The effect of power transformation on RCS – evidence from three millennial-length alpine chronologies

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Introduction

Tree-ring standardization in dendrochronology since its introduction by Douglass (1928), is often discussed and debated, especially when extracting different wavelengths from the resulting chronologies (e.g., Briffa et al. 1992, 2001; Cook et al. 1995; Esper et al. 2004; Fritts 1976). Individual series standardization techniques are commonly used to eliminate decreasing values with increasing tree age, the so-called age-trend (Fritts 1976). However, the traditional, individual series detrending precludes the reconstruction of variations longer than the samples individual segment length (Cook et al. 1995). Recently, effort has been made to reconstruct low frequency variations from long tree-ring chronologies, using age-related composite standardization techniques (e.g., Briffa et al. 1992, 2001; Cook et al. 2004; Esper et al. 2002). When tree-ring chronologies act as a proxy for climatic and/or environmental reconstruction, proper detrending is critical and the method should preserve high to low frequency variations.

For detrending, the Regional Curve Standardization (RCS, Becker et al. 1995; Briffa et al. 1992, 1996; Esper et al. 2003; Mitchell 1967) method is applied. This method can avoid the "segment length curse" (Cook et al. 1995) and allows the preservation of variations longer than the segment length of individual series. The three independently developed datasets discussed herein, possess reasonable sample size and sample distribution characteristics for age-related composite standardization techniques to be justifiably applied. Two different manners of calculating tree-ring indices within RCS are used.

In this manuscript, the tree-ring data and the detrending methods applied are first introduced. Second, differences and similarities of the Regional Curves (RC) are described. And third, the effect of calculating ratios or residuals plus variance stabilization on the growth levels, trends and variance of the resulting RCS chronologies is discussed.

Data and methods

Three independent ring width datasets from the Alps are compiled (Tab. 1). Data include 229 spruce *(Picea abies* K.*)* and 1110 larch *(Larix deciduas* Mill.*)* samples from Switzerland, and 418 stone pine *(Pinus cembra* L.*)* samples from Austria (Büntgen et al. 2004a, 2005; Nicolussi and Schieβling 2002), covering the western-central Alpine arc from 46°28'-47°00'N and 7°49'-11°30'E.

Table 1: Chronology characteristics.

	Species	Series #	Period AD	Chronology AD	MSL	AGR	Location	Source
spruce	PCAB	229	1108-2003	1163-2002	145	1.13	Valais/Engadin	Schmidhalter/ Neuwirth/Seifert
pine	PICE	418	645-1997	786-1997	198	0.99	Western Austria	Nicolussi
larch	LADE	1110	505-2003	738-2003	165	1.00	Valais/Engadin	Büntgen/ Schmidhalter/Seifert
total		1757	505-2003	738-2003	170	1.01	Central Alps	

Chronologies truncated at n < 5 series. MSL = mean segment length (years). AGR = average growth rate (mm).

Samples include wood from living trees, historical buildings (Büntgen et al. 2004b) and dry-dead and subfossil logs (Nicolussi and Patzelt 2000), all from elevations >1,500 m a.s.l. The composite records show a reasonable replication and fairly even distribution of samples during the past millennium (Fig. 1). Individual segment lengths range from 23-775 years, with a mean of 170 rings.

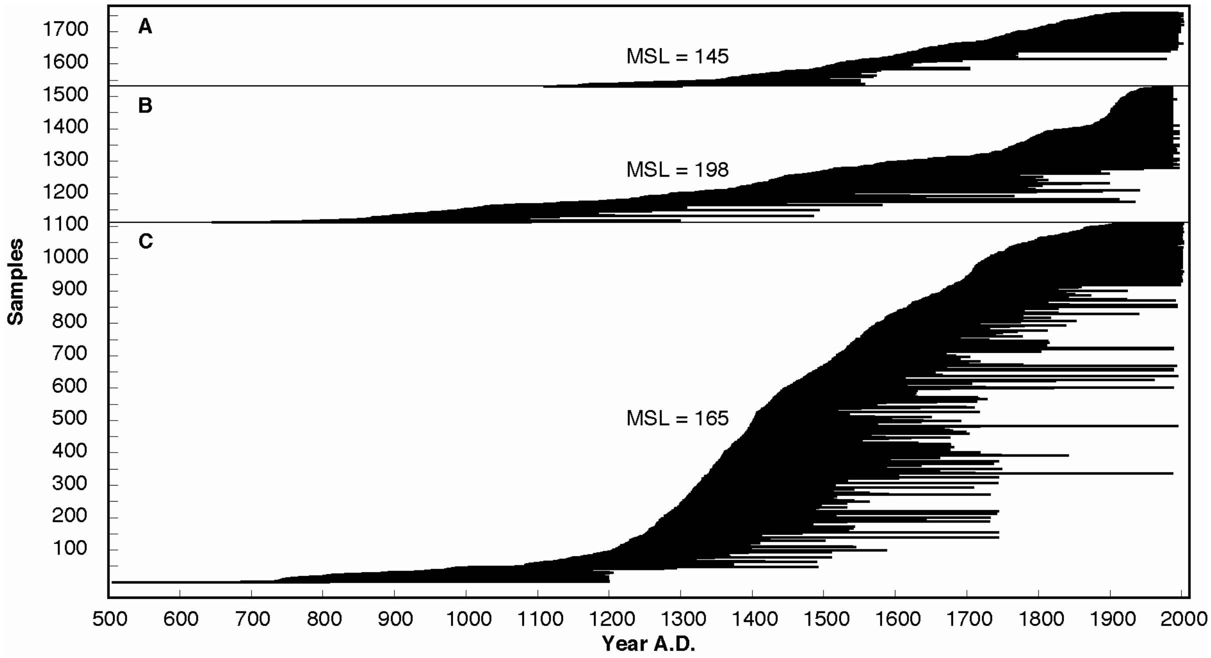

Figure 1: Sample replication and distribution of the three Alpine A spruce, B pine and C larch datasets used. The mean segment length (MSL, average number of rings per core or disc) is indicated.

Prior to detrending, all measurements were checked for missing rings and dating errors on a site-by-site basis using the program COFECHA (Holmes 1983). For RCS detrending, the program ARSTAN (Cook 1985) was used. RCS begins by aligning all individual tree-ring series by their innermost ring. In so doing, all series are set to the biological (cambial) age of one. Note that the innermost measured ring of a sample, and the actual first year of tree growth do not necessarily agree. In the pith offset (PO), the number of years estimated to the pith based on the growth rate after the missing segment can be used to estimate the offset between the innermost measured ring and the pith (Bräker 1981). The influence of the PO and its uncertainty on RCS is discussed by Esper et al. (2003). The age-aligned series collectively describe the age-related, biological growth trend, typical for the given species, site and region. A single growth function, or regional curve (RC, smoothed using a cubic spline (Cook and Peters 1981) of 10% the series length) is calculated as the mean of all age-aligned series (Fig. 3A-C). Anomalies of the raw measurements from the RC are interpreted as non-biological signals, and result from, for example climatic and/or ecological forcings (Briffa et al. 1996). The anomalies from the RC are taken, using two different methods for index calculation:

- *(i)* ratios of the actual-to-biologically expected ring width for each year and
- *(ii)* residuals of the actual-to-biologically expected ring width, after applying an adaptive power transformation (PT, Cook and Peters 1997). The PT is employed to series of original ring width prior to growth trend removal.

This transformation (in method *ii*) is necessary due to the heteroscedastic nature of raw ring width series, when residuals are applied. PT results in homoscedastic time series, with the yearly spread being independent of the growth level (Fig. 2B). Calculating ratios (in method *i*) also results in nearly homoscedastic time series.

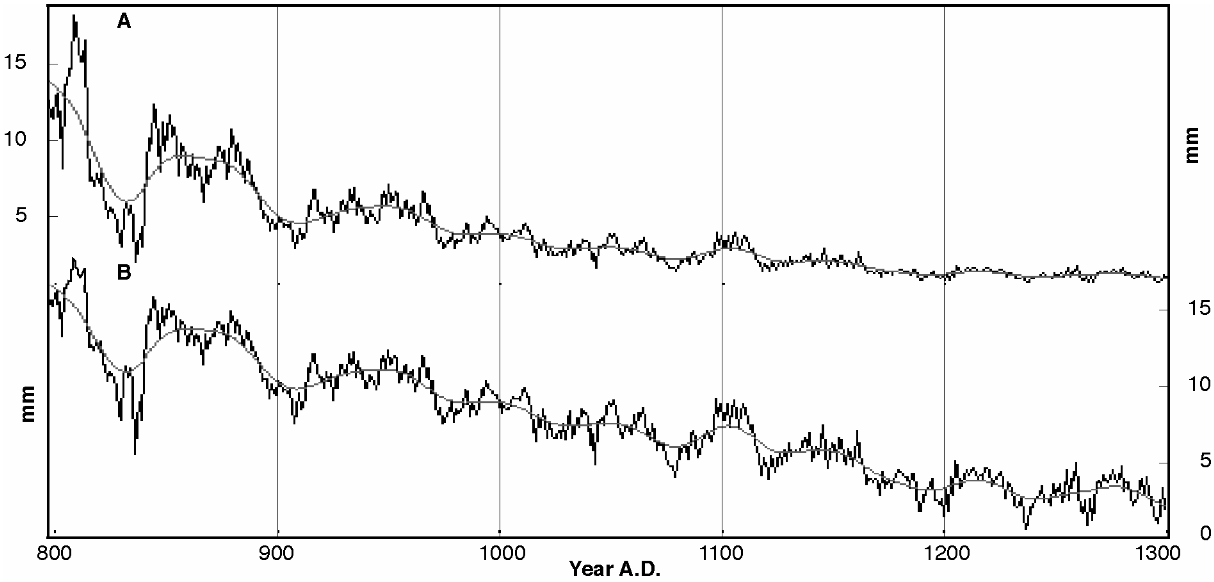

Figure 2: Variance stabilization by using adaptive power transformation. A Raw measurements from a subfossil, high elevation stone pine sample (gli 38_m) from western Austria. Decreasing growth level and variance with increasing age explains the heteroscedastic variance of raw ring width series (spread vs level relation), commonly eliminated by calculating ratios. The last 100 years of the sample have low values, potentially resulting in the "end-effect" problem, when computing ratios with individual detrending methods (Cook and Peters 1997; Cook et al. 1995). B Tree-ring width measurements of the same series after power transformation (p=0.15). The variance stabilization results in nearly homoscedastic time series that can be standardized by calculating residuals.

The deviations from the growth function are then re-aligned by their calendar year and the mean RCS chronology is calculated, using the robust, biweight mean (Cook 1985). The individual, RCS detrended measurements are dimensionless indices, without a defined mean, and thus allow low frequency variability to be preserved. For variance stabilization of the chronology, a technique that considers the number of samples per year and the average correlation coefficient between the single measurements were applied (Osborn et al. 1997). The chronologies shown, are truncated at a sample size <5 series. To minimize end-effect problems of smoothed chronologies (Fig. 4A), we applied a padding procedure of 10 years with the mean value from the 10 endmost years, representing half of the filter length (Mann 2004).

Results

Three datasets from the Alps indicate sensitivity and/or robustness with respect to the different ways of calculating RCS chronologies. The mean growth function (RC) for each species and calculation method is illustrated in figure 3. Their decline is an expected, reasonably systematic and fairly simple function of time (Bräker 1981). This mean age-related decrease is the basis for the RCS method (Briffa et al. 1992, 1996). RC for raw and PT measurements show notable level differences, reflect similar growth functions. The erratic ends at the higher cambial ages are caused by decreasing numbers of measurements per year (Fig. 3A-C). Due to higher replication of the larch and pine data at all age classes (Fig. 1), erratic ends are most significant for the spruce series. After PT, yearly mean growth values increase from 1.13 to 1.39, 0.99 to 1.26 and 1.00 to 1.31 for the spruce, pine and the larch data, and the series from the three chronologies are raised by the mean power (p) of 0.44, 0.35 and 0.54, respectively.

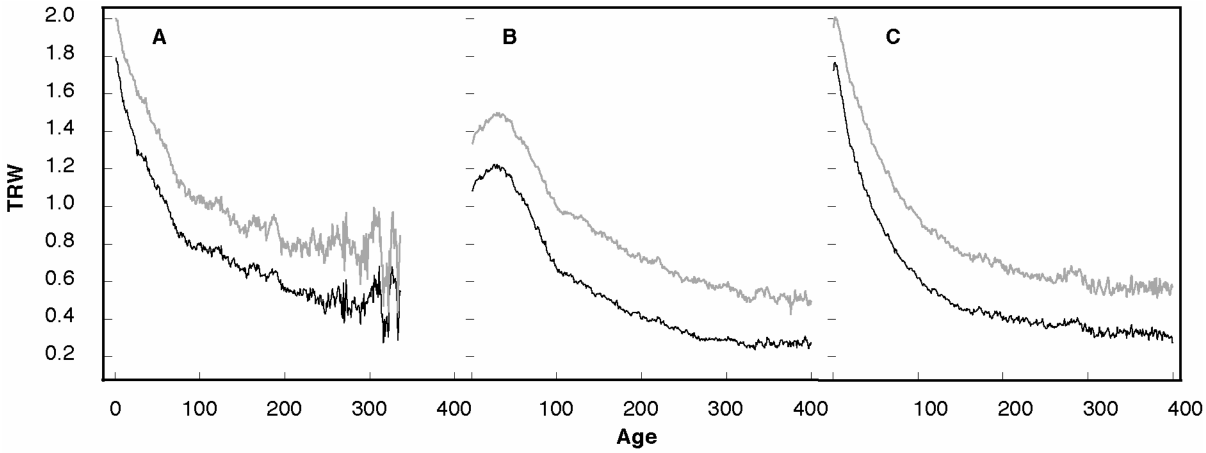

Figure 3: Arithmetic mean of the age-aligned data calculated from the raw (black) and power transformed (grey) for A spruce, B pine and C larch measurements. A general level increase is obtained after PT. RC would be 10-year cubic splines fit to these series.

The three composite data collections reflect substantial low frequency variation over the past millennium however the trend and amplitude differ slightly within the same species and more significantly between species. The chronologies possess common long-term growth behavior, e.g., high values prior ~1300 (except pine), a depression from around 1350-1820 and increasing values since ~1820 (Fig. 4A). Discrepancies depend on the data used, varying sample depth, the ecological variations, potential site disturbances and the signal preserved.

When calculating ratios, the chronologies obtain similar results with unreasonably high values if the RC reaches the “danger-zone” <0.5 mm (Fig. 3), and has a time-axis intercept near either end of the series. Further, a significant lack-of-fit between the ring width values and the RC can cause inflation. Nevertheless, the advantage of ratios is the correction for heteroscedasticity in raw ring width series (Fig. 2A). As alternative, the calculation of residuals plus PT is proposed (Fig. 2B).

Depending on calculations with ratios, or residuals plus PT, the RCS chronologies show greatest differences toward their ends, and similarities within the record’s middle sections (Fig. 4A, B). If reconstructions are based on ratios, rather than residuals, significant influence occurs in the earlier portion of the larch, slight for the spruce and none for the pine record. The recent trend since ~1820 seems to depend the species used. This rising trend is lower for the spruce and higher for the pine and larch data and likely expresses the “end-effect” problem described by Cook and Peters (1997) for individual series detrending. Besides long-term deviations, differences occur on annual scale. In particular, the larch chronology contains years with anomalously high discrepancies. These outliers mainly reflect larch budmoth events (e.g., Rolland et al. 2001; Weber 1997). To avoid low frequency deviations and annual outliers, caused by growth levels <0,5 mm, we suggest calculating with residuals plus PT.

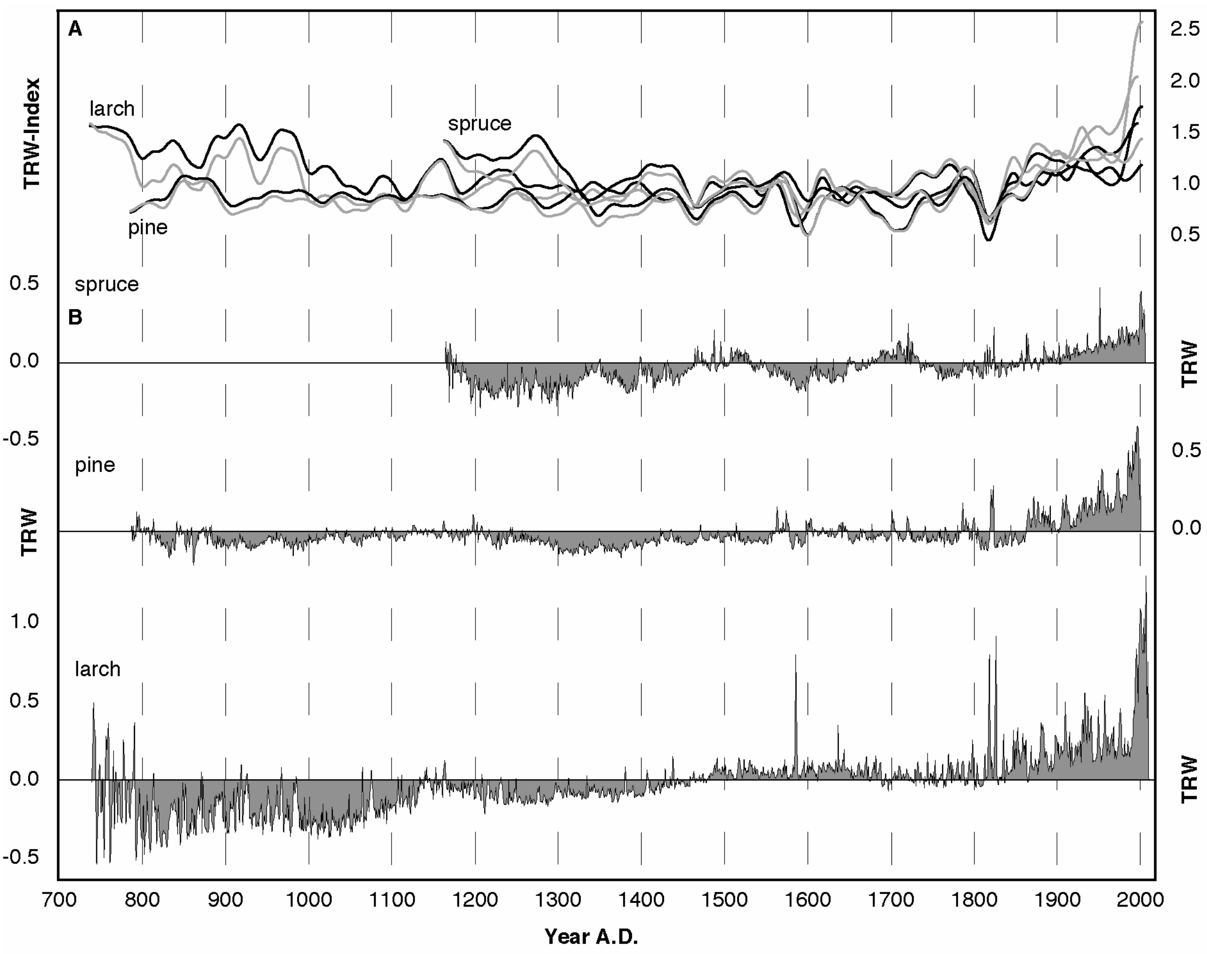

Figure 4: A Common multi-decadal trends and deviations of the 40-year smoothed RCS chronologies after using ratios (grey) and residuals plus PT (black), and B annual differences and long-term discord. In all cases ratios result in increased values in the 20th century relative to the earlier portion of the record.

Discussion

The RCS method contains a variety of uncertainties, e.g., index calculation, sample size, the influence of pith offset and species and site composition (Esper et al. 2003). Here we particularly focus on the bias of computing anomalies from a fitted growth curve function (RC). As explained by Cook and Peters (1997), bias in tree-ring indices obtained from calculating ratios can occur when *(i)* the fitted growth curve or RC decrease towards zero and *(ii)* the standardization curve diverges negatively from the local ring width near either end of the series. The problems described (Cook and Peters 1997), refer to individual series standardization. The degree of misfit between a series and it's detrending function, is generally much greater in the RCS method.

The three RCS chronologies indicate a significant dependence on methodology, specifically whether ratios or residuals plus PT are used for detrending, and particularly towards the series modern ends. Here more level offset of early vs. late periods is revealed. We show that differing methods of calculating RCS can cause bias from annual to centennial scales

(Fig. 4), however, with more minor effects on high frequency and more major effects on low frequency scales.

Datasets with high sample replication, even sample distribution and homogeneous growth levels allow the application of RCS. Samples without the pith and pith offset estimation (not shown) are still usable (Esper et al. 2003). The choice of either using ratios or residuals plus adequate variance stabilization is related to the dataset, thus a general recommendation is not given. Esper et al. 2003 showed similar results and proposed to always compare RCS chronologies after using ratios and residuals plus PT. A tendency for valid RCS results, based on ratios is indicated by generally higher growth levels (>0.5 mm), within the entire series. RCS runs with different species verify these results (Fig. 4A, B). We show a significant "end-effect" problem for the pine and larch chronologies, with adult wood centered towards the records recent end. Smaller "end-effect" bias of the spruce chronology is likely related to younger samples within the 20th century and generally higher growth values of the spruce trees. The positive deviations in the 20th century, seemingly caused by the "end-effect" problem, can have a significant impact at the beginning of the chronologies, when centering the resulting RCS chronologies ~1.0 (Fig. 4A). Hereby the end-effect is "distributed" to both ends of the records. To better understand this bias, further analyses on a single series basis are necessary.

Differing values during the records earlier portion can also be related to a reduction in sample size and in adequate truncation (e.g., =5 series). Due to the use of the most recent portion of a seven thousand year pine chronology with adequate sample size during the past millennia (Nicolussi & Schieβling 2002), lesser uncertainty exists for the Austrian data (Fig. 4B).

The importance of either, using ratios or residuals plus PT is expressed in Late Medieval temperatures, either above or below these of the 20th century (Fig. 4A). Substantial trend deviations late in the chronologies are predominantly caused by the index calculation method applied within RCS. A method individually adapted to the common growth level of the dataset used, is essential for placing the recent warming trend in the context of past climate variability.

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