Dear Editor,

This is the Point-by-point response to Report#2 with which we aim to answer all the suggestions and comments the reviewer made.

More important comments:

1. One of the advantages of the RCS standardization method is that it is usually presented as the method that best retains low frequency variability. This study presents another variant of RCS, based on an alignment of trees according to their size instead as according to their age. The obvious question would be how this variant behaves in the low-frequency domain compared to the RCS method. There is barely a word on this in the manuscript. As the bare minimum, both chronologies should be shown together in a figure, comparing the amplitude of low-frequency variations.

More detailed discussion on the RCS and BasPois methods is addressed in lines 35-49 of page 7, and 1-13 of page 8. In addition, as suggested by the reviewer, the Fig.6 now includes the additional standardization methods.

Related to this comment, it is unclear to me how the trees are really aligned in the BasPois chronology. The study mentions 'the 'square of the basal area' as the independent variable, but Figure 4 indicates cm2 es the units of the square of basal area. I think this is an error, and that more logically it is the basal area (not its square) the independent variable. This would match the units in Figure 4. Otherwise, I do not see the rationale of using the square of the area (it is probably the square of the diameter of the ring ?)

We apologized for the misunderstanding and have correctly mentioned the 'basal area'.

2. The physiological explanation for a response of the chronology to the mean of the monthly maximum temperature in the previous 21 months is basically a bit of hand waving. Maybe there is at this point no other explanation, but the authors could just candidly say it.

We have delved deeper on the possible explanation of the 21 months in the discussion, lines 10-18 page 9.

More particular points

3. The IPCC report, explains the acronym IPCC. All acronyms should be spelled out, even if they are obvious.

As suggested by the reviewer we have spelled out the acronym.

4. a high-resolution temperature reconstruction. High-resolution in time, I guess. The sentence in this context is unclear as it could refer to a spatially resolved reconstruction over this region

As suggested by the reviewer we have rephrased the sentence.

5. Iberian Range. Explain where the Iberian Range is located, at least broadly. The map shown in Figure 1 is of low-quality (at least in this pdf file) and should be improved for publication

As suggested by the reviewer we have included a reference to Figure 1 to guide the readers. We apologized for the low quality of the figure, which is low due to compression to .pdf format. Final figures will have high quality.

6. 'RE is a measure of shared variance between actual and estimated series ' This explanation of RE is not totally correct/specific. (the correlation is also a measure of shared variance). RE is better defined a measure of the typical size of the errors relative to the typical size of variations relative to the calibration mean.

As suggested by the reviewer we have improved the definition of RE. Lines 41 to 45, page 4.

7. To transfer the TRW chronology into a temperature reconstruction a linear regression model was used. This is too unspecific. There are many variants of linear regression. I guess that the authors have set temperature as dependent variable and the chronology as independent variable, and have used Ordinary Least Squares assuming gaussian independent errors to estimate the regression coefficient. All this information is needed to completely specify the regression model

As suggested by the reviewer we have improved the details of the linear regression used, lines 15-18 of page 5.

8.with a gradual decline of the growth until the cambial of 450. Cambial age from 500 to 550 until the cambial age of 450 years, I guess. Cambial age from 500 to 6550 years (?)

As suggested by the reviewer we have rephrased it to clarify.

9. Calibration of the four differently detrended mean chronologies reveals a highly negative correlation with maximum temperatures. With maximum temperatures or with monthly mean of daily maximum temperatures ? Taken the sentence in the manuscript literally, the authors mean the maximum temperature attained within the 21-month window. I do not think this is what they really mean.

As suggested by the reviewer we have correctly named the climate parameter as 'monthly mean of daily maximum temperature'.

10. Correlations with previous-year September (r = -0.39), and the ArstanSTD chronology correlates at r = -0.56 with September and October temperature of the previous year with a cumulative monthly mean of 21 months. Here and everywhere in the manuscript, this way of specifying the calendar window with highest correlations is confusing. I agree that it is not straight forward to explain, but the characterization of September temperature is misleading. It is clearly not the September temperature, but the mean (maximum) temperature over a 21-month window. Thea authors should find a better way of defining this quantity. In this partucular sentence, I would suggest something like ' the 21-month mean temperature centered in September or October'. An efficient way would be to define it in the Methods section, attach an acronym to it (e.g. T_21_Sept or T_21-Oct or similar) and subsequently use the acronym throughout the manuscript.

As suggested by the reviewer we have now used acronyms (explained in the methodology, lines 26-29, page 4) to indicate the climate parameter.

11. 'and the first principal component explains about 35% of the variance'. Have the chronologies been standardized to unit variance before the PCA ? Otherwise the amount of explained variance is not informative, since it would depend on the individual variances of the chronologies

Since PCA analyses is not used or commented anywhere else in the manuscript, we remove the sentence to avoid confusion.

12. It is remarkable that the 12 years of the XXI century. In a scientific text, in English it is usual to refer to the 21st century, but this may be a matter of taste. Please, check.

As suggested by the reviewer we now refer to 21st

13. ' The year-to-year temperature variability is ..' The reconstructions refer to a 21-month calendar window, so it is confusing to refer to the year-to year variability. This is actually not clearly resolved in the chronology. Perhaps better refer to high-frequency (biennial) variability

As suggested by the reviewer we have rephrased to clarify, line 46 of page 6, lines 1 and 3 of page 7.

14. The main driver of the large-scale character of the warm and cold episodes may be changes in the solar activity. This point can be quite controversial and it is definitively contrary to present understanding, which states that the most important forcing for the midlatitude temperature variations is the volcanic forcing. It also seems speculative in this text since the authors have not conducted any proper attribution test to separate solar and volcanic forcing, which are known to be strongly correlated.

We agree that stratospheric sulfate aerosols from large volcanic eruptions are a prime forcing of past millennium climate variability. However, this forcing typically acts on shorter (inter-annual to decadal) timescales, and does not necessarily mean that all regional reconstructions are similarly affected by these events. A prominent continental scale temperature reconstruction for Europe (Luterbacher et al. 2016 in ERL) recently found better agreement with high-end estimates for total solar irradiance over the past millennium (also involving model simulations). So, while we generally agree with the reviewer, it still seems reasonable to report the correlations between solar forcing and our regional recon, and point the low degrees of freedom after smoothing the data.

15. Overall, the correlation between the reconstruction and the solar activity is 0.34 ($p < 0.0001$), and increases to $r = 0.49$ after 11-year low pass filtering the series, thought the degrees of freedom are substantially reduced due to the increase autocorrelation. Another comment is that the number of degrees of freedom affects the statistical significance but not the magnitude of the correlation. A lower number of degrees of freedom does not per se on average artificially increase the correlation. thought - > though

Here, we are not saying that we would expect a higher correlation after smoothing. What we say is just that the r =0. 49 correlation is based on less degrees of freedom due to the low-pass filtering. As suggested by the reviewer 'thought' has been corrected.

16. The SEA (Fig.10) indicates some impact of volcanic eruptions on the short-term temperature variability within the reconstruction. It shows significance ($p < 0.05$) decrease in September's temperature with a lag of three years. The details of the SEA are obscure. The manuscript does not indicate which eruptions have been considered and how the significance has been established. This definitely needs a longer explanation

The manuscript does indicate that the major volcanic eruptions that have been considered were those identified by Crowley (2000) line 12 of page 5. We agree with the reviewer that Crowley (2000) may seem slightly outdated dataset and yet, even though new volcanic reconstructions have been published such as Gao et al., 2008 or Sigl et al., 2015, over the past 400 years the events are quite well understood and well dated and hence we used the highly impact Crowley (2000) volcanic list. We have included the year of the volcanic events in lines 12 and 13 of page 5.

***Note that the discussion has been reorganized.**

17. developed a 410-year maximum September temperature reconstruction developed a reconstruction of the monthly mean of daily maximum temperatures

As suggested by the reviewer the sentence has been rephrased.

18. signal to noise ratio, captures the regional climate signal accurately. A chronology never captures the climate signal accurately

As suggested by the reviewer the sentence has been rephrased.

19. In fact, climate variability is more size-dependent than age or species (De Luis et al., 2009). The impact of climate variability on trees may be more size-dependent, not the climate variability itself

The discussion referred to this issue has now been improved from lines 42-48 of page 7.

20. Memory effects in TRW data have been also studied regarding the delayed response in TRW (1~5 years) to post volcanic eruptions associated with a decrease in current's year temperature (D'Arrigo et al., 2013, Esper et al., 2014)....... According to the SEA (Fig.9), the volcanic eruptions have a significance reduction (95% confidence) of September's temperature (-1.98oC) with a three years lag.

This paragraph mixes two different effects, and it is not clear which one the authors are referring to. One effect is that the temperature response to eruptions is itself delayed, since volcanic aerosols need some time to spread globally in the stratosphere. The other effect is the physiologically delayed response of trees to sudden temperature drops (or to reduction in sunlight caused by the eruption).

The discussion has been here clarified in lines 20-39 of page 9.

21. 2012 in agreement with the raise of temperatures observed for last decades

rise in temperatures

As suggested by the reviewer 'raise' was changed for 'rise'.

22. between the chronology and the climate parameter chosen never drops from -0.54 below -0.54

Changed as suggested by the reviewer.

23. will trigger an incessant decrease in the tree-ring growth would also cause a continuous decrease in tree-ring growth

Rephrased as suggested by the reviewer.

24. Even though the CRU dataset extents the 1901-2013 period

The reader will wonder how is it possible that the CRU temperature records start in 1901 whereas the coverage of most meteorological stations starts in 1950. This would raise doubts on the quality of the pre-1950 temperature data

Prior to 1950 just some areas of Spain have a good coverage of meteorological stations. In the study area (Iberian Range) local instrumental weather stations are in fact not available prior to 1945. Since the CRU dataset interpolates climatic data sometimes within distances of more than 100 km, we focused on the generalized instrumental period in Spain to avoid including more bias than benefits by extending the calibration/verification period.

25. Even though the CRU dataset extents the 1901-2013 period, the general distribution of meteorological observatories in Spain did not begin until the mid-twentieth century (Gonzalez-Hidalgo et al. 2011)

spans the 1901-2013 period

Modified as suggested.

26. However, based on a TRW chronology, it is remarkable the high correlation coefficient for the full calibration period and the CRU dataset ($r = -0.78$).

the high correlation coefficient is remarkable

Modified as suggested.

27. However, previously to the Dalton minimum

prior to the Dalton Minimum

Modified as suggested.

28. Overall, the correlation between the reconstruction and the solar activity is 0.34 ($p < 0.0001$), and increases to $r = 0.49$ after 11-year low pass filtering the series which reconstruction of solar activity is being used here ?

This phrase has been removed from the discussion.

29. Figure 4, caption square of the basal area ? or basal area?

Basal area, we apologized for the mistake. Right citation has been corrected in the manuscript.

30. Figure 5, Figure 7 caption mean of daily maximum temperature

Changed as suggested.

31 Figure 9 purple shading indicates the mean square error based on the calibration I cannot see any purple shading in this pdf file

Due to .pdf compression some figures have lost image quality.

Solar forcing: which reconstruction of solar activity has been used here ?

The solar forcing published by Crowley (2000). Now indicated.

32. Figure 10, how many eruptions and which eruptions have been used

Indicated in lines 12 and 13 of page 5.

Temperature variability of the Iberian Range since 1602 inferred from tree-ring records

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Abstract

Tree-rings are an important proxy to understand the natural drivers of climate variability in the Mediterranean basin and hence to improve future climate scenarios in a vulnerable region. Here, we compile 316 tree-ring width series from 11 conifer sites in the western Iberian Range. We apply a new standardization method based on the trunk basal area instead of the tree cambial age to develop a regional chronology which preserves high to low frequency variability. A new reconstruction for the 1602-2012 period correlates at -0.78 with observational September temperatures with a cumulative mean of the 21 previous months over the 1945-2012 calibration period. The new IR2T_{max} reconstruction is spatially representative for the Iberian Peninsula and captures the full range of past Iberian Range temperature variability. Reconstructed long-term temperature variations match reasonably well with solar irradiance changes since warm and cold phases correspond with high and low solar activity, respectively. In addition, some annual temperatures downturns coincide with volcanic eruptions with a three year lag.

1. Introduction

The Intergovernmental Panel on Climate Change ~~IPCC report~~ (IPCC, 2013) highlighted a likely increase of average global temperatures in upcoming decades, and pointed particularly to the Mediterranean basin, and therefore in the Iberian Peninsula (IP), as a region of substantial modelled temperature changes. The Mediterranean area is located in the transitional zone between tropical and extra-tropical climate systems, characterized by a complex topography and high climatic variability (Hertig and Jacobeit, 2008). Taking into account these features, even relatively minor modifications of the general circulation, i.e. a shift in the location of sub-tropical high pressure cells, can lead to substantial changes in Mediterranean climate (Giorgi and Lionello, 2008), making the study area a potentially vulnerable region to anthropogenic climatic changes by anthropogenic forces, i.e. increasing concentrations of greenhouse gases (Lionello et al., 2006a)

Major recent efforts have been made in understanding trends in temperatures throughout the IP over the instrumental period (Kenaway et al., 2012; Pena-Angulo et al., 2015; Gonzalez-Hidalgo et al., 2015) and future climate change scenarios (Sánchez et al., 2004; López-Moreno et al., 2014). However, the fact that most of the observational records do not begin until the 1950s (Gonzalez-Hidalgo et al., 2011) is limiting the possibility of investigating the inter-annual to multi-centennial long-term temperature variability. Therefore, it is crucial to explore climate proxy data and develop long-term reconstructions of regional temperature variability to evaluate spatial patterns of climatic change and the role of natural and anthropogenic forcings on climate variations (Büntgen et al., 2005). In the IP, much progress has been made to reconstruct past centuries climate variability, including analysis of documentary evidences for temperature (i.e. Camuffo et al., 2010) and droughts reconstruction (i.e. Barriendos et al., 1997; Cuadrat and Vicente, 2007; Domínguez-Castro et al., 2010). Additionally, progress has been made to further understanding of long-term climate variability of the IP through dendroclimatological studies focussing on drought (Esper et al., 2014; Tejedor et al., 2015) and temperature (Büntgen et al., 2008; Dorado-Liñán et al., 2012, 2014; Esper et al., 2015a). Nevertheless, ~~a high resolution~~ a temperature reconstruction for central Spain is still missing.

Several studies have been made to develop a temperature reconstruction for the Iberian Range (IR, see Figure 1) using *Pinus uncinata* tree-ring data (Creus and Puigdefabreas, 1982; Ruiz, 1989). The results, in fact, showed a pronounced inter-annual to century scale chronology variability. However, their main result was a complex growth response function due to a mixed climate signal instead of a temperature reconstruction. Furthermore, Saz (2003) developed a 500-year temperature reconstruction for the Ebro Depression (North of Spain), but this chronology is based on a reduced number of cores and a standardized methodology that did not retain the medium and low frequency variance.

Here we present the first tree-ring dataset combining samples from three different sources from the eastern IR extending back from the Little Ice Age (1465) to present (2012). The aim of this study is to develop a temperature reconstruction representing the IR, and thereby fill the gap between records located in the northern and southern IP. A new methodology, based on basal area instead of the cambial-age, was applied to preserve high-to-low frequency variance in the resulting chronologies. Furthermore, the relationship between the tree-ring and climate data is reanalysed by adding memory to the climate parameters, since memory effects on tree-ring data are much less acknowledged (Anchukaitis et al., 2012). This analysis is challenging because of the mix of tree species and their unidentified responses to climate. The resulting reconstruction of September maximum temperatures over the past four centuries is compared with latest findings from the Pyrenees and Cazorla, and the relationship with solar and volcanic forcings at inter-annual to multi-decadal timescales.

2 Material and methods

2.1 Site description

We compiled a tree ring network from 11 different sites in the western IR (Table 1) in the province of Soria. Urbión is the most extensive forest of the IP including 120,000 ha between the Burgos and Soria provinces. It has a long forest management tradition. Therefore, all sites are situated at high elevation locations where forests are least exploited and maximum tree age is reached (Fig.1). The altitude of the sampling sites ranges from 1,500 to 1,900 meters above sea level (masl) with a mean of 1,758 masl. These forests belong to the Continental Bioclimatic Belt (Guijarro, 2013) characterized by moderate mean temperatures (9.5°C, Fig.2B) and a large seasonal range including more than 90 frost days and summer heat exceeding 30ºC . Mean annual precipitation for the period 1944-2014 is 927 mm (CRU TS.3 v.23 dataset by Harris et al., 2014) and reaches its maximum during December (Fig. 2AC).

Although scotts pine (*Pinus sylvestris*) is the dominant tree species of the region, other pinaceaes are found such as *Pinus pinaster*, *Pinus nigra* or *Pinus uncinata*. Especially remarkable is occurrence of *Pinus uncinata* growing above 1,900 masl and reaching its European southern distribution limits in the IR. The lithology of the study area consists of sandstones, conglomerates and lutites.

2.2 Tree ring chronology development

The new dataset is composed by 316 tree-ring width (TRW) series of Pinus uncinata (56) and *Pinus sylvestris* (260) located in the western IR (Tab. 1, Fig. 1). The most recent samples were collected during the field campaign in 2013 including old dominant and co-dominant trees with healthy trunks and no sign of human interference. We extracted two core samples from each tree at breast height (1.3 m) when possible, otherwise, we try to avoid compression wood due to steep slopes, compiling a set of 96 new samples from two sites, i.e. the outermost ring is 2012. Core samples were air-dried and glued onto wooden holders and subsequently sanded to ease growth ring identification (Stokes and Smiley, 1968). The samples were then scanned and synchronized using CoRecorder software (Larsson, 2012) (Cybis Dendrochronology, 2014) to identify the position and exact dating of each ring. The tree-ring width was measured, at 0.01 mm precision, using LINTAB table (Rinn, 2005). Prior to detrending, COFECHA (Holmes, 1983) was used to assess the cross-dating of all measurement series.

An additional set of 95 samples from three sites was provided by the project CLI96-1862 (Creus et al., 1992; Saz, 2003) i.e., the outermost rings range from 1992 to 1993. Finally, a set of 125 samples from five sites was downloaded from the International Tree Ring Data Bank (ITRDB,http://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/tree-ring). These data were developed in the 1980s by K. Richter and collaborators, i.e. the outermost rings range from 1977 to 1985.

In order to attempt a climate reconstruction for the western IR from this tree-ring network, we perform an exploratory analysis of the 11 tree-ring sites by creating a correlation matrix of the raw TRW series for each site and the correlation with a composite regional chronology. Calculations are computed for the common period (1842-1977) and for the full period (1465- 2012).

2.2.1 Standardization methods

The key concept in dendroclimatology is referred to as the standardization process (Fritts, 1976; Cook et al., 1990) where the aim is to preserve as much of the climate-related information as possible while removing the non-climatic information from the raw TRW measurements. However, with most of the standardization methods a varying proportion of the low-frequency climatic information is also lost in the process (Grudd, 2008). When the aim is to use tree-ring chronologies as a proxy for climatic reconstructions, an adequate standardization is critical and the best method should preserve high to low frequency variations (Büntgen et al., 2004). It is common practice to calculate a mean value function as the best estimate of the trees’ signal at a site (Frank et al., 2006).

We here applied four standardization methods to the 316 TRW measurement series to develop a single tree-ring index chronology. (i) To emphasize inter-decadal and higher frequency variations, each ring width series was fitted with a cubic spline with a 50% frequency response cut off at 67% of the series length (Cook et al., 1990). A bi-weight robust mean was calculated to assemble the ArstanSTD regional chronology. (ii) A residual chronology (ArstanRES) is produced after removing first-order autoregression to emphasize high-frequency variability. (iii) To preserve common inter-decadal and lower frequency variations, Regional Curve Standardization (RCS) was applied (Mitchell, 1967; Briffa et al., 1992, 1996; Esper et al., 2003). RCS is an age-dependent composite method and involves dividing the size of each tree-ring by the value expected from its cambial age. To assemble the chronology, all the series are aligned by cambial age. A single growth function (regional curve, RC) smoothed using a spline function of 10% of the series length is fit to the mean of all age-aligned series. A biweight robust mean was applied to develop the RCS chronology (RCS). To preserve high to low frequency variance, we additionally applied a novel standardization method based on the principles of RCS. However, instead of using the cambial age of the trees as the independent variable, we used their sizes, calculated as ~~the square of~~ the basal area of the tree in the year prior to ring formation. Then, a Poisson regression model was used to fit the individual tree-ring widths. Standardized indices were calculated as the ratio between the observed and predicted values, and a biweight robust mean was used to develop the Basal Area Poisson chronology (BasPois).

To evaluate uncertainty of the mean chronologies running interseries correlations (Rbar) and the express population signal (EPS) were calculated (Wigley et al., 1984). Rbar is a measure of the strength of the common growth 'signal' within the chronology (Wigley et al., 1984; Briffa and Jones, 1990), here calculated in a 50-year window sliding along the chronology. EPS is an estimate of the chronology's ability to represent the signal strength of a chronology on a theoretical infinite population (Wigley et al., 1984).

2.3 Climatic data, calibration and climate reconstruction

Monthly temperature (mean, maximum, and minimum) and precipitation values from the gridded CRU TS v.3.22 dataset (0.5º resolution) dataset for the period 1945-2012 were used (Harris et al. 2014). The three grid points closest to the tree-ring network were averaged to develop a regional time series (Fig. 1). In addition, we calculate a cumulative monthly mean for each of the four parameters (max., min., mean temperature, and monthly precipitation). The cumulative mean is calculated by adding the months gradually. First the previous month is added, and then further months are included up to 36 previous months. For the calculations we take into account the current and the previous year. To indicate the climate parameter an acronym will be set as $\text{Temperature}_{\text{max, mean, or min}}$_Cumulative months_Calendar month$^{\text{-1, for previous year}}$. For instance, the maximum temperature of the previous year October with 20 months of cumulative monthly mean will be referred as T_{max}_20_Oct^{-1}.

For calibration, we correlated the four chronologies (ArstanSTD, ArstanRES, RCS, and BasPois) with monthly climate data and the cumulative monthly mean derived. However, to be consistent statistically, the two chronologies which highlight high frequency variations, ArstanRES and ArstanSTD, were correlated with the detrended climatic data. To assess the stability of the correlation, we calculated a 30-year moving correlation shifted along 1945-2012 with the cumulative monthly mean from the current and the previous year. In addition, the maximum and minimum differences between the moving correlations were calculated. As a result, the climatic variable chosen for the reconstruction is supported by having the highest moving correlation with the least difference between the maximum and the minimum over the moving correlation period.

A split calibration/verification approach was perform over the periods 1945-1978 and 1979-2012 to evaluate the accuracy of the transfer model considering the following metrics; Pearson's correlation (r), coefficient of determination (r^2), reduction of error (RE), mean square error (MSE), the sign test (Cook et al., 1994) and the Durbin-Watson test (Durbin and Watson, 1951). R is a measure of the linear correlation between the chronology and climatic variable. R^2 indicates how well the data fit a statistical model. An r^2 of 1 indicates that the regression line perfectly fits the data; an r^2 of 0 indicates that there is not fit at all. RE compares the skill of the estimated values with that obtained by using the mean value of the calibration period for every year. It is particulary useful since it checks whether a proxy is able to follow the lower frequency changes in climate between the calibration and verification periods (Wahl and Amman, 2007) is a measure of shared variance between actual and estimated series and hence it provides a sensitive measure of the reliability of a reconstruction (Cook et al., 1994; Akkemik et al., 2005; Büntgen et al., 2008); it ranges from +1 indicating perfect agreement, to minus infinity. MSE estimates the difference between the modelled and measured while sign test compares the number of agreeing and disagreeing interval trends, from year-to-year, between the observed and reconstructed series (Fritts et al., 1990; Cufar et al., 2008). To verify that there is no autocorrelation in the residuals we perform the Durbin-Watson test. Additionally, a Superposed Epoch Analysis (SEA; Panofsky and Brier, 1958) was performed using dplR (Bunn, 2008) to assess post-volcanic cooling signals in our reconstruction. The approach has been used in studies of volcanic effect on climate (Fischer et al., 2007; D'Arrigo et al., 2009; Esper et al., 2013a, 2013b). The major volcanic events chosen for the analysis were those identified by Crowley (2000), in order of magnitude (1815, 1641, 1809, 1831, 1992, 1883, 1902, 1695, 1674 and 1783).

To transfer the TRW chronology into a temperature reconstruction a linear regression model was used. The temperature was set as the dependent variable and the chronology as the independent variable, then, we used Ordinary Least Squares assuming Gaussian independent errors to estimate the regression coefficient. The magnitude and the spatial extent of the climate signal are evaluated considering the CRU TS v. 3.22 gridded dataset for Europe.

3 Results

The correlation matrix (Fig. 3) shows not only the high inter-correlation between sampling sites and tree species but also the high correlation between each chronology and the regional chronology. The highest correlation is found between *Pinus uncinata* (VIN and CAV) located at the highest altitude. On the other hand, the weakest correlation is found between one of the lowest sites (s006) and the highest (VIN). The mean correlation among all sampling sites is r = 0.51 over the common period (1842-1977) is 0.51, and r = 0.46 over the full period of overlap, revealing a regionally common, external forcing controlling tree growth and justifying the development of a single chronology integrating the data from this IP tree-ring network.

The model (regional curve) of the RCS standardization method and the model of the BasPois method are presented in Fig.4. BasPois model (Fig.4a) indicates a growth of 130 mm when the size of the basal area is near 0 and a growth of 8mm when it reaches the maximum basal area. RCS model (Fig.4b) presents values of 250 mm of growth when the cambial age is 0 with a gradual decline of the growth until the cambial age of 450. At cCambial ages from 500 to 550 an has a slight increase in growth is observed most likely derived by low replication regarding trees with this ages. The four chronologies after different detrending methods are shown in Figure 6.

Calibration of the four differently detrended mean chronologies reveals a highly negative correlation with monthly mean of daily maximum temperatures (Fig. 5). The ArstanRES chronology shows moderate correlations with previous-year September (r = -0.39), and the ArstanSTD chronology correlates at r = -0.56 with both T_{max}_21_Sept^{-1} and T_{max}_21_Oct^{-1}. Considering the RCS chronology, the previous-year September T_{max}_21_Sept^{-1} signal increases to r = -0.57 with a cumulative monthly mean of 21 months. Finally, the best correlation is revealed for the BasPois chronology reaching r = -0.78 with T_{max}_21_Sept^{-1} maximum September temperature of the previous year with a cumulative mean of 21 months, which is, in fact a two year cumulative monthly mean. Even though the signals show the same seasonal patterns among the chronologies, the BasPois record always shows the highest correlations. Accordingly, we used the BasPois chronology for the calibration and reconstruction process.

The final BasPois network chronology (Fig.6) is based on 316 TRW series of *Pinus uncinata* and *Pinus sylvestris* spanning the 1465-2012 period. Since this chronology is derived from only living trees, mean chronology age increases from 47 years in 1966 to 528 in 1465. The mean sensitivity is 0.21, the ~~and~~ first-order autocorrelation is 0.83 and ~~. t~~The inter-series correlation (Rbar) reaches 0.26.~~, and the first principal component explains about 35% of the variance~~. The network chronology's signal to noise ratio is 48.52, and EPS exceeds 0.85 after 1602, constraining the reconstruction period to 410 years until 2012.

The selection of the best climate parameter to develop the reconstruction is presented in the Figure 7 where correlations between -0.54 and -0.86 representing only the most significant values are shown. Four parameters reveal the highest correlations over the full calibration period;~~:~~ T_{max}_22_Oct~~October of the current year with a cumulative monthly mean of 22 months~~; T_{max}_20_Sept^{-1},~~September of the previous year with a cumulative monthly mean of 20 months~~; T_{max}_21_Sept^{-1},~~September of the previous year with a cumulative monthly mean of 21months~~; and T_{max}_21_Oct^{-1}~~October of the previous year with a cumulative monthly mean of 21 months~~. The stability of the correlation and therefore the consistency of the signal are tested considering the minimum difference between the maximum and minimum correlation (Fig. 7b) over the full running correlation period. The smallest difference (0.24) is reached for September of the previous year with a cumulative monthly mean of 21months. Therefore, this parameter is chosen for the climate reconstruction. According to the 30-year moving correlations, maximum values are reached from 1973-2003 (r = -0.80), whereas the lowest 30-year correlation (r = -0.60) is reached from 1956-1986. In addition, the relationship between T_{max}_21_Sept^{-1}~~September of the previous year with a cumulative monthly mean of 21months~~ is spatially consistent throughout the Iberian Peninsula, reaching into southern France and northern Africa (Fig.11).

The transfer model is validated by the high correlation (r = -0.78) and significant coefficient of determination (r^2=0.61) over the full period 1945-2012. Through the split calibration/verification process, considering 1945-1978 and 1979-2012, the temporal robustness was tested revealing highly significant correlations for both periods ((r^2=0.41 and (r^2=0.55 respectively) and verifying the final reconstruction (Table 2 and Fig. 8). The Durbin-Watson test for the full period (1.45 p<0.0001) indicates no substantial autocorrelation in the residuals. To develop the final reconstruction spanning 1602-2012, we used a lineal regression model over the full period 1945-2012 with maximum temperature of September of the previous year with a cumulative monthly mean of 21months (Eq.1), denominated IR2T_{max}:

$$IR2T_{max} = 3.9759 * BasPoisChron + 15.769 \; (r^2=0.61; p < 0.0001) \qquad (1)$$

3.1 IR2T_{max} reconstruction

IR2T_{max} describes 410 years of maximum temperature of T_{max}_21_Sept^{-1}~~September with a cumulative monthly mean of 21 months~~ meaning it has memory of the last two years. Biennial t~~T~~emperature ranges from 13.52ºC (-2.13ºC with respect to the mean) in 1603 to 17.64ºC n (+1.94ºC with respect to the mean) in 2005 (Fig. 9). It is remarkable that from 1602, ~~the~~12 of the 25 warmests ~~years~~biennial periods ~~of the~~happen during the ~~XXI~~ 20th and 21st centuries~~happen to be within the 25 warmest years~~. IR2T_{max} covers a part of the Little Ice Age

Con formato: Superíndice

(Grove, 1988) from 1602 to the end of the nineteenth ~~XIX~~ century. The ~~year-to-year~~ temperature variability is 3.92ºC in the seventeenth century, 2.89ºC in the eighteen century, 3.17ºC in the nineteenth century and 3.07ºC in the twentieth century. The seventeenth and eighteen centuries were the coldest of the reconstruction with 73% and 80% of the biennials ~~years~~ with temperatures below the long-term mean, respectively. On the other hand, the nineteenth and the twentieth centuries were the warmest with 66% and 78% of the ~~years~~ biennial periods exceeding the mean.

The main driver of the large-scale character of the warm and cold episodes may be changes in the solar activity (Fig.9). The beginning of the reconstruction starts with the end of the Spörer Minimum. The Maunder minimum, from 1645 to 1715 (Luterbach et al., 2001) seems to cohere with a cold period from 1645 to 1706. In addition, the Dalton minimum from 1796 to 1830, is detected for the period 1810 to 1838. However, a considerably cold period from 1778 to 1798 is not in consonance with a decrease in the solar activity. Four warm periods, 1626-1637, 1800-1809, 1845-1859 and 1986-2012, have been identified to cohere with increased solar activity. Overall, the correlation between the reconstruction and the solar activity is 0.34 ($p < 0.0001$), and increases to r = 0.49 after 11-year low pass filtering the series, though~~t~~ the degrees of freedom are substantially reduced due to the increase autocorrelation.

The SEA (Fig.10) indicates some impact of volcanic eruptions on the short-term temperature variability within the reconstruction. It shows significance ($p < 0.05$) decrease in September's temperature with a lag of three years.

Figure 11 shows the spatial correlation between the reconstruction and the CRU TS v.3.22 for Europe and northern Africa. High coefficient of determination (r^2>0.4, $p < 0.0001$) indicates a robust agreement and spatial extend of the reconstruction over the Iberian Peninsula (IP), especially for the central and Mediterranean Spain. The spatial correlation, however, decreases towards the southwest of the IP and the north of Europe.

4 Discussion and conclusion

A novel detrending approach, considering a Basal Area-Poisson model (BasPois) instead of the traditional regional curve (Esper et al., 2003) has certainly improved the skill of the reconstruction and enabled retaining high-to-low frequency climate variance. The traditional approach of using RCS with the mean TRW curve of the age-aligned data only reached correlations with the T_{max}_21_Sept up to r = -0.57, while with the new approach reached r = -0.78.

Observed improvements in the reconstruction's skills associated to the BasPois detrending approach need to be determined in other species and environmental conditions. However, several theoretical and practical advantages can be highlighted: (1) Similarly to RCS, BasPois used all individual tree-ring measurements to complete a single detrending. High but also medium and low frequency variability is then successfully preserved in the chronology in a similar way as has been described for the RCS method. (2) Removing biological trends from raw tree-ring measurements represent the key objective of the detrending processes. However, it is usually difficult to determine the extent to which the effects of environmental factors on tree growth depend on age (genetic control) and/or on size (physiological control). Recent investigations suggest that key functional processes (and therefore potential physiological constraints) on trees are more dependent on their size than on their age (Mencuccini et al., 2005; Peñuelas, 2005). Climate growth relationships have indeed demonstrated to be strongly dependent on the size of the trees, with the differences between size classes even greater that the differences found amongst age classes or even between different species (de Luis et al., 2009). Hence, the size-based standardization considered in the BasPois approach could represents a suitable alternative to age-based standardization processes (such as RCS) in order to isolate the evidence of external, climatically driven forcing of tree growth. (3) The age of the trees and subsequently, the cambial age of each individual tree-ring, it is usually not possible to be exactly determined by standard dendrochronological samples. As a consequence, age-based standardization processes should be often based on age estimations instead of directly measured values. On the contrary, the diameter at breast height (DBH) is a parameter that is routinely obtained during the dendrochronological sampling and then, the size of each tree prior to the formation of any tree-ring can be directly and unequivocally determined. (4) Finally, and additional obvious advantage is related to the possibility to design a sampling strategy including trees of different size classes in order to obtain a more unbiased distribution of tree-rings in relation to the independent variable used for the detrending. To the best of our knowledgement, size-based standardization processes as tested for our database have not been applied elsewhere. Further research is needed to generalize the advantages of such approach.

According to the previously discussed novel detrending approach and based on a coherent network of 11 tree-ring sites in the IR including 316 TRW series we developed a 410-year maximum September temperature reconstruction. This record is the first climate reconstruction for the IR filling the gap between the temperature reconstructions developed for the north IP (Büntgen et al., 2008; Dorado-Liñán et al., 2012a, Esper et al., 2015a) and for the southern IP (Dorado-Liñán et al., 2014). The IR2T_{max} has been achieved using TRW as well as for the southern IP (Dorado-Liñán et al, 2014). However, for the Pyrenees, MXD (Büntgen et al., 2008, Dorado-Liñán et al., 2012a) or stable isotopes (Esper et al., 2015a) are needed to get skilful records for a temperature reconstruction.

The main statistics used to verify the accuracy of the reconstruction present similar values to those developed for the IP. For instance, the RE coefficient for the period 1945-2012 is 0.56 meaning that the reconstruction has indeed useful skills to develop a reconstruction. A relatively high signal to noise ratio indicates there is meaningful climatic information in the chronology. The mean correlation between sites for the common period (r = 0.51, Fig. 3) reveals substantial agreement between the sites and species. Correlation is strongest among high elevation sites including the sites VIN and CAV which are both derived from *Pinus uncinata*. The regional climate variability was retained quite accurately by the mean chronology (including 48.52 of signal to noise), which highlights the beauty of regional averages (Briffa et al., 1998).

The original, raw chronology extended over the 1465-2012 period, some 150 years longer than the final reconstruction. However, due to low EPS values prior to 1602, which is related to the low number of samples the final reconstruction was developed for the period 1602-2012.

In this study, we detected a maximum temperature correlation with T_{max}_21_Sept^{-1} of -0.78. Nonetheless, the negative temperature correlation is already shown for the previous September (r=-0.56, with BasPoisChron) without any cumulative monthly mean. That would mean that within the environment in which trees are growing and with respect to the mean, they will grow more in cold than in hot years. This negative temperature correlation has been reported in numerous dendroclimatic studies (i.e. Büntgen et al., 2006; van der Werf et al., 2007) including the most recently developed climatic reconstruction for the Iberian Peninsula by Dorado-Liñán et al. (2014) showing a negative correlation with previous summer temperatures. One of the strengths of the results is adding the cumulative monthly mean to the climate variables which maximizes the correlation to r=-0.78.

The development of climate parameters retaining temperature information of the past 2 years is certainly unusual and distinctive. However, memory effects in TRW data can arise from physiological processes already suggested by Schulman (1956) and Matalas (1962). Moreover, it is well known that TRW growth is conditioned by the storage of starch and sugar in parenchyma ray tissue and the remobilization of carbohydrates from root structures that were storage in previous growing seasons (Pallardy, 2010).

In addition, radial growth of trees is strongly conditioned by total needle biomass available in trees at the start of the growing season (Wang et al., 2012). In pine species, mean needle age range from 2 to 4 years (Pensa and Jalkanen, 2005) and the amount of needles formed is also controlled by temperature variations during the years of formation. As a consequence, effects of temperature variability occurred several years before tree-ring formation may play an important role in secondary growth (radial increment) indirectly through their direct effect in primary production (needles formation). Further research and specific experiments are however needed to confirm such influences and determine the physiological mechanisms behind a climate signal that extends back up to 21 months.

Memory effects in TRW data have been also studied regarding the delayed response in TRW (1~5 years) to post volcanic eruptions associated with a decrease in current's year temperature (D'Arrigo et al., 2013; Esper et al., 2014). Thus, developing the two year memory IR2T_{max} allowed us to maintain not only the low frequency signal, highlighting the warm and cold phases, which may be explained by the high correlation with solar activity during 410 years (0.34, p<0.001), but also the high frequency signal, emphasizing the memory effects of the volcanic eruptions in TRW, already studied by Briffa et al. (1998) and recently by Esper et al. (2015b). According to the SEA (Fig.9), the volcanic eruptions have a significance reduction (95% confidence) of September's temperature (-1.98ºC) with a three years lag. However, the IR2T_{max} is already considering the two previous year's temperature, which means the temperature decrease occurred the year after the extreme volcanic event in consistency with (Frank et al., 2007a). The stability of the signal was assessed by a 30-y moving correlation from 1945 to 2012, which shows a better correlation for the period 1979-2012 in agreement with the rise of temperatures observed for last decades which may be limiting TRW growth and therefore magnifying the climate signal. However, the relationship between the chronology and the climate parameter chosen never drops below -0.54 within the calibration period 1945-2012. The negative correlation with maximum temperature of previous September is in concordance with the values detected in Cazorla by Dorado-Liñán et al. (2014). Presumably, a continuous rise in temperatures, as suggested by the IPCC (2013), would also cause a continuous decrease in tree-ring growth.
will trigger an incessant decrease in the tree-ring growth.

Even though the CRU dataset extentsspans the 1901-2013 period, the distribution of meteorological observatories in the Iberian Range of Spain did not begin until the mid-twentieth century (Gonzalez-Hidalgo et al., 2011). In fact, the closest instrumental weather station, located in Vinuesa (Fig.1), began in 1945. However, due to the large amount of gaps in the time series, the CRU dataset was used instead for the split calibration/verification approach for the period

1945-2012. The advantages of regional climatic averages were already addressed by Blasing et al. (1981) stating that the average climatic record of the gridded dataset over the study area is representative of the regional climatic conditions, and does not reflect microclimate conditions which may be characteristic of the climatic record at a single station. Tree-ring data might therefore have more variance in common with the regionally averaged climatic record than with the climatic record of the nearest weather station. Generally, studies have shown that the measurements of MXD produce chronologies with an improved climatic signal (Briffa et al., 2002) as it was revealed for summer temperature reconstructions (Hughes et al., 1984; Büntgen et al., 2008; Matskosvsky and Helama, 2014). However, based on a TRW chronology, the high correlation coefficient is remarkable for the full calibration period and the CRU dataset (r = -0.78).

Throughout the IR2T_{max} reconstruction we identified the main warm and cold phases (Maunder minimum, Dalton minimum) related with long-term temperature variability generally attributed to changes in cycles of solar activity (Lean et al., 1995; Lassen et al., 1995; Haigh et al., 2015). In addition, similar cold and warm phases are observed comparing with the Pyrenees (Büntgen et al. 2008) and Cazorla (Dorado-Liñán et al., 2014) reconstructions. However, ~~previously~~prior to the Dalton minimum, a warm phase is detected in IR2T_{max} and the Cazorla reconstruction although it is not present in the Pyrenees or in the Alps (Büntgen et al., 2011).

Through the spatial extent and magnitude of the IR2T_{max} reconstruction over Europe it can be acknowledged that the reconstruction is effective and usable for most of the Spanish Iberian Peninsula. Working especially for the central and Mediterranean IP with very high coefficient of determination (r^2>0.4).

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References

Akkemik, Ü., Da deviren., N., Aras, A.: A preliminary reconstruction (A.D. 1635–2000) of spring precipitation using oak tree rings in the western Black Sea region of Turkey. Int. J. Biometeorol. 49(5):297–302, 2005.

Anchukaitis, K.J., Breitenmoser, P., Briffa, K.R., Buchwal, A., Büntgen, U., Cook, E.R., D'Arrigo, R.D., Esper, J., Evans, M.N., Frank, D., Grudd, H., Gunnarson, B.E., Hughes, M.K., Kirdyanov, A.V., Körner, C., Krusic, P.J., Luckman, B., Melvin, T.M., Salzer, M.W., Shashkin, A.V., Timmreck, C., Vaganov, E.A., Wilson, R.J.S.: Tree rings and volcanic cooling. Nat. Geosci., 5 (12), pp. 836-837, 2012.

Barriendos, M.: Climatic variations in the Iberian Peninsula during the late Maunder minimum (AD 1675-1715): An analysis of data from rogation ceremonies. Holocene, 7 (1), pp. 105-111, 1997.

Blasing, T. J., D. N. Duvick, and D. C. West: Dendroclimatic calibration and verification using regionally averaged and single station precipitation data, Tree-Ring Bulletin, 41, 37-43, 1981.

3332-z

Benedict, J. B. and Maisch, M.: The little ice age, Jean M. Grove, Methuen, London and New York, xxii + 498 pp. Geoarchaeology, 4: 363–365. 1989. doi:10.1002/gea.3340040406

Briffa, K.R. and Jones, P.D.: Basic chronology statistics and assessment. In: Methods of Dendrochronology: Applications in the Environmental Sciences (Eds. E.R. Cook and L.A. Kairiukstis), pp.137-152, 1990.

Briffa, K.R., Jones, P.D., Bartholin, T.S., Eckstein, D., Schweingruber, F.H., Karlén, W., Zetterberg, P., Eronen, M.: Fennoscandian summers from ad 500: temperature changes on short and long timescales. Clim. Dynam., 7 (3), pp. 111-119, 1992.

Briffa, K.R., Jones, P.D., Schweingruber, F.H., Osborn, T.J.: Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 years. Nature, 393 (6684), pp. 450-455, 1998.

Briffa, K.R., Osborn, T.J., Schweingruber, F.H., Jones, P.D., Shiyatov, S.G., Vaganov, E.A.: Tree-ring width and density data around the Northern Hemisphere: Part 1, local and regional climate signals. Holocene, 12 (6), pp. 737-757, 2002.

Bunn, A.G.: A dendrochronology program library in R (dplR). Dendrochronologia 26:115–124, 2008.

Büntgen, U., Esper, J., Schmidhalter, M., Frank, D.C., Treydte, K., Neuwirth, B., Winiger, M.: Using recent and historical larch wood to build a 1300-year Valais-chronology. In: Gärtner H, Esper J, Schleser G (eds) TRACE 2: 85-92, 2004.

Büntgen, U., Esper, J., Frank, D.C., Nicolussi, K., Schmidhalter, M.: A 1052-year tree-ring proxy for Alpine summer temperatures. Clim. Dynam., 25 (2-3), pp. 141-153, 2005.

Büntgen, U., Frank, D., Grudd, H., Esper, J.: Long-term summer temperature variations in the Pyrenees. Clim. Dynam., 31 (6), pp. 615-631, 2008.

Camuffo, D., Bertolin, C., Barriendos, M., Dominguez-Castro, F., Cocheo, C., Enzi, S., Sghedoni, M., della Valle, A., Garnier, E., Alcoforado, M.-J., Xoplaki, E., Luterbacher, J., Diodato, N., Maugeri, M., Nunes, M.F., Rodriguez, R.: 500-Year temperature reconstruction in the Mediterranean Basin by means of documentary data and instrumental observations. Clim. Change, 101 (1), pp. 169-199, 2010.

Cook, E.R., Briffa, K., Shiyatov, S., Mazepa, V.: Tree-ring standardization and growth trend estimation. In: Cook ER, Kairiukstis LA (eds), Methods of dendrochronology: applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht, pp 104–162, 1990.

Cook, E.R., Briffa, K.R., Jones, P.D.: Spatial regression methods in dendroclimatology: a review and comparison of two techniques. Int. J. of Climatol. 14, 379–402, 1994.

Creus, J., Puigdefabregas, J.: Climatología histórica y dendrocronología de *Pinus uncinata* R. Cuad Investig Geográfica 2(2):17–30, 1982.

Crowley, T.J.: Causes of climate change over the past 1000 years. Science, 289 (5477), pp. 270-277, 2000.

Čufar, K., de Luis, M., Eckstein, D., Kajfez-Bogataj, L.: Reconstructing dry and wet summers in SE Slovenia from oak tree-ring series. Int. J. Biometeorol. 52:607–615, 2008.

D'Arrigo, R., Wilson, R., Tudhope, A.: The impact of volcanic forcing on tropical temperatures during the past four centuries. Nat. Geosci., 2 (1), pp. 51-56, 2009.

D'Arrigo, R., Wilson, R., Anchukaitis, K. J.: Volcanic cooling signal in tree ring temperature records for the past millennium, J. Geophys. Res. Atmos., 118, 2013.

de Luis, M., Novak, K., Čufar, K., Raventós, J.: Size mediated climate-growth relationships in *Pinus halepensis* and *Pinus pinea*. TreesStructFunct, 23 (5), pp. 1065-1073, 2009.

Domínguez-Castro, F., García-Herrera, R., Ribera, P., Barriendos, M.: A shift in the spatial pattern of Iberian droughts during the 17th century. Clim. Past, 6 (5), pp. 553-563, 2010.

Dorado Liñán, I., Büntgen, U., González-Rouco, F., Zorita, E., Montávez, J.P., Gómez-Navarro, J.J., Brunet, M., Heinrich, I., Helle, G., Gutiérrez, E.: Estimating 750 years of temperature variations and uncertainties in the Pyrenees by tree-ring reconstructions and climate simulations. Climate of the Past, 8 (3), pp. 919-933, 2012.

Dorado Liñán, I., Zorita, E., González-Rouco, J.F., Heinrich, I., Campello, F., Muntán, E., Andreu-Hayles, L., Gutiérrez, E.: Eight-hundred years of summer temperature variations in the southeast of the Iberian Peninsula reconstructed from tree rings. Clim. Dynam., 44 (1-2), pp. 75-93, 2014.

Durbin, J., Watson, G. S.: Testing for Serial Correlation in Least Squares Regression, II. 16 Biometrika 38 (1–2): 159–179, 1951.

El Kenawy, A., López-Moreno, J.I., Vicente-Serrano, S.M.: Trend and variability of surface air temperature in northeastern Spain (1920-2006): Linkage to atmospheric circulation. Atmos. Res., 106, pp. 159-180, 2012.

Esper. J., Cook, E.R., Krusic, P.J., Peters, K., Schweingruber, F.H.: Tests of the RCS method for preserving low-frequency variability in long tree-ring chronologies. Tree-Ring Research 59, 81-98, 2003.

Esper, J., Büntgen, U., Luterbacher, J., Krusic, P.: Testing the hypothesis of post-volcanic missing rings in temperature sensitive dendrochronological data. Dendrochronologia 13, 216-222, 2013.

Esper, J., Schneider, L., Krusic, P.J., Luterbacher, J., Büntgen, U., Timonen, M., Sirocko, F., Zorita, E.: European summer temperature response to annually dated volcanic eruptions over the past nine centuries. B. Volcanol. 75, 2013.

Esper, J., Düthorn, E., Krusic, P., Timonen, M., Büntgen, U.: Northern European summer temperature variations over the Common Era from integrated tree-ring density records. J. Quat. Sci. 29, 487–494, 2014

Esper, J., Großjean, J., Camarero, J.J., García-Cervigón, A.I., Olano, J.M., González-Rouco, J.F., Domínguez-Castro, F., Büntgen, U.: Atlantic and Mediterranean synoptic drivers of central Spanish juniper growth. Theor. and Appl. Climatol., 2014.

Esper, J., Konter, O., Krusic, P., Saurer, M., Holzkämper, S., Büntgen, U.: Long-term summer temperature variations in the Pyrenees from detrended stable carbon isotopes. Geochronometria 42, 53-59, 2015.

Esper, J., Schneider, L., Smerdon, J.E., Schöne, B.R., Büntgen, U.: Signals and memory in tree-ring width and density data. Dendrochronologia, 35, pp. 62-72, 2015b.

Fischer, E.M., Luterbacher, J., Zorita, E., Tett, S.F.B., Casty, C., Wanner, H.: European climate response to tropical volcanic eruptions over the last half millennium, Geophys. Res. Lett., 34, L05707, 2007.

Frank, D., Esper, J., Cook, E.R.: On variance adjustments in tree-ring chronology development. In: Heinrich I et al. (Eds.) Tree rings in archaeology, climatology and ecology, TRACE, Vol. 4, 56-66, 2006.

Frank, D., Büntgen, U., Böhm, R., Maugeri, M., Esper, J.: Warmer early instrumental measurements versus colder reconstructed temperatures: shooting at a moving target. Quat. Sci. Rev. 26, 3298-3310, 2007a.

Fritts, H.C., Guiot, J., Gordon, G.A., Schweingruber, F.H.: Methods of calibration, verification, and reconstruction. In Methods of Dendrocrhonology, 1990.

Fritts, H.C.: Tree rings and climate. Academic Press, London, 1976.

Giorgi, F., Lionello, P.: Climate change projections for the Mediterranean region, Glob. Planet. Change, Volume 63, Issues 2–3, September, Pages 90-104, 2008.

González-Hidalgo, J.C., Brunetti, M., de Luis, M.: A new tool for monthly precipitation analysis in Spain: MOPREDAS database (monthly precipitation trends December 1945 November 2005). Int. J.Climatol., 31 (5), pp. 715-731, 2011.

Gonzalez-Hidalgo, J.C., Peña-Angulo, D., Brunetti, M., Cortesi, N. MOTEDAS: A new monthly temperature database for mainland Spain and the trend in temperature (1951-2010). Int.J.Climatol., 2015.

Grudd, H.: Torneträsk tree-ring width and density ad 500-2004: A test of climatic sensitivity and a new 1500-year reconstruction of north Fennoscandian summers. Clim. Dynam., 31 (7-8), pp. 843-857, 2008.

Guijarro, J.A.: Tendencias de la temperatura en España. En García Legaz, C. y Valero, C. (Coords). Fenómenos meteorológicos adversos en España. AEMET y CCS. Madrid, 2013.

Haigh, J.D., Cargill, P.: The Sun's Influence on Climate, pp. 1-207, 2015.

Harris, I., Jones, P.D., Osborn, T.J., Lister, D.H.: Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. Int. J. Climatol., 34 (3), pp. 623-642, 2014.

Hertig, E. and J. Jacobeit: Assessments of Mediterranean precipitation changes for the 21st century using statistical downscaling techniques. Int. J.Climatol. 28(8): 1025-1045, 2008.

Holmes, R.L.: Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bull 43:69–78, 1983.

Hughes, M.K., Schweingruber, F.H., Cartwright, D., Kelly, P.M.: July-August temperature at Edinburgh between 1721 and 1975 from tree-ring density and width data. Nature, 308 (5957), pp. 341-344, 1984

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp, doi:10.1017/CBO9781107415324.

Larsson, L.A.: CoRecorder&CDendro program. Cybis Elektronik & Data AB. Version 7.6, 2012.

Lassen, K., Friis-Christensen, E.: Variability of the solar cycle length during the past five centuries and the apparent association with terrestrial climate.J. Atmos. Sol.-Terr. Phys , 57 (8), pp. 835-845, 1995.

Lean, J., Beer, J., Bradley, R.: Reconstruction of solar irradiance since 1610: implications for climate change. Geophys. Res. Lett, 22 (23), pp. 3195-3198, 1995.

Lionello, P., Malanotte-Rizzoli, P., Boscolo, R., Alpert, P., Artale, V., Li, L., Luterbacher, J., May, W., Trigo, R., Tsimplis, M., Ulbrich, U., Xoplaki, E.: The Mediterranean climate: An overview of the main characteristics and issues. Developments in Earth and Environmental Sciences, 4 (C), pp. 1-26, 2006a.

López-Moreno, J.I., El-Kenawy, A., Revuelto, J., Azorín-Molina, C., Morán-Tejeda, E., Lorenzo-Lacruz, J., Zabalza, J., Vicente-Serrano, S.M.: Observed trends and future projections for winter warm events in the Ebro basin, northeast Iberian Peninsula. Int.l J. Climatol., 34 (1), pp. 49-60, 2014.

Luterbacher, J., Rickli, R., Xoplaki, E., Tinguely, C., Beck, C., Pfister, C., Wanner, H.: The Late Maunder Minimum (1675-1715) - A key period for studying decadal scale climatic change in Europe. Clim. Change, 49 (4), pp. 441-462, 2001.

Luterbacher, J., Xoplaki, E., Casty, C., Wanner, H., Pauling, A., Küttel, M., Rutishauser, T., Brönnimann, S., Fischer, E., Fleitmann, D., Gonzalez-Rouco, F.J., García-Herrera, R., Barriendos, M., Rodrigo, F., Gonzalez-Hidalgo, J.C., Saz, M.A., Gimeno, L., Ribera, P., Brunet, M., Paeth, H., Rimbu, N., Felis, T., Jacobeit, J., Dünkeloh, A., Zorita, E., Guiot, J., Türkes, M., Alcoforado, M.J., Trigo, R., Wheeler, D., Tett, S., Mann, M.E., Touchan, R., Shindell, D.T., Silenzi, S., Montagna, P., Camuffo, D., Mariotti, A., Nanni, T., Brunetti, M., Maugeri, M., Zerefos, C., Zolt, S.D., Lionello, P., Nunes, M.F., Rath, V., Beltrami, H., Garnier, E., Ladurie, E.L.R.: Chapter 1 Mediterranean climate variability over the last centuries: A review, 2006.

Matalas, N.C.:Statistical properties of tree ring data. Hydrol. Sci. J. 7, 39–47, 1962.

Matskovsky, V.V., Helama, S.: Testing long-term summer temperature reconstruction based on maximum density chronologies obtained by reanalysis of tree-ring data sets from northernmost Sweden and Finland. Clim.Past 10, 1473–1487, 2014.

Mencuccini, M., Martínez-Vilalta, J., Vanderklein, D., Hamid, H.A., Korakaki, E., Lee, S., Michiels, B.: Size-mediated ageing reduces vigour in trees. Ecol. Lett., 8 (11), pp. 1183-1190, 2005.

Mitchell, V.L.: An investigation of certain aspects of tree growth rates in relation to climate in the central Canadian boreal forest. Technical report 33pp. Department of Meteorology, University of Wisconsin, 1967.

Pallardy, S.G.: Physiology of Woody Plants. Academic Press, 2010.

Panofsky, H.A., Brier, G.W.: Some applications of statistics to meteorology. University Park, Pennsylvania, p. 224, 1958.

Pena-Angulo, D., Cortesi, N., Brunetti, M., González-Hidalgo, J.C.: Spatial variability of maximum and minimum monthly temperature in Spain during 1981–2010 evaluated by correlation decay distance (CDD). Theor. and Appl. Climatol., 122 (1-2), pp. 35-45, 2015.

Pensa, M. and R. Jalkanen: Variation in needle longevity is related to needle-fascicle production rate in Pinus sylvestris. Tree Physiology 25, 1265–1271, 2005.

Peñuelas, J.: Plant physiology—a big issue for trees. Nature, 437:965–966, 2005.

Rinn, F.: TSAPWinTM – Time series analysis and presentation for dendrochronology and related applications, Version 4.69, 2005.

Ruiz, P.: Análisis dendroclimático de *Pinus uncinata Ramond* en la Sierra Cebollera (Sistema Ibérico). Cuadernos de Investigación Geográfica 15(1-2): 75-80, 1989.

Ruiz-Flaño, P.: Dendroclimatic series of Pinus uncinata R. in the Central Pyrenees and in the Iberian System. A comparative study. Pirineos 132:49–64, 1988.

Sánchez, E., Gallardo, C., Gaertner, M.A., Arribas, A., Castro, M.: Future climate extreme events in the Mediterranean simulated by a regional climate model: A first approach. Glob. Planet. Change, 44 (1-4), pp. 163-180, 2004.

Saz, M.A.: Análisis de la evolución del clima en la mitad septentrional de España desde el siglo XV a partir de series dendroclimáticas. Servicio de Publicaciones de la Universidad de Zaragoza, Zaragoza, 1105 pp, 2003.

Schulman, E.: Dendroclimatic Changes in Semiarid America. Tucson, University of Arizona Press, pp. 142, 1956.

Smith, J. G. and Weston, H. K.: Nothing particular in this year's history, J. Oddball Res., 2, 14-15, 1954.

Stokes, M.A., Smiley, T.L.: An introduction to tree-ring dating, 2nd edn. The University of Arizona Press, Tucson, 1968.

Tejedor, E., de Luis, M., Cuadrat, J.M., Esper, J., Saz, M.Á.: Tree-ring-based drought reconstruction in the Iberian Range (east of Spain) since 1694. Int. J. of Biometeorol., 12 p, 2015.

Van der Werf, G.W., Sass-Klaassen, U., Mohren, G.M.J.: The impact of the 2003 summer drought on the intra-annual growth pattern of beech (Fagus sylvatica L.) and oak (Quercus robur L.) on a dry site in the Netherlands, Dendrochronologia, Volume 25, Issue 2, Pages 103-112, 2007.

Vicente-Serrano, S.M. and Cuadrat, J.M.: North Atlantic oscillation control of droughts in north-east Spain: Evaluation since 1600 A.D. Clim. Change, 85 (3-4), pp. 357-379, 2007.

Wang, F., Letort, V., Lu, Q., Bai, X., Guo, Y., de Reffye, P., and Li, B.: A Functional and Structural Mongolian Scots Pine (Pinus sylvestris var. mongolica) Model Integrating Architecture, Biomass and Effects of Precipitation. PLoS ONE 7(8): e43531, 2012.

Wahl, E.R. and C.M., Ammann: Robustness of the Mann, Bradley, Hughes reconstruction of Northern Hemisphere surface temperatures: examination of criticisms based on the nature and processing of proxy climate evidence. Clim. Change 85: 33–69, 2007.

Wigley, T.M.L., Briffa, K., Jones, P.D.: On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology.J. Clim. Appl. Meteorol., 23:201–213, 1984.

1 Table 1. Tree ring sites characteristics

Code	Site	Source	Lat	Long	Elevation	Species	Tree no	Sample no	Tree-rings	Period
s047	Urbión Covaleda	ITRDB	41.98	-2.87	1750	PISY	15	31	6549	1567-1983
s048	Urbión Duruelo	ITRDB	42.02	-2.90	1840	PISY	8	17	3590	1671-1983
s049	Urbión Quintenar	ITRDB	42.03	-3.03	1840	PISY	12	27	4713	1593-1985
s050	Urbión Vinuesa	ITRDB	42.00	-2.85	1750	PISY	4	8	1942	1681-1983
s006	Urbión	ITRDB	42.03	-2.7	1634	PISY	11	22	2397	1842-1977
CAV	Castillo de Vinuesa	UNIZAR	42.01	-2.75	1900	PIUN	18	36	9236	1593-2012
COV	Covaleda	IPE-CSIC-UNIZAR	41.93	-2.83	1500	PISY	16	48	14696	1568-1993
HER	Barranco de las heridas	IPE-CSIC-UNIZAR	41.94	-2.84	1500	PISY	25	32	9347	1562-1993
NEI	Neila	IPE-CSIC-UNIZAR	42.05	-3.08	1850	PISY	9	15	4822	1587-1992
URB	Picos de Urbión	UNIZAR	41.96	-2.82	1750	PISY	28	60	11328	1733-2012

VIN	Castillo de Vinuesa	IPE-CSIC-UNIZAR	42.03	-2.73	1900	PIUN	13	20	7653	1465-1992
						Total	159	316	76273	

UNIZAR University of Zaragoza, *IPE-CSIC* Spanish National Research Council, *ITRDB* International Tree-Ring Databank

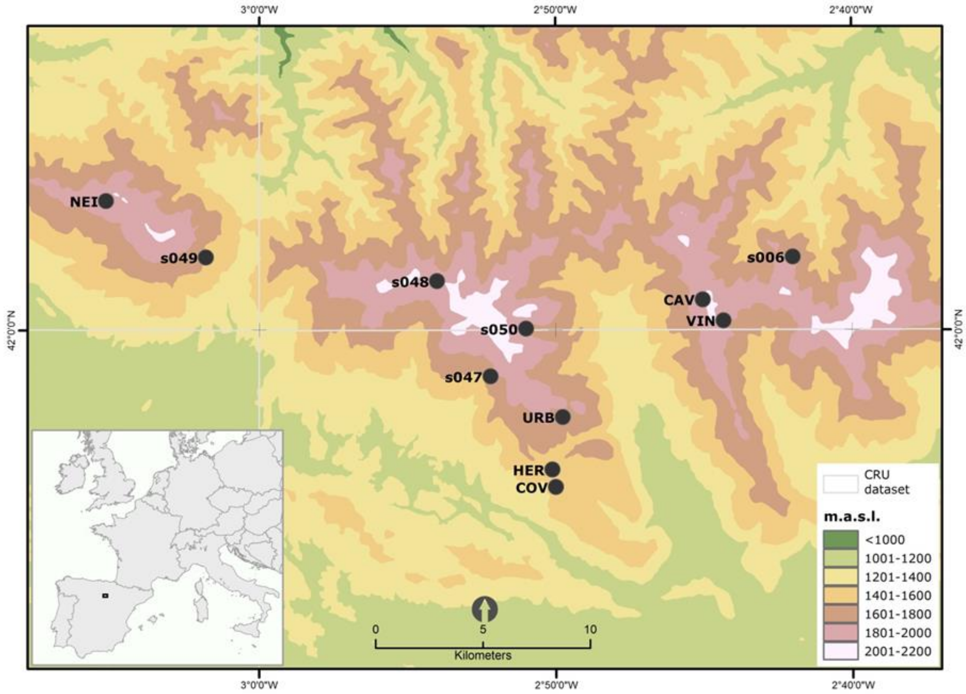


Figure 1. Map showing the tree ring study sites and the climate data (CRU TS v.3.22) grid points in the Western Iberian Range (Soria).

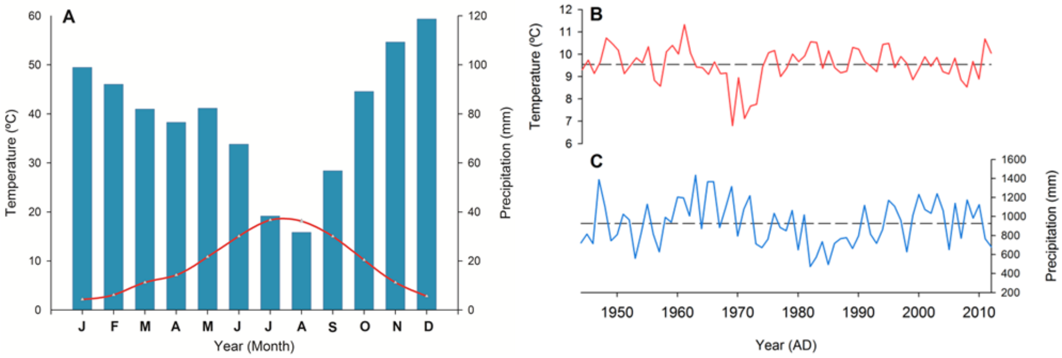
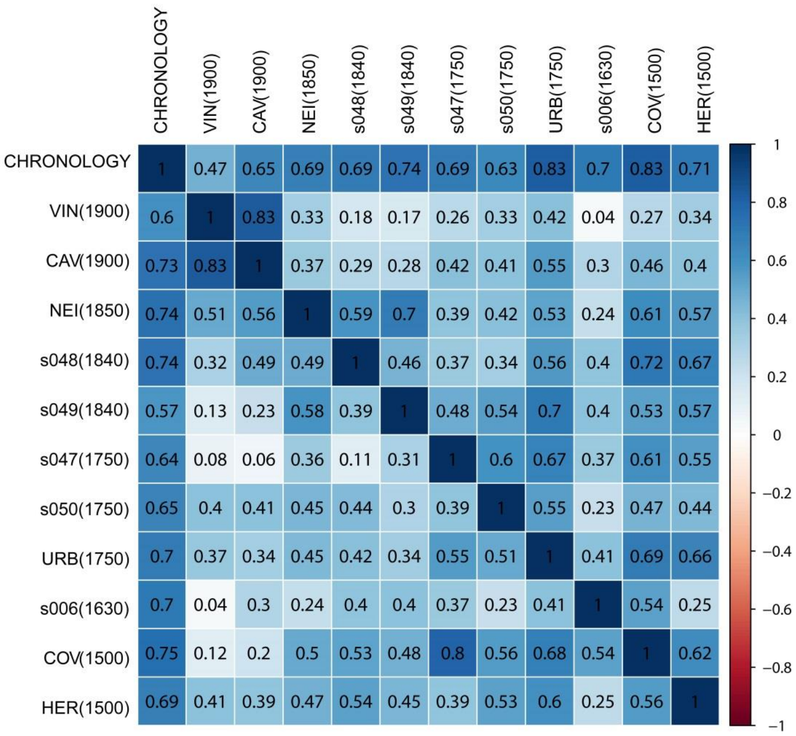


Figure 2. Climate diagram (A), mean temperature (B), mean precipitation (C) calculated using data from CRU TS v.3.22 over the period 1944-2012 (Harris et al 2014).



	CHRONOLOGY	VIN(1900)	CAV(1900)	NEI(1850)	s048(1840)	s049(1840)	s047(1750)	s050(1750)	URB(1750)	s006(1630)	COV(1500)	HER(1500)
CHRONOLOGY	1	0.47	0.65	0.69	0.69	0.74	0.69	0.63	0.83	0.7	0.83	0.71
VIN(1900)	0.6	1	0.83	0.33	0.18	0.17	0.26	0.33	0.42	0.04	0.27	0.34
CAV(1900)	0.73	0.83	1	0.37	0.29	0.28	0.42	0.41	0.55	0.3	0.46	0.4
NEI(1850)	0.74	0.51	0.56	1	0.59	0.7	0.39	0.42	0.53	0.24	0.61	0.57
s048(1840)	0.74	0.32	0.49	0.49	1	0.46	0.37	0.34	0.56	0.4	0.72	0.67
s049(1840)	0.57	0.13	0.23	0.58	0.39	1	0.48	0.54	0.7	0.4	0.53	0.57
s047(1750)	0.64	0.08	0.06	0.36	0.11	0.31	1	0.6	0.67	0.37	0.61	0.55
s050(1750)	0.65	0.4	0.41	0.45	0.44	0.3	0.39	1	0.55	0.23	0.47	0.44
URB(1750)	0.7	0.37	0.34	0.45	0.42	0.34	0.55	0.51	1	0.41	0.69	0.66
s006(1630)	0.7	0.04	0.3	0.24	0.4	0.4	0.37	0.23	0.41	1	0.54	0.25
COV(1500)	0.75	0.12	0.2	0.5	0.53	0.48	0.8	0.56	0.68	0.54	1	0.62
HER(1500)	0.69	0.41	0.39	0.47	0.54	0.45	0.39	0.53	0.6	0.25	0.56	1

Figure 3. Correlation of the raw chronologies sorted by elevation. Top right shows the correlations calculated over the common period 1842-1977. Bottom left shows the correlation over the full period of overlap between pairs of chronologies

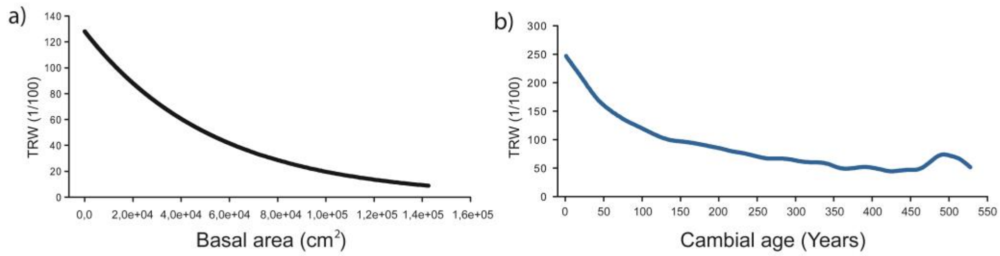


Figure 4. a) Represents the model of the BasPois method, b) represents the regional curve of the RCS method.

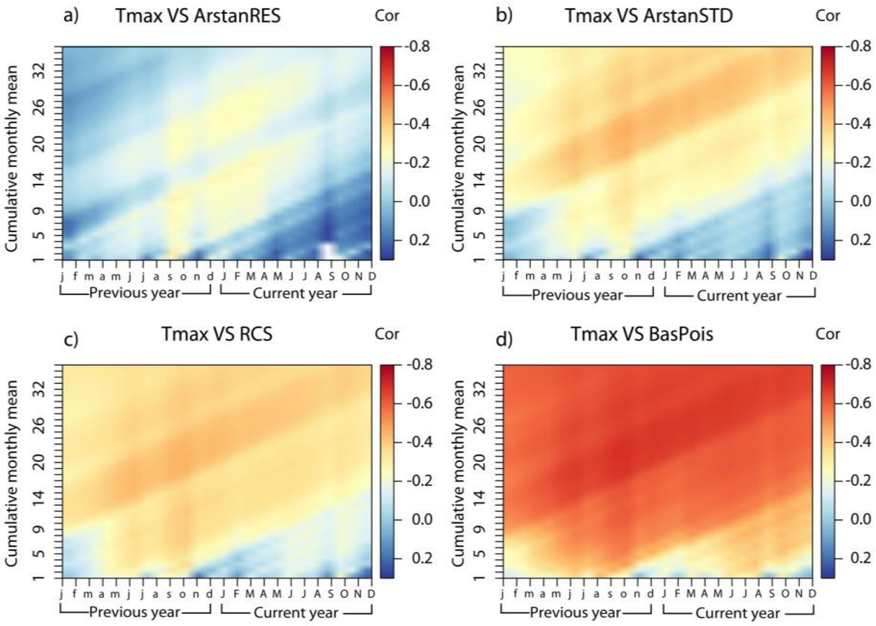


Figure 5. Correlation between the monthly mean of daily maximum temperature (from January of the previous year to December of the current year with a cumulative monthly mean from 1 to 36 months) and the residual Arstan chronology (a), the standard Arstan chronology (b), the RCS standard chronology (c) and the Basal Area-Poisson standard chronology (d).

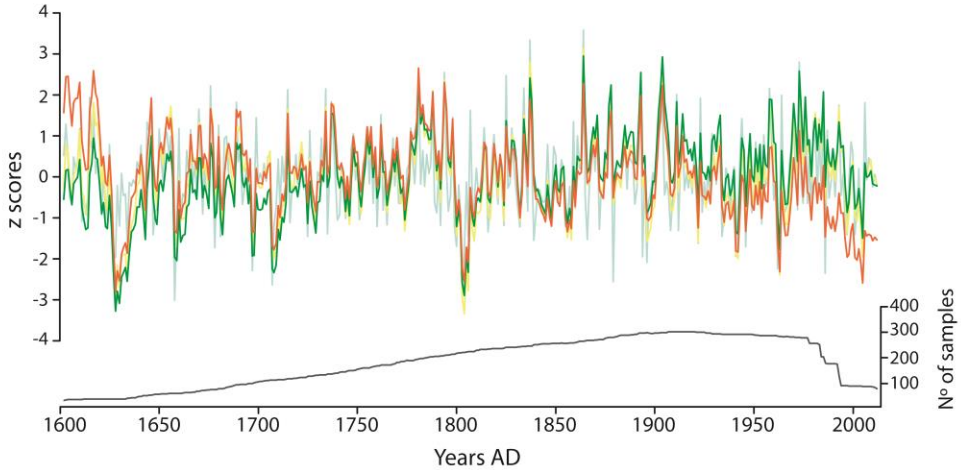


Figure 6. The four chronologies after different detrending methods for the EPS>0.85 period; BasPois chronology (in orange ~~black~~), RCS chronology (in green), ArstanSTD chronology (in yellow), ArstanRES chronology (in blue) and number of samples (in black).~~number of samples (blue) and EPS statistic (computed over 30-y window lagged by 15 years) back to 1465. Vertical dashed line highlights the EPS=0.85 threshold in 1602~~.

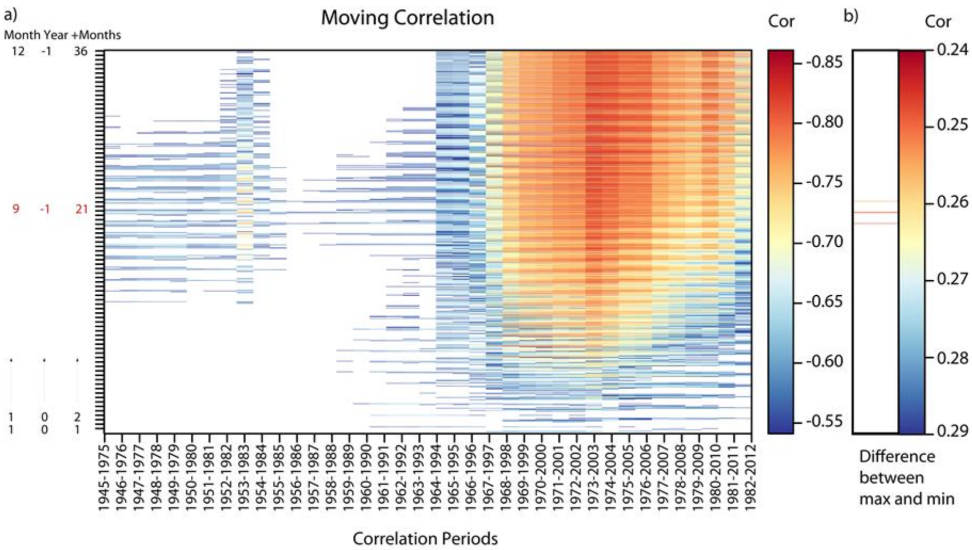


Figure 7.a) 30-year moving correlation from 1945 to 2012 between the monthly mean of daily maximum temperature, from January of the current year (1,0,1) to December of the previous year

(12, -1, 36) with a cumulative monthly mean from 1 to 36 months and the BasPois chronology. Red numbers indicates the chosen climatological parameter; 9, September, -1, previous year, 21, months used for the cumulative monthly mean. b) The four best parameters are represented. Reddish line indicates the least difference between the maximum and minimum correlation in the correlation periods.

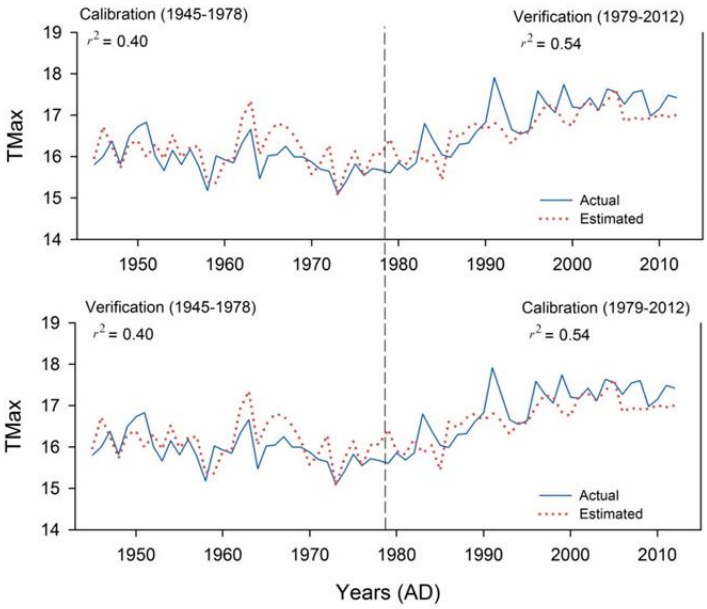


Figure 8. Calibration and verification results of the CRU data based $Tmax_{Sep-1}$ reconstruction

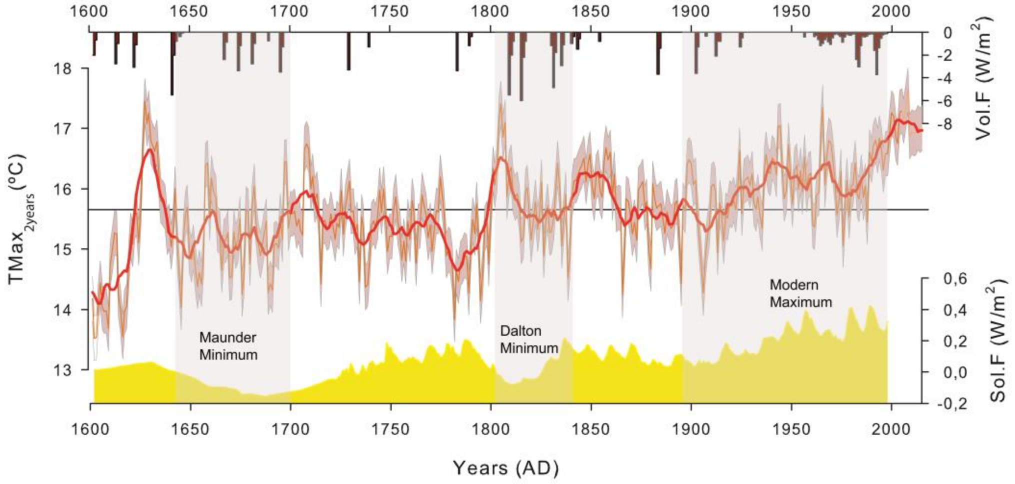


Figure 9. IR2T_{max} reconstruction since AD 1602 for the Iberian Range. Bold red curve is an 11-year running mean, grey~~purple~~ shading indicates the mean square error based on the calibration period correlation. Yellow shading at the bottom shows solar forcing and bars on top indicate volcanic forcings (Crowley, 2000).

	Calibration 1945-1978	Verification 1978-2012	Calibration 1979-2012	Verification 1945-1978	Period 1945-2012
Years	34	34	34	34	68
Correlation	-0.64	0.73	-0.74	0.64	-0.78
R^2	0.41	0.55	0.55	0.41	0.61
MSE	0.43	0.42	0.42	0.43	0.43
Reduction of error	0.40	0.65	0.65	0.40	0.56
Sing test	28+/6-	24+/10-	28+/6-	24+/10-	52+/16-
Durbin-Watson	1.31 $p<0.01$	1.53 $p<0.05$	1.53 $p<0.05$	1.31 $p<0.01$	1.45 $p<0.001$

Table 2. Calibration/verification statistics of the IR2T_{max} reconstruction

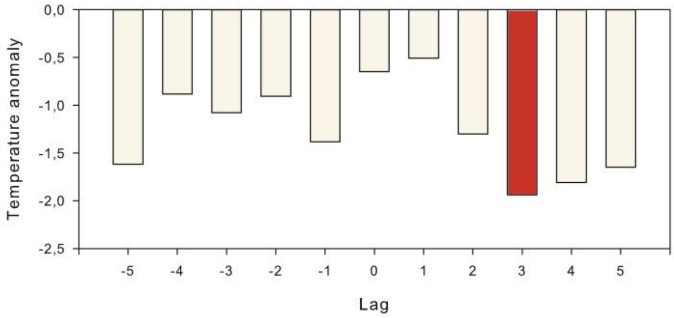


Figure 10. Superposed epoch analysis with a back and forward lag of 5 years. Significance (*p<0.05*) at 3 years after the extreme volcanic events identified in Crowley (2000).

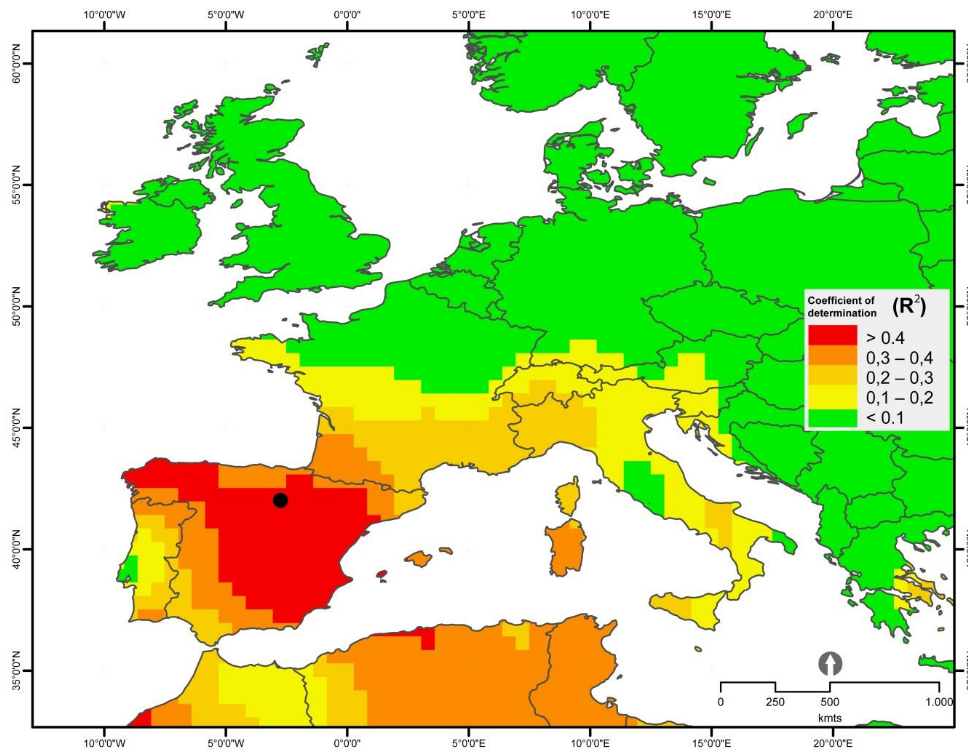


Figure 11. Map showing the spatial correlation patterns of the BasPois chronology with the gridded T_{max}_21_Sept^{-1}September of the previous year with a cumulative monthly mean of 21months data. Correlation values are significant at *p*<0.0001.