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Solar and Climatic Factors Affecting Tree-Ring Growth of Mountain Birch (*Betula pubescens*) beyond the Northern Timberline on Kola Peninsula, Northwestern Russia

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Abstract: A 105-year chronology (AD 1917–2021) was developed from mountain birch (*Betula pubescens* Ehrh.) from beyond the coniferous treeline on the Kola Peninsula in Northwestern Russia (68.86 N, 34.69 E). A total of 22 trees were cored, including the oldest living mountain birch of 105 years old. The highest correlations occurred for the May temperature ($r = 0.39$, $p < 0.01$) and July sunshine duration ($r = -0.39$, $p < 0.05$). The increase in radial growth in May seemed to be caused by snowmelt giving rise to soil temperature, which can lead to a resumption in radial growth after winter dormancy. The negative correlation with the July sunshine duration seemed to be connected to changes in the spectral composition of solar radiation in the red to far-red ratio in the end of the polar day in July. The application of wavelet coherency revealed a significant (>95%) connection between the radial growth of *B. pubescens*, and solar activity in frequency bands encompassed the main solar cycles: 5.5 years (the second harmonic of the Schwabe cycle), 11 years (the Schwabe cycle) and 22 years (the Hale cycle). The results show that the northernmost birch trees in Europe are suited for tree-ring research. This allows us to expand the area of dendrochronological research further beyond the conifer treeline above the Polar Circle.

Keywords: northern treeline; *Betula pubescens*; Kola Peninsula; tree-ring chronology; growing season; solar radiation

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1. Introduction

Forest ecosystem responses to global climate change have recently attracted increasing scientific attention. It is known that tree growth is limited by the following environmental factors: temperature, precipitation, sunlight, etc. Trees at the forest tundra boundary (northern timberline) experience the most severe climatic conditions, including short growing season, low temperature and lack of sunlight and, therefore, are considered to be more sensitive to climate change [1].

Some tree-ring studies conducted at northern timberlines in Fennoscandia have shown that the radial growth variation in local conifer trees is mainly related to current summer temperatures [2–4]. Additionally, several studies have reported significant correlation between solar activity and the radial growth of coniferous trees growing in northern Scandinavia and Kola Peninsula (Northwestern Russia) [5–7]. Solar radiation, as one of the main manifestations of solar activity, is one of the main environmental factors influencing the photosynthesis and transpiration of trees, with consequences for tree growth [8–15]. Despite northern treeline trees tending to be more sensitive to changes in solar radiation, there are still rather few studies on the effects of quality and quantity of radiation received by trees at high latitudes [8,10,12–16]. Moreover, previous dendroclimatological studies have not touched on the effects of sunshine duration on the radial growth of trees on the Kola Peninsula.

Presently, the forest-tundra ecotone beyond the coniferous treeline in northern Scandinavia and Kola Peninsula is dominated by mountain birch (*Betula pubescens* Ehrh. ssp. *tortuosa*) [2,17–20]. In addition, according to palynological evidence, during the early Holocene (9500 cal. yr BP), birch forests expanded across the Kola Peninsula as far north as the modern Barents Sea coastline [17,21]. Thus, *B. pubescens* is one of the most common tree species at the northern timberline on Kola Peninsula. Unfortunately, no dendrochronological and dendroclimatological studies of birch have been implemented in the region. Dendrochronological studies on birch are very limited. This could be because of difficulties realized in cross-dating due to its irregular growth patterns, diffuse porous rings, light wood color and the occurrence of missing rings [22]. Nevertheless, near its distributional limits such as the alpine treelines in Asia [23–27] and Japan [9], birch has a strong climatic response and is suited for dendrochronological research. Few researchers have also investigated the effects of climatic conditions on the birch tree-ring growth at the northern timberline in Fennoscandia [20,22,28–31]. Some other noteworthy tree-ring studies have also been conducted on birch species occurring in North America [32,33], China [34], and Russia, in Siberia [35] and Kamchatka [36]. Interestingly, a dendrochronological study of a birch tree was recently used to solve a high-profile crime in Poland [37]. In another case, the radial growth of downy birches showed a significant growth decline due to artificial smoke pollution applied to hide the German battleship Tirpitz during World War II in Kåfjord, Northern Norway [30,38]. These studies showed a high potential of birch for dendrochronology and dendroclimatology. Birch trees have different physiological and phenological features than conifers. The ability of downy birch to grow on poorly developed and polluted sites predetermines *B. pubescens* to be used in dendrochronology [30]. Thus, broadleaf tree species, such as *Betula pubescens*, show great potential to further extend the present tree-ring network.

The objectives of this study were to develop a high-latitude tree-ring chronology of mountain birch (*Betula pubescens* Ehrh. ssp. *Tortuosa*, also called *B. pubescens* Ehrh. ssp. *czerepanovii* N.I. Orlova) from beyond a coniferous treeline on the Kola Peninsula and to identify the main natural factors influencing the tree growth of mountain birch in the region. For this, the tree-ring chronology of *B. pubescens* was compared to climate and solar activity data with the help of the Multiple-Taper Method (MTM) of spectral analysis, discrete wavelet transform and wavelet coherence (WTC).

2. Materials and Methods

2.1. Study Site

The study site is located in the northeastern part of the Kola Peninsula (68°51′688 N; 34°41′393 E; 238 m a.s.l.) (Figure 1). The Kola Peninsula lies predominantly north of the Arctic Circle and is bounded by the Barents Sea to the north and the White Sea to the south. It extends between latitudes of 66° N and 70° N, and it spans longitudes of 30° E to 42° E, with a total area of around 145,000 km^2 [39]. Sandy and sandy loamy sediments of glacial, marine and glaciofluvial origin are parent rocks all over the territory of the Kola Peninsula; the predominant soils in the studied area are classified as Al–Fe–humus podzols [40]. The climate is very heterogeneous and modified by the proximity to the Barents Sea, with a mean temperature of −11 °C in January (the coldest month) and +9 °C in July (the warmest month). The mean annual temperature in the study site is close to 0 °C [41] (Figure 2a). The mean annual precipitation is about 600–700 mm and occurs primarily in June–October [39] (Figure 2a).

The polar day in the study area lasts ~2 months from May 22 to July 22 [42]. On average, July is the sunniest month in Teriberka, with ~235 h of sunshine (Figure 2b).

In the study region, the growing season extends from early June until the middle of September; the snow cover period lasts from the middle of October until the end of May [41]. Two vegetation zones were defined in the region, taiga and tundra, with an ecotone between the two [18]. The most prevalent taiga species are *Pinus sylvestris* L. (Stots pine), *Picea abies* [L.] (Karst) (Norway spruce) and *B. pubescens*. The taiga-tundra ecotone is dominated by *B. pubescens* [43]. *P. sylvestris* forms the coniferous treeline [43]. Our study site is located in the taiga-tundra zone, some 30 km north of the coniferous treeline and ~45 km south of Barents Sea (Figure 1).

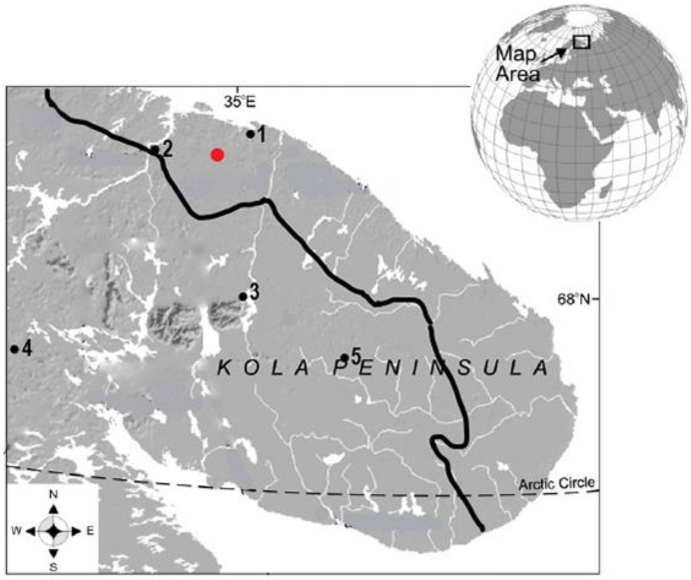

Figure 1. Map showing locations of sampling site (red circle) and meteorological stations (black circles): 1—Teriberka (69°10′ N, 35°10′ E), 2—Murmansk (68°58′ N, 33°05′ E), 3—Lovozero (67°51′ N, 35°10′ E), 4—Kovdor (67°34′ N, 30°28′ E), 5—Krasnoshchelye (67°20′ N, 37°02′ E).

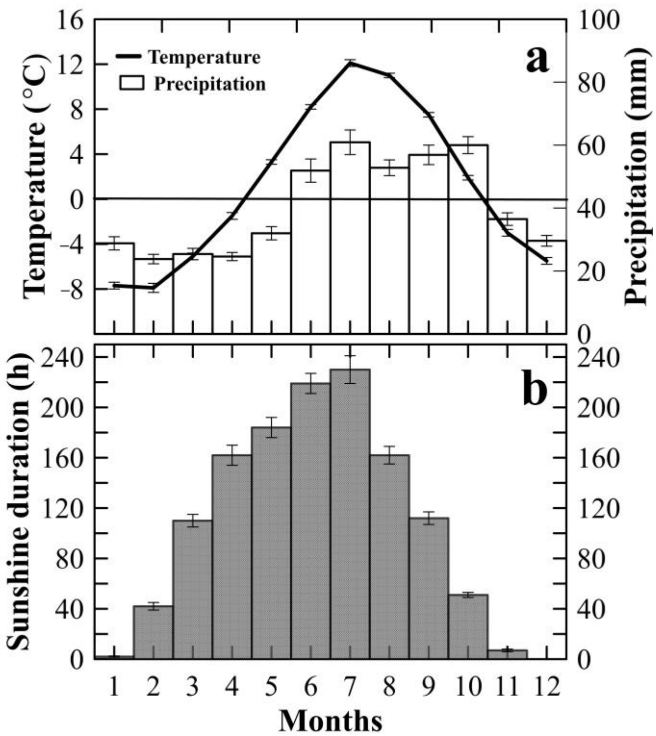

Figure 2. Annual variations in the climate parameters: (**a**) temperature and precipitation; (**b**) sunshine duration (sum per month).

2.2. Chronology Development

A total of 22 trees were cored in the autumn of 2021 after the end of the growing season. One or two cores per tree were taken; cores were then dried and glued into wooden holders. The preparation for tree-ring measurements included core grinding and staining with Phloroglucinol to improve the contrast of tree-ring boundaries. Cores of poor quality (e.g., rotted, fragmented) were excluded from further analysis. Totally, 25 cores from 16 trees were successfully cross-dated. The samples were measured with an accuracy of 0.01 mm using the image analysis system TREMET [44]. The measured tree-ring series were then cross-dated and quality checked using the COFECHA program [45]. The data were then standardized using the ARSTAN program by applying a Hugershoff curve or a negative exponential curve [46].

2.3. Data Sets

Climatic factors affecting the tree-ring width of *B. pubescens* were investigated. The Teriberka meteorological station (69°10′ N; 35°10′ E) is near (~50 km) the sampling site (Figure 1). Five monthly climatic parameters were used for the analysis: mean temperature (TM) and sum of precipitation (PP) for the period of 1959–2021 (Figure 2a); sunshine duration (SD) for the period of 1983–2021 (Figure 2b); total and low (CL) cloud amount for the period of 1966–2021. Additionally, taking into account that the climate of the Kola Peninsula is very heterogeneous, we also used monthly temperature data for the period of 1959–2021 from four other meteorological stations: Murmansk (MUR; 68°58′ N; 33°05′ E), Lovozero (LVZ; 67°51′ N, 35°10′ E), Kovdor (KOV; 67°34′ N, 30°28′ E) and Krasnoshchelye (KRS; 67°20′ N, 37°02′ E) (Figure 1). The climatic data from all meteorological stations were obtained from the All-Russia Research Institute of Hydrometeorological Information—World Data Center (RIHMI–WDC), Roshydromet [47].

As a proxy of total solar irradiance (TSI), we used the annual sunspot number R_z [48]. The yearly means of R_z were obtained from the WDC-SILSO, Royal Observatory of Belgium, Brussels [49].

2.4. Statistical, Spectral and Wavelet Analysis

To investigate the tree growth–climate relationships, we calculated the Spearman's rank correlation coefficients between the TRW chronology and TM, SD, CL, PP and R_z during the relevant periods. The Spearman's correlation is a nonparametric statistic assessing monotonic relationships (whether linear or not). Statistical significance of correlation coefficient was evaluated via *t*-statistics.

The MTM spectra [50] were used to evaluate the occurrence of the main periodicities in the time series. This non-parametric method allowed us to avoid using an a priori specified model for the process and to minimize the spectral leakage caused by the finite length of the data set. The MTM spectral analysis was applied using the software SSA-MTM "Toolkit for Spectral Analysis" (Version 4.4) [51]. Significance levels were tested against white-noise and red-noise backgrounds [51].

Wavelet analysis was performed to assess the main periodicities and their evolution in time–frequency domain [52]. In the continuous wavelet transform (CWT), the Morlet function was applied as a mother wavelet because of its suitability for analysis of geophysical and climatic time series [53]. To examine the relationship between two time series, the cross-wavelet transform was applied [52,53]:

$$W_{xy} = W_x W_y^*, \tag{1}$$

where W_x and W_y denote continuous wavelet transforms of time series X and Y; * denotes the complex conjugate. The WTC was used to evaluate a localized correlation coefficient in the time–frequency domain between two time series [52]:

$$R^2 = \frac{\left|S\left(s^{-1}W_{xy}\right)\right|^2}{S\left(s^{-1}|W_x|^2\right)S\left(s^{-1}|W_y|^2\right)}, \tag{2}$$

where S denotes smoothing in both time and scale. The statistical significance levels of WTCs were estimated using the Monte Carlo method against a red-noise model [53].

The original signal was decomposed using the discrete wavelet decomposition [54] into four frequency bands: D_1(2–4 year, n = 1), D_2(4–8 year, n = 2), D_3(8–16 year, n = 3), and D_4(16–32 year, n = 4).

All time series were standardized (zero mean, unit standard deviation).

3. Results

3.1. Chronology Statistics

Based on tree-ring width analysis, a tree-ring width (TRW) chronology (AD 1917–2021) was developed from living trees of *B. pubescens* (Figure 3). One of the trees sampled was relatively old, up to 105 years. This is one of the highest ages compared to other birch trees studied in northernmost Russia [19]. Tree age in the current study is higher than that reported in Aune et al. [19], who found the average tree age of *B. pubescens* at treelines of the Kola Peninsula to be 70.8 ± 28.1 years. The oldest (258 years) northernmost birch tree in the world was found at the sub-Arctic altitudinal treeline in Northern Sweden (68°20′ N, 19°00′ E) [22].

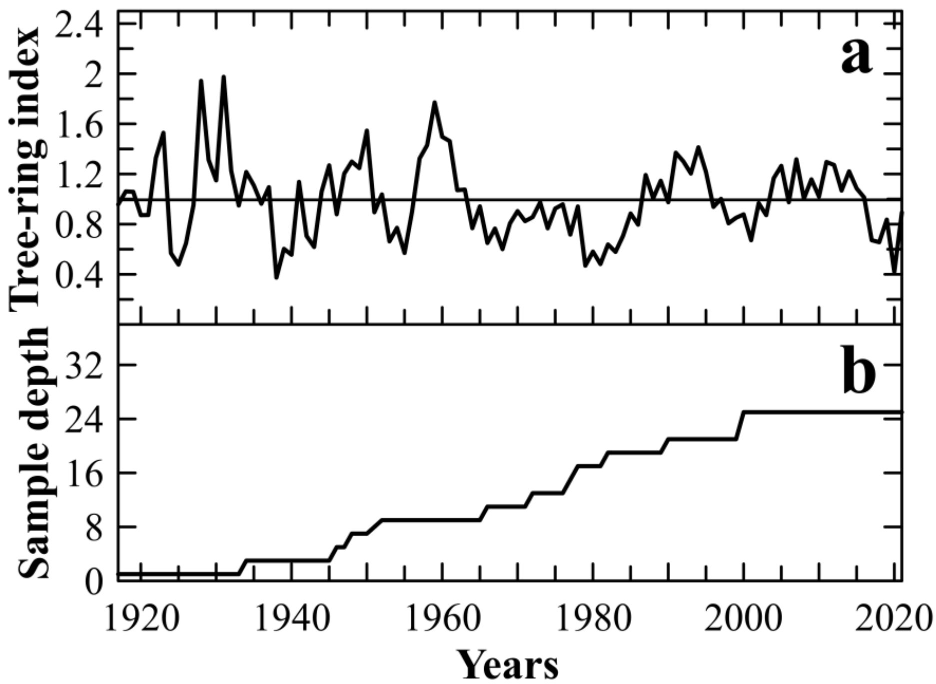

Figure 3. Standardized tree-ring-width chronology (**a**) and sample replication (number of series) (**b**) of *B. pubescens* at northern treeline on the Kola Peninsula, Northwest Russia.

The reliability of the birch chronology was tested using several descriptive statistics (Table 1). The mean sensitivity (MS) and standard deviation (SD) as measures of inter-annual variation in tree-ring width were 0.38 and 0.54, respectively (Table 1). According to Ferguson's classification, a value of MS > 0.3 is considered to be high [55]. The mean inter-series correlation (R_{BAR}) is 0.37 (Table 1), being comparable to *B. pubescens* in Northern Norway [30,38], *B. ermanii* in the Changbai Mountains, Northeast China [34] and *B. utilis* in the western Himalayas [24]. In addition, the correlation is higher than for that of Himalayan birch in the central Himalayas [22,26]. Otherwise, the correlation is lower than that of *B. pendula* in the permafrost areas of northern Siberia [35]. Generally, as compared with arid and semi-arid sites, trees in subalpine-temperate regions have lower inter-series correlations [25]. The Expression Population Signal (EPS; Table 1) is used to assess the degree to which a site chronology represents a hypothetical chronology based on an infinite number of cores; chronologies with an EPS > 0.85 are often considered to be reliable [55].

Therefore, the basic statistics (Table 1) indicate a significant dendrochronological potential of our birch chronology [46,55].

Table 1. General statistics of *Betula pubescens* chronology.

Parameters	Value
Chronology time span (year)	AD 1917–2021 (105)
Number of cores (trees)	25 (16)
Standard deviation (SD)	0.54
Mean sensitivity (MS)	0.38
First-order autocorrelation	0.50
Mean inter-series correlation (R_{BAR})	0.37
Express population signal (EPS)	0.9

3.2. Tree Growth–Climate Relationship

The downy birch chronology indicated that ring width was correlated with the May temperature of the current year for all meteorological stations (Table 2). Correlations between monthly climatic parameters from each of the five stations and the tree-ring data showed that Teriberka correlated best with our study site tree rings (Table 2). Correlation coefficients indicated that monthly temperatures were positively correlated with the TRW index of *B. pubescens*, except for the current July (Table 2, Figure 4a). However, only the correlations in the previous December and current March–May were statistically significant at the 0.05 level (Figure 4a). Interestingly, the correlation coefficient of downy birch chronology with the current-year July temperature was 0, indicating that the summer season (JJA) temperature was not a growth-limiting factor for *B. pubescens* at our sampling site. Correlations of TRW chronology with precipitation were mostly weak and insignificant except for the previous November and December ($p < 0.05$; Figure 4a), suggesting that the radial growth was probably influenced by the snow cover conditions of the previous year. The TRW index was also negatively correlated with the July sunshine duration in the current year; otherwise, no significant correlations were found between the rings and any other monthly value of sunshine duration (Figure 4b). This significant ($r = -0.39$; $p < 0.05$) negative relationship indicates that sunshine duration is the dominant climatic factor controlling the radial growth of *B. pubescens* beyond the northern timberline. Additionally, the current-year July low cloud amount was positively correlated with the tree-ring-width index ($p < 0.05$; Figure 4b). The correlations with total (not shown) and low cloud cover were weak and statistically insignificant from the previous to current September, except for the current July (Figure 4b).

Table 2. Correlation coefficients between the standard ring-width chronology of *Betula pubescens* and the monthly temperature data of nearest meteorological stations (1959–2021).

Month	MUR (70)	TER (50)	KRS (200)	LVZ (95)	KVD (250)
January	0.18	0.22	0.14	0.14	0.12
February	0.19	0.17	0.17	0.11	0.17
March	0.27 *	0.24	0.22	0.23	0.27 *
April	0.3 *	0.29 *	0.19	0.25	0.22
May	0.34 **	0.39 **	0.30 *	0.36 **	0.25 *
June	0.08	0.14	0.11	0.08	0.05
July	0	0	0	−0.12	0
August	0.25	0.11	0.15	0.18	0.19
September	0.09	0.12	0.07	0.11	0.14

* $p < 0.05$, ** $p < 0.01$. MUR—Murmansk (68°58′ N, 33°05′ E), TER—Teriberka (69°10′ N, 35°10′ E), KRS—Krasnoshchelye (67°20′ N, 37°02′ E), LVZ—Lovozero (67°51′ N, 35°10′ E), KVD—Kovdor (67°34′ N, 30°28′ E). Distances (km) between the core collection site and meteorological stations are indicated in parentheses.

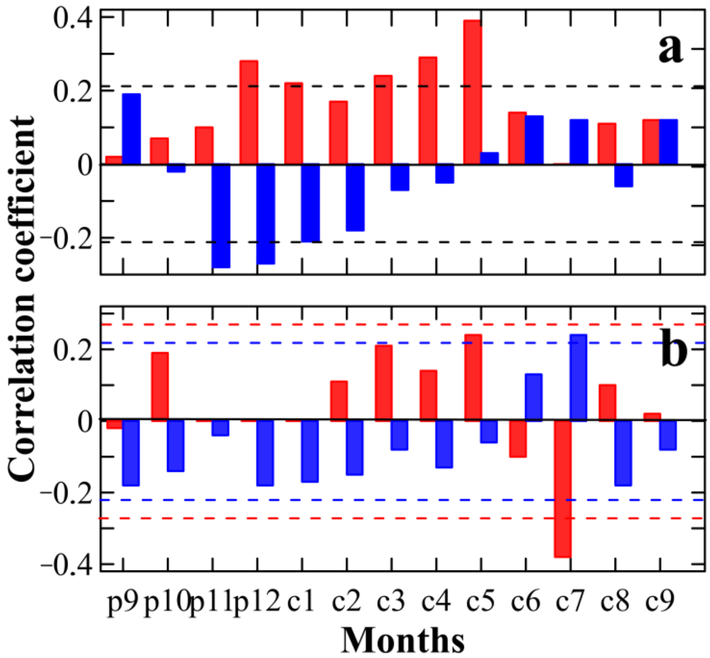

Figure 4. Correlation coefficients between the standardized tree-ring-width chronology of *B. pubescens* and monthly climatic data: (**a**) mean temperature (red) and precipitation (blue), (**b**) sunshine duration (red) and low cloud cover (blue). The dashed lines indicate significant levels ($p < 0.05$).

3.3. Spectral MTM and Wavelet Analysis

Figure 5 shows the results of MTM spectral analysis of the annual time series of TRW and R_z. The results of analysis revealed significant (>95%) periodicities of 2–3, 4.4 and 13–20 years in tree-ring (TRW) time series (Figure 5a). The periodicity of 13–20 years may be related to solar activity variations; indeed, periodicities around 11 years (Schwabe cycle) were present in the series of solar activity (Figure 5b).

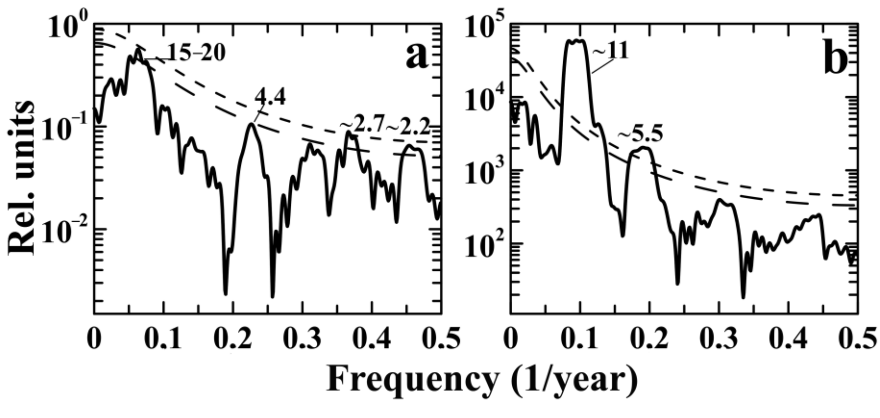

Figure 5. MTM spectrum analysis: (**a**) the *B. pubescens* standard tree-ring chronology, (**b**) annual average of sunspot number R_z. Dashed lines show 95% ans 99% confidence levels.

To evaluate changes in the time–frequency domain of these spectral maxima obtained using the MTM method, we applied the discrete wavelet decomposition and WTC analysis [52,53]. Inter-annual variabilities of the TRW–R_z connections at a period range of 4–8 years demonstrated an intermittent relationship throughout the large portion of record (Figure 6a,b). For instance, the TRW–R_z is strong and significant (above the 95% confidence level) around 1970–1995, and it is weak (below the 95% confidence level) around

1917–1926, 1932–1948 and 1995–2021 (Figure 6b). Arrows indicate that the two series have a non-stationary relative phase connection during these time intervals (Figure 6b).

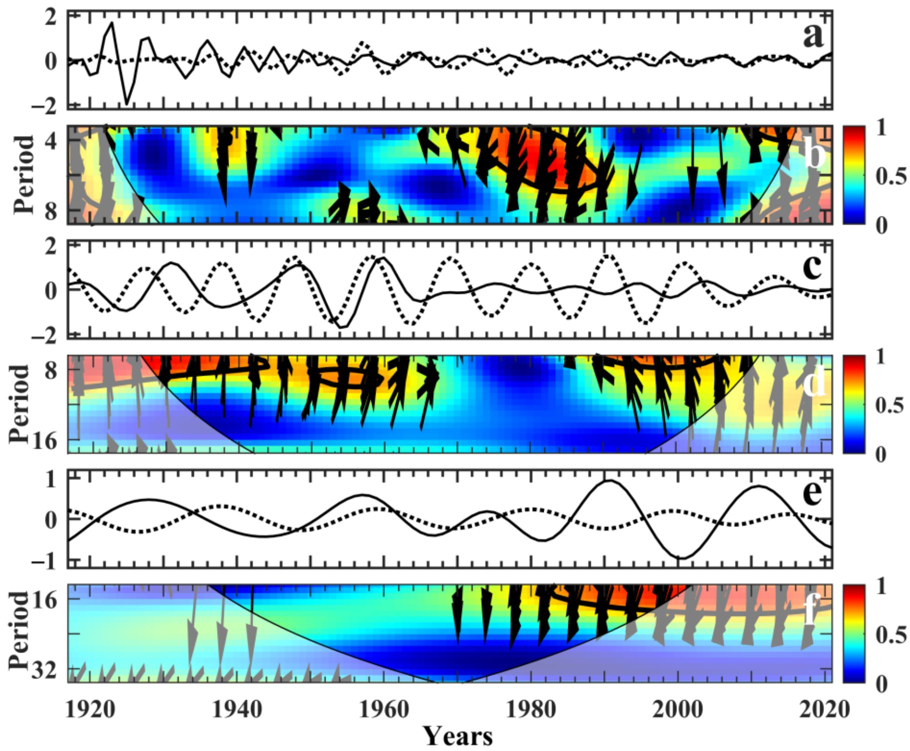

Figure 6. The levels of wavelet decomposition and corresponding WTC plots of tree-ring-width (bold line) and sunspot number R_z (dashed line) data over 1917–2021: (**a**)—the D_2 (4–8 years), (**b**) WTC in the D_2 band, (**c**) the D_3 (8–16 years) decomposition level, (**d**) WTC in the D_3 year band, (**e**) the D_4 (16–32 years) decomposition level, (**f**) WTC in the D_4 band. Black arrows in WTC plots show the relative phase relationships (with in-phase pointing right, anti-phase pointing left). Black contours show the 5% significance level against red noise.

The TRW–R_z coherence at a period range of 8–16 years demonstrates a strong (>95%) power only around 1917–1965 and a weaker (<95%) one over a period of 1986–2021 (Figure 6d). Arrows indicate a non-stationary phase relationship between tree rings and solar activity during these time intervals. The 11-year signal in the TRW–R_z connection is completely absent between 1970 and 1986 (Figure 6d).

The TRW–R_z connection in the D_4 band that encompasses the 22-year solar cycle is also weak and demonstrated insignificant (<95%) power between 1917 and 1980 (Figure 6f). The signal became significantly stronger around 1980–2021 (Figure 6f).

4. Discussion

Environmental factors controlling tree growth (temperature, water availability, sunshine duration, nutrient supply, intra- and interspecies competition, etc.) are rather different in different regions; furthermore, trees growing in extreme conditions (i.e., at or beyond treelines) respond more strongly to climatic variations.

Based on the correlations between the tree-ring widths and climatic factors, the mean monthly temperature and sunshine duration apparently played a key role in regulating the radial growth of *B. pubescens* in the study area. The May temperatures correlated significantly ($r = 0.39$, $p < 0.01$) with the birch chronology. In contrast, the correlations with summer (June–August) temperatures were found to be weak and insignificant; moreover, the correlation between tree-ring width and July temperature was close to 0 (Figure 4a). Similar correlation patterns with a significant maximum in May and minimum in July were found for the other temperature series from meteorological stations on the Kola Peninsula (Table 2), which confirmed the reliability of the results obtained. These findings are similar to the other results, showing a significant ($r = 0.33$, $p < 0.05$) correlation of downy birch tree-ring growth with the mean (May–June) temperatures in Northern Norway [30]. For instance, in the boreal zone of Finland, *B. pubescens* showed the strongest response in bud burst to May temperatures, with increasing power towards the north [56]. Additionally, the onset of wood formation in downy birch in northern Fennoscandia is dependent on bud burst, triggered by the spring temperatures [15,18,30,31,56]. Indeed, maximum wood formation in deciduous species has been proved to occur at the end of May [57]. The thermal growing season on the Kola Peninsula begins on 30 May on average (1981–2010), and the earliest onset was found between 20 and 25 May [41]. Thus, our findings showed that the spring (not summer) temperature is one of the main factors limiting the radial growth of downy birch at northern treelines on the Kola Peninsula. However, according to some previous studies, growth variation in trees at northern latitudes is mainly related to current summer temperatures [2,4,20]. This is why the annual tree-ring widths are often used to reconstruct summer temperature in the region [2,6]. These discrepancies in the results could be explained by the differences in species, time intervals and places of study [56,58] and require further research. Actually, the territory of the Kola Peninsula is very heterogeneous climatically due to the influence of different factors: Gulf Stream, latitudinal, longitudinal and altitudinal influence, oceanic and continental impact [41]. It is subdivided into at least eight biogeographic provinces, with different climatic and growing season patterns [41]. Therefore, the climatic responses and growing seasons of trees in different parts of the Kola Peninsula can vary significantly. Similarly, bud burst of *B. pubescens* in Finland showed a stronger response to May temperatures towards the north [56]. Thus, the importance of spring temperature for tree growth revealed in this study is in agreement with the findings of other studies for northern high latitudes [19,30,31,56].

One of the possible explanations for the discovered effect of the influence of spring temperatures on the radial growth of *B. pubescens* is an increase in soil temperature in May on the Kola Peninsula. According to Bandekar and Odland [59], soil temperatures regulate the start of a growing season after snowmelt in the northernmost forests. In the study place, the snowmelt takes place in May, giving rise to soil temperature [18]. Thereafter, rapid water and nutrient absorption by roots can lead to enhanced tree growth [1]. Indeed, it has also been reported that the soil at a depth of 10 cm was warmed and its temperature was above 3.2 °C for a few days after the snowmelt in May in the tundra on the Kola Peninsula [60]. According to some findings, the roots of trees begin to function only above 3.2 °C [61]. To protect themselves from freeze-induced dehydrative stress during dormancy, northern treeline trees accumulate sugar solutes that contribute to the maintenance of the membrane bilayer [62]. On the Kola Peninsula, this healthy mixture (or birch sap) starts to flow from roots to buds of downy birch at the beginning of May [63]. In May, just prior to the bud burst, a rapid increase in water content in buds of *B. pubescens* from Northern Fennoscandia was observed [8]. Our results support a possible advantage of the current air May temperature over summer (JJA) temperature for mountain birch radial growth at northern treelines on the Kola Peninsula. The tree-ring-width growth investigated in this study did not demonstrate any significant correlation with the current-year precipitation (Figure 4a).

Some researchers have pointed out that the radial growth of birch trees was affected not only by the climatic conditions of the current year but also by those of the previous year [20,34]. These findings are confirmed in our study as the tree-ring growth of *B. pubescens* is positively (negatively) correlated with the previous December temperature (precipitation) (Figure 4a). Increased winter precipitation falling as snow could result in long-lasting snow cover in spring, resulting in delayed growth initiating at the northern timberline [64].

The most interesting result from the present study is a significant negative correlation of *B. pubescens* radial growth with July sunshine duration in the current year (Figure 4b).

Interestingly, no clear relationship was observed between the tree-ring widths and current July temperature (Figure 4a). There may be two possible explanations for these findings. The northernmost trees receive continuous light throughout the polar day, which lasts ~2 months in the study area from May 22 to July 22 [42]. So, continuous light supplies uninterrupted energy from the Sun, but under higher light intensities for light-saturated conditions, trees become exposed to more light than the tree can use for photosynthesis [14]. Under these stress conditions, photoinhibition of photosynthesis occurs when the rate of photosynthesis begins to decrease, causing a decline in tree growth [10,14]. However, this reason cannot explain the fact that a strong negative correlation is observed only in July and not in June, when the value of solar insolation is highest and the sunshine duration is nearly the same in the study place (Figure 4b). In fact, continuous light is not constant, and the quantity and quality of solar light vary depending on latitude, season and time of day [14]. Some recent research showed that trees from high latitudes tend to be more sensitive to changes in the spectral composition of solar radiation, especially in the red to far-red (R:FR or 660:730 nm) ratio [12–14,65]. These spectral fluctuations in solar light in the R:FR ratio are believed to be enough to regulate the growing season and phenology of arctic trees during the polar day [10,12–14,65]. For instance, bud burst of *B. pendula* from northern Finland has been shown to respond to F:FR drops during twilight when the sun was near or below horizon [65]. This finding is also supported in the present study by the negative correlation between the tree-ring width of *B. pubescens* and sunshine duration in July. It is the month of the end of the polar day and the increase in twilight duration in the study area. Therefore, the growth of northernmost mountain birch on the Kola Peninsula seems to be influenced by the variations in the spectral component of solar radiation in the R:FR ratio at the end of the polar day in July. This is consistent with our previous studies [7,66], which suggested that FR solar radiation could be one of the main limiting factors affecting tree and algae growth at high latitudes. Additionally, solar radiation in the visible and FR bands seemed to influence tree growth at high latitudes during Grand Solar Minima, like Maunder Minimum of solar activity (1645–1715 AD) [7].

Solar radiation reaching the Earth's surface could affect the radial growth of trees, either directly or through temperature variations. In the present study, the WTC analysis between tree rings and solar activity indices (R_z) showed a statistically significant (or close to the significant level) high power in frequency bands, indicating the main solar cycles: 5.5 years (the second harmonic of the Schwabe cycle), 11 years (the Schwabe cycle) and 22 years (the Hale cycle). Moreover, the tree-ring width periodicities around 15–20 years may be associated with possible forcing by the 18.6-year lunar nodal tidal cycle [67] or frequency combination in the solar spectra [68].

Our results suggest that the May air temperature and FR solar radiation at the end of polar day are the main factors limiting the radial growth of mountain birch in the study area. This finding is consistent with the results reported by Huang et al. [15], who found that photoperiod and spring temperature were the dominant drivers triggering the onset of wood formation in Northern Hemisphere conifers. Further studies are needed to determine how solar radiation and spring temperature regulate the wood formation in *B. pubescens* at northern treelines on the Kola Peninsula.

5. Conclusions

Based on northernmost mountain birch tree-ring samples from the Kola Peninsula, a 105-year chronology was developed, currently the only chronology of this species in Arctic Russia. The results of the correlation analysis support a possible advantage of the current May over summer (JJA) temperatures for dendroclimatological analysis of *B. pubescens* growth at northern treelines on the Kola Peninsula.

Sunshine duration, showing negative significant ($p < 0.05$) correlation with tree rings during the current July, is another limiting factor for *B. pubescens* growth. This negative relationship seemed to be caused by the changes in the spectral composition of solar radiation in the R:FR ratio at the end of the polar day in July. The results of WTC analysis revealed a significant (>95%) connection between tree-ring width and sunspot number in the frequency bands encompassing the main solar cycles: 11 years (the Schwabe cycle), 22 years (the Hale cycle) and 5.5 years (the second harmonic of the Schwabe cycle). The periodicity around 15–20 years in tree-ring width may also be related to the ~18.6-year lunar nodal tidal cycle.

In summary, the results of the present study confirm the possibility of using *B. pubescens* trees from the northern treelines of the Kola Peninsula for dendrochronological analysis, which allows us to expand the area of dendrochronological research further beyond the conifer treeline above the Polar Circle. Further studies are needed to confirm our preliminary findings and provide us with a better understanding of *B. pubescens* adaptations in the Arctic under polar day conditions.

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