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Original article

CRUST: Software for the implementation of Regional Chronology Standardisation: Part 2. Further RCS options and recommendations

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ABSTRACT

A number of processing options associated with the use of a "regional curve" to standardise tree-ring measurements and generate a chronology representing changing tree growth over time are discussed. It is shown that failing to use pith offset estimates can generate a small but systematic chronology error. Where chronologies contain long-timescale signal variance, tree indices created by division of the raw measurements by RCS curve values produce chronologies with a skewed distribution. A simple empirical method of converting tree-indices to have a normal distribution is proposed. The Expressed Population Signal, which is widely used to estimate the statistical confidence of chronologies created using curve-fitting methods of standardisation, is not suitable for use with RCS generated chronologies. An alternative implementation, which takes account of the uncertainty associated with long-timescale as well as short-timescale chronology variance, is proposed. The need to assess the homogeneity of differently-sourced sets of measurement data and their suitability for amalgamation into a single data set for RCS standardisation is discussed. The possible use of multiple growth-rate based RCS curves is considered where a potential gain in chronology confidence must be balanced against the potential loss of long-timescale variance. An approach to the use of the "signal-free" method for generating artificial measurement series with the 'noise' characteristics of real data series but with a known chronology signal applied for testing standardisation performance is also described.

Introduction

In Part 1 (Melvin and Briffa, 2014) of this 2-part discussion of the CRUST program for standardising tree-ring data, we focussed on the concept and application of the signal-free implementation of Regional Curve Standardisation (SF RCS). We demonstrated the advantages this offers over the use of simple RCS by describing a number of experiments with known tree-growth forcing signals applied in different contexts to simulated and actual tree-ring data sets. SF RCS was shown to capture introduced step changes of signal as well as long-term signal trends with minimal or no distortion in many cases. In this Part 2, we discuss a number of other issues with the use of RCS and present several further examples that suggest specific implementations available within CRUST. We discuss the use of pith-offset estimates; the use of ratios or differences to calculate indices; and the estimation of chronology confidence. We also discuss the application of RCS where the measurement data from various sources are combined and the use of multiple RCS curves to overcome some problems encountered in RCS. Some other CRUST options are mentioned and potential users of CRUST are referred to online versions of the program manual, installation instructions and program code which contain a more detailed list of specific CRUST implementation options.

The use of pith offset estimates

When trees are hollow, the boles are partly rotten, or where coring fails to hit the centre of a tree, ring measurements do not start at the pith. The missing radius between first measured ring and pith can be estimated either by using diameter measurements or by interpolating the distance to the geometric centre of the tree, using the curvature of the innermost rings of the sample (Nicolussi et al., 1995, Section 4.1; Esper et al., 2003). The approximate rate of growth near the centre of the tree can be used to estimate the number of years between pith and the first measurable ring (Bräker, 1981) producing pith offset estimates (PO). The PO of cores from living trees can be consistently larger than the PO obtained from the cross sections normally taken from sub-fossil trees (Luckman

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and Wilson, 2005). From experience with tree cores, the accuracy of missing-radius estimates is generally no better than ±10% and where there is suppressed growth in the early sections of some trees PO of the number of missing years may be even less accurate than this.

It is common practice with RCS, where PO are not available, to assume that the first measured ring of each tree has a ring age of one. Relative to this presumption, the use of PO for trees where rings do not reach the pith will change the position (with regard to ring age) of each tree's contribution to the RCS curve and also the position along the RCS curve from which each tree's expected growth values are selected. An extreme example is provided in the case of a hollow tree where, without PO, the small rings of old age are averaged with the larger rings of early growth from other trees thus erroneously reducing the magnitude of the early section of the true RCS curve. In this situation the series of small rings from the hollow tree are then detrended using the initial (faster growth rate) section of the RCS curve. With reasonably estimated PO data, the small rings of the hollow tree are averaged into the lower growth rate section of the RCS curve which is then more correctly used to detrend the measurements from the slower-growing outer section of the tree. Thus the use of PO tends to increase the magnitude of the early parts of the RCS curve, accentuate the early period of juvenile growth and, more correctly, increase the overall slope of the RCS curve.

Not using PO for individual trees will produce a less accurate RCS curve, increased chronology noise, and the potential for wider error bars in the chronology. As well as increased noise generally, a failure to use PO will likely introduce a systematic, "end-effect", bias into a chronology. This is because, after an initial increasing phase, ring width tends to reduce with increasing ring age and the difference created by using PO is to increase the overall slope of the RCS curve. This change of slope is transferred to the series of tree indices; earlier indices having lower values and later indices having higher values, relative to indices created without the use of PO. For the central part of a long chronology, where the first and last sections of overlapping series of tree indices are averaged together, the artificial increases and decreases of slope may cancel. In this case the change in the slope of the RCS curve will have little net effect on chronology indices (Esper et al., 2003; Melvin, 2004). At the modern end of the chronology, where the final portions of all tree index series are averaged together, the slope of the RCS curve becomes more critical and, even with data from large numbers of trees, there can be a resulting systematic bias in the chronology introduced by the omission of PO data.

Fig. 1 shows some examples of the differences created when using and not using PO, in both RCS curves and corresponding chronologies. Measurement sets were standardised using one-curve SF RCS and the results without using pith offset estimates are shown in blue and with the use of pith offset estimates shown in red. The Torneträsk maximum latewood density (MXD) (S88G1112A.mxd) measurements (Melvin et al., 2012) were used to produce Fig. 1a and d. For these MXD data, the central portion of the RCS curve (corresponding to ring ages 50–300 years) is approximately a straight line (Fig. 1a) and using/not using PO shows little effect on the slope of tree-index series. The change in indices is restricted to rings <50 old and this is noticeable in the chronology differences in the period 1750–1800 (Fig. 1d) when sample counts are rapidly increasing. The Torneträsk tree-ring width (TRW) (S88G0812.raw) measurements (Melvin et al., 2012) were used for Fig. 1b and e. The use of PO changes the slope of the RCS curve (Fig. 1b) and the increased slope produces a small reduction in the chronology indices in the final century (Fig. 1e) and an increase in values in the 18th century. The Dulan TRW (Sheppard et al., 2004) data (file name chin005.rwl) provide another, more extreme example (though these data were not originally processed using RCS). These data are from multiple cores from many trees that can exhibit a strip-bark-like growth form in old age. The RCS curve without PO is roughly horizontal (Fig. 1c) and the chronology (Fig. 1f) has a large downward slope. Using PO, simply based on the earliest measured ring of each tree, produces a sloping RCS curve and a chronology which is consistent with others from the region (see Yang et al., 2014, Figure SMB7).

Because the RCS curve is "smooth" and has no high-frequency component, the use of PO only affects the medium- and low-frequency variance of the chronology (on multi-decadal time scales and longer). Some previous work has concluded that the use of PO makes little difference to the resulting chronologies (e.g. Esper et al., 2003; Luckman and Wilson, 2005), at least for the specific examples these authors explored. However, their conclusions were based on correlation analyses. Correlation, with its implicit data-series normalisation and high weighting of individual extreme values, is not suitable for the evaluation of the small (i.e. relative to the amplitude of high-frequency signals) difference in low-frequency variance between chronologies produced with or without PO data.

In RCS where PO are used, it is necessary to use a smoothing curve that is sufficiently "flexible" to follow the relatively rapid changes in the magnitude of radial tree growth in the first decades of growth and a "stiff" curve to smooth the oldest rings (Melvin et al., 2007). The juvenile maximum in TRW can occur as early as the first decade (e.g. see Fig. 1c) and most of the changes created by the use or not of PO may be lost by using smoothing that is too stiff e.g. a spline with cut-off frequency 10% of the maximum tree length as used by Esper et al. (2003), or the negative exponential and straight lines discussed by Briffa and Melvin (2011, Section 5.6.1).

The use of PO can produce notable differences in the shape of the RCS curve with corresponding changes produced in the resulting chronologies (e.g. Esper et al. (2007), Figure S3 or Briffa and Melvin (2011), Figure 5/11). When using linear regression to reconstruct climate, the relative slopes and means of the predictor chronologies and predictand climate series are critical and any systematic chronology bias over the most recent century will translate into differences in reconstructed climate. Because the chronology error generated by not using PO is generally a systematic positive bias it could become particularly relevant in the context of large regional or hemispheric-mean reconstructions (e.g. Briffa, 2000; D'Arrigo et al., 2006; Esper et al., 2009). In such cases much of the high- and medium-frequency variance in different predictor chronologies is not common and will be largely removed in the averaging. However, even a relatively small difference in chronology slope over the calibration period could become significant for large regional reconstruction where it is consistent over many sites.

Of course, the use of PO will have no effect if the RCS curve is a horizontal line. A systematic end-effect bias is not always apparent and was not found by us in the case of MXD data from Icefields, western Canada (Luckman and Wilson, 2005). However, there remains a high probability that in many situations the use of PO will change the values of tree indices and the chronology to some extent. Though failure to use PO may result in only a small, medium-frequency end effect bias in RCS chronologies this may still influence subsequent climate reconstructions. Using PO will, therefore, improve chronology accuracy where tree counts are limited and will remove the potential for one type of "end effect" bias. It is recommended that the pith offset information should be recorded as a routine part of tree-ring sampling and PO recorded during the measurement process. Wherever possible, PO should be used in RCS processing.