

- Cluster analysis. The correlation between MXD and I_{UVB} was used to select the data (group I), which have a response to changes in I_{UVB}. The correlation between MXD and IDM was used to select the data (group II), which have a response to climate changes.
- Factor analysis. The percentage of explained variance was assessed considering 2 main factors (I_{UVB}, IDM) in groups I and II. A cumulative variance percentage (%) for IDM is calculated as a percentage of explained variances for T and P.
- Regional (generalized) R-MXD (R-MXD1 and R-MXD2) tree ring density series, containing UV-B signal (group I) and climatic signal (group II) were calculated.
- Decomposition of regional R-MXD1 and R-MXD2 series into components allows extracting UV-B and climate-responsive signals from dendrochronological signal. The maximum number of components is 1/2 of the length of the studied

series. Each component contains a percentage (a fraction) of tree-ring density series. For normalized MXD series, the fraction of the components from dendrochronological signal corresponds to the percentage of the explained variance of principal components in the factor analysis. Trend of regional series (component 1) was considered independently.

RESULTS AND DISCUSSION

IDM was used to evaluate climate changes (Fig. 4) for the period 1932-1974, during which it is possible to assess the changes in UV-B radiation using instrumental data. Instrumental data allow describing climate change over the past 100 years (1875-1974). The climate changed from “humid” ($40<IDM\leq50$) to “moderately humid” ($35<IDM\leq40$) (Rieder, *et al.*, 2008). Fig. 4 shows that there are high variations in conditions of conifer growth in the Swiss Alps.

Mountainous forest area of the Alps, located at altitudes from 800 m to 2000 m, is known for its steep slopes, higher atmospheric humidity, and longer snowy winters. Norway spruce (PCAB) grows in more humid regions. The analysis of R correlations between PCAB MXD series and I_{UVB} (Fig. 5) showed that the altitude of tree growth does not affect the maximum tree response to UV-B radiation for the sites presented in Table 1. Only MXD time series were used to analyze the responses of different coniferous trees to UV-B radiation. 75 out of 160 maximum density series (46% of samples) have a significant positive correlation with April average I_{UVB} values (maximum dose per season). 11 MXD series negatively correlated with I_{UVB}. 57

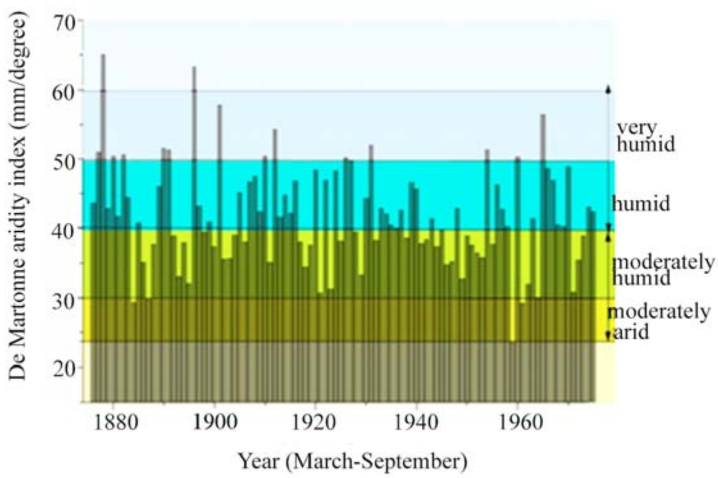

Fig. 4: Mean IDM for March-September and classification of the climate for 1875-1974 according to the temperature and precipitation data obtained from the Davos weather station

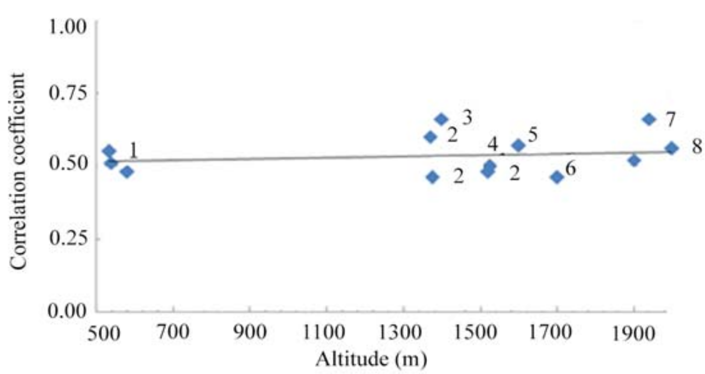

Fig. 5: Correlation between PCAB MXD series and IUVB depending on the altitude

MXD series (36% of samples), showing a significant negative correlation with IDM (in March-September) did not respond to I_{UVB} changes in April. Finally, 19 remaining series did not have any climatic signal or it was below the significant level. Despite the fact that time series were selected according to April values of I_{UVB} , the general tree response to UV-B changes, i.e., during the entire vegetation period is of interest. The results of correlation analysis, which aimed to study the relationship between MXD and I_{UVB}, as well as between MXD and IDM, are presented in Fig. 6. Only 10 MXD series simultaneously responded to changes in climate (IDM) and in UV-B radiation. Climate changes had a more significant impact on trees. It can be concluded that conifers have one or the other limiting factor.

Correlation is strong when R is 1.0–0.5 and moderate when R is 0.3–0.5. After the correlation analysis, MXD series were divided into two groups and were analyzed on variance is considered for MXD of group I and MXD of group II. Percentage of total variance is further used to reconstruct UV-B and climatic signals. Thus, the spatio-temporal MXD variation in the large sample of time series can be studied using the factor analysis (the method of principal components). Variance, the variability of tree ring density, can be decomposed into constituent parts, influenced by various factors. The equal number of MXD series is used in each group (70). Group II (57 series) also included 13 MXD series which had negative correlation with IDM below the significance level. The results of the factor analysis are presented in Table 2. The percentage of the explained total variance of MXD was presumably associated with:

- UV-B (38.03%), temperature (19.67%), and precipitation (7.3%) for group I;
- Temperature (44.7%), precipitation (15.9%), and UV-B (8.5%) for group II.
- Cumulative percentages were 68.1% (group I) and 69.2% (group II).

The coefficients of R correlation between MXD and I_{UVB} series are statistically significant during vegetation period. Positive maximum R correlations

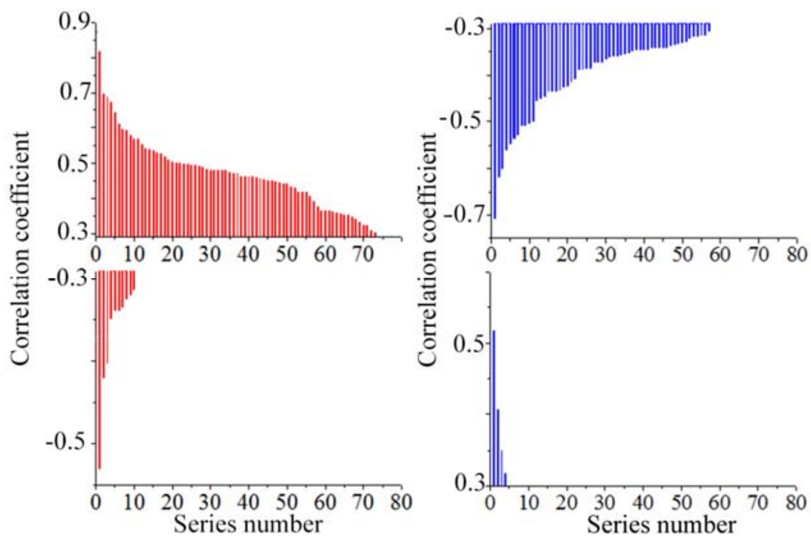

Fig. 6: Correlation between MXD and UV-B (left) and between MXD and IDM (right)

Table 2: Principal components distributed over groups: I) MXD series of UV-B-responsive trees and II) MXD series of climatic-responsive trees

Factor	Total variance (%)		Cumulative	
	group I	group II	group I	group II
1	38.0 (UV-B)	44.7 (T)	38.0 (UV-B)	60.6 (IDM)
2	19.7 (T)	15.9 (P)	27.0 (IDM)	8.5 (UV-B)
3	7.3 (P)	8.5 (UV-B)	Cumulative (IDM + UV-B) % 68.1	69.1

between MXD and I_{UVB} for trees in group I are represented by the following values: 0.40 (March), 0.82 (April), 0.76 (May), 0.40 (June), 0.65 (July), 0.66 (August), and 0.60 (September). Similarly, the number of UV-B-affected MXD series varies from month to month, with their maximum number observed in April, August, and September. Fig. 7 is 3D visualization of varimax raw rotated principal components from MXD series. Values of principal components in each group fit the surface according to negative exponential smoothing method. For group I, the maximum variance is observed in the direction of component, associated with the impact of UV-B radiation (factor 1). Temperature (factor 2) enhances the effects of other factors, i.e., UV-B (factor 1) and precipitation (factor 3). Thus, T and P parameters can be combined into a single factor ID by assigning to it the total percentage of explained variance. The shape of the ellipse connecting factor values (Fig.8) is determined by correlation coefficients between principal components of the studied factors. The more elongated the ellipse, the higher the correlation. The differences in the relationship between UV-B and IDM in group I for the period 1940-1952 (Fig. 8a) and 1953-1964 (Fig. 8b) indicate that factor 2 enhances the effect of the main factor (factor 1). Both factors lead to the growth of tree ring density in the period of synchronous changes in IDM and UV-B.

The changes in weather conditions (indices IDM) and UV-B (indices TOC) were synchronous (R=0.65) during 1940-1952, which has led to an increase in

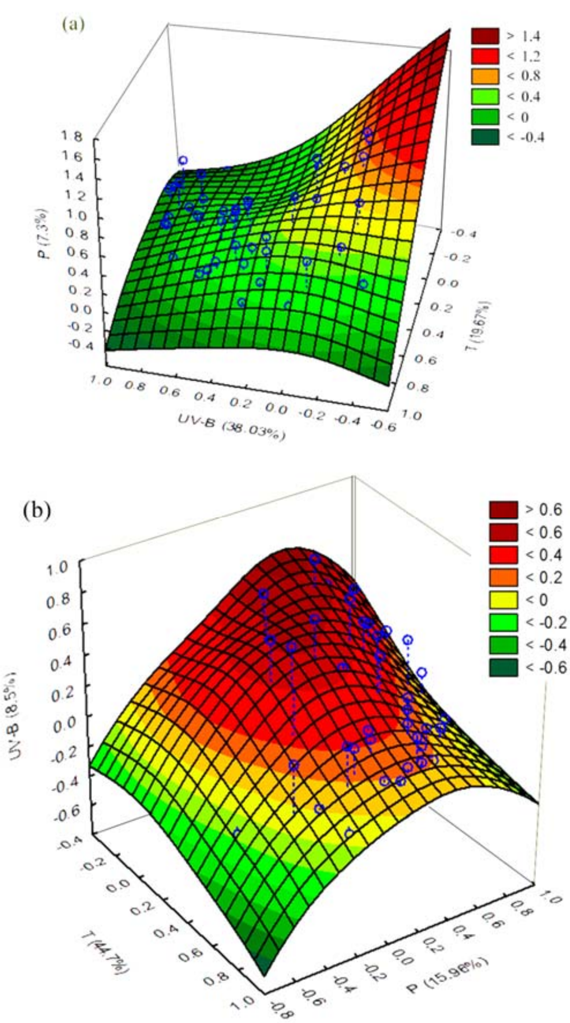

Fig. 7: 3D scatter plots visualizing a relationship between UV-B, temperature, and precipitation in groups (a) I and (b) II according to data the of the factor analysis of the MXD series variance for the period 1875-1974 using the varimax raw rotation

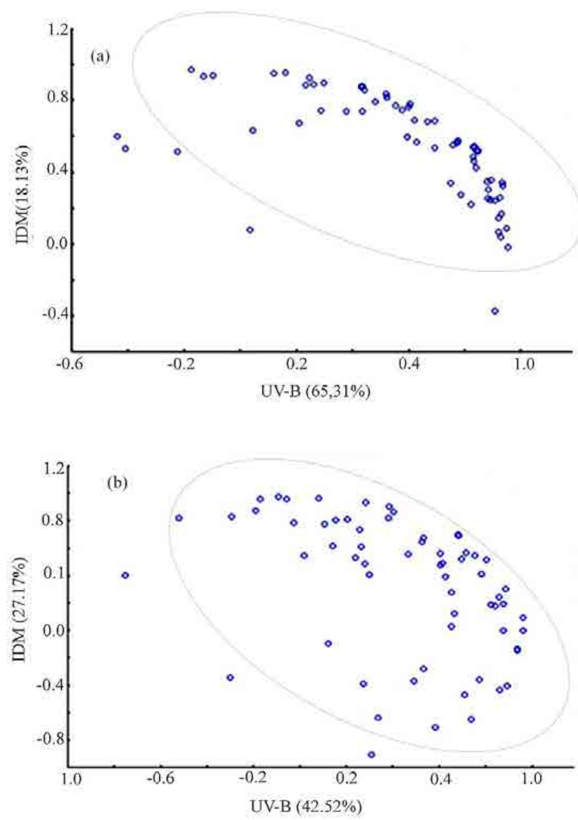

Fig. 8: Relationship between UV-B and IDM in group I for (a) (1940-1952) and (b) (1953-1964) according to the data of factor analysis of the MXD series variance in these periods

UV-B impact on trees and increasing MXD amplitude for this period (Fig. 9).

Anomalous temperature changes lead to an increase in UV-B effect on tree rings. This is manifested by an increase in total variance due to temperature changes. In order to assess the influence of precipitation on tree ring density, a combination of several factors should be analyzed. Anomalous changes in precipitation lead to a redistribution of the total variance between the principal components.

Generalized R-MXD1 and R-MXD2 series were decomposed into 50 components (number of vectors = 1/2 of number of series) using the SSA-Caterpillar method (Fig. 10). The first component was 18% in the regional R-MXD1 series and 17% in R-MXD2. Components are long-period trends. UV-B signal accounted for 38% (2-4, 19 components) of the R-MXD1 series data set and climatic signal accounted for 61% (2-8, 19 components) of the R-MXD2. The results, presented in Table 3, confirm that UV-B atmospheric changes in the period of 1932-1974 were moderate.

A variety of environmental factors can affect trees. One of these factors is usually dominant, while others can either strengthen or mitigate its effect. The consequences of such interplay will be completely different for the ecosystem. Using statistical methods, the dendrochronological signal was decomposed into signals from different sources. UV-B signals (tree responses to UV-B exposure) were extracted from climatic ones. Climate variations (IDM), which are synchronous with TOC (UV-B) can strengthen or

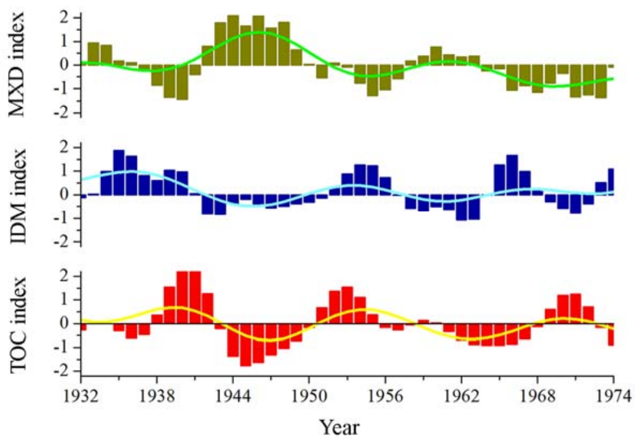

Fig. 9: Time series of normalized indices MXD, IDM, and TOC (correlating with UV-B)

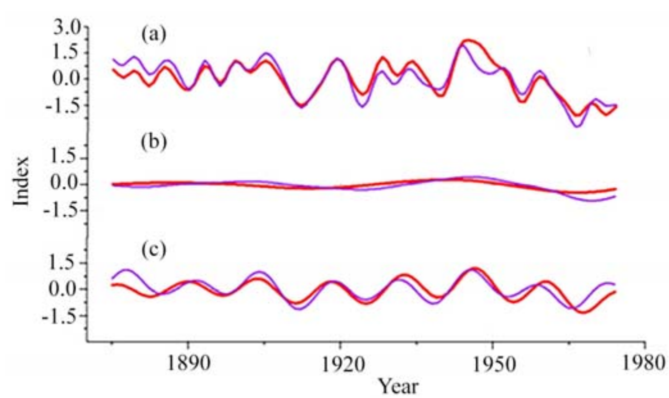

Fig. 10: R-MXD decomposition of group I (red curve) and group II (blue curve) into components: (a) regional MXD1 and MXD2; (b) long-term trends; and (c) UV-B signal (group I) and climatic signal (group II)

mitigate UV-B signals in MXD. It can be assumed that the negative effect of UV-B on coniferous forests can play a global role in some aridity conditions. Such impact will be dangerous and can change the forest composition. It is important to perform large-scale study to predict the forest state in the future. Similar to all plants, trees are constantly affected by UV-B radiation. UV-B exposure depends on the dose. Natural UV-B doses are lower than those used in experiments. Nevertheless, in nature photosynthesis decreases at lower doses. There are no available measurements of UV-B threshold levels for mature trees (Mikhailenko, *et al.*, 2014; Chen, *et al.*, 2015). Anatomic changes in needles occur due to UV-B, temperature and precipitation effects. As a result, the rate of photosynthesis decreases, which in turn leads to the decrease in tree-ring density. (Kłusek, *et al.*, 2015). Stress can also shorten the lifetime of needles. The effects of UV-B exposure are accumulated during the entire lifespan of the needles. A lag of 1-2 years or higher in the correlation between MXD and TOC can be due to replacement of needles. Changes in tree root system and crown occur in the response to soil moisture deficit. Division and expansion rate of tree-ring cells becomes slower in mature conifers (Becklin, *et al.*, 2016). Thus, it leads to an increase in tree-ring density. The tree quickly responds to water deficit. Radial growth of wood is impossible in severe drought conditions. The study revealed a strong response of conifer species to UV-B exposure (correlation coefficients were $R > 0.55$). Using the SSA-Catepillar method, R-MXD was decomposed into the following components: UV-B signal (58.7%), climatic signal (19.4%), and residual signal

Table 3: Effect of UV-B and climate on regional tree ring density in the Swiss Alps

	1875-1974		1932-1974			
	group I R-MXD1 and UV-B	group II R-MXD2 and IDM	group I R-MXD1 and UV-B	group I UV-B signal	group II R-MXD2 and IDM	group II Climatic signal
April		Monthly changes were not considered	R = 0.56, p < 0.05	R = 0.55	Monthly changes were not considered	
March-September	Instrumental data are absent	R = –0.35, p < 0.05. Climatic signal R = – 0.45, p < 0.05	R = 0.27 insignificant	R = 0.41	R = –0.38, p < 0.05	R = –0.51, p < 0.05

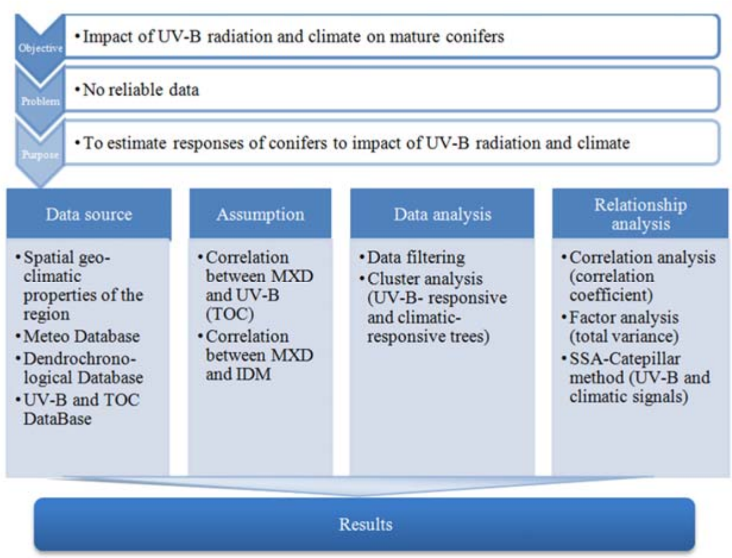

Fig.11: A block diagram illustrating the developed method

(2%). The results are consistent with the results of the factor analysis, which was used earlier to process the raw data (MXD sampling). The variability in the R-MXD1 time series was analyzed for anomalous behavior. Two temperature anomalies in the 1940s–mid-1950s and mid-1950s–mid1960s in the Swiss Alps have been mentioned above. One anomaly is observed only in the regional R-MXD1 time series, i.e., in the 1940s–mid-1950s. Changes in the tree-ring density exceed 2σ (SD = 0.56) for this period. Temporal coincidence of trends in IDM and TOC (UV-B) stress factors can be considered as an anomalous increase in UV-B. UV-B effects on trees for March-September were studied. UV-B can influence the growth of tree-ring cells when coniferous trees have the processes similar to those of deciduous trees such as bud swelling and sap flowing. The pattern of tree-ring formation is uneven during the growing season. Earlywood is formed in April-June and the latewood is formed in July-September. The highest level of UV-B exposure on the maximum density is observed when trees a waken after winter dormancy (early growth). In this period, the seasonal increase in UV-B reaches its highest values. Temperature exposure on the maximum density was observed in August. The correlation coefficients between density and UV-B and between density and temperature were positive during the entire growing season. The level of the correlation between density and temperature was lower, i.e. the correlation was weaker. Data analysis methods allow detecting UV-B signal in tree-rings. R-MXD time series is an informative indicator of tree structural changes in the Alps. Dendrochronological data show a strong UV-B signal. R-MXD1 time series has a strong response to UV-B ($R = 0.55$, $p < 0.05$). Therefore, it can be a basis to reconstruct past TOC and UV-B variations. Experiments studies of the UV-B exposure on conifers involved seedlings

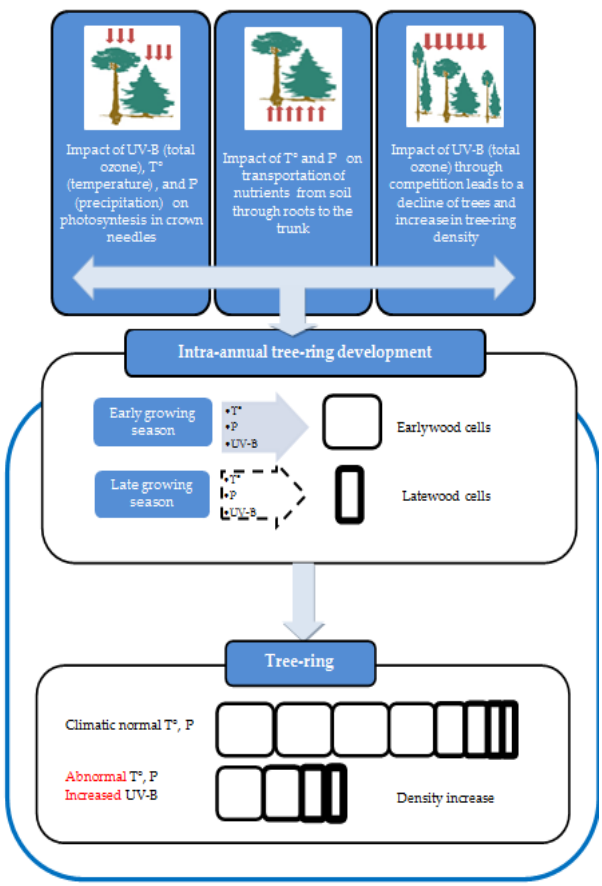

Fig. 12: A block diagram of UV-B (TOC), temperature (T) and precipitation (P) effect on tree-ring structure (cells)

(Frank and Esper, 2005). Dendrochronological data are mainly used to study wood density of trunk in mature conifers. Only changes related to tree rings were analyzed.

Indirect indicators were used to assess the occurred changes:

1)tree-ring parameters indicate the processes in the crown and roots;

2)TOC variations define UV-B changes;

3)IDM measures changes in temperature and moisture.

A block diagram was suggested based on the obtained results, (Fig. 11). The diagram illustrates data mining technique to detect tree-ring responses. Another block diagram (Fig. 12) illustrates various environmental effects on the tree ring.

Fig. 12 shows the impact of UV-B, temperature, and precipitation on tree-ring cell size and cell wall thickness. Obviously, there exists an adaptation mechanism, which links processes in the tree-ring and regulates their effects. Hormonal functions of plants (vegetables) growing on the Pamir's slopes were studied in the 1990s (Shomansurov, 1994). Experimental and field investigations showed that hormonal regulation helps plants adapt to stress factors (UV-B, low temperature, and aridity). Hormones are considered responsible for the central process in plant morphogenesis (cell expansion) (Foremanet, *et al.*, 2003). At the same time, as it is shown for conifers, functions of growth hormones are constantly regulated, changed, and controlled by genetic system at tissue level when tree ring cells are formed during vegetation season (Uggla, *et al.*, 2001; Vaganov, *et al.*, 2006; Vaganov, *et al,* 2010; Bhalerao and Fischer, 2014).Combined effects of UV-B radiation, low temperature, and drought limit the plant growth at high altitude sites. As for average altitudes, UV-B is a limiting factor in plant growth. The most responsive period for plants is early summer. At low temperature and drought, the concentration of abscisic acid (ABA) increases. The decrease in auxin and gibberellin concentrations in plants correlates with the increase in UV-B. The growth rate of UV-B-responsive plants increases while the growth rate of climatic-responsive plants remains unchanged (Shomansurov, 1994). Hormonal balance in trees, exposed to increased UV-B, is regulated by:

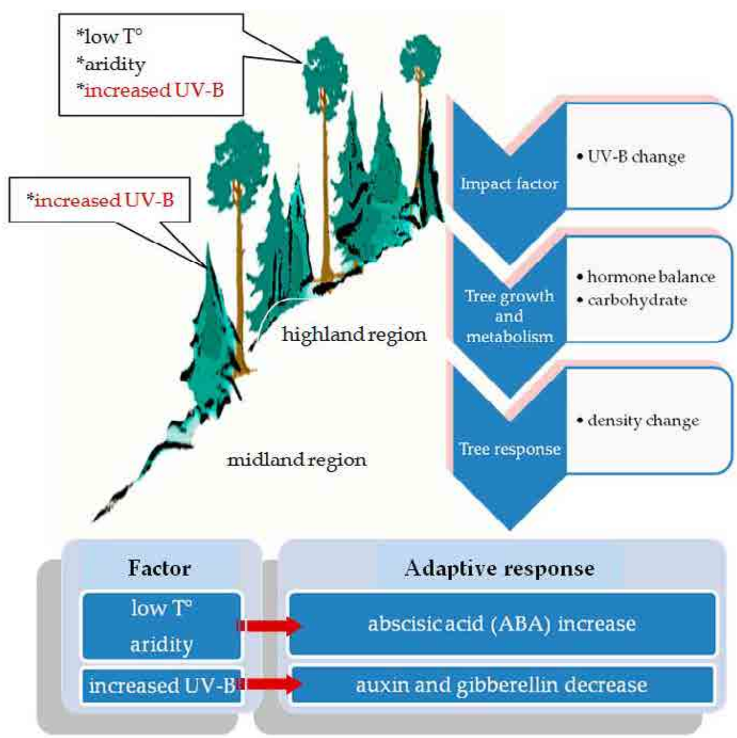

Fig. 13: The diagram shows the impact of UV-B, temperature and precipitation on tree response at different altitudes

1) A decrease in auxin and gibberellin concentrations to inhibit growth(Uggla, *et al*., 2001);
2) An increase in the level of the plant hormone ABA to regulate stress adaptation (Vanhaelewyn, *et al*., 2016).

In the first case, in most conifers, the transport of carbohydrates is reduced. Cell expansion, including latewood cells, is inhibited. The xylem density increases, which can lead to an increase in the tree-ring density. The other smaller part of coniferous trees can involve the second type of regulation. Thick walls of the cells are formed in the latewood. In this case, large amounts of transportable sugars act as building materials (cellulose, etc.) for cell walls. Metabolic processes during the formation of cell walls can gradually slow down and lead to the accumulation of soluble sugars (Tegelberg, 2002). As a result, tree-ring density decreases.

Fig. 13 presents functional relationship between hormonal regulation and wood formation.

CONCLUSION

Changes in UV-B (TOC) and climatic parameters (temperature and precipitation) since 1932 till 1974 have statistically insignificant long-period trends which are close to zero. The late 1980s are characterized by the abrupt decrease in the level of stratospheric ozone and associated UV-B radiation growth as well as the increased impact of other environmental factors. The assessment of the period, favorable for the growth of coniferous trees (1932-1974), when UV-B and ozone changes were stable, helps to understand how subsequent changes in environmental conditions, such as modern warming, ozone reduction and ultraviolet growth, affect forests. The study of the conditions for the growth of trees in the past also allows making predictions for better forest management. In this study, it was shown that MXD in UV-B-responsive conifers increases with the level of UV-B radiation. A method to extract UV-B signals from dendrochronological data was suggested. The method allows calculating generalized R-MXD series, which can be used to reconstruct past UV-B and TOC behavior in the Swiss Alps. It is probable that MXD increases if UV-B-stress causes a decrease in auxin and gibberellin concentrations. The impact of UV-B on cell wall formation in tree rings can be an object for modeling in the mountain areas around the world. The functional links can be represented as follows: the factors (UV-B, temperature and precipitation) do not effect directly on the tree ring density, they affects firstly the hormone production which then changes the density. Thus, the study should be continued. The future steps are to set a mathematical model or (and) to obtain experimental results.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

ABBREVIATIONS

ABAL	*Abies alba*
ABA	Abscisic acid
Eq.	Equation
FFT	Fast Fourier Transform
IDM	Index aridity of De Martonne
LADE	*Larix deciduas*
Lat., N°	Latitude, north degrees
Lon., E°	Longitude, earth degrees
M	Meters
Mm	Millimetres of precipitation
MXD	Maximum tree-ring density of conifers (maximum density)
P	Precipitation
p	Probability levels (probability of error)
PCAB	*Picea abies*
PICE	*Pinus cembra*
R	Correlation coefficient
R-MXD	Regional maximum density
R-MXD1	Regional maximum density of group 1
R-MXD2	Regional maximum density of group 2
SSA	Singular Spectrum Analysis
STD	Standard deviation
T	Air temperature

TEMIS	Tropospheric Emission Monitoring Internet Service
TOC	Total ozone content (total ozone column)
I_{TOC}	TOC index
UV-B	Ultraviolet-B
I_{UVB}	UV-B index
X	MXD marker
%	Percentage
°	Degrees

REFERENCES

Ageev, B.G.; Gruzdev, A.N.; Bondarenko, S.L.; Sapozhnikova, V.A., (2013). Long-term H_2O and CO_2 trends in conifer disc tree rings and meteorological parameters. J. Life Sci., 7: 1002-1008(**7 pages**).

Bebi, P., Seidl, R., Motta, R., Fuhr, M., Firm, D., Krumm, F., Conedera, M., Ginzler, C., Wohlgemuth, T., Kulakowski, D., (2017). Changes of forest cover and disturbance regimes in the mountain forests of the Alps. For. Ecol. Manage. 388: 43–56 (**14 pages**).

Becklin, K.M.; Anderson, J.T.; Gerhart, L.M.; Wadgymar, S.M.; Wessinger, C.A. Ward J.K., (2016). Examining plant physiological responses to climate change through an evolutionary lens. Plant Physiol., 172(2): 635-649 (**15 pages**).

Begert, M.; Schlegel T.; Kirchhofer W., (2005). Homogeneous temperature and precipitation series of Switzerland from 1864 to 2000. Int. J. Climatol. 25: 65–80 (**16 pages**).

Beniston, M., (2006). Mountain weather and climate: A general overview and a focus on climatic change in the Alps. Hydrobiologia. 562: 3–16 (**14 pages**).

Bhalerao, R.P.; Fischer, U., (2014). Auxin gradients across wood-instructive or incidental? Physiol Plant. 151(1): 43-51 (**9 pages**).

Bigler, C.J.; Bräker, O.U.; Bugmann, H.; Dobbertin, M.; Rigling, D., (2006). Drought as an inciting mortality factor in Scots pine stands of the Valais, Switzerland. Ecosystems. 9: 330-343(**14 pages**).

Bondarenko, S.L., (2006). Study of main components of long-period variations of stratospheric ozone according to reconstructed and instrumental data by caterpillar method. Proceedings of SPIE - The International Society for Optical Engineering. 1: 6160H(**7 pages**).

Boucher, O., (2010). Stratospheric ozone, ultraviolet radiation and climate change. Weather. 65: 105–110 (**6 pages**).

Casale, G.R.; Meloni, D.; Miano, S.; Palmieri, S.; Siani, A.M., (2000). Solar UV-B irradiance and total ozone in Italy: Fluctuations and trends. J. Geophys. Res. 105 (D4): 4895–4901 (**7 pages**).

Chen, F.; Yuan, Y.; Wei, W.; Zhang, T.; Shang, H.; Yu, S., (2015). Divergent response of tree-ring width and maximum latewood density of Abies faxoniana to warming trends at the timberline of the western Qinling Mountains and northeastern Tibetan Plateau, China. Silva Fennica. 49 (4): article id 1155 (**16 pages**).

Cuny, H.E.; Rathgeber, C.B.; Frank, D.; Fonti, P.; Fournier, M., (2014). Kinetics of tracheid development explain conifer tree-ring structure. New Phytologist. 203: 1231–1241 (**11 pages**).

De Micco, V.; Campelo, F; De Luis, M.; Bräuning, A.; Grabner, M.; Battipaglia, G.; Cherubini, P., (2016). Intra-annual density fluctuations in tree rings: How, when, where, and why? IAWA J. 37(2): 232–259 (**28 pages**).

Foreman, J., Demidchik, V.; Bothwell, J.H.; Mylona, P.; Miedema, H.; Torres, M.A.; Linstead, P.; Costa, S.; Brownlee, C.; Jones, J.D.; Davies, J.M.; Dolan, L., (2003). Reactive oxygen species produced by NADPH oxidase regulate plant cell growth. Nature. 422: 442-446(**5 pages**).

Frank, D.; Esper, J., (2005). Characterization and climate response patterns of a high-elevation, multi-species tree-ring network in the European Alps. Dendrochronologia. 22: 107–121 (**15 pages**).

Gobiet, A.S.; Kotlarski, M.; Beniston, G.; Heinrich, J.; Rajczak, J.; Stoffel, M., (2014). 21st century climate change in the European Alps – A review. Sci. Total Environ. 493: 1138–1151 (**14 pages**).

Golyandina, N.; Zhigljavsky, A., (2013). Singular spectrum analysis for time series. Berlin, Heidelberg, Springer. (**120 pages**).

Gruzdev, A.N.; Bezverkhnii, V.A., (2006). Quasi-biennial variations in ozone and meteorological parameters over Western Europe from ozone sonde data. Izvestiya, Atmos. Oceanic Phys., 42 : 203-214(**12 pages**).

Kłusek, M.; Melvin, T.M.; Grabner, M., (2015). Multi-century long density chronology of living and sub-fossil trees from Lake Schwarzensee, Austria. Dendrochronologia. 33: 42-53 (**12 pages**).

Krupa, S.V., (2000). Ultraviolet-B radiation, ozone and plant biology. Environ. Pollut., 110 : 193-194 (**2 pages**).

Liu, Q.; Callaghan, T.V.; Zuo, Y., (2004). Effects of elevated solar UV-B radiation from ozone depletion on terrestrial ecosystems. J. Mount. Sci. 1(3): 276-288(**13 pages**).

Mavrakis, A.; Papavasileiou H., (2013), NDVI and E. de Martonne indices in an environmentally stressed area (Thriasio Plain – Greece), Procedia Technology. 8: 477–481 (**6 pages**).

Meinzer, F.C.; Lachenbruch, B.; Dawson, T.E., (2011). Size- and age-related changes in tree structure and function. Springer, Netherlands (**514 pages**).

Mikhailenko, I.M.; Kanash, E.V.; Timoshin, V.N. (2014). Model of plant linear growth in conditions of oxidation stress induced by UV-B radiation. Agrobiology. 1: 17-25(**9 pages**).

Philipona, R., (2013). Greenhouse warming and solar brightening in and around the Alps. Int. J. Climatol. 33: 1530–1537 (**8 pages**).

Rieder, H.E.; Holawe, F.; Simic, S.; Blumthaler, M.; Krzyścin, J.W.; Wagner, J.E.; Schmalwieser, A.W.; Weihs, P., (2008). Reconstruction of erythemal UV-doses for two stations in Austria: A comparison between alpine and urban regions. Atmos. Chem. Phys. 8: 6309-6323 (**14 pages**).

Saurer, M.; Kress, A.; Leuenberger, M.; Rinne, K.T.; Treydte, K.S.; Siegwolf, R.T.W., (2012). Influence of atmospheric circulation patterns on the oxygen isotope ratio of tree rings in the Alpine region. J. Geophys. Res. 117: D05118 (**12 pages**).

Schmatz, D.R.; Ghosh, S.; Heller, I., (2001). Tree ring web and alternative chronologies. In Kaennel, M.; Bräker, O.U. (eds.) International conference tree rings and people. Davos, 22-26 September 2001, Abstracts, Birmensdorf, Swiss Federal Research Institute WSL. 120 (**1 page**).

Shomansurov, S., (1994). Reaktsiya rasteniya na uf svet i drugiye ekologicheskiye faktory vysokogoriy Pamira.avtoreferat dis. doktora biologicheskikh nauk (Response of plants to UV radiation and other environmental factors at high altitudes in Pamir. Autoref diss. doct. biol. sci.). Inst. Plant Physiol., Moscow, Russia. (in Russian); (**40 pages**).

Silkin, P.P.; Ekimova, N.V., (2012). Relationship of strontium and calcium concentrations and the parameters of cell structure in Siberian spruce and fir tree-rings. Dendrochronologia. 30(2): 189-194 (**6 pages**).

Stübi, R.; Schill, H.; Klausen, J.; Vuilleumier, L.; Gröbner, J.; Egli, L.; Ruffieux, D., (2017). On the compatibility of Brewer total column ozone measurements in two adjacent valleys (Arosa and Davos) in the Swiss Alps . Atmos. Meas. Tech. 10: 4479–4490 (**12 pages**).

Suchar, V.A.; Robberecht, R., (2016). Integration and scaling of UV-B radiation effects on plants: from molecular interactions to whole plant responses. Ecology and Evolution. 6(14): 4866-4884 (**19 pages**).

Suvorova, G.G., (2016). Analysis of pine stands biological productivity in age groups using forest management data. Bulletin Irkutsk State Univ., Biol., Ecol. 16: 43-52(**10 pages**) (in Russian with English abstracts).

Tegelberg. R., (2002). Impact of elevated ultraviolet-B radiation on three northern deciduous woody plants. PhD Thesis in Biology, University of Joensuu, Finland (**30 pages**).

Trošt, S.T., (2014) Broadleaf and conifer tree responses to long-term enhanced UV-B radiation in outdoor experiments: a review. Acta Biol. Sloven. 57: 13–23(**11 pages**).

Turtola, S., (2005). The effects of drought stress and enhanced UV-B radiation on the growth and secondary chemistry of boreal conifer and willow seedlings. PhD dissertations in Biology, University of Joensuu (**82 pages**).

Turunen, M.; Latola, K., (2005). UV-B radiation and acclimation in timberline plants. Environ. Pollut., 137(3) : 390-403.(**14 pages**).

Uggla, C.; Magel, E.; Moritz, T.; Sundberg, B., (2001). Function and dynamics of auxin and carbohydrates during early wood/latewood transition in Scots pine. Plant Physiol., 125: 2029–2039 (**11 pages**).

Vaganov, E.A.; Hughes, M.K.; Shashkin, A.V., (2006). Growth dynamics of conifer tree rings images of past and future environments. Berlin, Heidelberg, Sp. Vetlag (**343 pages**).

Vaganov, E.A.; Kuznetsova, G.V.; Svistova, V.I.; Kruglov V.B., (2010). Anatomy of tree rings in Siberian pine grafts. Lesovedenie. For. Sci., 3: 59–70, (in Russian), (**12 pages**).

Van der A, R.J.; Allaart, M.A.F.; Eskes, H.J., (2015a). Extended and refined multi sensor reanalysis of total ozone for the period 1970-2012. Atmos. Meas. Tech. 8: 3021-3035 (**15 pages**).

Van der A, R.; Allaart, M.; Eskes, H., (2015b). Multi-sensor reanalysis (MSR) of total ozone, version 2. Dataset. Royal Netherlands Meteorological Institute (KNMI)

Vanhaelewyn, L.; Prinsen, E.; Van Der Straeten, D.; Vandenbussche, F. (2016). Hormone-controlled UV-B responses in plants. J. Exp. Bot. 67: 4469–4482 (**14 pages**).

Verma, V.; Ravindran, P.; Kumar. P.P. (2016). Plant hormone-mediated regulation of stress responses. Plant Biol. 16: 86–95 (**10 pages**).

Wang, Qing-Wei; Hidema, Jun; Hikosaka, K., (2014). Is UV-induced DNA damage greater at higher elevation? Am. J. Bot. 101(5): 796-802 (**7 pages**).

Wieser, G.; Oberhuber, W.; Walder, L.; Spieler, D.; Gruber, A., (2010). Photosynthetic temperature adaptation of *Pinus cembra* within the timberline ecotone of the Central Austrian Alps. Ann. For. Sci. 67(2): 201 (**8 pages**).

Zang, C.; Hartl-Meier; C., Dittmar; C., Rothe, A.; Menzel, A., (2014). Patterns of drought tolerance in major European temperate forest trees: climatic drivers and levels of variability. Glob. Change Biol. 20: 3767–3779(**14 pages**).

Zheng, J., Liu, Y., & Hao, Z. (2015). Annual Temperature Reconstruction by Signal Decomposition and Synthesis from Multi-Proxies in Xinjiang, China, from 1850 to 2001. PLoS ONE, 10(12), e0144210 (**12 pages**).

Zuev, V.V.; Bondarenko, S.L., (2007). Issledovanie ozonosfery metodami dendrokhronologii (Ozonosphere Research by Dendrochronological Methods). Inst. Opt. Atm. Sib. Otd. Ross. Akad. Nauk, Russia (in Russian), (**168 pages**).

Zuyev, V.V.; Bondarenko, S.L.; Savchuk, D.A.; Bocharov, A.Yu., (2009). Territorial zoning for the purpose of reforestation from changes of total ozone content in the atmosphere (exemplified by the Tomsk region). Geogr.hy Natural Resour., 30(3): 242-245(**4 pages**).

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