Spatiotemporal changes in temperature sensitivity of Siberian tree growth

Alexander V. Kirdyanov[1,2,3], Alberto Arzac[3], Anatoly S. Prokushkin[2,3], Dmitriy V. Ovchinnikov[2], Alexander I. Bondarev[2], Pavel P. Silkin[4], Tatiana Bebchuk[1], Jan Esper[5,6], Ulf Büntgen[1,6,7]

[1]Department of Geography, University of Cambridge, CB2 3EN, UK

[2]Sukachev Institute of Forest SB RAS, Federal Research Center 'Krasnoyarsk Science Center SB RAS', Akademgorodok, Krasnoyarsk, 660036, Russian Federation

[3]Siberian Federal University, 79 Svobodnii, Krasnoyarsk, 660041, Russian Federation

[4]Institute of Geography RAS, 29 Staromonetniy Lane, Moscow, 119017, Russian Federation

[5]Department of Geography, Johannes Gutenberg University, 55099, Mainz, Germany

[6]Global Change Research Centre, 61300 Brno, Czech Republic

[7]Department of Geography, Masaryk University, 61137 Brno, Czech Republic

** Corresponding author: ak2118@cam.ac.uk (Alexander V. Kirdyanov)*

Abstract

Anthropogenically induced climate change largely affects the functioning of vegetation communities worldwide. In the world's largest land biome, the boreal forest, a persistent decoupling of tree growth from rising summer temperatures has been recorded in recent decades. This so-called 'Divergence Problem' (DP) has been studied over the past 30 years, yet the causes and spatial patterns within the boreal forest zone are not well understood. Here, we present tree-ring evidence on varying DP in *Larix gmelinii* from the globally northernmost forest island on Taymyr Peninsula and *Larix sibirica* from the southern taiga in central Siberia. Tree-ring width and maximum latewood density data reveal DP to be substantially stronger in the south indicating that growth-climate relationships in Siberian larch passed beyond a tipping point under warmer climate and increased anthropogenic pressure. In the north, the temperature remained strong and temporally stable underscoring the skill of tree-ring chronologies for long-term climate reconstructions. These findings highlight the regional heterogeneity of tree growth responses to global warming within the boreal forest zone, from which spatially varying consequences for carbon and water cycle dynamics must be expected. Our study emphasizes the importance of updating tree-ring chronologies in remote regions within boreal forest zone to foster understanding of spatiotemporal patterns in biomass allocation, permafrost degradation, and DP across this large biome.

Keywords: Arctic dimming; Boreal forests; Dendroclimatology; Divergence Problem (DP); Global warming; Spatiotemporal heterogeneity

Introduction

Constantly increasing anthropogenic activity induces local to global environmental and climatic changes that largely affect the functioning of ecosystems worldwide with numerous consequences for terrestrial vegetation (Newbold et al., 2015; Piao et al., 2020; Weiskopf et al. 2020). Exceptionally vulnerable boreal forests are currently experiencing unprecedented rates of recent warming and increased frequency of weather extremes, intensity of wildfires, rates of permafrost degradation, scale of logging and technogenic emissions, etc. (Gauthier et al., 2015; Ponomarev et al., 2016, 2023; Box et al., 2019; Kharuk et al., 2021; Anisimov and Reneva 2006; Anisimov et al., 2007; Holloway and Lewkowicz, 2020, Kirpotin et al., 2021). The effect of all these factors and processes may already be observed in the current status of different components of boreal forest ecosystems, including trees (Tei et al., 2017).

Tree radial growth at the circumpolar high latitude forest belt in the norther hemisphere was shown to be presumably limited by temperature variability (Jacoby and D'Arrigo, 1989; Vaganov et al., 1996, 1999; Davi et al., 2003; Briffa et al., 2004; Anchukaitis et al., 2017; Björklund et al., 2023). In recent decades, however, the decoupling of tree growth in these ecosystems to rising instrumental summer temperatures, the so-called 'Divergence Problem' (DP) (D'Arrigo et al., 2008), has been observed in high- or low-frequency domains or both. The DP questions the ability of northern forests to increase biomass productivity rates following the current warming. If the DP becomes a widespread phenomenon, it will also have great implications to the ability of tree-ring data to serve as a proxy for temperature during past warm periods (Büntgen et al., 2021a) and predict future response of forest growth to rising temperature (Camarero et al., 2021).

DP was first reported by Jacoby and D'Arrigo (1995) for white spruce in Alaska and lately described for a variety of sites and tree species, mostly in high-latitude and high-elevation ecosystems (see D'Arrigo et al. 2008 for a review). The evidence of the DP as a widespread phenomenon in circum-polar high latitude forests was provided from the analysis of tree growth regional composites in northern hemisphere (Briffa et al., 1998; Wilson et al. 2007). The DP was also found in several high-elevation forests in lower latitudes (Zhang et al., 2009; Jiao et al., 2015; Li et al., 2020). However, some studies since then show that the DP is not observed in all temperature limited sites, implying that the DP is a spatially heterogeneous phenomenon (Anchukaitis et al., 2013, 2017; Büntgen et al., 2021a, 2024; Yin et al., 2021).

Potential causes for the DP were detailed in D'Arrigo et al. (2008), and they include a number of biological and environmental issues: increased limiting effect of drought on tree growth that overcomes the influence of temperature, non-linear tree radial growth response to rising temperature under changing environment, changes in stratospheric ozone concentration. The choice of the correct target temperature variable was also related to the DP emergence. The dependence of the DP emergence on methodological pitfalls associated to tree-ring chronology development and the quality and applicability of the instrumental temperature measurements were reviewed by Esper and Frank (2009) and Frank et al. (2007). Recently, the role of industrial pollution and Arctic dimming as a major factor for the DP in some regions was examined in an extended portion of the high-latitude boreal forest belt in Siberia (Kirdyanov et al., 2020; Büntgen et al., 2021b). However, the current understanding of the scale and causes of the DP, as well as the consequences of this phenomenon are far from being complete.

Here, we analyze tree-ring width (TRW) and maximum latewood density (MXD) data from two latitudinally distant forest regions in central Siberia to test tree growth for the loss of sensitivity to temperature under progressively warming climate and increasing anthropogenic pressure. We define the timing and the scale of the DP at these ecologically different environments and discuss the obtained results with respect to possible reasons and consequences of the DP.

Materials and Methods

Wood samples were collected in two vegetation zones of boreal forest in central Siberia with considerably different climate conditions: forest-tundra ecotone and southern taiga (Fig. 1). Climate in the study area is characterized as extremely continental, with low annual mean temperatures of -12.5 °C in the northern region (WMO 20891 'Khatanga'; 1929–2022) contrasting to much warmer, but still negative mean annual temperatures of -1.7 °C in the southern region (WMO 29263 'Yeniseisk'; 1871–2022 and -1.3 °C during 1929–2022). The warmest and coldest months in both regions are July and January with monthly temperatures 12.6 °C and -32.1 °C in forest-taiga and 18.3 °C and -21.9 °C in southern taiga (18.5 °C and -21.5 °C for 1929–2022), respectively. Annual precipitation totals are around 280 mm in forest-tundra and around 480 mm, of which 42% and 38% fall during summer months (from June to August), respectively.

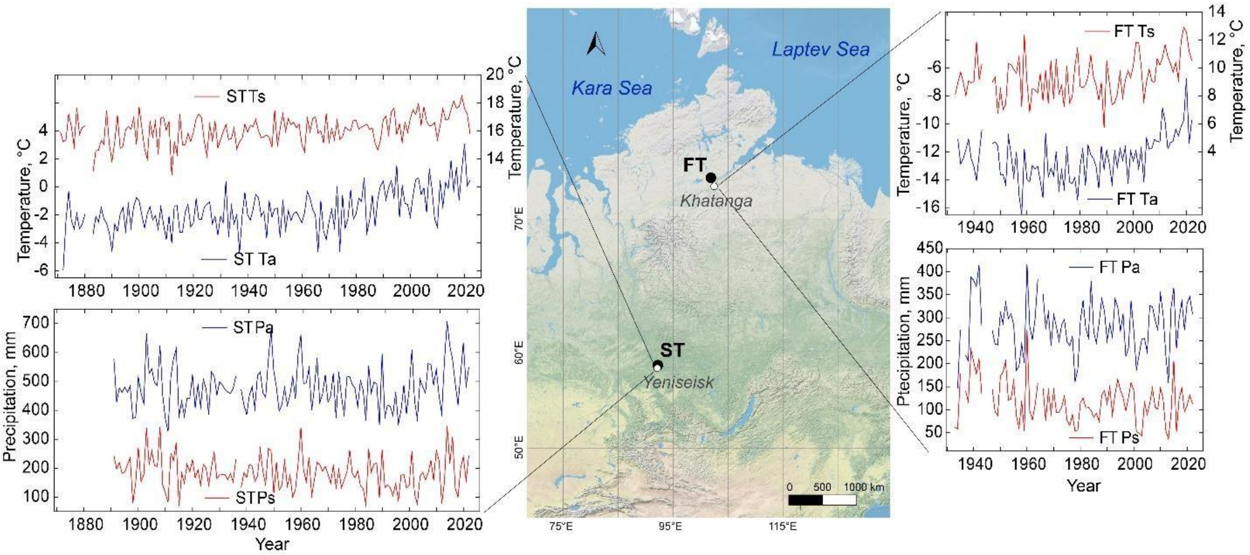

Fig. 1. Study sites and climate data. The map shows the location of tree-ring sites (black circles) and meteorological stations (white circles). The diagrams show summer (red) and annual mean (blue) temperatures and precipitation recorded at the Khatanga and Yeniseisk meteorological stations near the FT for ST tree sites.

Summer (June–August) and annual temperature means at the forest-tundra region were first relatively stable or slightly decreasing from 1929 to 1989 at a rate of -0.04 ($P > 0.05$) and -0.20 °C/decade ($P > 0.05$), respectively (Fig. 1). From the 1990, temperatures are increasing by 0.86, and 1.01 °C/decade in summer and annually, respectively ($P < 0.005$). In southern taiga, seasonal temperature means exhibited increases from 1871 to 1969 with 0.05 °C/decade ($P > 0.05$) in summer and annually, and the increase accelerated since 1970 to 0.31 and 0.51 °C/decade ($P <$

0.0001) for summer and annual temperature means, respectively. The 1st order autocorrelation coefficients for summer temperature are 0.26 and 0.23 for forest-tundra and southern taiga, respectively, but it increases to 0.31 for May-August temperature in southern taiga. Annual and seasonal precipitation totals in both forest-tundra and southern taiga do not show statistically significant changes ($P > 0.01$).

The dominant tree species in northern central Siberia is *Larix gmelinii* (Rupr.) Rupr. (Tolmachev 1931; Abaimov et al., 1997). In the south, larch is represented by *Larix sibirica* Ledeb. In 2010–2011, we collected wood cores at two sites in forest-tundra (FT1 and FT2, 72.5°N and 102.0°E) and one site in southern taiga (ST, 58.5°N and 92.0°E) (Table) to represent different tree growth conditions for *Larix* spp. in central Siberia. The distance between the regions is > 1600 km, and while the FT sites were established at the world's northernmost forest island Ary-Mas characterized by harsh climate, the conditions at ST are milder (Fig. 1). Wood cores from these sites were used to measure tree-ring density profiles and obtain MXD data according to the standard procedure (Schweingruber, 1988). To update the tree-ring chronologies, the additional dendrochronological site was established in the forest-taiga region in 2019 close to the existing sampling plots, and the southern taiga site was revisited in 2022. The wood material from 2019 and 2022 was used for tree-ring width (TRW) measurements on a LINTAB measuring system (RINNTECH e.K., Heidelberg, Germany). The obtained individual series were cross-dated using the TSAP-win (Rinn, 2003). Cross-dating was statistically verified with COFECHA (Version 6.02P; http://www.ldeo.columbia.edu/tree-ring-laboratory/resources/software).

Individual TRW series were standardized with negative exponential line using the ARSTAN software (https://www.geog.cam.ac.uk/research/projects/dendrosoftware/, last accessed on 14.02.2024). For MXD series, cubic smoothing splines with 50% frequency-response cutoff at 2/3 of the individual series length were used. Bi-weight robust means of the individual measurement series were used to produce dimensionless index chronologies. The standard version of the chronologies was chosen for most of the further analyses. The residual version was only used for correlating with monthly and precipitation totals, which do not show statistically significant trends. For the forest-tundra region, we developed three local TRW and two MXD chronologies, which have different sample depth (Table) and were highly significantly correlated (at least $P < 0.001$). To avoid overweighting the influence of the site with the higher sample replication, we first developed local chronologies individually and then averaged the local index chronologies into regional chronologies for FT. In the southern taiga region, tree-ring parameter chronologies were obtained for the combined material from the two field campaigns. To estimate the quality of the chronologies, their standard dendrochronological statistics were calculated: the coefficient of sensitivity, 1st order correlation coefficient and expressed population signal (EPS).

To assess the climate sensitivity of the TRW and MXD chronologies, Pearson's correlation coefficients were calculated against monthly temperature means and precipitation totals from the nearest meteorological stations (Fig. 1) from previous year September to September of a current year. June–July (JJ) and summer (JJA) temperatures, as well as total precipitation during summer and the season with mean monthly temperature below 0 °C (w) were used to assess seasonal climate influences. For the cold season, precipitation totals were calculated from previous September to current year May in forest-tundra and from previous October to current year April in southern taiga. To evaluate the temporal stability of the relations between tree-ring chronologies and climate records, we used the running correlations calculated for a 31-year window with one-year step. For this, we used temperature means for at least two warm months (including May in southern taiga) as the variables most correlated with tree-ring data. Finally, spatial correlation between the MXD chronologies and gridded seasonal temperature means (CRU TS4.07, Harris et al., 2020) were calculated for the first and last ~ 40-year long periods of the available instrumental temperature measurements from the nearest meteorological stations and covered by MXD data. In the forest-tundra region, we slightly increased the window for the spatial correlations to 41 and 42 years to cover the entire period of meteorological observations in Khatanga. Presenting spatial correlations for the same period starting in 1901 for the two studied sites is not reliable because of lack of valid temperature records in the forest-tundra region that correctly represent conditions before the installation of the meteorological station in Khatanga.

Results

The regional TRW and MXD chronologies from forest-tundra (FT) continuously cover the past 438 years (1582 – 2019) and 304 years (1708 – 2011), respectively (Table, Fig. 2). The TRW and MXD chronologies from southern taiga (ST) extend over the past 311 years (1711 – 2021) and 240 years (1770 – 2009), respectively. The mean TRW in forest-tundra varies within a wide range from 0.26 ± 0.19 mm to 0.44 ± 0.25 mm with lower values recorded for older trees and a chronology with longer mean segment length (MSL). Trees in southern taiga grow faster (mean TRW > 1.00 mm) with denser MXD (> 1.00 g/cm^3) compared to forest-tundra. The coefficient of sensitivity is high in TRW index chronologies in forest-tundra (> 0.300) and lower in southern taiga (0.218). MXD chronologies are characterized by even lower mean sensitivity. The expressed population signal (calculated for the 50-year periods) is higher than the commonly accepted threshold of 0.85 since at least 1867 for all TRW index chronologies (Wigley et al., 1984). These statistics and high correlation coefficients between local tree-ring chronologies ($P < 0.005$) show that the combined regional chronologies FT in forest-tundra and local chronology ST in southern taiga are suitable for dendroclimatic analysis.

TRW indices from FT demonstrate a clear increasing trend from the late 1990s, which follows the TRW decline after the peak in the 1940s (Fig. 2A). In southern taiga, TRW demonstrated an increase from 1949, but with a significant drop in 2013-2016 and the following highest values in 2020 and 2021 (Fig. 2C). In general, MXD indices were relatively stable in forest-tundra from 1930s, but with a slight decrease in the 1990s and consequent recovery (Fig. 2B). In southern taiga, MXD indices decreased from the 1910s to the early 1980s, then increased into the 1990s and decreased after the mid-1990s.

Table. Chronology characteristics (TRW = tree-ring width, MXD = maximum latewood density, MSL = mean segment length, Rbar = inter-series correlation, 1st order autocorrelation were calculated for the period of the available temperature data from the nearest meteorological stations Khatanga and Yeniseisk)

Region	Site	Tree-ring parameter	N of series	Period, years	MSL	Mean ± SD	Mean sensitivity	1st order autocorrelation
Forest-tundra	FT1	TRW	14	1708 – 2010	125	0.42 ± 0.28 mm	0.48	0.46
	FT2	TRW	14	1924 – 2011	74	0.44 ± 0.25 mm	0.32	
	FT3	TRW	41	1582 – 2019	217	0.26 ± 0.19 mm	0.58	
	FT1	MXD	14	1708 – 2010	125	0.85 ± 0.13 g/cm³	0.16	0.36
	FT2	MXD	14	1924 – 2011	74	0.79 ± 0.11 g/cm³	0.12	
Southern taiga	ST	TRW	24	1711 – 2021	131	1.05 ± 0.54 mm	0.22	0.64
	ST	MXD	15	1770 – 2009	126	1.01 ± 0.10 g/cm³	0.05	0.37

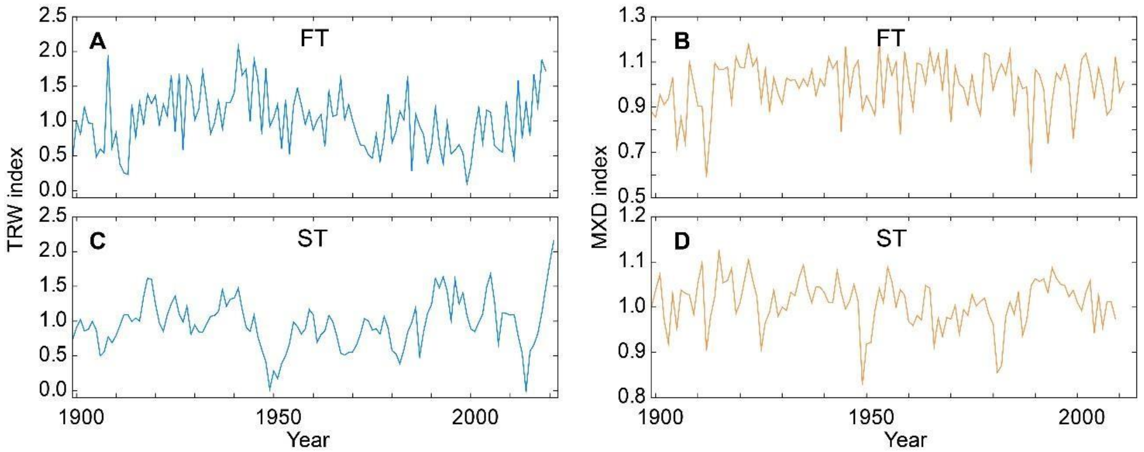

Fig. 2. Tree-ring width (A, C) and maximum density (B, D) standard chronologies for the forest-tundra (FT) and southern taiga (ST) sites

The growth-climate response analysis of the regional chronologies from forest-tundra since 1929 shows that TRW indices significantly positively correlate with mean July temperatures ($P < 0.01$) (Fig. 3A). However, MXD demonstrates higher correlations and for a longer summer period from June to August. Both the FT chronologies positively correlate with summer seasonal (June–July and June–August) temperature means (up to $r = 0.66$, $P < 0.01$ for MXD and summer temperature). TRW at ST significantly correlates only with May and May-August temperature (r = 0.23, $P < 0.01$) (Fig. 3B). On the contrary, MXD shows a strong dependence on monthly and seasonal temperature means with the highest correlations with JJA and MJJA temperature means (up to $r = 0.47$, $P < 0.01$). The dependence of tree-ring parameters on precipitation is generally weaker (not shown). Correlations of the FT residual chronologies with neither monthly nor seasonal precipitation totals are statistically significant ($P > 0.01$). In southern taiga, TRW also does not show a statistically significant relation to precipitation, but MXD negatively correlates with July and summer precipitation totals (r = -0.32 and -0.36, $P < 0.01$, respectively).

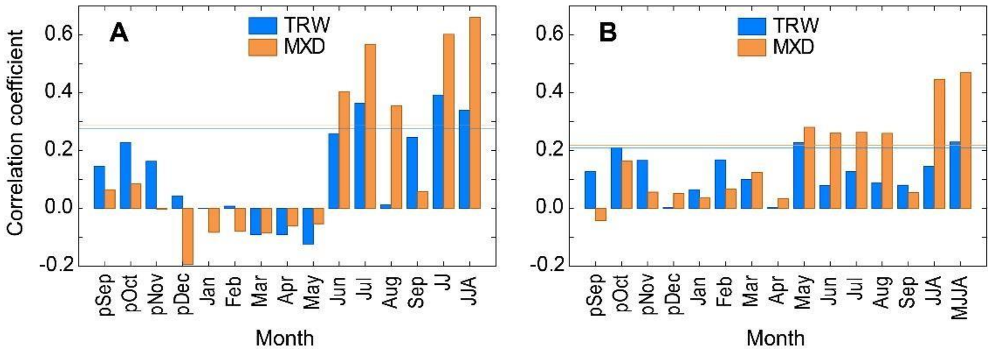

Fig. 3. Climate signals. Correlation coefficients of the standard TRW and MXD chronologies with monthly and seasonal temperature means from previous-year to current-year September of ring formation in the forest-tundra (A) and southern taiga (B) sites. Seasonal means were calculated for June – July (JJ), summer (JJA), and May – August (MJJA). Two horizontal lines indicate significance level $P < 0.01$ for TRW and MXD.

Running correlations of MXD index chronology from FT with summer temperature means are high, and reach r = 0.71 and 0.72 ($P < 0.001$) for summer and July – August temperatures, respectively (Fig. 4A). Correlations with the mean temperature of the first two summer months (JJ) are slightly lower (mean $r = 0.63$, $P < 0.001$). Temporal stability of the temperature signal in MXD is confirmed by a vast spatial coverage of strong field correlations with gridded summer temperature means over the two 40-year long periods (Fig. 4B,C). Over the first four decades of the available MXD data in forest-tundra from 1929 to 1969, the correlations $r > 0.4$ ($P < 0.01$)

reach 60°N in the south and spread between the Ob' Bay (the Gulf of Ob') in the north-west and Lena Delta in the north-east (Fig. 4B). Over the 1970 – 2011 period, the area covered with statistically significant (correlations of the FT chronology slightly decreased in the west, but the area with highest correlations $r > 0.6$ increased in the north-to-south direction (Fig. 4C).

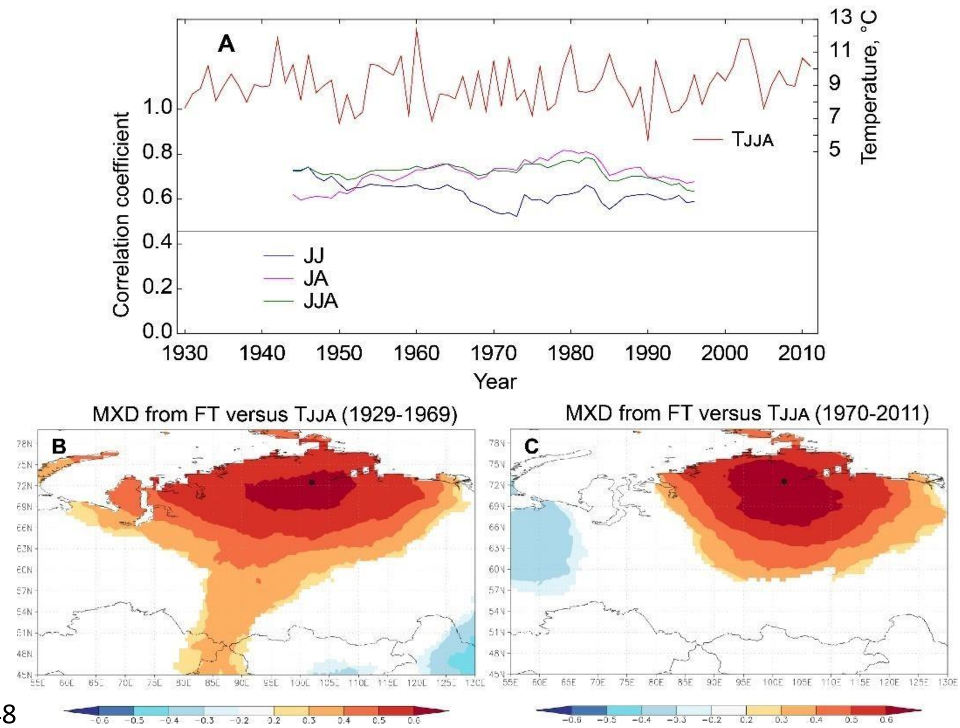

Fig. 4. JJA temperature means in Khatanga (red) with 31-year window running correlations between the maximum latewood density (MXD) standard chronology and summer month temperature means at the forest-tundra site FT (A). Corresponding correlation fields from 1929 – 1969 (B) and 1970 – 2011 (C). Horizontal line indicates the significance level $P < 0.01$.

Running correlations of MXD from ST with summer and MJJA temperature means are generally high during the first decades of the 20th century and the influence of three-month and MJJA temperature means remains statistically significant ($P < 0.01$) till 1933 (r calculated for the 1918 – 1948 period) (Fig. 5A). The MXD dependence on MJ and JA is lower, but still mostly significant at $P < 0.01$ till the 1920s. The correlations rapidly decrease in the 1930s, but become significant for the majority of temperature means in the early 1950s for about a decade. From 1965 (r calculated for the 1950 – 1980 period) correlations are generally insignificant ($P < 0.01$), except for July-August mean temperatures. Over the 1901 – 1940 period, correlations with MJJA temperature means $r > 0.4$ ($P < 0.01$) for the southern taiga MXD chronology spread between 45°N and 75°N from south to north (Fig. 5B). The area with high correlations extends from 65°E to 105°E in the northern latitudes and from 75°E to 100°E in the south of Siberia. For the period from 1970 – 2009, low, but still statistically significant correlations were found for a remote region to the east of the study site ST (Fig. 4C).

Surprisingly, running correlations with monthly and seasonal precipitation totals did not identify any significant ($P < 0.01$) positive influence of precipitation on MXD during the recent decades in forest-tundra and southern taiga of central Siberia (not shown).

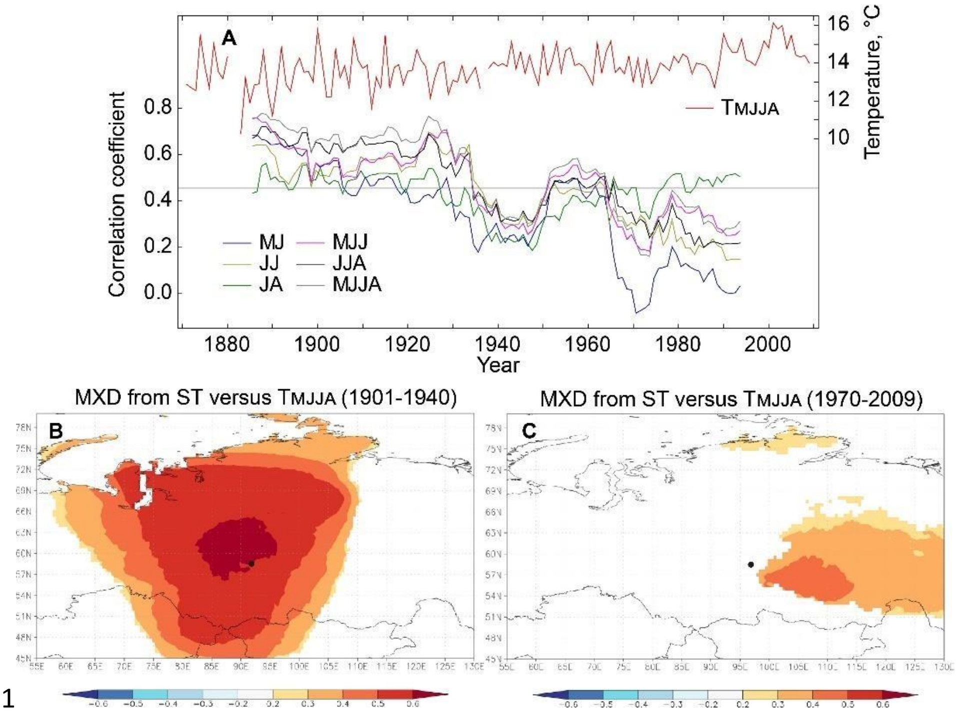

Fig. 5. MJJA temperature means in Yeniseisk (red) with 31-year window running correlations between the maximum latewood density (MXD) standard chronology and warm month (from May to August) temperature means at the southern taiga site ST (A). Corresponding correlation fields from 1901 – 1940 (B) and 1970 – 2009 (C). Horizontal line indicates the significance level P < 0.01.

Discussion

Our results show that larch trees in forest-tundra of central Siberia are generally older and form narrower tree rings compared to southern taiga. These findings, as well as the higher sensitivity of TRW and MXD chronologies from the harsh climate at the northern treeline in comparison to tree-ring statistics from milder conditions are not surprising (Fritts, 1976). Seasonal growth of trees in northern Siberia starts later and demonstrates stronger dependence on summer temperature (Vaganov et al., 1996, 1999; Knorre et al., 2006; Kirdyanov et al., 2007, 2024; Esper et al., 2010; Bryukhanova et al., 2013; Rinne et al., 2016; Büntgen et al., 2021a; Hantemirov et al., 2022; Kharuk et al., 2023c), which is also confirmed by our results. On the contrary, the effect of climate on trees growing under a more favorable temperature regime and hydroclimate in southern taiga is less pronounced, which explains the low correlation of TRW from ST with climate variables. However, MXD from the southern taiga site ST contain a surprisingly strong temperature signal confirming the superiority of this tree-ring parameter for dendroclimatology not only at high latitudes and elevations (Briffa et al., 1988, 2004; Büntgen et al., 2024), but also for the conditions with lower climate constrains of tree growth in southern Siberia.

TRW in forest-tundra generally follows summer temperature dynamics, including the recent warming (see Figs. 1 and 2A). In addition, a strong response of MXD to temperature is constant in time and shows similar spatial coverage over the two ~ 40-year long periods. The absence of a marked increase of MXD in recent decades following the regional summer warming since the 1990s can be considered as the only evidence of the DP in our FT study sites. However, we have no MXD data for the most recent decade and cannot judge MXD changes during the period of the most striking temperature increase. On the contrary, the MXD record in southern taiga demonstrates a strong decline of latewood formation dependence on late spring and summer temperatures starting from the 1930s, which is a typical manifestation of the DP problem (D’Arrigo et al., 2008). Moreover, the spatial coverage of significant correlations also crucially decreased in space (see Fig. 5B and 5C). These shifts in tree-growth response to temperature between the study sites from different vegetation zones of boreal forests demonstrate the spatial heterogeneity in the strength and timing of the DP within central Siberia. Spatial heterogeneity of the DP was earlier described in literature (Briffa et al., 1998; D'Arrigo et al., 2008). However, in this study we provide evidence for the DP in the southern taiga region in Siberia, which is located >1600 km south of forest-tundra. This finding partly contradicts to earlier literature stating that the DP phenomenon is mostly expressed at high latitudes and to a lesser extent at lower latitudes (Briffa et al. 1998; Cook et al. 2004; Büntgen et al. 2008, 2016, 2024).

Possible causes for the DP emergence have already been previously indicated and tested in literature (D'Arrigo et al., 2008; Frank et al., 2007; Esper and Frank 2009). These causes may considerably vary between regions, but the inability of tree-ring data to follow temperature increase was specified as one of the most remarkable reasons. In our northern study region, summer temperature is still generally < 12°C. This is likely below the threshold above which temperature ceases direct limiting of tree growth (Vaganov et al., 2006) and cannot cause the DP. On the other hand, it has been earlier shown that there is clear evidence for the DP at a regional scale in northern central Siberia (Briffa et al., 1998; Kirdyanov et al., 2020), which was likely to be initiated by dimming due to SO_2 emissions from Norilsk industry and long-distance atmospheric transport from lower latitudes (Kirdyanov et al., 2020; Büntgen et al., 2021b). The direct and indirect effect of airborne pollution on vegetation in the region was also detected by Panyushkina et al. (2016) and Kharuk et al. (2023a,b). However, a relatively small DP in our northern study sites is not surprising because it has been shown earlier that the DP can be a site-specific phenomenon even within the same region (Büntgen et al., 2021a, 2024; Yin et al., 2021). This allows us to consider tree rings as a valuable proxy for summer temperatures under an accurate choice of tree-ring sites and parameter.

In southern taiga, summer temperature was increasing throughout the period of the instrumental records since the 1870s (Fig. 1). Taking into account relatively high mean summer temperatures of up to 19.4 °C in 2012 and generally > 15.5 °C for the 31-year long periods, we may assume that even slight warming could lead temperature to reach the threshold, above which it does not directly limit tree-ring growth during most of the growing season (Vaganov et al., 2006). To find out the cause of the DP in the southern region, we have to also consider the fact that the ST site was established in a human-populated area. Although we have chosen a location that is remote from settlements, and with no marks of direct anthropogenic or natural disturbance, we may not exclude the influence of some of these factors on tree growth in the past. Thus, the broader studied area was heavily logged in the 20th century (Mironov 2009; Danilin and Crow 2008), which induced changes in the regional hydrological regime (Onuchin et al., 2017; Wei et al., 2022; Jones et al., 2022; Zhao et al., 2021), further affecting forest ecosystem biogeochemistry and dynamics, as well as tree growth over vast territories (Kreutzweiser et al., 2008; Thaxton et al., 2023). Similarly, insect outbreaks and low-intensity fires may also affect the dependence of tree growth on temperature (Gustafson et al., 2010; Itter et al., 2019; Trindade et al., 2011; Wirth et al., 2002; de Andrés et al., 2022, Chebakova et al., 2022). Therefore, more data on the site and regional forest history are needed to make a proper conclusion about the causes that initiated DP at our study site in the first half of the 20th century.

Here we analyzed data from only two regions in central Siberia, and found a large heterogeneity in the DP strength and possible causes for the phenomenon emergence. At the same time, a recent study demonstrated the evidence for a regional-scale DP in the high-latitude forest belt within the same area (Kirdyanov et al., 2020). These two somehow controversial findings point out the need for a better understanding of the spatiotemporal changes in tree growth sensitivity to temperature within various regions of boreal forests, and especially Siberia (Büntgen and Rees 2023), which is poorly represented in the international tree-ring data bases. It can only be achieved with an accurate site-by-site study of newly collected and updated tree-ring data from remote locations in boreal forests. These data are also urgently needed to further unravel the effect of changing climate on forest ecosystems, their carbon sequestration and the environment (López-Blanco et al., 2024).

Conclusions

Our results demonstrate the 'Divergence Problem' in tree-ring maximum latewood chronologies from two distant and environmentally different vegetation zones within boreal forests in central Siberia: forest-tundra and southern taiga. The DP in these two regions differs in intensity and may be caused by different climatic and environmental factors. Nevertheless, we report the current suitability of the carefully selected tree-ring records from the north of central Siberia for temperature reconstructions. Further increase of decoupling between tree growth and temperature may have significant consequences for carbon and water cycle dynamics under a warmer climate and has to be investigated with a denser network of updated tree-ring data.

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