# Supplementary Material

***Non-stationary response of tree growth to climate trends along the Arctic margin***

*Hofgaard et al.*

**Table S1** Climate data for study sites and correlation between station data and grid data. Temperature and precipitation data for Norwegian sites refer to the meteorological normal period 1961-1990 (eKlima, 2017), and for the Russian site to the period 1881-1980 (Science and applied guide to the climate of USSR, 1988). Climate information for individual study site refers to the nearest meteorological station located in a landscape similar to the study site they represent (cf. Figure 1). E2 is represented by two stations due to lack of near-by station at comparable altitude. The grid data, CRU TS3.22, (Harris and others 2014) was obtained from Climate Explorer (http://climexp.knmi.nl). The used grid size is 0.5° latitude per 1° longitude centred on each site.

| Study site | | W1 | W2 | C1 | C2 | E1 | E2 | |
|---|---|---|---|---|---|---|---|---|
| Meteorological station | | Tromsø | Dividalen | Banak | Karasjok | Kirkenes | Murmansk | Yukspor |
| Distance and direction from study site | | 82 km, NE | 11 km, SE | 12 km, SE | 50 km, S | 16 km, NW | 140 km, N | 20 km, E |
| Altitude (m a.s.l.) | | 100 | 228 | 5 | 130 | 89 | 57 | 910 |
| Temperature (°C) | Annual average | 2.5 | 0.8 | 0.6 | -2.4 | -0.6 | 0.2 | -3.7 |
| | Coldest month[1] | -4.4 | -9.4 | -10.0 | -17.1 | -11.1 | -11.2 | -12.5 |
| | Warmest month (July) | 11.8 | 12.8 | 12.7 | 13.1 | 12.1 | 12.6 | 9.0 |
| Precipitation (mm) | Annual sum | 1031 | 282 | 345 | 366 | 430 | 488 | 1066 |
| Correlation between station data and grid data[2] | | | | | | | | |
| | Annual temperature | 0.977 | 0.968 | 0.968 | 0.998 | 0.969 | nd | nd |
| | Total annual precipitation | 0.935 | 0.696 | 0.725 | 0.951 | 0.925 | nd | nd |

[1]January for all sites except E2 where February is the coldest

[2]Computed over 1961-1990; all correlations are significant ($P$ <0.001); data not available for Russian stations

**Table S2** Percentage of variance explained by axis 1 to 6 after Principal Component Analyses of site-specific high-pass chronologies for 1800-2006 and selected climate trend periods (cf. Figure 2 for period selection). Bold indicates largest value per axis.

| Period | Axis 1 | Axis 2 | Axis 3 | Axis 4 | Axis 5 | Axis 6 |
|---|---|---|---|---|---|---|
| 1800-2006 | 67.5 | 12.8 | **8.2** | 5.2 | **3.9** | 2.3 |
| 1800-1869 | 68.3 | 12.3 | 7.6 | 5.4 | 3.6 | **2.9** |
| 1870-1939 | **69.8** | 13.5 | 7.5 | 5.0 | 2.9 | 1.4 |
| 1940-1984 | 67.4 | 14.5 | 8.0 | **6.1** | 2.5 | 1.6 |
| 1985-2006 | 63.2 | **17.8** | 7.8 | 5.6 | 3.5 | 2.1 |

**Table S3** Significant spatial-field correlation ($P < 0.05$) between monthly temperature and high-pass chronologies given for the two warming periods and intervening cooling period. Monthly temperature data were retrieved from the CRU TS 4.00 0.5° lat. x 0.5° long. grid data set (Harris and others 2014) using Climate Explorer (http://climexp.knmi.nl). The first column of each period presents significant monthly variables: red for July$_t$ (cf. Figure 6) and bold for dominating climate variables (Pearson correlation > |0.4|). + or – in the second column per period indicates positive and negative correlation, respectively. Capital letters in the third column presents indicated geographical location of spatial field correlations. The analyses were run for 15 monthly variables spanning from June the year prior to growth (June$_{t-1}$) to August the year of growth (August$_t$).

| Location/ID | | | 1901-1939 | | | 1940-1984 | | | 1985-2006 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| West | Coast | W1 | | | | | | | **July$_{t-1}$** | - | SE |
| | | | Apr$_t$ | + | SE | Feb$_t$ | - | SE | **Apr$_t$** | - | E |
| | | | **May$_t$** | + | S | | | | May$_t$ | - | NE |
| | | | June$_t$ | + | E | **June$_t$** | + | S | June$_t$ | - | E |
| | | | **July$_t$** | **+** | **S** | **July$_t$** | **+** | **SE** | July$_t$ | - | SE |
| | | | Aug$_t$ | + | S | | | | | | |
| | Inland | W2 | | | | Nov$_{t-1}$ | + | E | | | |
| | | | July$_{t-1}$ | - | W | July$_{t-1}$ | - | E | **June$_{t-1}$** | + | SE |
| | | | Apr$_t$ | + | SW | Mar$_t$ | + | S | May$_t$ | + | S |
| | | | | | | | | | June$_t$ | - | SE |
| | | | **July$_t$** | **+** | **SW** | **July$_t$** | **+** | **S** | July$_t$ | + | S |
| Central | Coast | C1 | Dec$_{t-1}$ | + | S | JJA$_{t-1}$ | + | SW/S/S | **Oct$_{t-1}$** | - | SE |
| | | | Apr$_t$ | + | SW | Mar$_t$ | + | SW | **June$_{t-1}$** | + | SW |
| | | | May$_t$ | + | SW | June$_t$ | + | S | **June$_t$** | - | SE |
| | | | **July$_t$** | **+** | **SW** | **July$_t$** | **+** | **S** | July$_t$ | - | S |
| | | | **Aug$_t$** | + | SW | | | | | | |
| | Inland | C2 | | | | | | | **June$_{t-1}$** | + | SW |
| | | | Nov$_{t-1}$ | + | E | June$_{t-1}$ | + | SW | **July$_{t-1}$** | + | SE |
| | | | Dec$_{t-1}$ | + | SW | July$_{t-1}$ | + | E | **Sep$_{t-1}$** | + | SW |
| | | | **Apr$_t$** | + | SW | Mar$_t$ | + | SW | May$_t$ | + | SW |
| | | | **May$_t$** | + | S | June$_t$ | + | S | **June$_t$** | - | SE |
| | | | **July$_t$** | **+** | **SW** | **July$_t$** | **+** | **S** | **July$_t$** | **+** | **W** |
| | | | **Aug$_t$** | + | SW | | | | | | |
| East | Coast | E1 | Oct$_{t-1}$ | - | S | | | | | | |
| | | | **Nov$_{t-1}$** | + | E | | | | July$_{t-1}$ | + | E |
| | | | Dec$_{t-1}$ | + | SW | June$_{t-1}$ | + | SW | **Sep$_{t-1}$** | + | SW |
| | | | **Apr$_t$** | + | SW | Jan$_t$ | + | W | **Jan$_t$** | + | SW |
| | | | May$_t$ | + | SW | Mar$_t$ | + | SW | **Feb$_t$** | + | SW |
| | | | June$_t$ | + | W | | | | | | |
| | | | **July$_t$** | **+** | **S** | **July$_t$** | **+** | **SE** | **July$_t$** | **+** | **E** |
| | | | **Aug$_t$** | + | S | | | | Aug$_t$ | + | E |
| | Inland | E2 | **Nov$_{t-1}$** | + | SE | July$_{t-1}$ | - | E | | | |
| | | | **Dec$_{t-1}$** | + | SW | Aug$_{t-1}$ | + | S | **Sep$_{t-1}$** | + | SW |
| | | | Jan$_t$ | + | SW | | | | | | |
| | | | Mar$_t$ | - | SE | Mar$_t$ | + | W | | | |
| | | | | | | May$_t$ | + | SW | | | |
| | | | **July$_t$** | **+** | **S** | **July$_t$** | **+** | **S** | **July$_t$** | **+** | **SE** |
| | | | | | | | | | Aug$_t$ | + | E |

**Table S4** Significant spatial-field correlation ($P$ < 0.05) between monthly temperature and high-pass chronologies given for sequential 20-year intervals with 10-year overlap for the 1901-2006 period. . Monthly temperature data were retrieved from the CRU TS 3.22 0.5° lat. x 0.5° long. grid data set (Harris and others 2014) using Climate Explorer (http://climexp.knmi.nl). The first column of each interval indicates dominating monthly variables: red dot if July$_t$ (cf. Figure 7), (none) no significant climate variable. The main variable for intervals with no July$_t$ correlation are marked in bold. + or – in the second column per interval indicates positive and negative correlation, respectively. Capital letters in the third column give indicated geographical location of spatial field correlations. The analyses were run for 15 monthly variables spanning from June the year prior to growth (June$_{t-1}$) to August the year of growth (August$_t$).

| | Location/ID | | 1902-1921 | 1911-1930 | 1921-1940 | 1931-1950 | 1941-1960 | 1951-1970 | 1961-1980 | 1971-1990 | 1981-2000 | 1987-2006 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| West | Coast | W1 | ● + S | **Oct$_{t-1}$** - S<br>Nov$_{t-1}$ + W/E<br>Dec$_{t-1}$ - N<br>May$_t$ + S | Mar$_t$ - W<br>Apr$_t$ - SE<br>**May$_t$** + N | July$_{t-1}$ - N | **Aug$_{t-1}$** + NW<br>Jan$_t$ + W<br>Aug$_t$ + W | ● + NW | ● + W | Sep$_{t-1}$ - SW<br>Oct$_{t-1}$ - SW<br>**Nov$_{t-1}$** + S | Nov$_{t-1}$ + S | ● - S |
| | Inland | W2 | Aug$_{t-1}$ - W/SE<br>**Jan$_t$** - N | ● + NW | ● + NW | July$_{t-1}$ - N<br>**Aug$_{t-1}$** + SE | **June$_{t-1}$** - NE<br>**Aug$_{t-1}$** + SE<br>Feb$_t$ - S<br>**Mar$_t$** + S<br>Apr$_t$ - E<br>May$_t$ + S<br>June$_t$ - S<br>Aug$_t$ - E | ● + SE | ● + w | ● + w | ● + NW | ● + NW |
| Central | Coast | C1 | Apr$_t$ - S<br>June$_t$ + S | ● + NW | ● + N | ● + NW | ● + NW | ● + N | June$_{t-1}$ - SW<br>Dec$_{t-1}$ + SW<br>**Feb$_t$** + N | **Nov$_{t-1}$** + SW<br>May$_t$ - W | ● + NW | ● - S |
| | Inland | C2 | (none) | ● + W | ● + NW | ● + W | ● + NW | ● + N | Oct$_{t-1}$ + SE<br>Feb$_t$ + SE<br>Apr$_t$ + S | **Nov$_{t-1}$** + SW<br>June$_t$ - S | ● + NW | **Feb$_t$** - S<br>**May$_t$** + S<br>June$_t$ - SW |
| East | Coast | E1 | ● + N | ● + N | ● + N | ● + NW | ● + W | ● + N | ● + NE | ● + NE | ● + NE | ● + E |
| | Inland | E2 | (none) | ● + S | ● + N | Aug$_{t-1}$ + SE<br>Apr$_t$ - E<br>May$_t$ + S | ● + N | ● + NE | ● + N | ● + N | ● + NE | ● + E |

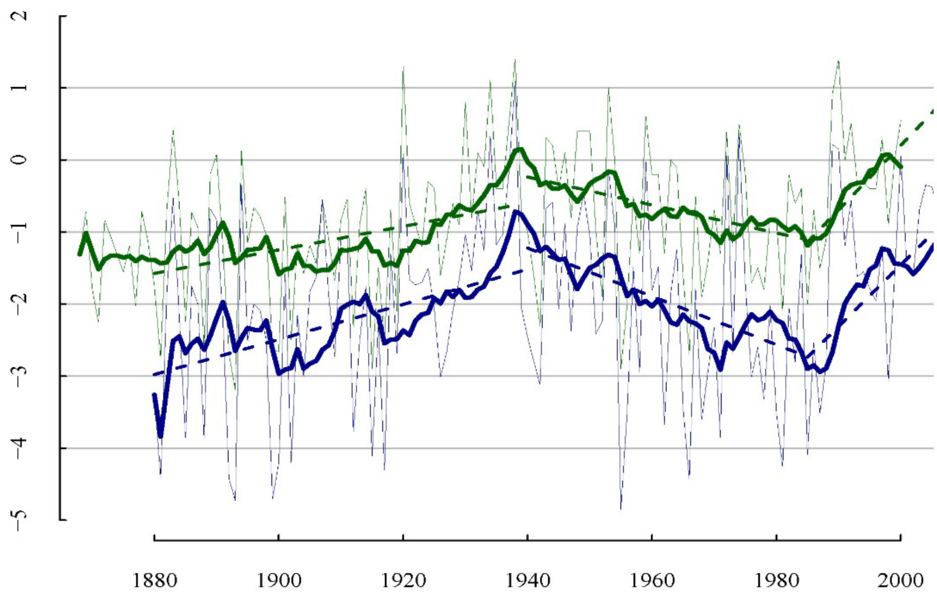



**Figure S1** Variations in annual mean temperature at two sites close to the study area: Abisko (green lines) and Karasjok (blue lines) over the 1870/1880 to 2006 period. Thick lines show 10-year running average and thin lines annual values. Dashed lines show linear regressions on 10-year running mean data for the two warming periods and the intervening cooling period. Abisko meteorological station is situated 80 km SSW of W2 and Karasjok meteorological station 55 km SSE of C2. Data source: Abisko Scientific Research Station (www.polar.se) and Norwegian Meteorological Institute (www.met.no). Regression statistics based on annual data and 10-yr running mean data is presented below.

Regressions on annual data

| | Abisko | | | | Karasjok | | | |
|---|---|---|---|---|---|---|---|---|
| | Intercept | Slope | Adj. R squared | P value | Intercept | Slope | Adj. R squared | P value |
| 1880-1939 | 46.565 | 0.023 | 0.143 | 0.002 | -59.158 | 0.030 | 0.142 | 0.002 |
| 1940-1984 | 19.213 | -0.01 | -0.003 | 0.359 | 42.508 | -0.023 | 0.033 | 0.121 |
| 1985-2006 | -137.231 | 0.069 | 0.076 | 0.158 | -174.113 | 0.087 | 0.187 | 0.025 |

Regressions on 10-yr running mean data

| | Abisko | | | | Karasjok | | | |
|---|---|---|---|---|---|---|---|---|
| | Intercept | Slope | Adj. R squared | P value | Intercept | Slope | Adj. R squared | P value |
| 1880-1939 | -40.103 | 0.020 | 0.560 | 0.000 | -50.943 | 0.025 | 0.619 | 0.000 |
| 1940-1984 | 33.148 | -0.017 | 0.680 | 0.000 | 59.692 | -0.031 | 0.748 | 0.000 |
| 1985-2006 | -50.190 | 0.025 | 0.382 | 0.006 | -103.900 | 0.051 | 0.778 | 0.000 |

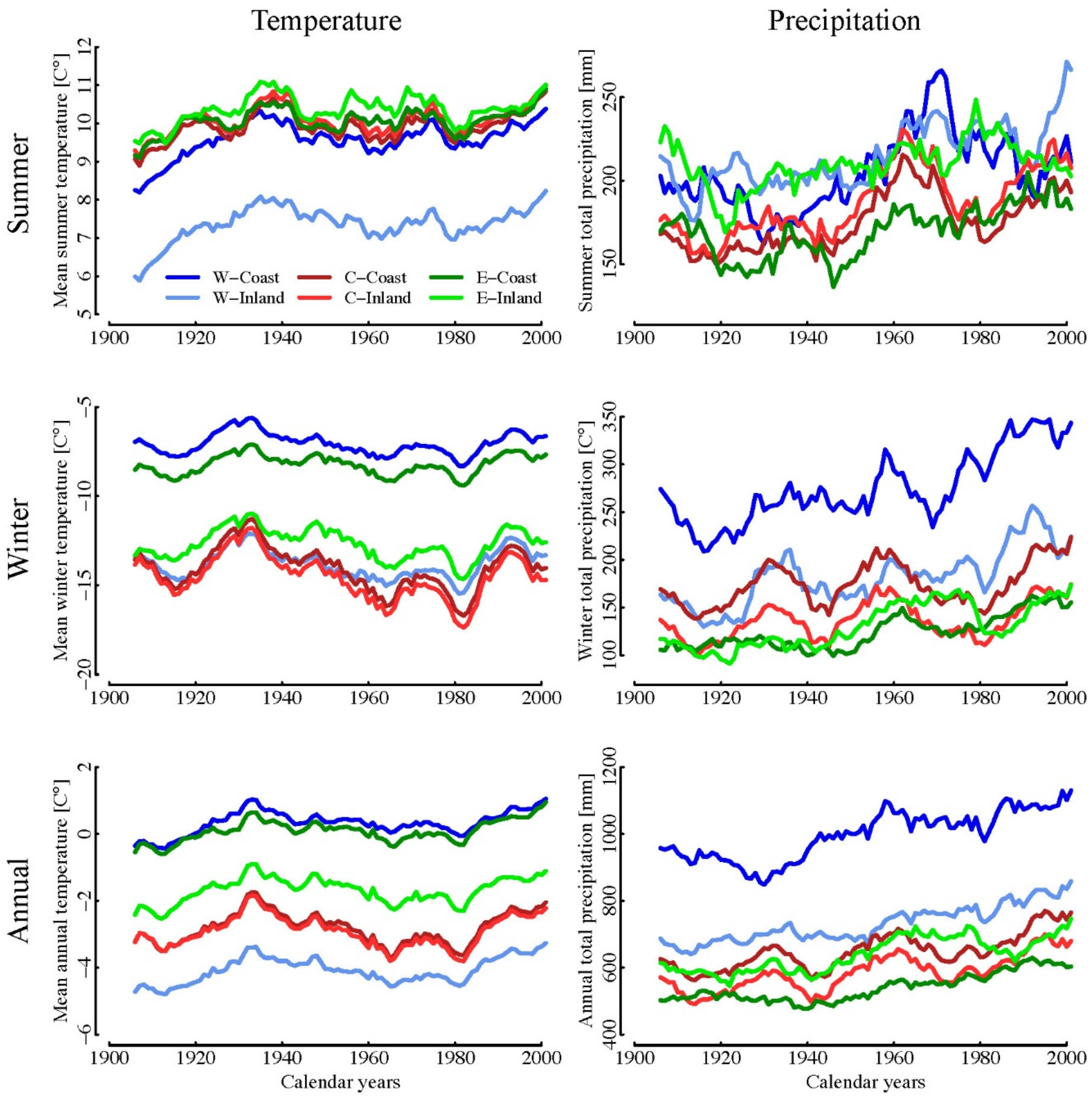
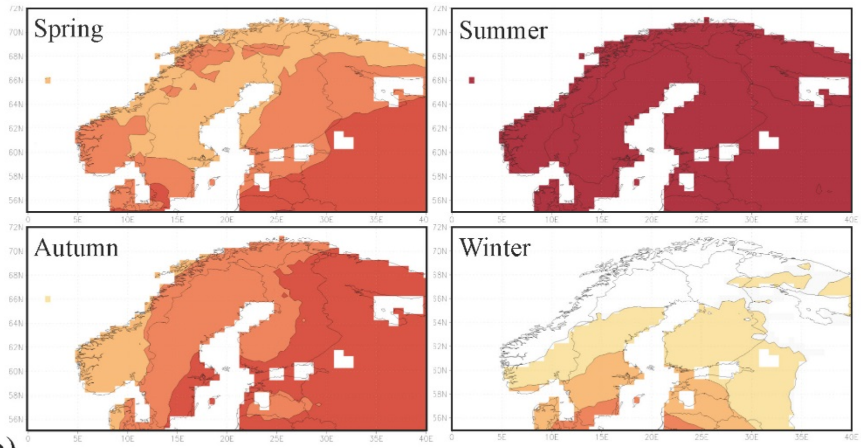



**Figure S2** Grid-based seasonal and annual mean temperature and total precipitation trends for all sites over the 1901-2006 period, shown as 11-year running average (smoothing spline) for each site. The data, CRU TS3.22 (Harris *et al.* 2014), was obtained from KNMI Climate Explorer (http://climexp.knmi.nl). The used grid size is 0.5° latitude per 1° longitude centred on each site. Summer is June to August, and winter December to February.

(a)




(b)

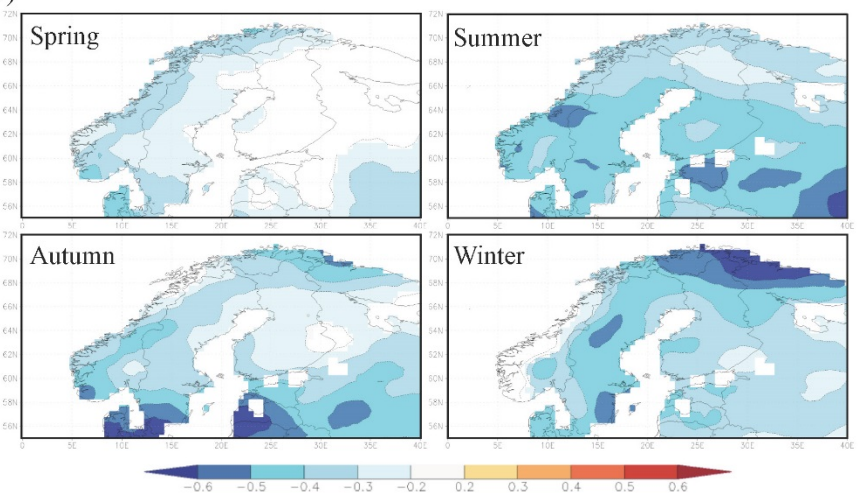



**Figure S3** Pointwise correlation between geopotential 500mb (ERA 20-C , Compo *et al.* 2011) and seasonal grid climate data (CRU TS 4.01 (Harris and others 2014)) in the study area over the 1901-2006 period. Seasonal climate include mean temperature (a) and total precipitation (b) for spring (MAM), summer (JJA), autumn (SON) and winter (DJF). The figure was built using Climate Explorer (http://climexp.knmi.nl).

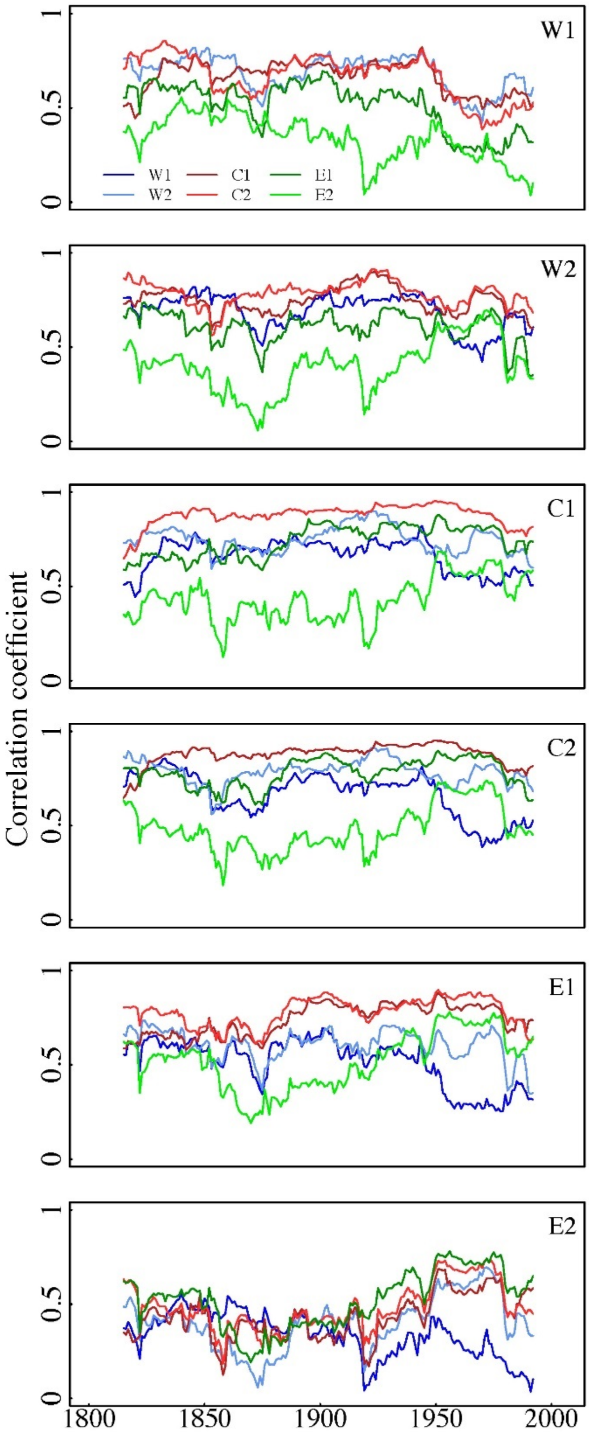



**Figure S4** Growth correlations between sites during the 1800-2006 period, computed as bootstrapped moving correlations between high-pass chronologies over 30-year windows shifted one year at a time. Each site panel show correlation with other sites indicated by site-specific colour. The x-axis refers to the central year of each 30-year period. The lowest significant correlation coefficient observed is r = 0,247 (95% percentile range of one thousand bootstrap iterations).

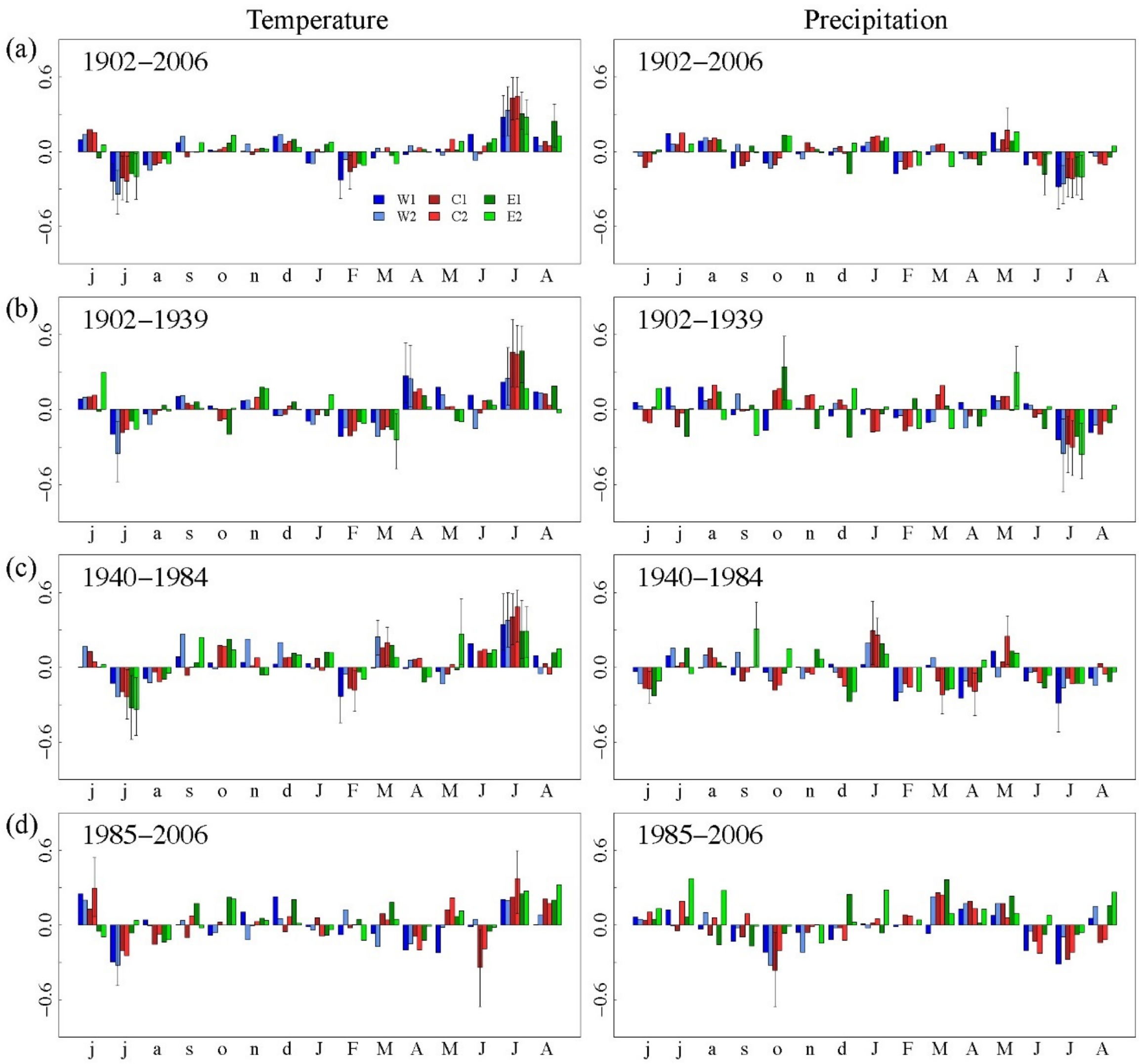



**Figure S5** Association between mean temperature (left-hand panels) and total precipitation (right-hand panels), and ring width indices, presented as response function values between high-pass chronologies from all sites (indicated with different colors) and monthly CRU TS 3.22 climate grid data (Harris and others 2014) using Climate Explorer (http://climexp.knmi.nl). Sign of response function coefficients are shown for 15 monthly variables spanning from June the year prior to growth (lowercases) to August the year of growth (uppercases) during four periods (a) 1902-2006, (b) 1902-1939, (c) 1940-1984 and (d) 1985-2006. Error bars are shown for statistically significant values ($P < 0.05$).

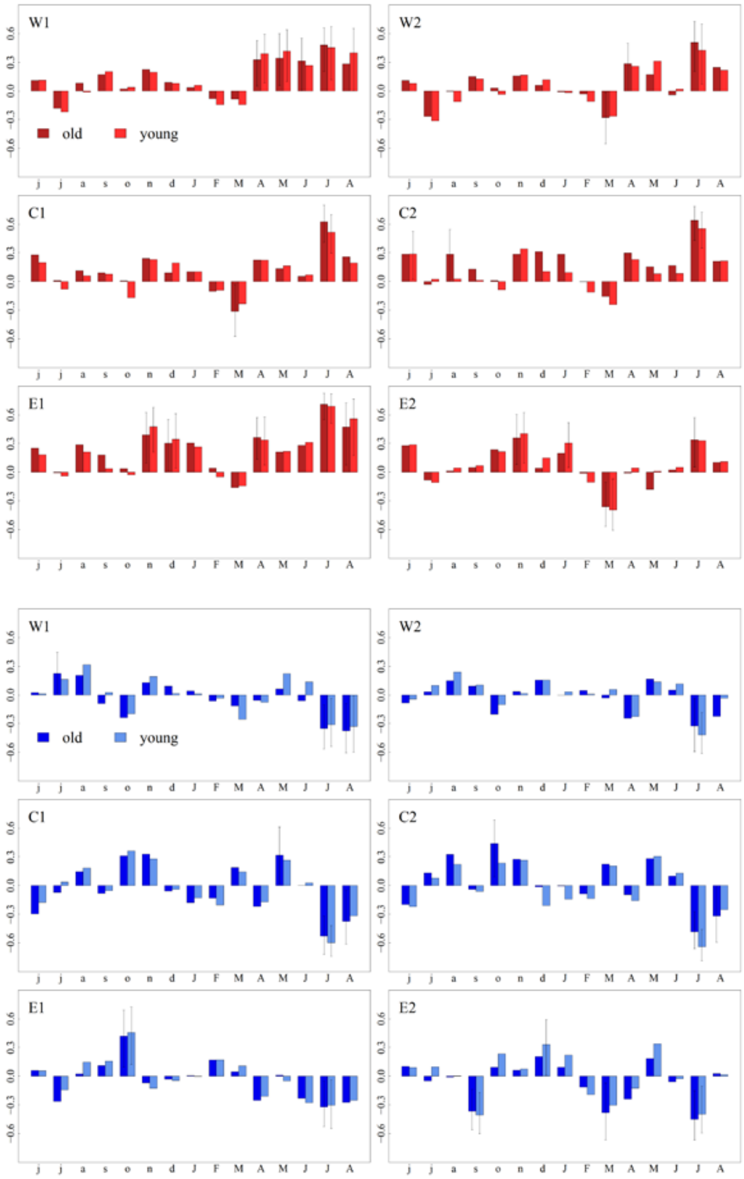



**Figure S6** Association between monthly mean temperature (red; upper panels) and monthly total precipitation (blue; lower panels), and ring width indices of old (dark color) and young trees (light color) over the 1902-1939 period, presented as correlation between site-specific high-pass chronologies and monthly CRU TS 3.22 climate grid data (Harris and others 2014) downloaded from Climate Explorer (http://climexp.knmi.nl). Sign of correlation coefficients are shown for 15 monthly variables spanning from June the year prior to growth (lowercases) to August the year of growth (uppercases). Division into old and young trees is based on the median age of all trees per site covering the 1902-1939 period. Error bars are shown for statistically significant values ($P < 0.05$).

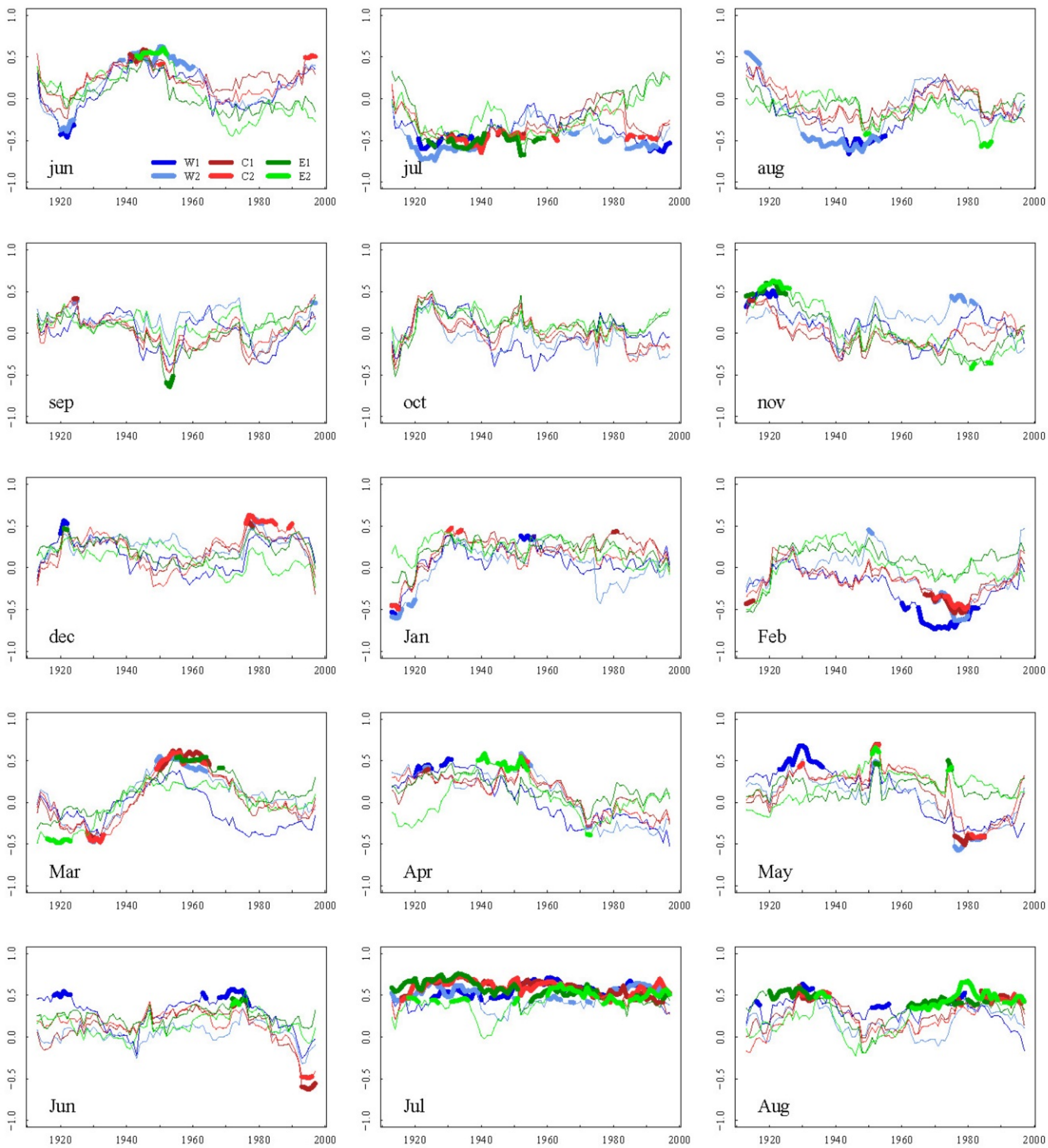



**Figure S7** Temporal variation in correlation between site-specific high-pass chronologies and monthly CRU TS 3.22 climate grid data (Harris and others 2014; extracted from Climate Explorer, http://climexp.knmi.nl) shown for each month. Climate data includes monthly mean temperature from 1901 to 2006. Monthly variables span from June the year prior to growth (lowercases) to August the year of growth (uppercases). Correlation coefficients were computed using a 20-year moving window shifted 1 year at a time; with the middle year plotted. Bold lines indicate significant correlations (95% bootstrapping confidence interval).

## References only cited in Supplementary Material

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