Supplementary information

1 Correction procedure

An improvement of the chronology estimation, subsequent to RCS and signal-free (SF) methods, was previously attained by applying a Matskovsky's (2011) correction (C) method. The following protocol was applied to data:

1) Generate signal-free RCS-chronology ($RC1SF_1$) and SF-measurements by applying the RC1SF method (for details, see Section 2.4.2). A signal-free RCS chronology is constructed by averaging indices produced with raw data divided by the signal-free RC. SF-measurements represent initial tree-ring measurements but with removed common (climatic) signal (Fig. S1a).

2) Smooth obtained SF measurements using spline function with TVRS (Time-varying response smoothing; Melvin et al., 2007) algorithm to produce smoothed SF measurements (SF-curves, Fig. S1a). These curves are considered to represent non-climatic low-frequency variations of the initial tree-ring measurements. In ideal situation (separately growing trees that weren't disturbed by any factor during their lifetime) they will represent aging curves not affected by climate, but usually they contain some distortions.

3) Compute a novel type of $RC1SF_3$-chronology by averaging the obtained smoothed SF measurements as initial data entering the process (instead of original tree-ring measurements). This yields a standardized tree-ring chronology that exhibits deviations from 1 (Fig. S1b). While an $RC1SF_2$ chronology, built from non-smoothed SF measurements, does not deviate from 1 (by the construction), the chronology built from smoothed SF measurements ($RC1SF_3$) does. The smoothed SF measurements (SF-curves) do not theoretically speaking contain common signal (as they are supposedly signal-free) whereas in practice they do exhibit variations common to each other. Smoothing the SF-series and thus producing the curves leads to emphasis on long-period variations only. In comparison to signal-free RCS iterative approach (Melvin and Briffa, 2008), these deviations from 1 are not attributable to year-to-year common signal variations but the remaining growth variations on longer timescales. They become estimated by eliminating the year-to-year signal from the series of measurements, i.e. by smoothing them. As the common (high-frequency) signal is already eliminated, these deviations are considered to be biases arising from the data set error. The

data set error also can be thought of as low-frequency non-climatic component of the original signal-free RCS-chronology ($RC1SF_1$).

4) The final step is to subtract these errors (deviations from 1) from the initial signal-free RCS-chronology ($RC1SF_1$) to correct it and to get RC1SFC chronology: $RC1SFC = RC1SF_1 - (1 - RC1SF_3)$ (Fig. S1b).

All steps can be applied to a multiple-RC-chronology (RC2SF), thus forming RC2SFC-chronology.

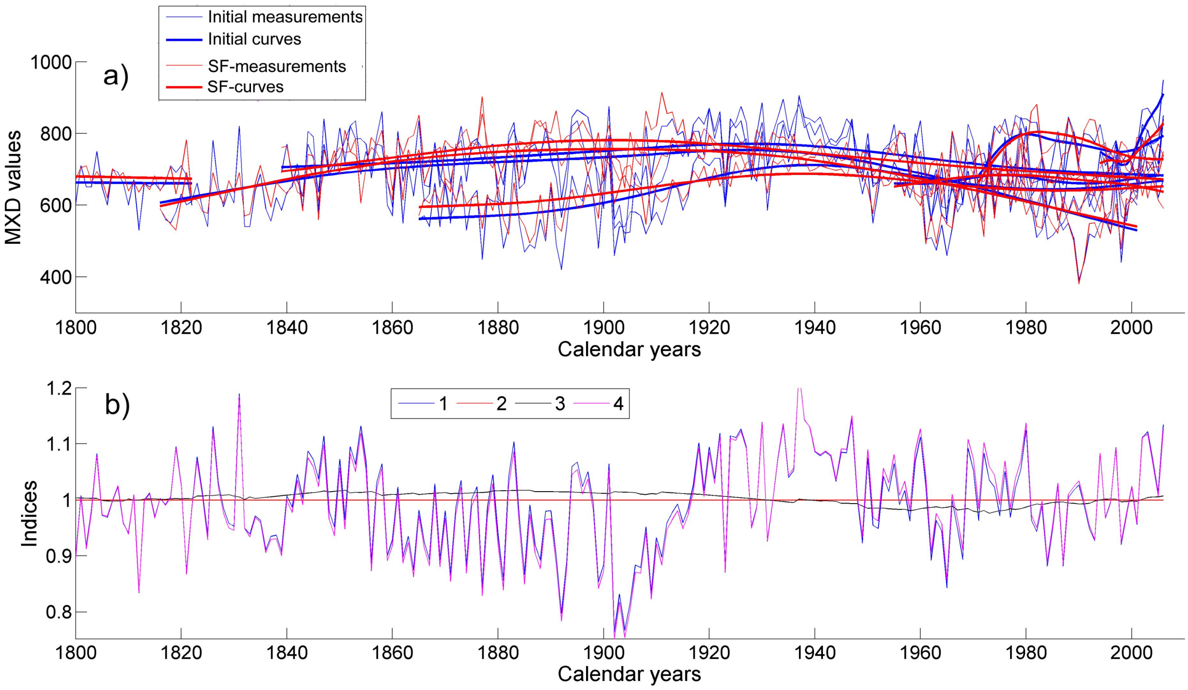

Figure S1. a) Initial and signal-free measurements from FENN data set. Bold lines show smoothed series. For viewing convenience series for only 6 trees are shown. b) Chronology correction: 1 – $RC1SF_1$ chronology built from initial measurements; 2 – $RC1SF_2$ chronology built from SF measurements (equals to unity); 3 – $RC1SF_3$ chronology built from SF-curves; 4 – corrected RC1SFC chronology: $RC1SFC = RC1SF_1 - (1 - RC1SF_3)$.

2 Subsampling algorithm

Sub-sampling of FENN data was supposed to highlight any difference arising in the FENN data set when artificially reduced to the sample depth of TORN data set (Section 2.5). For this purpose, the following algorithm was used:

1) MXD series of the FENN data set were removed in random order until the sample depth of that FENN sub- data set was equal or smaller by one than the real sample depth of TORN data set for each time interval. Examples of FENN sub- data set sample depth are shown on Fig. 4a.

2) The RC2SFC chronology was built from the FENN sub- data set.

3) First two steps were repeated 1000 times, and the median, 2.5th and 97.5th percentiles were plotted to reflect the mean and 95% confidence limits of the sub- data set chronologies (Fig. 4b).

3 Temperature reconstruction method

MXD based JJA temperatures were reconstructed using non-smoothed and smoothed variance adjustment and linear regression methods (Lee et al., 2007; Section 2.6). Instead of initial data, the smoothed methods use ‘low-pass’ filtered instrumental and proxy data for calibration. The non-smoothed regression gives a slightly higher calibration/verification statistics than smoothed variance adjustment (Table S3). Yet, the regression provides much wider uncertainty intervals, in comparison to the variance adjustment (not shown). For our data, these results confirm the regression as a less robust method. The variance adjustment performs overall best with 15-year smoothing. This can be evaluated from statistics over both the calibration and verification periods (Table S3) as indicated by the relatively high values for the coefficient of determination, reduction of error, coefficient of error, correlation coefficient, and relatively low values of the root mean square error. For these reasons, the smoothed (15-year moving average; Cook and Peters, 1981) variance adjustment for calculating the reconstruction and uncertainty intervals was applied. This means that the series were smoothed with 15-yr moving average before calibration.

4 Uncertainty estimates

Uncertainties of the temperature reconstruction were thought to come from 3 independent sources (Section 2.7): RC uncertainty (#1), data replication uncertainty (#2) and calibration uncertainty (#3). All the uncertainties were estimated using bootstrapping procedure, in a step by step fashion from uncertainty #1 through #3. We resampled with replacement the sample of interest (which were the MXD values for each cambial age and each of the two RCs for uncertainty #1, the MXD indices for each calendar year for uncertainty #2, and the mean chronology indices for instrumental period for uncertainty #3) for 1000 times getting bootstrap distribution of statistics needed, and used $\alpha/2*100$ and $(1-\alpha/2)*100$ percentiles of this distribution for confidence limits, $\alpha = 0.05$. To estimate the uncertainty #2, the $\alpha = (0.05)^{0.5}$ was used to compute the final 95% confidence interval. This calculation was made under the assumption of independence of uncertainties #1 and #2. To estimate the uncertainty #3, the $\alpha = (0.05)^{0.25}$ was used for uncertainties #1 and #2 combined with $\alpha = (0.05)^{0.5}$ for uncertainty #3, in order to yield the final 95% confidence interval. This calculation was made under assumption of independence of the uncertainties #1, #2 and #3.

Table S1. Correlation of TORN and FENN chronologies for different smoothing. Common period is AD 542-2006. Bold font – the highest correlation for row and column, underlined font – the highest value, italics fort – the highest value for the same standardization method. Insignificant correlation values are shown in smaller font. Significance thresholds, adjusted for equivalent degrees of freedom for smoothed data (Gu, 2000), are (p=0.05): 0.25 for 50yr splines, 0.34 for 100yr splines, 0.44 for 200yr splines and 0.54 for 300yr splines. S88G1112A (Melvin et al., 2013) and N-SCAN (Esper et al., 2012) are original chronologies for the TORN and FENN data sets correspondingly.

Non-smoothed	FENN-RC1	FENN-RC1SF	FENN-RC1SFC	FENN-RC2SF	FENN-RC2SFC	N-SCAN
TORN-RC1	0.666	0.667	0.667	**0.681**	**0.685**	0.660
TORN-RC1SF	0.664	0.666	0.667	0.679	**0.683**	0.657
TORN-RC1SFC	0.666	0.667	*0.668*	0.679	**0.687**	0.658
TORN-RC2SF	0.646	0.647	0.647	0.659	**0.663**	0.637
TORN- RC2SFC	0.649	0.650	0.650	0.657	**0.662**	0.642
S88G1112A	**0.671**	**0.672**	**0.671**	0.675	**0.676**	**0.668**

50yr splines smoothing	FENN-RC1	FENN-RC1SF	FENN-RC1SFC	FENN-RC2SF	FENN-RC2SFC	N-SCAN
TORN-RC1	0.545	0.549	0.556	**0.590**	**0.613**	0.516
TORN-RC1SF	0.544	0.549	0.559	0.589	**0.610**	0.512
TORN-RC1SFC	**0.552**	**0.557**	***0.567***	0.590	**0.619**	**0.520**
TORN-RC2SF	0.487	0.492	0.500	0.526	**0.551**	0.448
TORN- RC2SFC	0.483	0.487	0.499	0.507	**0.536**	0.451
S88G1112A	0.535	0.540	0.552	0.552	**0.569**	0.516

100yr splines smoothing	FENN-RC1	FENN-RC1SF	FENN-RC1SFC	FENN-RC2SF	FENN-RC2SFC	N-SCAN
TORN-RC1	0.505	0.510	0.523	0.557	**0.592**	**0.471**
TORN-RC1SF	0.507	0.513	0.528	**0.557**	**0.591**	0.469
TORN-RC1SFC	**0.509**	**0.515**	***0.532***	0.551	**0.592**	0.470
TORN-RC2SF	0.431	0.437	0.453	0.475	**0.514**	0.383

TORN- RC2SFC	0.407	0.411	0.431	0.435	**0.480**	0.366
S88G1112A	0.463	0.469	0.491	0.481	**0.515**	0.439
200yr splines smoothing	FENN-RC1	FENN-RC1SF	FENN-RC1SFC	FENN-RC2SF	FENN-RC2SFC	N-SCAN
TORN-RC1	0.486	0.493	0.512	0.550	**0.591**	0.443
TORN-RC1SF	0.492	0.499	0.520	**0.553**	**0.591**	0.447
TORN-RC1SFC	**0.497**	**0.504**	***0.527***	0.550	**0.595**	**0.452**
TORN-RC2SF	0.390	0.398	0.419	0.448	**0.493**	0.332
TORN-RC2SFC	0.356	0.362	0.387	0.398	**0.450**	0.305
S88G1112A	0.401	0.408	0.437	0.431	**0.473**	0.370
300yr splines smoothing	FENN-RC1	FENN-RC1SF	FENN-RC1SFC	FENN-RC2SF	FENN-RC2SFC	N-SCAN
TORN-RC1	0.522	0.531	0.552	0.583	**0.620**	0.473
TORN-RC1SF	0.528	0.537	0.559	0.586	**0.621**	0.478
TORN-RC1SFC	**0.535**	**0.543**	***0.566***	**0.586**	**0.623**	**0.484**
TORN-RC2SF	0.410	0.419	0.442	0.470	**0.513**	0.346
TORN- RC2SFC	0.379	0.387	0.411	0.421	**0.470**	0.320
S88G1112A	0.433	0.442	0.471	0.456	**0.492**	0.393

Table S2. Correlation of TORN, FENN and FULL chronologies with Tornedalen June, July, August (JJA) temperatures. Common period is AD 1802-2006. Bold font – the highest correlation values. S88G1112A (Melvin et al., 2013) and N-SCAN (Esper et al., 2012) are original chronologies for the TORN and FENN data sets correspondingly.

TORN	Non-smoothed	50yr splines smoothing	FENN	Non-smoothed	50yr splines smoothing	FULL	Non-smoothed	50yr splines smoothing
RC1	0.778	0.931	RC1	0.756	0.755	RC1	0.792	0.904
RC1SF	0.779	0.945	RC1SF	0.757	0.759	RC1SF	0.793	0.908
RC1SFC	0.773	0.941	RC1SFC	0.765	0.803	RC1SFC	0.790	0.904
RC2SF	**0.783**	**0.955**	RC2SF	0.768	0.824	RC2SF	**0.798**	**0.931**
RC2SFC	0.779	0.939	RC2SFC	**0.773**	**0.840**	RC2SFC	0.795	0.920
S88G1112A	0.781	0.951	N-SCAN	0.765	0.802	-	-	-

Table S3. Calibration/verification statistics for reconstruction of JJA temperature by non-smoothed and smoothed variance adjustment (upper table) and linear regression methods (lower table). R^2 - coefficient of determination, full period; R^2_c - coefficient of determination, calibration period; *RE* - reduction of error; *CE* - coefficient of error; *r* - correlation coefficient, full period; *r_c* - correlation coefficient, calibration period; *r_v* - correlation coefficient, verification period; *RMSE* - root mean square error, full period; *RMSE_c* - root mean square error, calibration period; *RMSE_v* - root mean square error, verification period. Bold font – best values.

Variance adjustment	R^2	R^2_c	*r*	*r_c*	*r_v*	*RE*	*CE*	*RMSE*	*RMSE_c*	*RMSE_v*
calibration period 1802-1905 Non-smoothed	0.529	0.546	0.791	0.774	0.766	0.583	0.418	0.793	0.769	0.816
10 yr smoothing	0.611	0.595	0.791	0.774	0.766	0.678	0.552	0.721	0.726	0.717
15 yr smoothing	0.617	**0.598**	0.791	0.774	0.766	0.686	0.562	0.715	**0.723**	0.708
20 yr smoothing	**0.622**	0.592	0.791	0.774	0.766	**0.700**	**0.581**	**0.711**	0.729	**0.692**
25 yr smoothing	0.616	0.583	0.791	0.774	0.766	0.696	0.576	0.716	0.736	0.696
calibration period 1906-2010 Non-smoothed	0.551	0.531	0.791	0.766	0.774	0.621	0.489	0.775	0.733	0.815
10 yr smoothing	0.621	0.584	0.791	0.766	0.774	0.694	0.588	0.711	0.690	0.732
15 yr smoothing	**0.625**	**0.586**	0.791	0.766	0.774	**0.699**	**0.594**	**0.708**	**0.689**	**0.727**
20 yr smoothing	0.623	0.583	0.791	0.766	0.774	0.697	0.592	0.710	0.691	0.728
25 yr smoothing	0.618	0.579	0.791	0.766	0.774	0.693	0.587	0.714	0.694	0.733
calibration period 1802-2010 Non-smoothed	0.581	0.581	0.791	0.791	-	-	-	0.748	0.748	-
10 yr smoothing	0.623	0.623	0.791	0.791	-	-	-	0.709	0.709	-
15 yr smoothing	0.625	0.625	0.791	0.791	-	-	-	0.708	0.708	-
20 yr smoothing	**0.626**	**0.626**	0.791	0.791	-	-	-	**0.707**	**0.707**	-
25 yr smoothing	0.626	0.626	0.791	0.791	-	-	-	0.707	0.707	-

Linear regression	R^2	R^2_c	r	r_c	r_v	*RE*	*CE*	*RMSE*	*RMSE_c*	*RMSE_v*
calibration period 1802-1905 Non-smoothed	**0.623**	**0.599**	0.791	0.774	0.766	**0.696**	**0.576**	**0.709**	**0.722**	**0.697**
10 yr smoothing	0.545	0.517	0.791	0.774	0.766	0.632	0.487	0.780	0.793	0.766
calibration period 1906-2010 Non-smoothed	**0.625**	**0.586**	0.791	0.766	0.774	**0.699**	**0.594**	**0.708**	**0.688**	**0.727**
10 yr smoothing	0.616	0.576	0.791	0.766	0.774	0.691	0.583	0.716	0.696	0.736
calibration period 1802-2010 Non-smoothed	**0.626**	**0.626**	0.791	0.791	-	-	-	**0.707**	**0.707**	-
10 yr smoothing	0.616	0.616	0.791	0.791	-	-	-	0.716	0.716	-

References

Gu, C. Multidimensional Smoothing with Smoothing Splines. In Smoothing and Regression: Approaches, Computation, and Application ed. M.G. Schimek. NewYork: Wiley, 2000.