

Testing the application of Regional Curve Standardization to living tree datasets

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Introduction

How to detrend tree-ring series is a crucial point in dendrochronology. There are many different approaches to remove age-related trends and unfortunately none of them can objectively answer the question, which is the best. It is the opinion of the individual researcher whether to choose a stochastic, a deterministic, or an empirical method, not to mention the plethora of options within each of these broad categories (Cook & Kariukstis 1990).

The classical deterministic detrending method fits a modified negative exponential curve or straight line to the tree-ring series. Stochastic methods use low-pass filter such as the cubic smoothing spline with a fixed or relative 50% frequency cut-off of a certain wavelength (Cook & Peters 1981). The so-called regional curve standardization (RCS) is a commonly applied empirical based upon the presumption that for a given species and site a common age related biological growth signal exists, independent of when the trees were growing.

With the task to reconstruct long-term climate variation in mind, Cook et al. (1995) note that “the maximum length of recoverable climate information is ordinarily related to the lengths of the individual tree-ring series” and usually ranges around a third of the mean segment length. To overcome this so-called “segment length curse” Briffa et al. (1992) re-popularized the empirical RCS method (Mitchell 1967). RCS allows for the possibility of systematic over or underestimation of the actual tree growth level during any particular time period due to changing environmental conditions and thus permits climatic information to be preserved on time-scales longer than the individual segment lengths (Cook et al. 1995). As tree-ring data are one of the most important data sources to place recent climate trends in a long-term context, researchers have heavily favored using RCS for climate reconstruction purposes during the past decade or so (Frank et al. 2010).

In RCS, all core segments are aligned by their cambial age and averaged to obtain the regional growth curve (RC). The RC is further smoothed, either by deterministic or stochastic means, to reduce high frequency variance and then applied to remove the age trend of each single series. After the regional curve derivation the detrended single series are reset to their calendar age. With this detrending method the century-scale fluctuations may be successfully preserved, however the correlation between individual samples decreases leading to a greater uncertainty than using “traditional” methods, thus a high sample replication is needed (Briffa et al. 1992).

Other more subtle challenges and limitations with RCS have only recently been recognized. With RCS, care has to be taken that one might even lose low-frequency when all samples span the full length of the chronology, because the overall climate signal is contained in the regional curve and therefore completely removed by standardization (Briffa & Melvin 2011). Thus ideally RCS is applied to composite datasets including trees with a uniform distribution of both germination and death (or sampling) dates. Yet, in practice such datasets are rare, and the desire to preserve long-term climate information from sites with only living trees is desired.

Briffa & Melvin (2011) recently described three major possible biases in applying RCS with living only data:

i) The “trend-in-signal” bias, which occurs when the growth-forcing signal has variance on timescales close to or greater than the length of the chronology. During detrending the average slope of each sample is removed and therefore distortions of the chronology, especially towards

the beginning and the end, may occur. In most cases this bias is of more minor concern since the existence of a trend overlying the chronology is unknown.

ii) The “different-contemporaneous-growth-rate” bias describes the problem if a single RC systematically differs from the age trend of fast or slow-growing trees, due to differences in non-climatic factors such as exposition, soil quality, or competition. If in one period fast-growing trees outnumber the slow ones (or vice versa), false medium-frequency trends might become apparent (Briffa & Melvin 2011).

iii) The combination of variations in the longevity of trees, sampling practice and different growth rates of contemporaneous trees can lead to the “modern-sample” bias. Assuming that large trees have a higher risk of mortality trees are more likely to be killed by an extreme event when they are close to their maximum size. A slow growing tree takes longer to reach this size and therefore can become older (Black et al. 2008, Bigler & Veblen 2009). This bias becomes most obvious in chronologies with only living samples from some old, yet primarily young trees. The regional curve may overestimate the old and slow-growing trees at the beginning of the chronology and underestimate the overall chronology in the later years and hence lead to an increased rise of chronology indices, where the new young and faster growing trees contribute to the RC (Briffa & Melvin 2011).

Other challenges related to RCS application include the use of a single RCS curve to detrend data from clearly differing sites (e.g. Esper et al. 2002). Measurements at a specific site may be systematically under- or overestimated, due to the different growth levels at these particular sites with the bias depending upon the differences in chronology length and age structure among the sites. It is therefore required to normalize those single site chronologies before averaging them together to mitigate trends evolving due to changing site replication. A final recognized systematic bias in RCS curves may arise from not having information (i.e. pith offset (PO) estimates) on the quantity of rings missing between the innermost sampling ring and the stem pith. This absence will “reduce the expected ring width maximum in early years of tree growth and consequently lower the expected trend of declining growth with increasing age” (Briffa & Melvin 2011). The use of pith-offset estimates (POE) is generally recommended, as it will increase the accuracy of the growth curve.

In this study we focus on applying regional curve standardization (RCS) to samples from only living *Pinus nigra* from Mt. Olympus, Greece. The dataset consists of seven potentially drought sensitive sites and 556 samples, collected with the aim to reconstruct past summer moisture variability. The sites span the lower to upper elevation range of black pine forest in this area (850m – 1700m) and are distributed around the Mt. Olympus massive to capture different slope exposures and luff-lee conditions. We only use latewood width (LWW) measurements, as a previous investigation (Klesse 2012) revealed that this parameter contains the strongest response to summer drought conditions (May-July). We aim to assess and ideally overcome challenges related to employing RCS on this dataset with the ultimate aim to reconstruct inter-annual to multi-centennial climate variability. Accordingly, all site chronologies are screened for the above mentioned possible biases, the steps to construct the best possible master chronology are explained, and a preliminary May-July Standardized Precipitation Index (SPI) reconstruction for the last 400 years is shown.

Testing for biases in the Mt. Olympus dataset

Fig. 1a shows the seven TRW chronologies, detrended with an individual RC (smoothed with a 50-year spline) fitted for each site. Great similarities in the lower-frequency behaviour of the three old sites (PPP, PIGA and XEP) including a decreasing trend from the second half of the 17th century until the end of the 19th century and a strong upward shift (1895-1912) at the turn of the century. During the period of overlap the younger LIA and VPA sites shares this common low-frequency variability, where as the two other sites (REB and CHR) agree less well in the low-frequency domain.

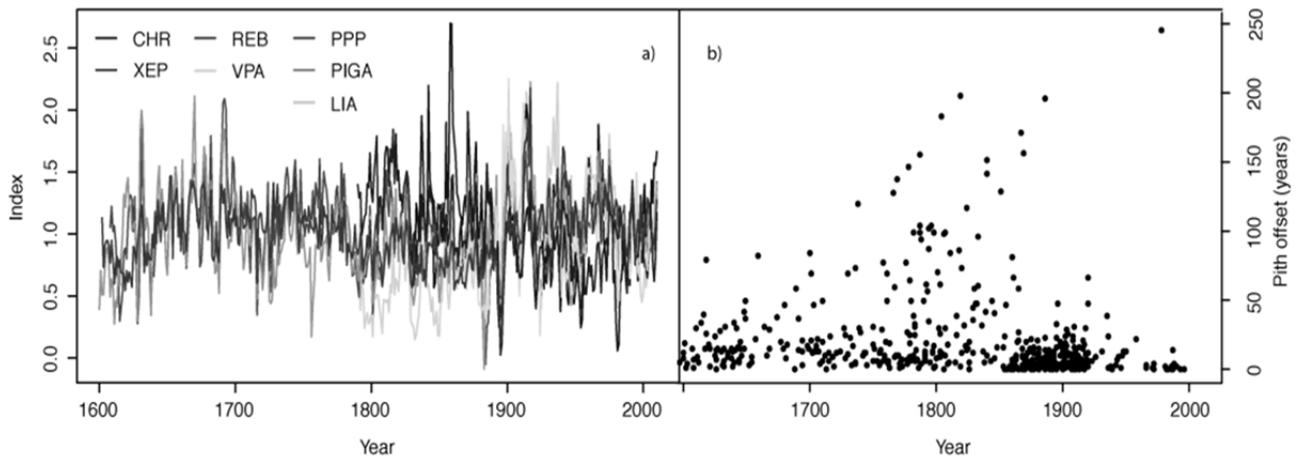


Figure 1: a) Seven individually detrended RCS_{TRW} chronologies from Mt. Olympus, Greece and b) showing pith offset estimates of 556 individual cores from all seven sites as a function of the calendar year of the innermost measured ring.

The PO distribution is generally homogeneous over time, with the exception that high PO values above 100 years accumulate in the 18th and 19th century (Fig. 1b). These high POs primarily arose while truncating some samples that could not be confidently crossdated due to their extremely low growth and many missing rings. The latewood RC from all sites combined without PO is shifted approximately 15 years towards the juvenile phase (Fig. 2a), but has the same slope. While the RCs are quite similar, in practice the innermost rings of a sample with a 150 year PO would be divided by ~ 0.2 , whilst if the PO data were not considered the detrending starts with values over 0.4 – a huge difference. In this study only about 20 of 556 samples have large PO and their consideration tends to have a rather small influence. Differences are most extreme at the PPP site for TRW, where the slope without POE is much shallower than with POEs (Fig. 2b). Most of the segments start within the first 200 years of the chronology (Fig. 2c). If the POs are disregarded growth of those samples with a small PO (<50 years) is heavily underestimated, thus leading to inflated values at the beginning of the chronology. The opposite happens with the samples with many rings missing to the pith. They will be divided by a higher growth curve, the overall chronology lowered for the next 150 years (Fig. 2d). When PO data are ignored, most chronologies show higher values at the beginning due to a shallower growth curve and the fact that the first rings of the oldest samples are generally close to the pith. High PO values seldom occur and therefore their influence on the shape of the chronology is low. The more evenly distributed POE are in size and time, the lower are the differences in the resulting chronologies.

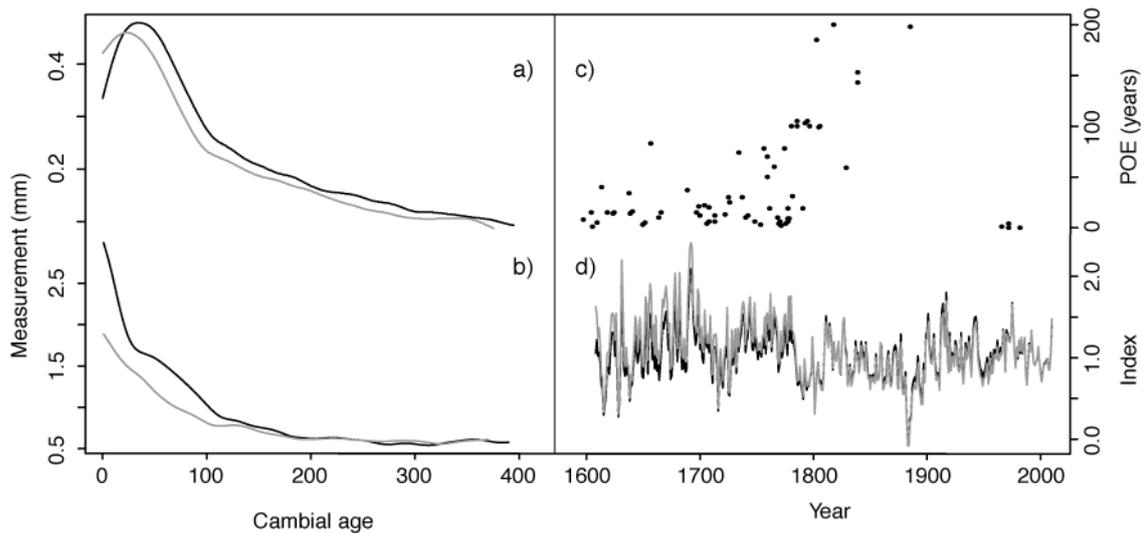


Figure 2: Comparisons of regional curves with (black) and without pith offset estimates (POE) (grey) with a) showing the differences using all 556 LWW samples and b) the extreme case of TRW at the PPP site. c) temporal distribution of the pith offset estimates for the PPP site and d) the resulting RCS chronologies with and without the use of POEs (black and grey, respectively) for PPP.

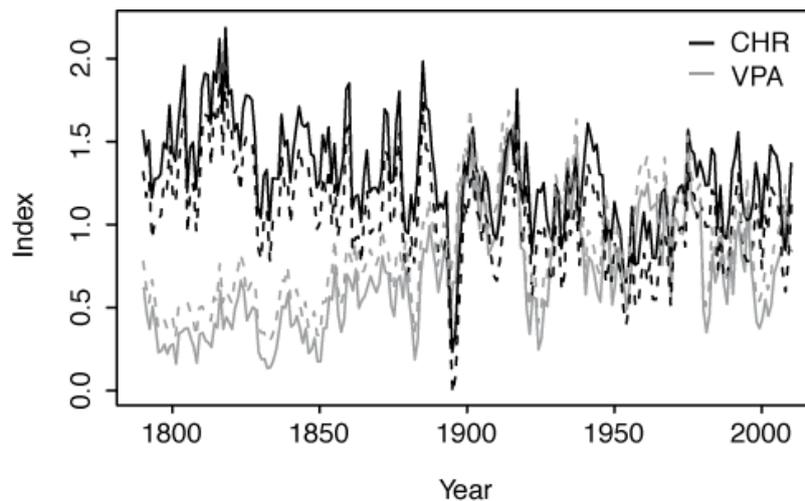


Fig. 3: CHR and VPA RCS_{TRW} chronologies detrended with the same RC untreated (solid lines) and normalized (dashed lines).

To illustrate the challenges in using a single RC to detrend different sites, we show in Fig. 3 the CHR and VPA TRW chronologies after detrending with the overall growth curve of all seven sites. Several problems are readily observed. The first problem is the different overall slope of both chronologies prior to 1900. CHR decreases constantly, while VPA has a steep upward trend. The second problem is the obviously different mean of both curves. This results from the overall RC, leading to high values in the fast growing, high elevation CHR site and the opposite at VPA. After normalization over the common period 1840-2010 this growth level difference is nearly eliminated (dashed lines in Fig. 4), but still the slope discrepancies remain. CHR is the only site where both the individual detrending and the overall regional curve display this unusual decreasing trend. A possible explanation can be found in the “different-contemporaneous-growth-rate” bias. In the first years of the possible “site history” only a few trees were growing. We hypothesize that low competition led to high growth rates. With passing years more and more trees germinated and competed for resources, leading to declining growth rates in the individual trees. This anomalous behavior, patterns consistent with the different-contemporaneous-growth-rate bias, and the

generally weaker response to summer drought (Klesse 2012) lead to the exclusion of CHR from the regional master chronology.

In contrast, the VPA site shows a pronounced upward trend in the second half of the 19th century. Sample replication increases the most between 1870 and 1910 where about 20 single series start contributing to chronology. The resulting rise of the slope could potentially be attributed to these new samples as can be noticed in Fig. 4. However, the mean of the 20 oldest samples shows still an upward trend albeit not as strong as in the younger series. As the younger samples outnumber the old ones 2:1, the growth curve and hence the overall mean is likely biased in the direction of the younger and faster growing series in accordance with the “modern-sample” bias described earlier. In the present case, this bias appears to be of temporally limited impact. Considering the similar low frequency trends in the three old sites, where no (XEP, PPP) or only three (PIGA) young trees (germination after 1880) contribute to chronology, the site VPA is not excluded from the regional RCS chronology. Conventional detrending with conservative negative exponential fits (not shown) yields quite similar patterns (e.g. greater growth in the 20th century in comparison to the 19th century) further suggesting the robustness of the RCS chronology.

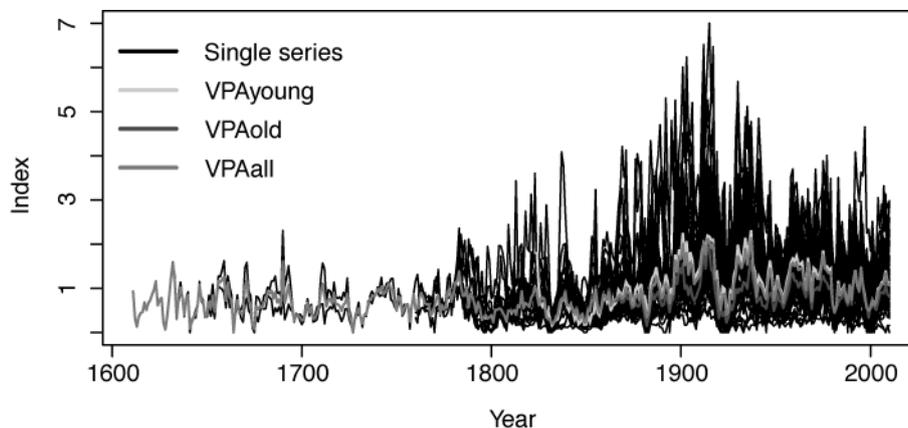


Figure 4: Single series of the RCS_{TRW} chronology of VPA (black) and the mean of the 20 oldest samples (dark grey), the 46 youngest samples (light grey) and the overall mean (grey).

We next sought to construct a Mt. Olympus final chronology from six of the sampled sites. The easiest way to build this Mt. Olympus chronology would be to use a single growth curve for all samples (hereafter referred to as RCS_{single}). The robust use of RCS_{single} requires a more or less equal distribution of all series and all sites over time. If individual growth curves display overall the same shape but on different levels as in this present study's case, RCS_{single} could be employed if the age and replication structure of all sites over time is similar. Otherwise, this method is prone to distortions due to changing sample and site replication.

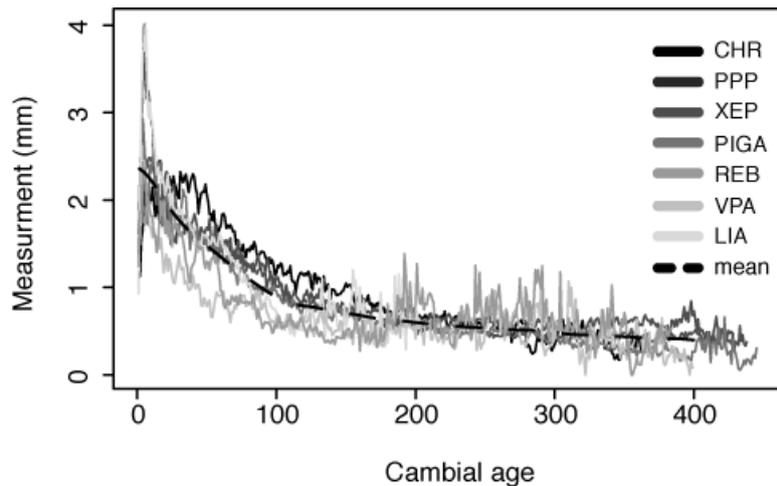


Figure 5: Raw RC_{TRW} curves of all seven sites (sorted according to their elevation) and their smoothed mean (dashed line, 50-year spline).

The RC curves for our individual sites have a similar shape, but if the smoothed mean growth curve is compared against the raw site growth curves major departures can be easily detected (Fig. 5). From the age of 200 onwards all series nicely fit the composite RC. Before that, the slow growing low elevation sites (VPA and REB) are heavily overestimated and the faster growing high elevation sites are underestimated (CHR, XEP, PPP). This underestimation of the (mainly) old sites in their first 200 years leads to increased index values. As a consequence the beginning of the RCS_single chronology displays inflated values, because only faster growing old trees of the high elevation sites build the chronology at this time. When a lot of the young slow growing trees start contributing to the chronology around 1850 the chronology trends downward because the overall growth curve is too high for all low elevation sites (which start at 1790, 1840 and 1900, Fig. 6b) and overestimates nearly all series in the last 110 years (Fig. 6a). Thus RCS_single does not seem to be an appropriate method for developing a regional Mt. Olympus chronology.

The splitting and recombination of the sites should circumvent the problems with RCS_single when the site chronologies are normalized before merging together. The distortions at both ends are decreased (Fig. 6a), but are nevertheless still clearly visible when compared to the individually detrended regional chronologies. These distortions are also due to the slightly different shapes of growth curves the single sites. For example at LIA the first 10-15 years will be underestimated and after the cambial age of 90 overestimated. Given the fact, that nearly all single series of LIA start from 1890 to 1920, this leads to increased values around 1900 and a slow decrease from 1980 onwards. LIA consequently has a steeper downward slope than it should have when detrended with its appropriate individual growth curve. These tests revealed significant difficulties in the collective detrending of data from six sites. We concluded that application of individual growth curves to each site and then merging them seems to be the most appropriate way to build the regional RCS chronology.

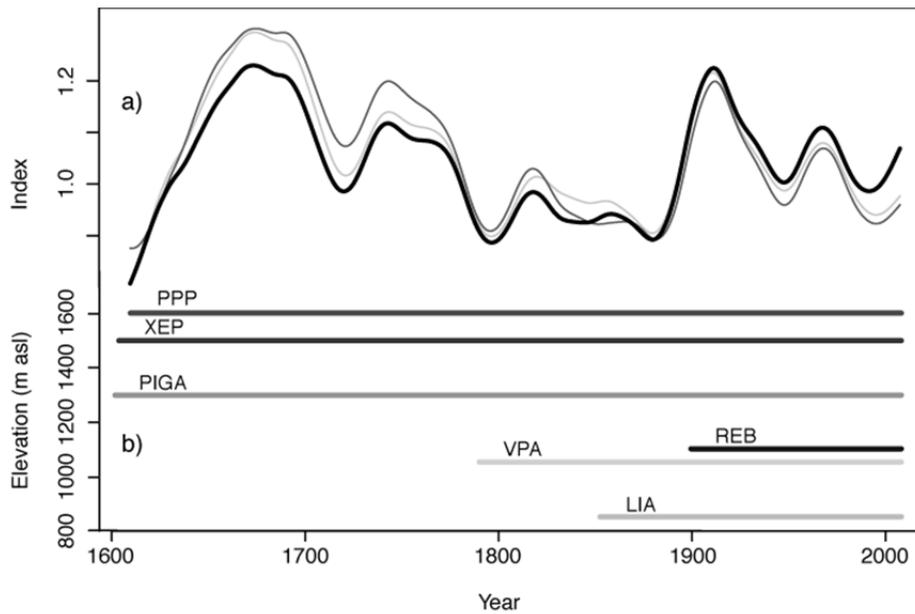


Fig. 6: **a)** 50-year smoothed RCS regional chronologies. *RCS_single* (dark grey), *RCS_recombined* (light grey) and *RCS_individual* (black). **b)** The time spans of the individual sites included in the master RCS chronology as a function of their elevation in m asl.

A final consideration, which was not yet discussed, is the even-aged site REB. Like CHR it showed no low growth in the 19th century as the other five sites. Climate response analysis showed high sensitivity of REB to summer drought. As one of the study's objectives was to reconstruct past moisture variability, this site could be still of use. Therefore the standard deviations of the *RCS_individual* chronologies were examined, with and without REB. This analysis revealed great consistency in the 20th century however a large increase in standard deviation before 1900. Based upon these patterns REB was truncated so that only the last 110 years contribute to the regional RCS chronology.

Discussion and Conclusion

In this study we performed methodological trials to produce a chronology that robustly preserves inter-annual to low-frequency climate signals from a living tree dataset. After carefully merging the individually detrended site chronologies the final latewood width chronology explains 42% of the variance of the May-July standardized precipitation index ($r=0.65$). Our preliminary reconstruction shows very good agreement with other high frequency reconstructions of the Eastern Mediterranean (Fig. 8) (e.g. Xoplaki et al. 2003, Akkemik & Aras 2005, Touchan et al. 2007). The recent drying trend (1975-2000), known from instrumental data is also well captured by the tree-ring data. However, the reconstruction suggests that the current status quo (i.e., late 20th- early 21st century dry conditions that are a concern for agriculture and human societies) is well within the range of natural variability experienced during the past 400 years.

To achieve an unbiased RCS chronology, a multi-site strategy and the use of POE are of major importance. In addition to the common knowledge that a high sample replication is required for RCS, we found it is also helpful that these samples are distributed among several sites with different age structures. This sampling design allows for the systematic testing of biases. The use of POE greatly increases the accuracy of the RC. We also recommend to detrend the sites individually to achieve the best curve fit possible, especially when the sites do not span the same time period and growth levels are different.

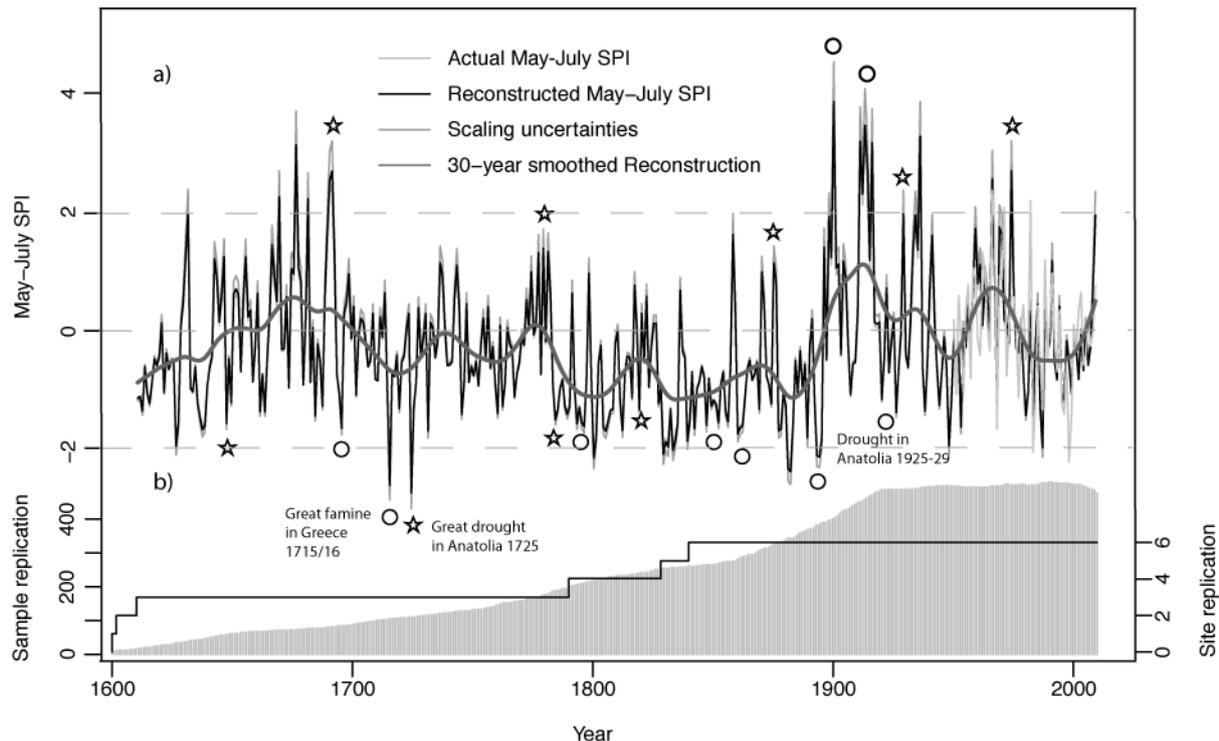


Figure 7: a) Actual and reconstructed May-July SPI with b) sample and site replication over time. Asterisks (circles) represent pointer years (periods) also mentioned in other climate reconstruction literature of the Eastern Mediterranean.

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