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Tree-ring sampling in the Sierra de Guadarrama, 10.2008

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Title: 500 years of tree ring-based drought reconstructions for the Central Iberian Peninsula

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1. Purpose of the visit - Motivation

A significant progress has recently been made in understanding European climate variability over the past 150 to about 500 years through studies of long instrumental station records (Auer et al., 2007), documentary evidences (Brázdil et al., 2005), tree-ring chronologies (Büntgen et al. 2007a; Frank and Esper 2005b), and multi-proxy compilations (Luterbacher et al., 2004; Pauling et al., 2006). Specifically, dendroclimatology has offered a vast wealth of information along the last decades that ranges from inter-annual to multi-centennial time-scales (see references herein). Recent temperature reconstructions for the Pyrenees, Alps and Tatra Mountains (Büntgen et al., 2005, 2006, 2007a, 2007b, 2008), and drought reconstructions for northern Morocco (Esper et al., 2007) have demonstrated that tree-ring data can successfully preserve a vital amount of low-frequency information, i.e., the Medieval Warm Period, the Little Ice Age and again the recent warming trend.
Temperature sensitive tree growth in Europe is, however, mainly restricted to the northern boreal forest and high-elevation sites across the Alps and western Carpathian arc. In contrast, dendroclimatic evidence is reduced for the expansive mid- to low-latitudes. Ironically, the Mediterranean region has been defined as one of the major climate change hotspots (Giorgi 2006), where future rates of temperature increase and precipitation decrease are expected to be most rapid (Diffenbaugh et al., 2007; Gao and Giorgi, 2008). For southern Europe, temperature-controlled formation of tree-ring width (TRW), if it takes place at all (Nicault et al., 2008a, b), is limited to the upper treeline across the Pyrenees (Schweingruber, 1985). Previous studies of TRW (Ruiz-Flaño, 1988; Rolland and Schueller, 1994; Camarero et al., 1998; Tardif et al., 2003; Andreu et al., 2007) and treeline responses to climate (Camarero and Gutiérrez, 2004; Camarero et al., 2005; Wiegand et al., 2006) focused on local scales and living trees, but were never extended to reconstruction purposes.

The above context pictures a situation in which the past climate variability is scarcely represented in terms of tree ring information in southwestern Europe and specifically over the Iberian Península. Between the estimates of Pyrenees temperature (Büntgen et al., 2008) and Moroccan drought (Esper et al., 2007) lies a vast area, within which a reduced amount of dendro-climatological information is available. Génova and Cancio (1999) and Génova (2000) reported on the existence of ca. 400-yr old forest sites in the center of the Iberian Peninsula. Manrique and Cancio (2000) showed results for tree ring-based temperature and precipitation reconstructions across Iberia. An additional potential source of dendrochronological information is provided for eastern Iberia by Andreu et al (2007) and used in Mediterranean drought reconstructions by Nicault et al. (2008a, 2008b). Their approach, though interesting, revealed reconstructions with limited low-frequency variability and a lack of specific site information. Since these initial studies are most likely limited in the preservation of any potential long-term trend due to the methodological age-detrending procedures applied (Esper et al., 2003), and their outcome is also not publicly available, there is a need for additional tree-ring research over the Iberian Peninsula. This was the main purpose for this project.

Under the overall motivation herein described, members of the Swiss Federal Research Institute WSL (Zürich, Switzerland) and of the Dept. Astrophysics and Atmospheric Physics, Universidad Complutense de Madrid (Spain), organized an initial fieldwork campaign at the end of October 2008. An intense forest evaluation and tree-ring sampling was carried during one week and across most natural reservoirs in the Sierra de Guadarrama (NW of Madrid). Within this campaign, a network of young, mature and oldest forests stands in the region was sampled *(see table 1 for details)*. The selected sites were chosen to include the maximum growth sensitivity to climate, i.e., assumed summer drought. That is, sites were located on steep slopes with relatively dry soils, spanning an altitudinal gradient from 800-1900m asl. Most of the dominant pine species (Pinus sylvestris, nigra, pinea and pinaster) were sampled to allow the possibility not only for climate reconstruction but also for ecological comparison.

The main objective of the period at the Swiss Federal Research Institute WSL was the treatment as so many samples, from the campaign, as it was possible. By treatment it's meant herein the whole process that spans from initial steps like the classification of the core to the development of a chronology as it will be explained later.

As a result from this exchange visit, from the 15 sites sampled in Madrid in October 2008 *(see Table 1)*, three of them were deeply processed at the WSL. These three sites were mainly chosen because of the expected (maximum) tree ages and their enormous sample replication *(Table1 1)* . The three sites were Valsaín (VA, *Pinus sylvestris*), Jarosa (JA, *Pinus nigra*) and Peñalara (RU, *Pinus sylvestris*).

site	code	species	lat	lon	m asl	exposition	geology	Date
1	MC	*Pinus sylv.*	40°47.275' N	04°03.410' W	1800	south-east	granite/ gneiss	18.10.2008
2	**RU**	***Pinus sylv.***	**40°47.125' N**	**04°02.350' W**	**1850**	**south-west**	**granite/ gneiss**	**18.10.2008**
3	RL	*Pinus sylv.*	40°47.100' N	04°02.005' W	1650	south-west	granite/ gneiss	18.10.2008
4	CA	*Pinus sylv.*	40°47.025' N	04°00.742' W	1800	south-east	granite/ gneiss	19.10.2008
5	LB	*Pinus sylv.*	40°45.541' N	04°00.206' W	1550-1650	south-east	granite/ gneiss	19.10.2008
6	SP	*Pinus pinaster*	40°22.715' N	04°20.088' W	700	north	granite/ gneiss	20.10.2008
7	PS	*Pinus pinea*	40°22.715' N	04°20.088' W	700	north	granite/ gneiss	20.10.2008
8	HO	*Pinus sylv.*	40°51.159' N	03°56.060' W	1750-1800	south-west	granite/ gneiss	21.10.2008
9	OH	*Pinus sylv.*	40°48.339' N	03°56.881' W	1830	north	granite/ gneiss	21.10.2008
10	**JA**	***Pinus nigra***	**40°39.872' N**	**04°09.833' W**	**1300-1400**	**south-east**	**granite/ gneiss**	**22.10.2008**
11	CL	*Pinus sylv.*	40°41.591' N	04°09.035' W	1500-1700	south-east	granite/ gneiss	22.10.2008
12	NV	*Pinus sylv.*	40°59.277' N	03°48.634' W	1700-1780	south-east	granite/ gneiss	23.10.2008
13	FD	*Pinus sylv.*	40°48.386' N	03°56.880' W	1800-1900	north	granite/ gneiss	23.10.2008
14	DF	*Pinus sylv.*	40°48.413' N	03°56.459' W	1850	west	granite/ gneiss	23.10.2008
15	**VA**	***Pinus sylv.***	**40°47.251' N**	**04°02.478' W**	**1800-1900**	**north**	**granite/ gneiss**	**24.10.2008**

Table 1. Site characteristics of the newly developed Guadarrama TRW network. The sites studied at the WSL are highlighted in bold.

2. Work description at the WSL

During the time at WSL, the main work carried out was the processing and subsequent chronology development of the three sites (JA, RU and VA), and their comparison with other (available via the ITRDB) chronologies, already existing, from the same area. Growth-climate response analysis were also started for the final chronologies and continued later at UCM in Madrid.

The process for obtaining our chronologies is described in detail below, but the main point to remark from this process is the final result: three well replicated chronologies ending in 2008 and spanning around 450 years back in time.

After the chronology development, the comparison with other TRW records from the same region was carried out. This comparison showed the existence of a similar behavior within the different time-series, which already suggests a common driver of tree growth.

Below is described briefly the process followed with the samples: sample preparation, ring width measurement and chronology development.

2.1. Sample preparation

All the samples from each site were compiled and mounted on wooden strips, glued and labeled. After that, the samples were sanded to improve the detection of rings and their subsequent measurement *(see Figure 1).*

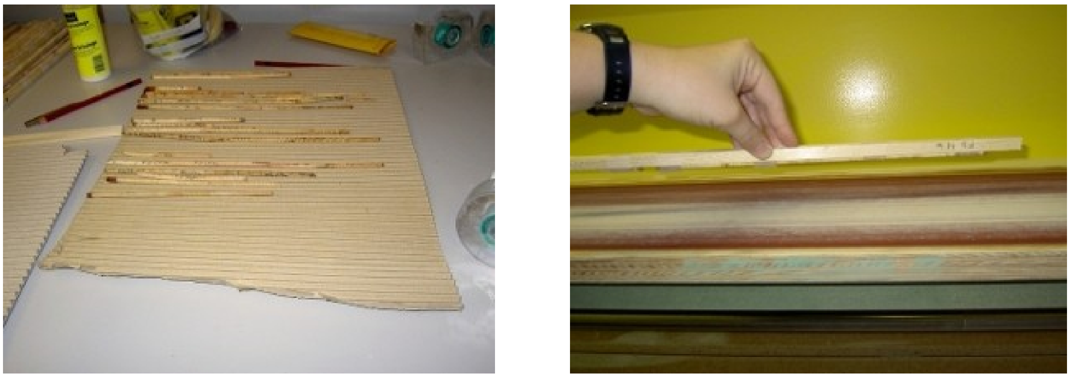


Figure1. Classification of some samples in the laboratory (left) and sand process of one core (right).

2.2. Ring width measurement

The cores were dated, by identifying each ring with a calendar year, starting with 2008 for the first ring after the bark (the core was dated from bark to the pith and 2008 corresponds to the last year with a complete growing season for the tree). Much of the practical routine as a student being trained involved dating the cores. This was carried out dotting the cores, using three dots to mark the beginning of a century, two dots for the half-century and one for each decade.
In some cases, mainly at the beginning of the core (20^{th} century), the density of rings was very high becoming difficult to distinguish different rings. Then, a piece of chalk was used to highlight the area, or this part was sanded again to try to improve the view *(see Figure 2)*.
In this step it was also possible to approximate a number of missing rings to the pith, the so-called pith offset. Although this number was an approximation, it provided a better idea about the age of the tree, and it proved to be useful later.

After dated, each core was measured using the program WinTSAP (Rinn 2005). When the measurement process was finished, the cross dating of the data began. The cross dating was carried out first using the cases when two cores per tree were available, doing the cross dating between them, obtaining from them a signal more reliable than in the case of only one core pro tree, and being easier to identify the cases of missing rings. Later, the rest of the cores were introduced and the main problems of the samples - like missing rings or density fluctuation - were identified using the program COFECHA (Holmes, 1983). Most of these problems were solved by measuring the sample again or having a more accurate view of the rings (to exclude false rings).

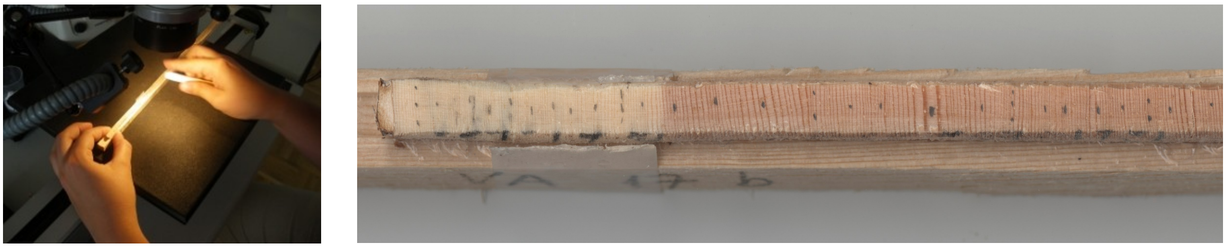


Figure 2. Use of a piece of chalk to identify difficult rings, during the measurement process (left). Detail of one dated core, with the dots system to locate the calendar year (right).

2.3. Chronology development

Once that the three chronologies were developed, the next task was to provide a context for them, with more chronologies from the same area, to study the similarity with other sites or species.
Therefore we added 21 existing TRW chronologies as downloaded from the ITRDB *(http://www.ncdc.noaa.gov/paleo/treering.html*). These chronologies are all located in the area of the Sierra de Guadarrama (from 40-42ºN and 2-6ºE) and were developed by Richter et al., (1991), Génova (2000) and Schweingruber (1985). The resulting database contains 24 different TRW sites chronologies *(Table 2)*.

The three chronologies developed in this work are among the largest ones in Table 2. Also they reach the year 2008, what means 17 more years than the most recent chronology available -CE, in 1991-, and the number of cores in them is fairly bigger than in most of the others, reaching the number of 74 in VA.
Table 2 shows a description of the 24 site chronologies used herein, indicating the code of the site, tree species, geographical coordinates, altitude (m asl), number of trees and cores contained in the chronology, starting year of the oldest core within all the cores in the chronology (column 'start'), starting year of the chronology for which there is, at least, a replication of 5 or more cores from that year (column 'start>5'), the year of the end of the chronology, the mean segment lenght (msl) and the average growth rate (agr).
The mean sample replication (mean number of cores) of the 24 sites is 25 series, ranging from 12-74 series in the extreme cases. The mean segment length (msl) or average number of years per sample (Cook et al., 1995) is 209, ranging from 109-406 and the average growth rate (agr) per year is 1.32 mm, ranging from 0.71-2.10 mm/year *(see Table 2 for more details)*.

site	code	specie	lat	lon	m asl	trees	cores	start	start>5	end	msl	agr
1	BO	*Pinus nigra*	40°21' N	2°08' W	1250	6	12	1688	1757	1988	237	1.14
2	TM	*Pinus nigra*	40°18' N	2°08' W	1350	9	17	1615	1737	1988	225	1.19
3	CE	*Pinus nigra*	40°26' N	4°47' W	1350	7	14	1754	1815	1991	172	1.42
4	**JA**	***Pinus nigra***	**40°40' N**	**4°10' W**	**1300-1400**	**37**	**49**	**1502**	**1570**	**2008**	**255**	**0.71**
5	PH	*Pinus nigra*	40°29' N	4°47' W	1450	9	17	1667	1715	1988	213	1.51
6	AN	*Pinus nigra*	40°26' N	4°56' W	1500	6	12	1687	1751	1989	221	1.18
7	TO	*Pinus nigra*	40°01' N	2°05' W	1500	9	17	1485	1564	1988	406	0.71
8	RI	*Pinus nigra*	40°47' N	4°00' W	1600	11	24	1523	1584	1988	241	1.08

9	TA	*Pinus nigra*	40°52' N	2°08' W	1750	9	16	1610	1757	1988	205	1.24
10	GH	*Pinus sylves.*	40°20' N	5°10' W	1465	12	25	1813	1835	1985	131	1.82
11	GN	*Pinus sylves.*	40°20' N	5°08' W	1470	12	26	1769	1791	1985	146	1.88
12	GC	*Pinus sylves.*	40°49' N	4°03' W	1550	13	27	1726	1782	1983	138	1.29
13	PE	*Pinus sylves.*	40°52' N	4°12' W	1650	7	14	1715	1770	1988	189	1.30
14	UC	*Pinus sylves.*	41°59' N	2°52' W	1750	14	31	1567	1587	1983	211	1.44
15	GI	*Pinus sylves.*	40°48' N	3°59' W	1800	20	39	1749	1753	1983	174	1.52
16	UD	*Pinus sylves.*	42°01' N	2°54' W	1840	8	17	1671	1758	1983	211	1.41
17	UQ	*Pinus sylves.*	42°02' N	3°02' W	1840	12	27	1593	1725	1985	175	1.36
18	GR	*Pinus sylves.*	40°48' N	3°57' W	1850	10	23	1599	1683	1984	234	1.29
19	**RU**	***Pinus sylves.***	**40°47' N**	**4°02' W**	**1850**	**18**	**31**	**1551**	**1657**	**2008**	**201**	**1.09**
20	**VA**	***Pinus sylves.***	**40°47' N**	**4°02' W**	**1800-1900**	**48**	**74**	**1554**	**1572**	**2008**	**328**	**0.86**
21	EQ	*Pinus sylves.*	42°02' N	2°42' W	1900	11	22	1842	1859	1977	109	2.10
22	GL	*Pinus sylves.*	40°47' N	3°48' W	1950	14	26	1661	1702	1985	186	1.43
23	SP	*Pinus sylves.*	40°52' N	4°06' W	1950	11	22	1527	1580	1988	326	0.83
24	PU	*Pinus sylves.*	40°48' N	4°02' W	2050	13	24	1663	1731	1977	178	1.47

Table 2. Characteristics of the 24 site chronologies herein used. The three chronologies developed in this work are highlighted in bold.

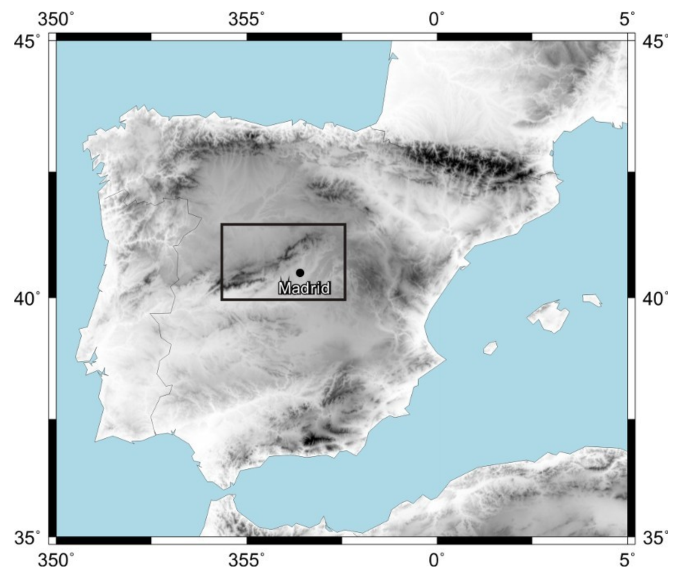


Figure 3. Situation of Madrid in the Iberian Peninsula and the box where the sites in Sierra de Guadarrama are located.

Figure 3 shows the situation of Madrid within the Iberian Peninsula and the region including all the chronologies in Table 2. In Figures 4, 5 and 6 the different characteristics of the chronologies included in the database are shown, such as altitude of the sites, species of the trees, author of the chronology, amount of samples, and years of the beginning and end of the truncated chronologies. The sites are placed between almost 900 m to 2050 m asl, on both sides of the mountains and contain two species, *Pinus nigra* and *Pinus sylvestris*. The truncated chronologies, i.e. the chronologies with at least 5 samples *(see Table 2),* start between 1564 and 1859 and finish between 1977 and 2008 (the last year is related to the author of the chronology and the date of the sampling).

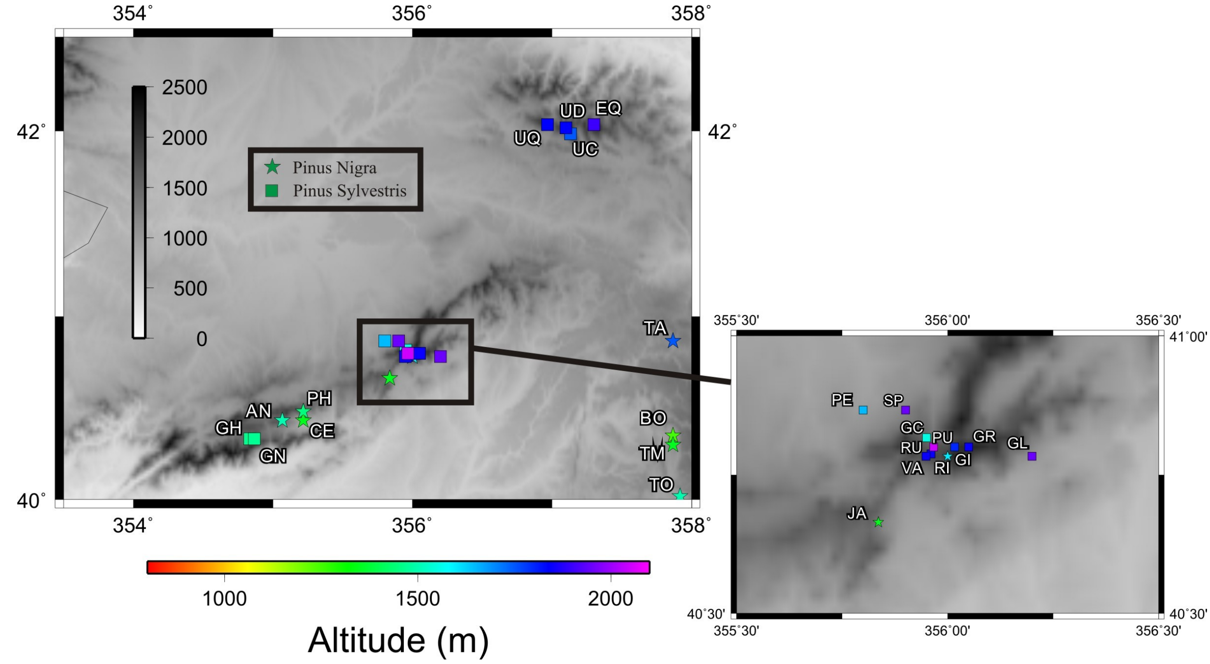


Figure 4. All the sites in the database (Table 2) are included in this plot. Symbols indicate tree species: Pinus nigra (star) and Pinus sylvestris (square). Symbols colors indicate the altitude of the site (see scale). See acronyms in Table 2.

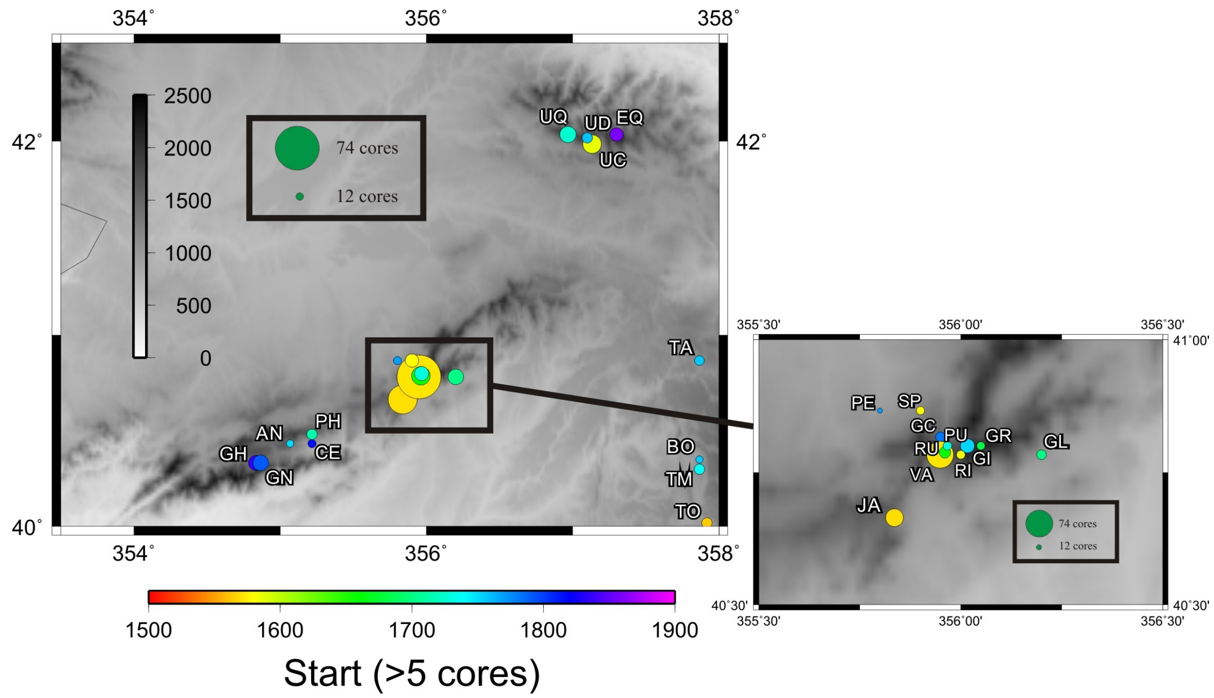


Figure 5. Number of cores included in the chronology (symbol size) and year of the beginning of the chronology with at least 5 replications (colors).

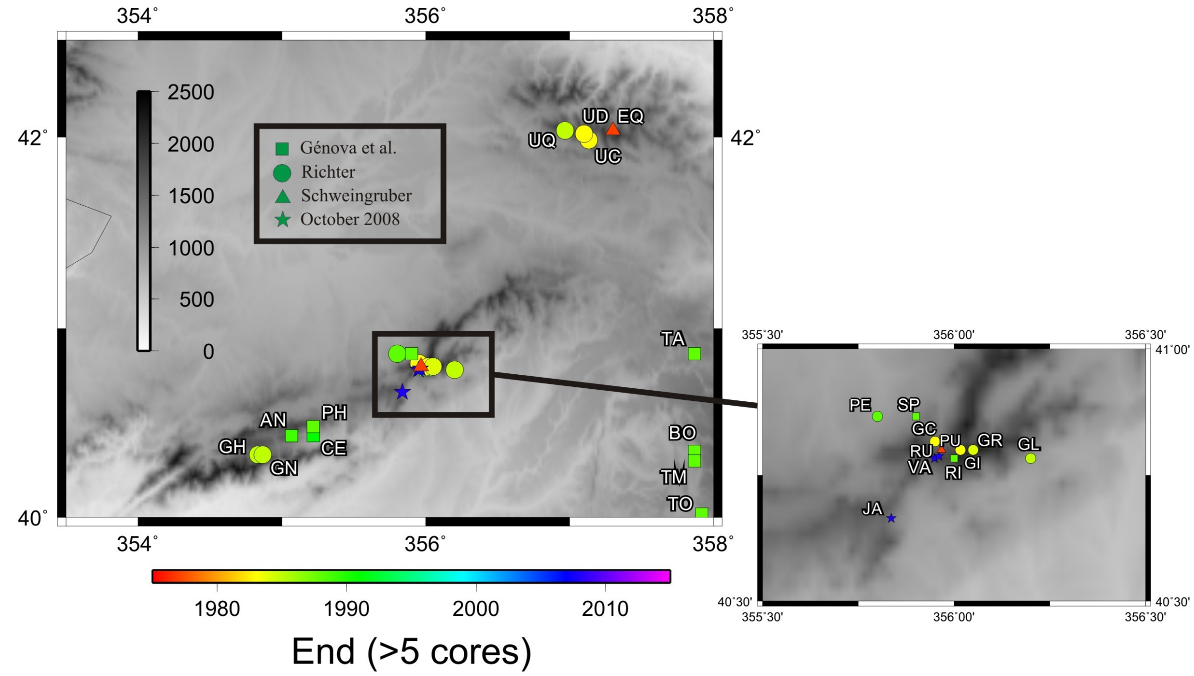
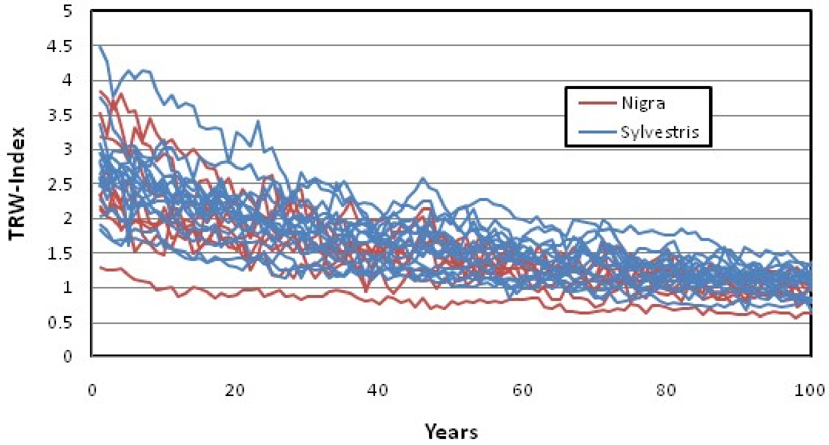


Figure 6. Authors generating the various existing chronologies (symbols). Stars highlight the three chronologies developed herein. Colors indicate the last year of the chronology.

All the chronologies were detrended with the program ARSTAN (Cook, 1985), where several techniques were carried out to remove the age trend inherent to the raw measurement series. This is made for each core in the chronology and the detrended chronology is built from the average of the detrended cores. Specifically, we used a 150 spline, a 300 spline, a negative exponential function (Cook and Peters 1981) and the regional curve standardization method (RCS; Esper et al. 2003) to detrend the raw measurement series. A power transformation (PT) of the data was also carried out and these PT-data were detrended with the 150 spline, the 300 spline and the negative exponential function (Cook and Peters 1997).

RCS involves the removal of the age trend archetype estimated from a collection of TRW series and constructing a mean chronology of the entire data set (Esper et al., 2003). The resulting Regional Curves (RCs), the age trend archetype, describe mean growth trends for the given site and species (Büntgen et al., 2007b). The behavior of the different species is similar, but the *sylvestris* overall, indicate higher growth levels, shown in the RCs graphic below *(Figure 7-top)*. The different behavior of the RCs when the pith offset information is also shown *(Figure 7-bottom)*.
The pith offset information allows to understand, for example, why one of our sites (JA, *Pinus nigra*) has its RCs below all the others (in *Figure 7-top*, the last red line). Introducing the pith offset information its RC is located with the rest of the *Pinus nigra's* RC ensemble (red color in *Figure 7-top*). This behavior is shown in *Figure 7-bottom.* When the light red line (representing the JA RCs with the pith offset information included) is above the previous JA RCs (dark red line).



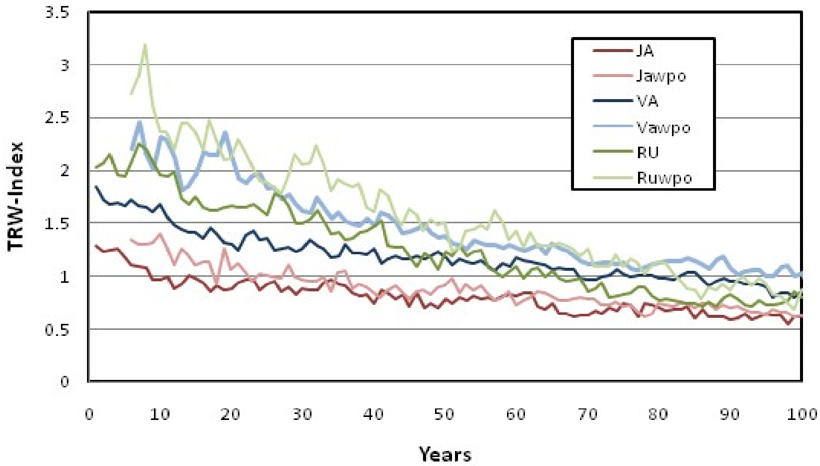
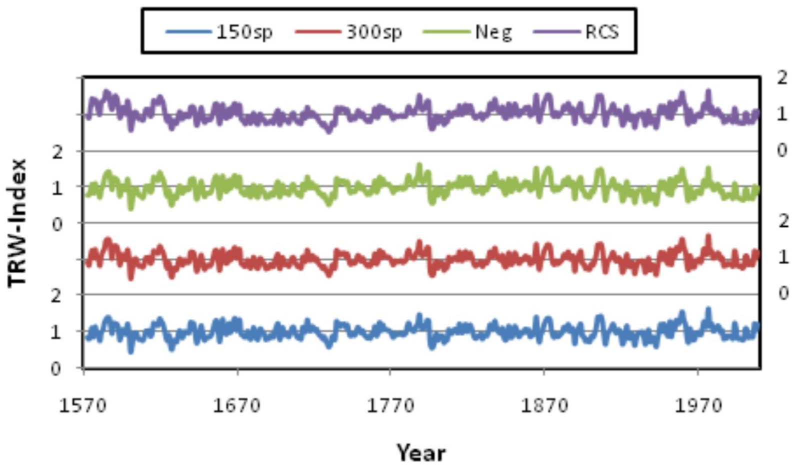


Figure 7. RCs of the database are shown (top). The difference in the RCs when the pith offset is introduced, is shown for our three sites (bottom). Bottom pannel shows the RCs if the original chronologies and the three corresponding ones "with the pith offset" (wpo versions).

The different detrendings that were applied to the chronologies present very similar results. One of the oldest chronologies, VA, was chosen to illustrate how similar they are. Figure 8 shows as an example the resultant chronology for VA after the various detrendings.



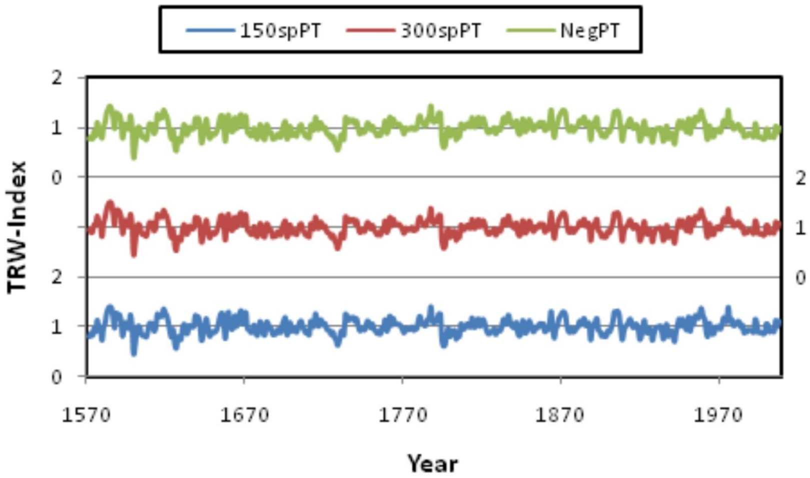


Figure 8. The chronologies for Valsain after the different detrendings. Using the RCS, the 150 spline, the 300 spline and the negative exponential function (top) and 150 spline, 300 spline and negative exponential function after a power transformation (PT) of the data (bottom).

The similarity between the curves is supported by correlations, that are always higher than 0.9. The filter outputs resulting from the 300 spline function will be used for the next steps in all the chronologies. This is a somewhat arbitrary decision based on the similarity of all filter outputs, though there is no impact on the rest of the results reported in this text.

2.3.1 Signal detection

This section describes the comparison which has been done between the different chronologies after the age trend has been removed with the 300 spline function detrending.

For this purpose, the correlations between all the chronologies were calculated (not shown in this report) and the temporal series represented. The results indicated that there was a better correspondence of chronologies within the same tree specie, but also the altitude plays an important role in the case of *Pinus sylvestris*, presenting more similarity in the case of higher altitude sites (above 1800m asl) than in lower ones.
Despite of the different species, a similar behavior is noticeable in JA, RU and VA during the whole period. The three chronologies are shown in Figure 9, with the detrending outputs and also these data after an 11-yr low pass filter, for a better inspection of the low frequency variability. From 1700 up 2008 the similar multidecadal variability of growth is presented in the 3 sites. This is supported by the correlation for the original data (for the 11-yr filter data) being above 0.7 (0.8) between RU and VA -the two *Pinus sylvestris* sites- and above 0.4 (0.6) in the case of JA with RU and VA during the last century. A similar low frequency trend in the three series, mainly observed during the last three centuries, show the same periods of growth, with some extreme years, reflected in some way, in all the chronologies (Figure 9).

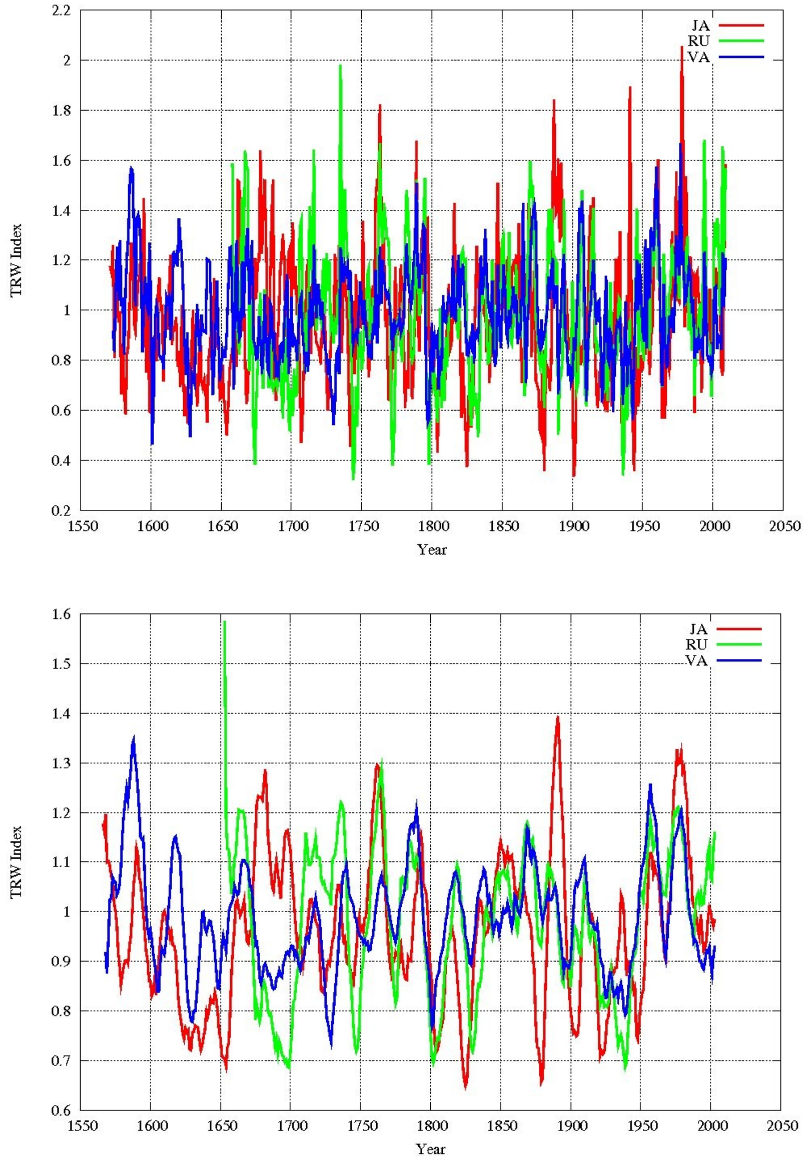
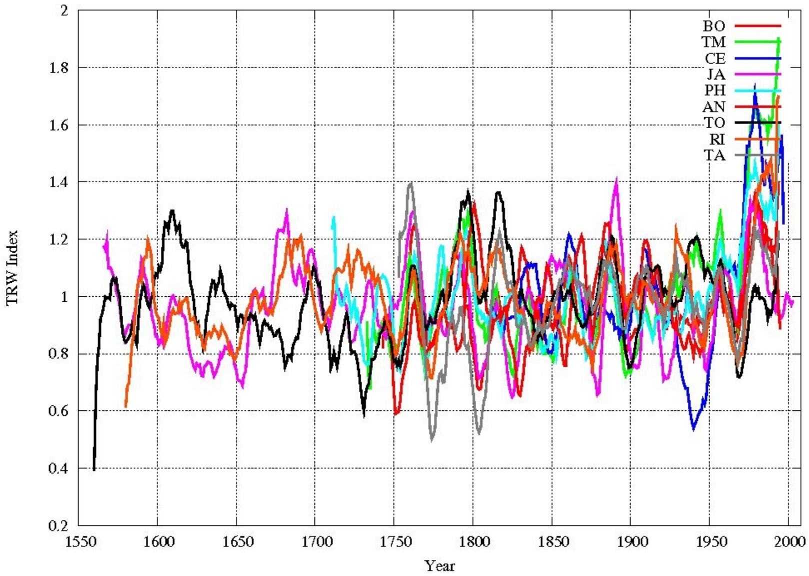


Figure 9. The JA, RU and VA chronologies corresponding; the raw data (top), and the 11-yr low pass filtered data (bottom).

Figure 10 shows 11-yr filter outputs for two groups of chronologies including JA, RU and VA. The left pannel shows all the *Pinus nigra* chronologies (including JA) and the right side one the *Pinus sylvestris* above 1800 m asl (including RU and VA). Although in the case of *Pinus sylvestris* the similarities are more evident, in both of them there are similarities in the growth of the trees and the dispersion of the chronologies is small (excepting some periods in *Pinus nigra* like around 1850 or 1940). This is supported with a mean correlation value above of 0.4 (0.5) for *Pinus nigra* and 0.44 (0.55) for *Pinus sylvestris* during the period 1750-2000 (1900-2000).



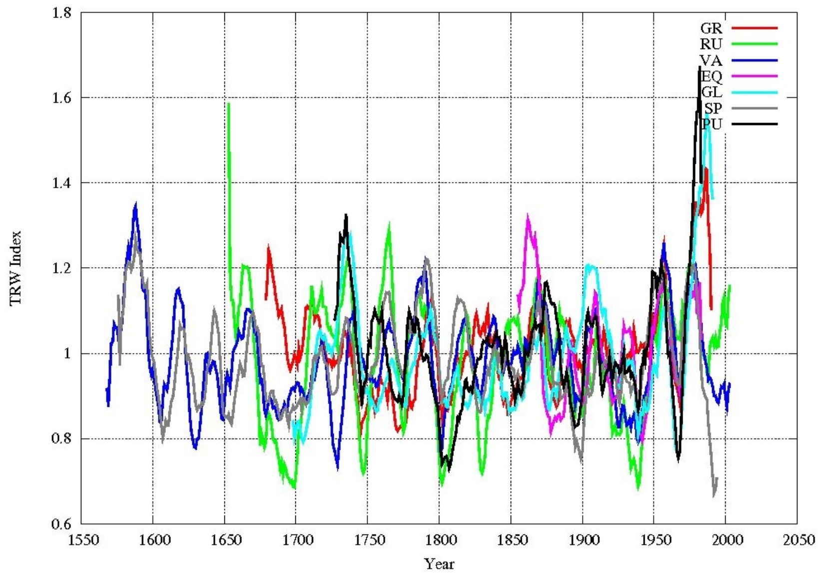


Figure 10. The Pinus nigra chronologies (top), and the Pinus sylvestris above 1800 m asl (bottom). All series are 11-yr low pass filter outputs.

From these plots, the most important thing to keep in mind is that there is a similar behavior between the trees of the same specie, independently of the spatial location (always considering the small spatial window described above). This similar behavior is better observed in a low frequency frame.

To summarize all of these results, particularly concerning to our three chronologies, the correlation values of JA, RU and VA with the rest of the sites are shown in Figure 11.

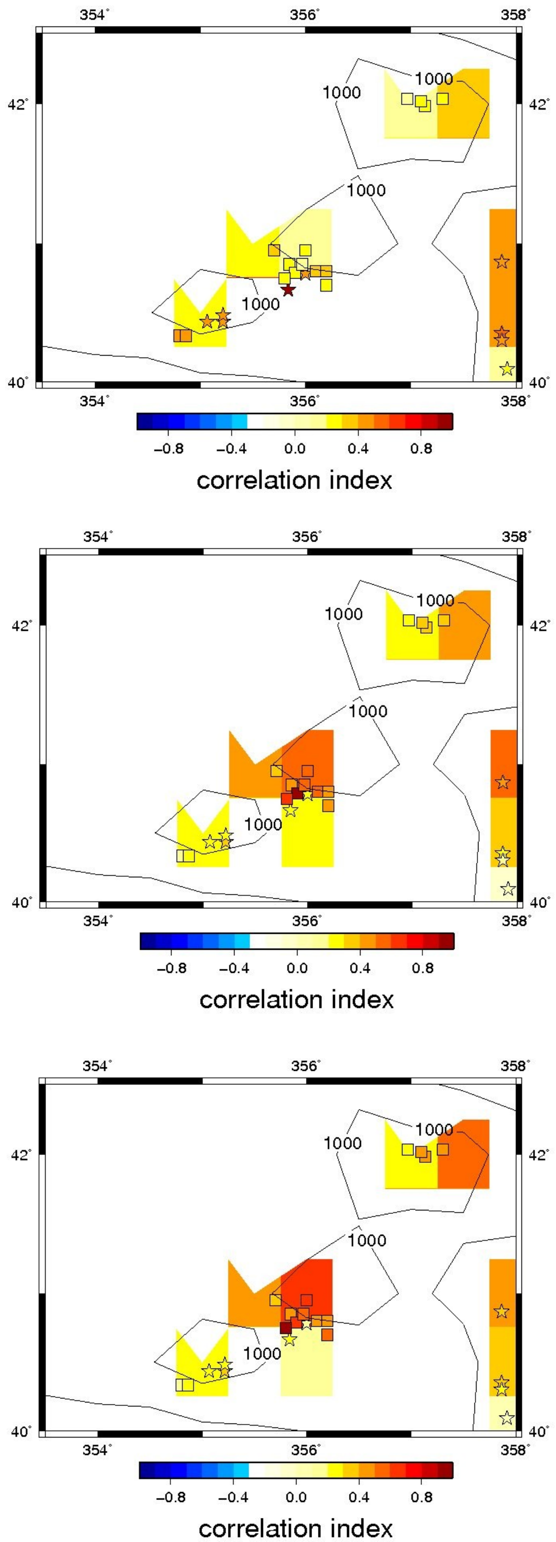


Figure 11. Correlation maps of all chronologies in Table 2 with JA, RU and VA (top, middle and bottom pannels). Symbols depict species (star for Pinus nigra and square for Pinus sylvestris), and colors show the correlation value. Color shading indicate the correlation index averages.

In the case of JA, *Pinus nigra*, the correlation is higher with the trees of the same species, reaching 0.7, but for the *Pinus sylvestris* there are, in some cases, correlations around 0.4 ($p < 0.01$).
For the cases of the *Pinus sylvestris*, RU and VA, the correlations are also higher with the same specie, but in theses cases the geographical location seem to be more important than in the case of JA, obtaining a better correlation with the trees in the same area, i.e. in the central group sites.

After these correlations and the temporal series represented, it is clear that there is a some what common behavior of the chronologies during the last 400-500 years. This similar growth may be explained by some mechanism, which has guided the tree ring width during that time in the area of Sierra de Guadarrama. The working hypothesis has been that the common forcing factor for growth are climate related.

3. Growth-climate response

Under the assumption that climate may have been a determinant factor for growth, the last century of data in the chronologies has been compared with several datasets of instrumental data: precipitation, water contribution to the local reservoirs and temperature. The main objective is to identify potential links between the growth of the trees and the climate. Drought indices would have been an alternative good candidate but have not been considered herein.
A comparison of instrumental data and the chronologies was carried out (for the common period, i.e. the last or half of the last century according to the variable), using the raw and the filtered (11-yr low pass filter) data for each variable (precipitation, water input to reservoirs and temperature).
In the case of precipitation, as it will be explained later, there were two databases available, one with regional and another one with higher spatial resolution. For water contribution to reservoirs and temperature, only a local database from Madrid was used. The climatic data, in all the cases, have monthly resolution, and the chronologies resolution is annual. In order to compare the instrumental data with the tree ring data a suite of different ad hoc seasons were defined using the instrumental data.

The following sections report the main results obtained with each factor. Only a reduced account of the main results is provided and focusing only on the JA, RU and VA chronologies.

3.1. Precipitation totals

An instrumental database, which contains 99 meteorological stations distributed over the entire Iberian Peninsula with information of precipitation for the period 1899-1999 was herein used (updated from González-Rouco et al. 2001).
Correlations between the JA, RU and VA chronologies and the closest instrumental stations were calculated (not shown in this report) and different cases were considered. The correlations were calculated between the chronologies and the annual mean precipitation, the monthly precipitation (for each month), different seasons of the calendar year, and also with the hydrological year (from October to September).

Figure 12 shows, as an example, the chronology at JA compared with annual precipitation in all available precipitation series closest to the area of interest: Segovia (SGV), Ávila (AVL), Guadalajara (GDJ), Madrid (MDD), Talavera (TLV) and Toledo (TLD).

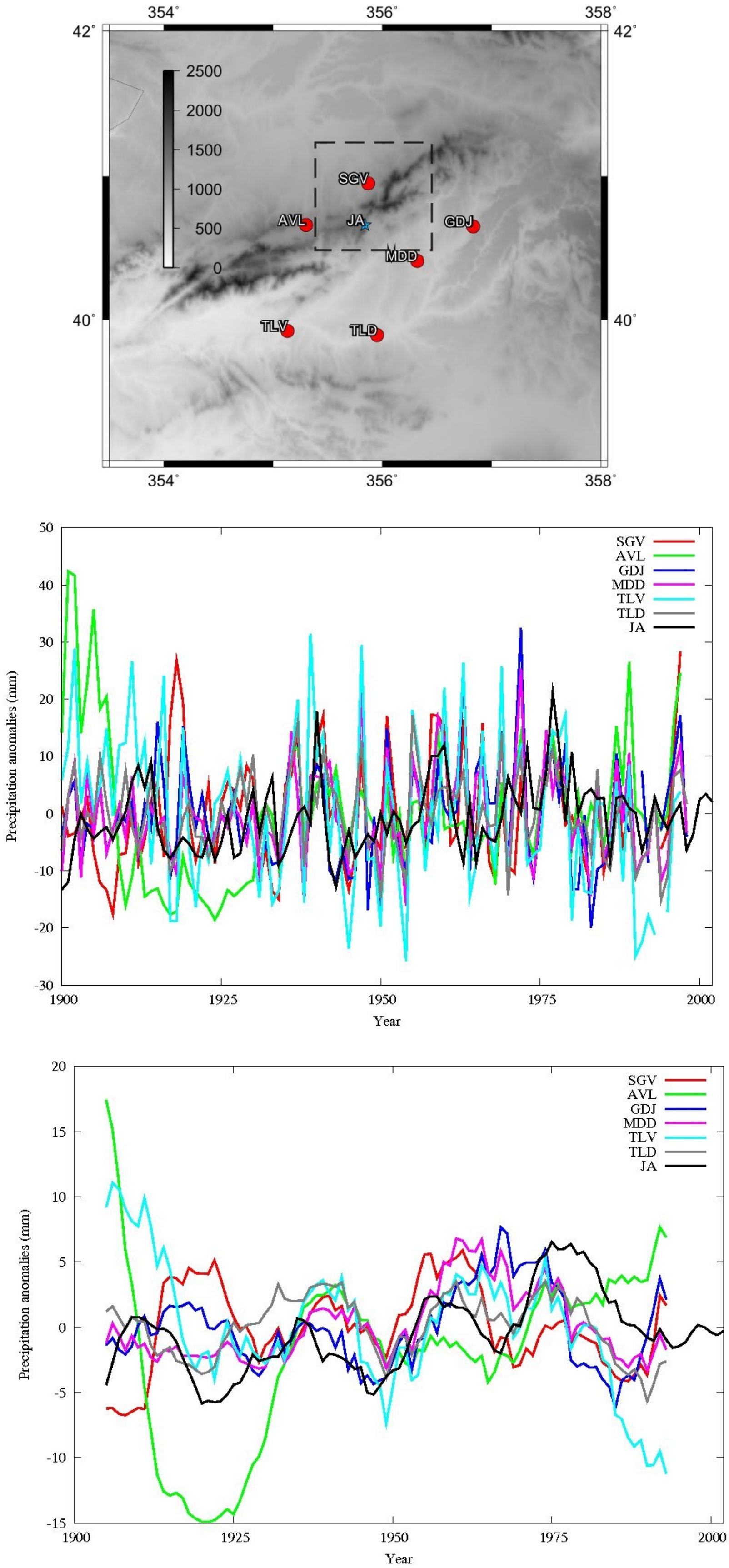
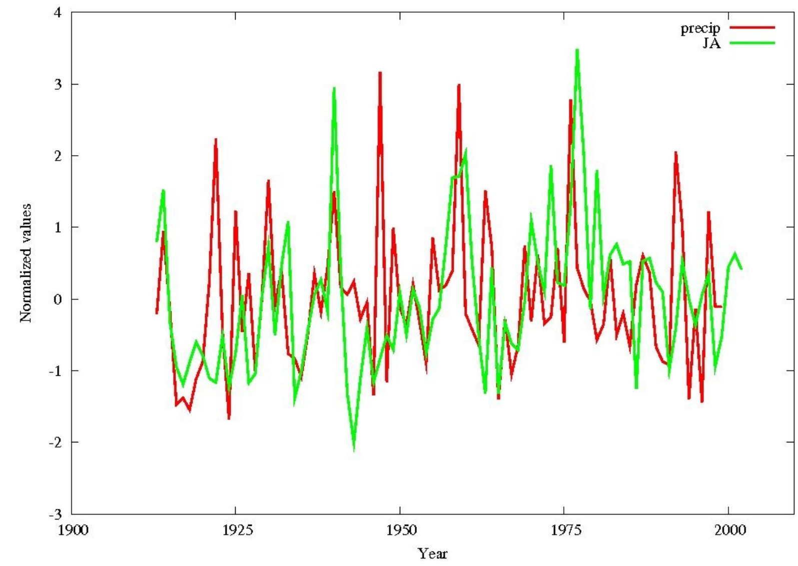


Figure 12. Location of the closest precipitation series to JA chronology (top). Temporal series of precipitation from the six meteorological stations and the chronology of Jarosa (JA, with rescaled data to compare easily with precipitation), anomalies (middle) and 11 years filtered anomalies data (bottom).

The different precipitation series (Figure 12-middle and bottom) show a similar behavior, depicting wet and dry periods. The JA chronology agrees broadly with such sequence of values. This fact indicates that some relation may exist between the TRW and the precipitation values in the area. Figure 13 shows the MDD precipitation series and the JA chronology and support this relation between precipitation data and TRW. For the 3-yr low pass filter data (Figure 13-bottom) the correlation value between MDD and JA reaches 0.46, i.e. the agreement is strong enough that the possibility that precipitation is an important factor controlling the growth cannot be ruled out.



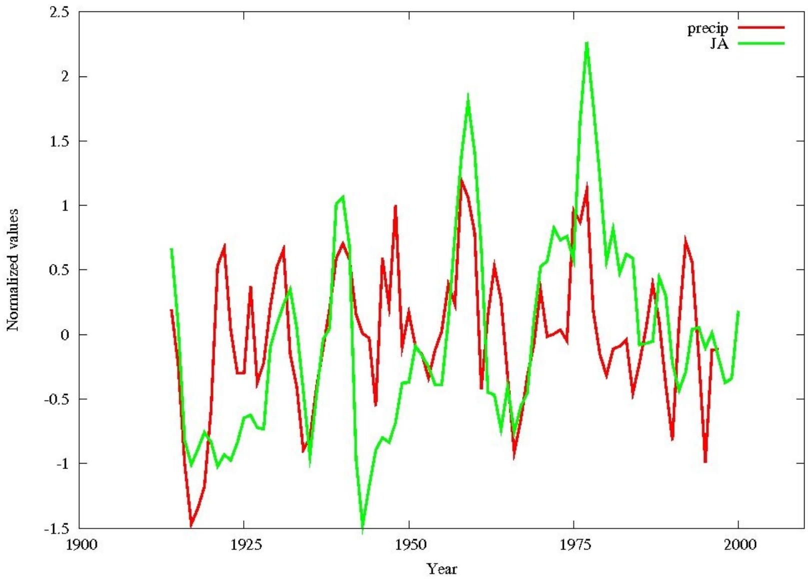


Figure 13. Temporal series of precipitation from Madrid (MDD) in June-August season and the chronology of Jarosa (JA): raw (top) and 3 years low pass filtered data (bottom).

The highest correlation value was found to be 0.54 between JA and precipitation (raw values) for Ávila (AVL, the closest location to JA, *see Figure 12-top*) in the June-July-August season (Figure 14). The other correlation values between JA and other months/seasons, and also in the case of the *Pinus sylvestris* chronologies (RU and VA), were lower.

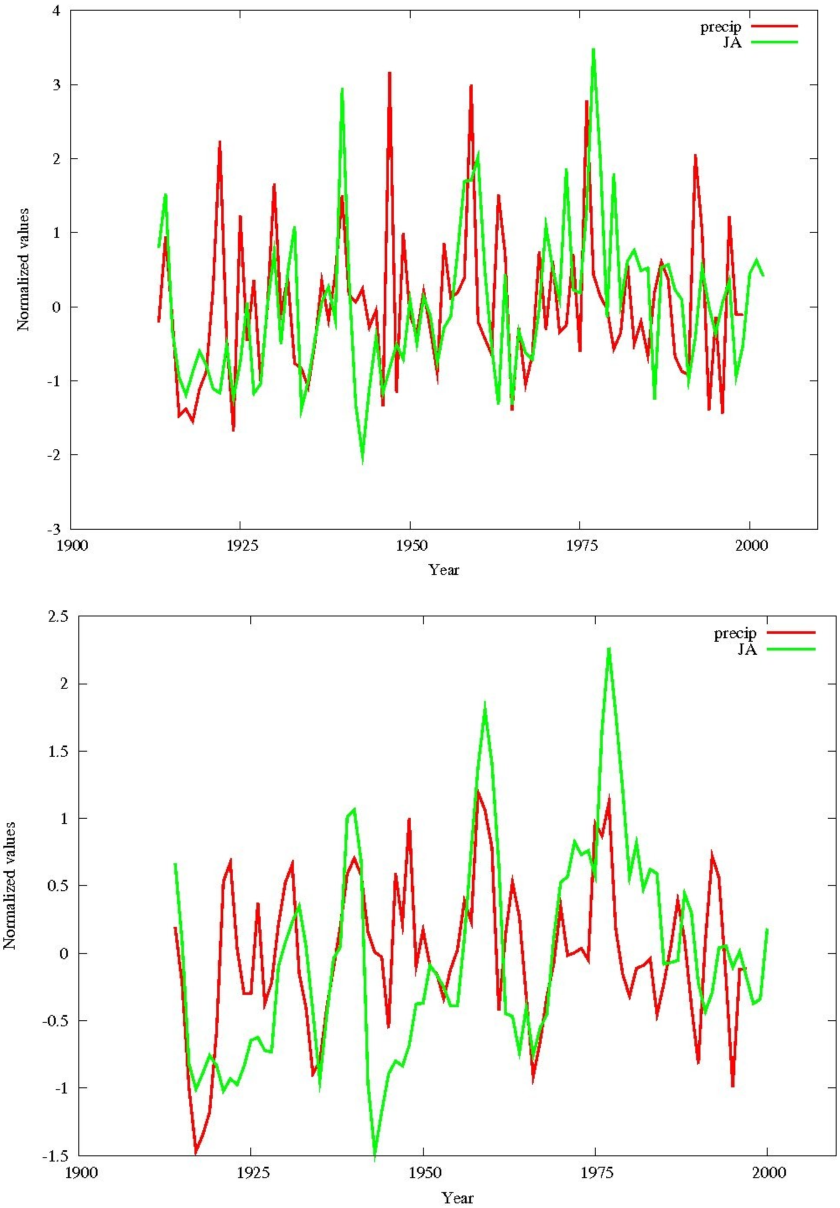


Figure 14. Temporal series of precipitation from Ávila (AVL) in June-August season and the chronology of Jarosa (JA): raw (top) and 3 years low pass filtered data (bottom).

An additional feature that should be noticed in Figure 12 is the high spatial variability of precipitation. Even if the different sites show a similar long term sequence of wet and dry periods, there is considerable variability in their timings and amplitudes. It is remarkable that the JA chronology falls well into this range of variability. This also suggests the necessity of data closer to the chronology sites so that the spatial variability of precipitation is diminished. Based on this, a new database, with closer locations to JA, RU and VA sites is used (Felipe Fernández, unpublished data). Several locations, *Navacerrada (NVC), Rascafria (RSC), Soto del Real (SOT), Manzanares el Real (MNZ), Embalse de Navacerrada 1 (EMB.NVC1), El Boalo (BOA), Hoyo de Manzanares (HOY), Cercedilla (CRC), Embalse de Navacerrada 2 (EMB.NVC2), Torrelodones (TRR), San Lorenzo del Escorial (SLZ), Galapagar (GLP),* are chosen to compare with the JA, RU and VA chronologies. Figure 15 shows the locations of these series and also the position of the chronologies. The area of Figure 15 is highlighted with a box in Figure 12-top to provide a better geographical context.

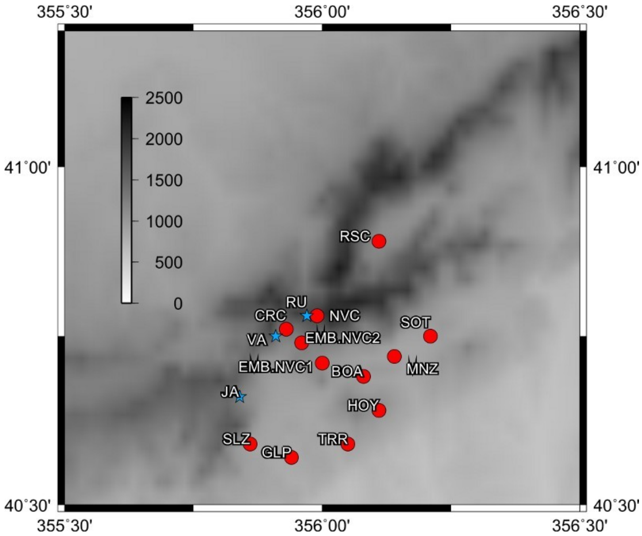
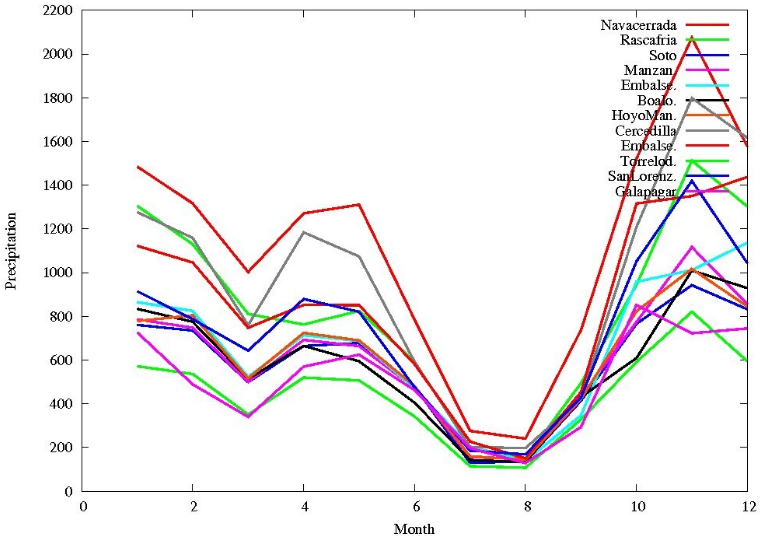


Figure 15. Precipitation series studied (red circles) and JA, RU and VA chronologies (blue stars) located in Sierra de Guadarrama.

The dataset shown in Figure 15 provides information of a more local character that could in principle be argued to be more adequate for comparison with the chronologies in the same area. The time span is however reduced to the 1960-96 period.

Figure 16-top shows the annual cycle of precipitation at all sites in Figure 15. A similar behavior arises though different amplitudes become evident highlighting the different yearly amounts of precipitation. Figure 16-bottom shows the time evolution of precipitation for May. All sites present a similar evolution, more homogeneous than that shown in Figure 12-top. This suggests that a mean series of precipitation in the area of Sierra de Guadarrama can be established, and this series will be considered a good reference to compare with the chronologies.



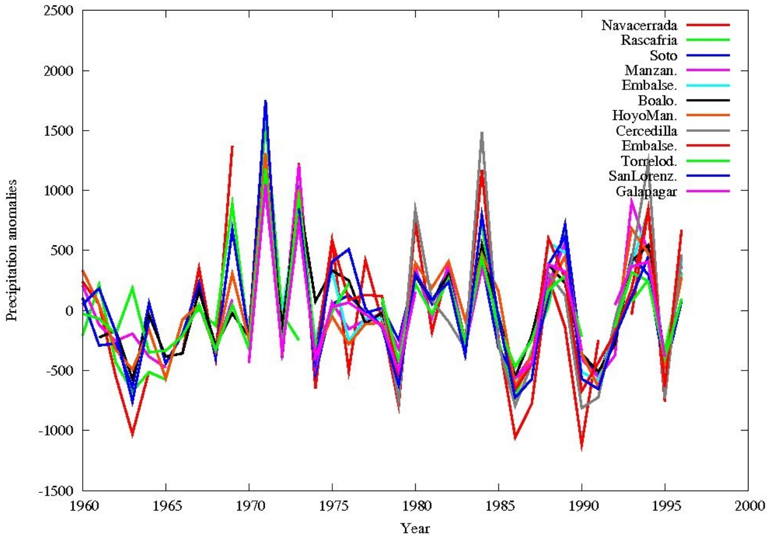


Figure 16. Annual cycle of precipitation from some locations close to Sierra de Guadarrama (top) and the temporal evolution of the precipitation of May for the same locations (bottom).

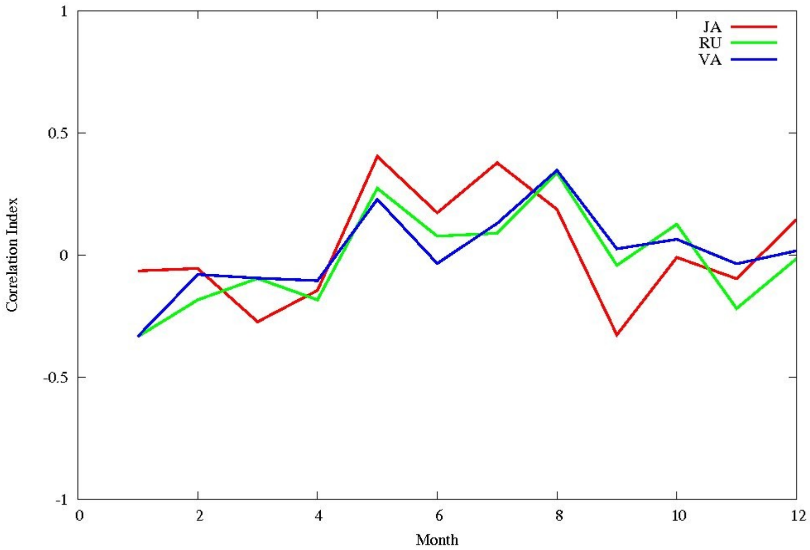
The chronologies were compared to the precipitation of each month. As in the previous case, a suite of different seasons was built covering different possibilities of growth seasons. 17 cases were considered: starting with March-April-May (MAM), and extending the period stepwise to September (M-S), later starting with April-May (AM), and extending up to September (A-S); similarly from May-June (M-J) to May-September (M-S) and from June-July (JJ) to June-September(J-S). Apart from these seasons, the hydrological year (from October to September) and a 18-months year (from previous May to December) were also considered.

Figure 17-top shows correlation between each chronology and monthly precipitation. The summer months show the highest correlation values. Figure 17-bottom shows the results for all the seasonal cases. The highest correlation value is 0.48 and it corresponds to the JA chronologies with the May-August season (Figure 18). The maximum correlation values are found for the JA chronology and, specially, for the summer seasons, but in all the cases the values are lower than 0.48 (May-August). For the *Pinus sylevestris* chronologies, the highest correlation value is 0.34, found between VA chronology and the month of August.

These correlation indexes may suggest some level of support the growth-climate relation, but they are not high enough to attribute all the TRW behavior to the precipitation.

It is also interesting to highlight the continuous growth of correlations in Figure 17 as the seasons are defined to be more focused on summer, May to August, precipitation.

Overall, the results of this comparison suggest that there is a relation between tree growth and precipitation in the area.



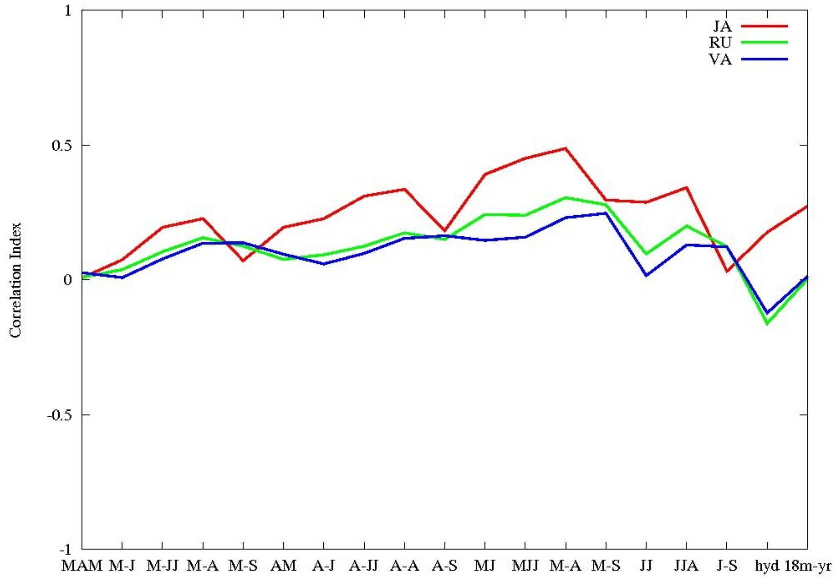


Figure 17. Correlation indexes between the chronologies and the monthly value of the precipitation series (top) and between the chronologies and the different seasons considered as possible seasons of growth (bottom).

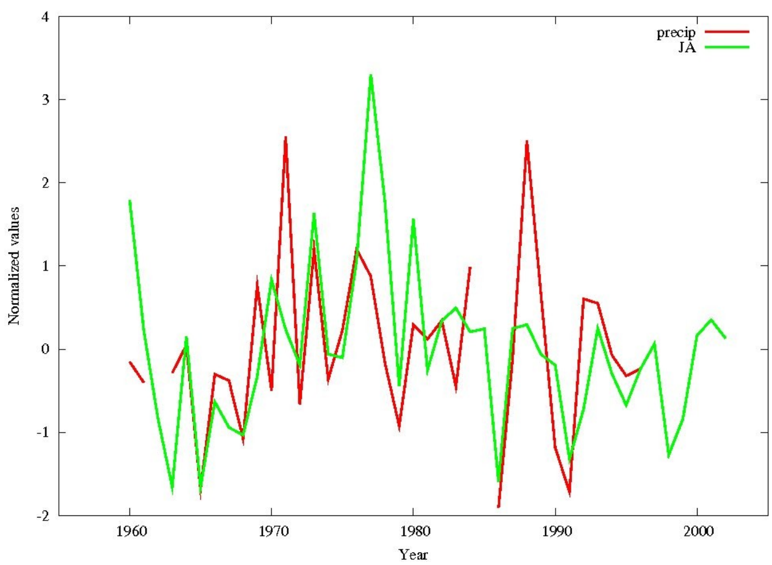


Figure 18. Mean precipitation series from Sierra de Guadarrama in May-August season and the chronology of Jarosa (JA).

3.2. Water balance

The monthly water contributions to six reservoirs and their relation to TRW is considered in this section under the hypothesis that this variable can be related to precipitation and drought. The reservoirs considered were *Valmayor (VA), Aceña (AC), Jarosa (JA), Navacerrada (NV), Navalmedio (NV) and Pinilla (PI),* located close to the JA, RU and VA chronologies sites (*see Figure 19*) in the Sierra de Guadarrama. This variable could be interpreted as an indirect drought index of the area during the last century.

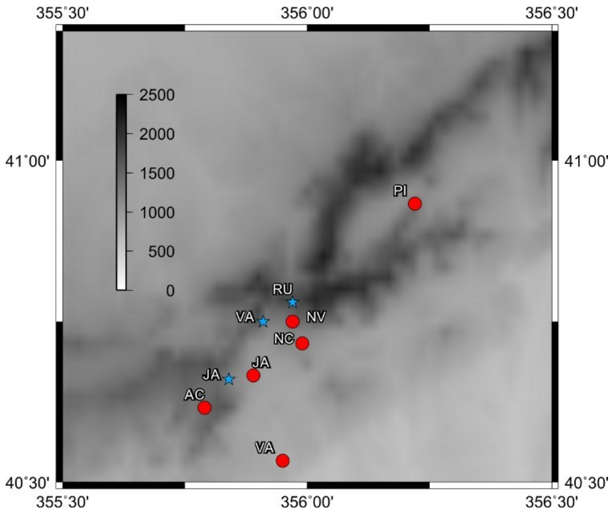
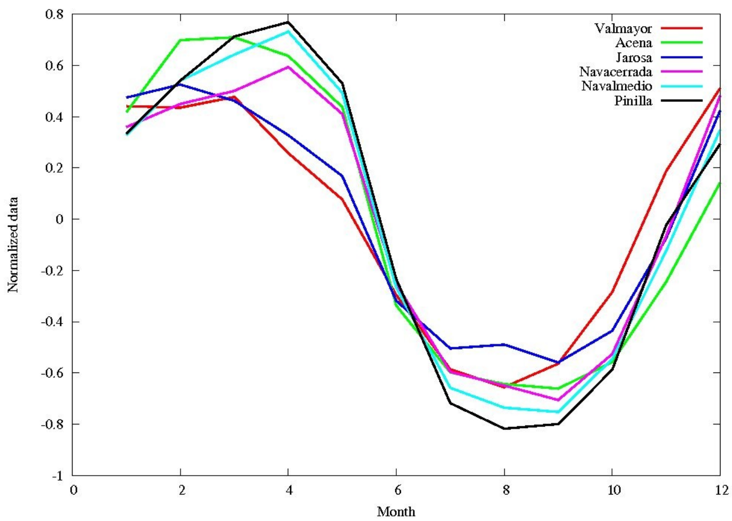
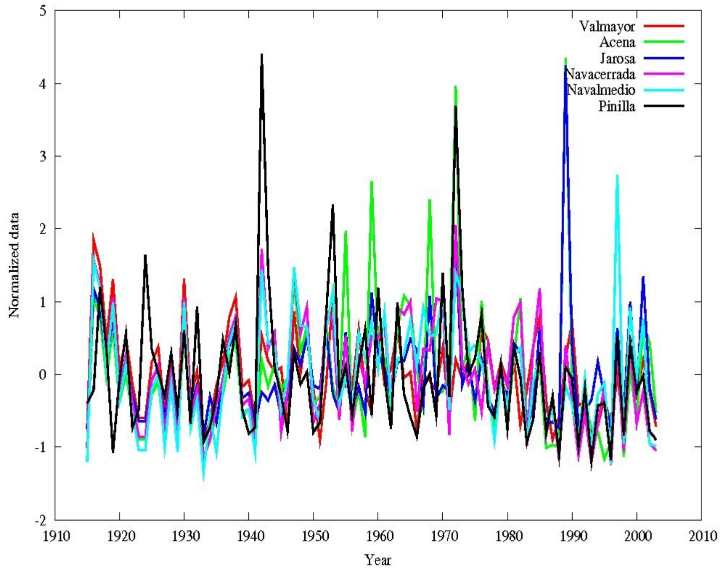


Figure 19. Location of the six reservoirs (red circles) in the area of Sierra de Guadarrama and the JA, RU and VA chronologies (blue stars).

Figure 20 shows, as in the case of precipitation (3.1, Figure 15), the annual cycles for the available sites as well as the time series for May and for September. The reason for showing two months is to illustrate how different is the signal in the summer months (Figure 20-bottom) if compared to the rest of the months, that show a more homogeneous evolution in time (Figure 20-middle). It is unclear at this stage what can be the reasons for this different behavior. Several possibilities may include a different, more localized catchment regime in summer, control routines on the reservoir that affect data quality, impact of evaporation and drought, etc.





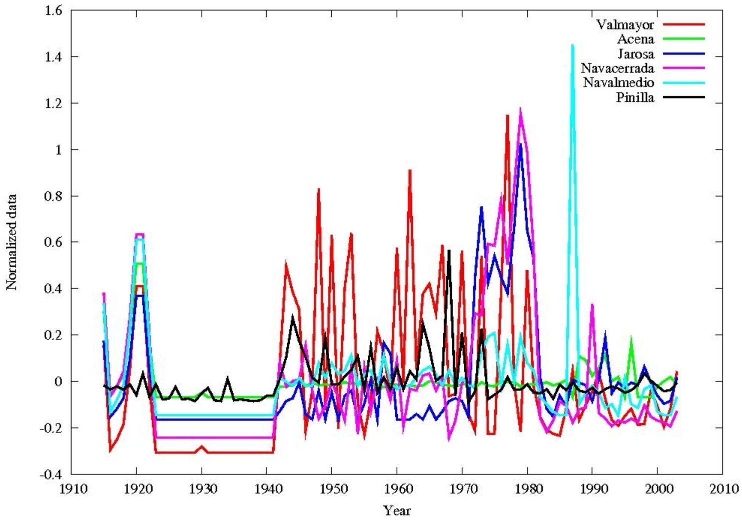


Figure 20. Annual cycle of water contribution to the reservoirs close to Sierra de Guadarrama (top) and the temporal evolution of the contribution of May (middle) and of September (bottom).

Figure 21 shows the correlations of the series with JA, RU and VA chronologies, using the same seasons like in the case of the precipitation. JA shows the highest correlation value, 0.34, corresponding to the June-August season (Figure 22). In the case of *Pinus sylvestris* is 0.29, between RU and the month of August, the hisghest correlation value. The correlation indexes are very low but seem to indicate that there exists some relation between this water information and the TRW, that increases as the analysis focuses more on the summer months. Due to the high spatial variability of water input in the summer months and the larger values at Valmayor, the series in Figure 21 are biased for the values of this site.

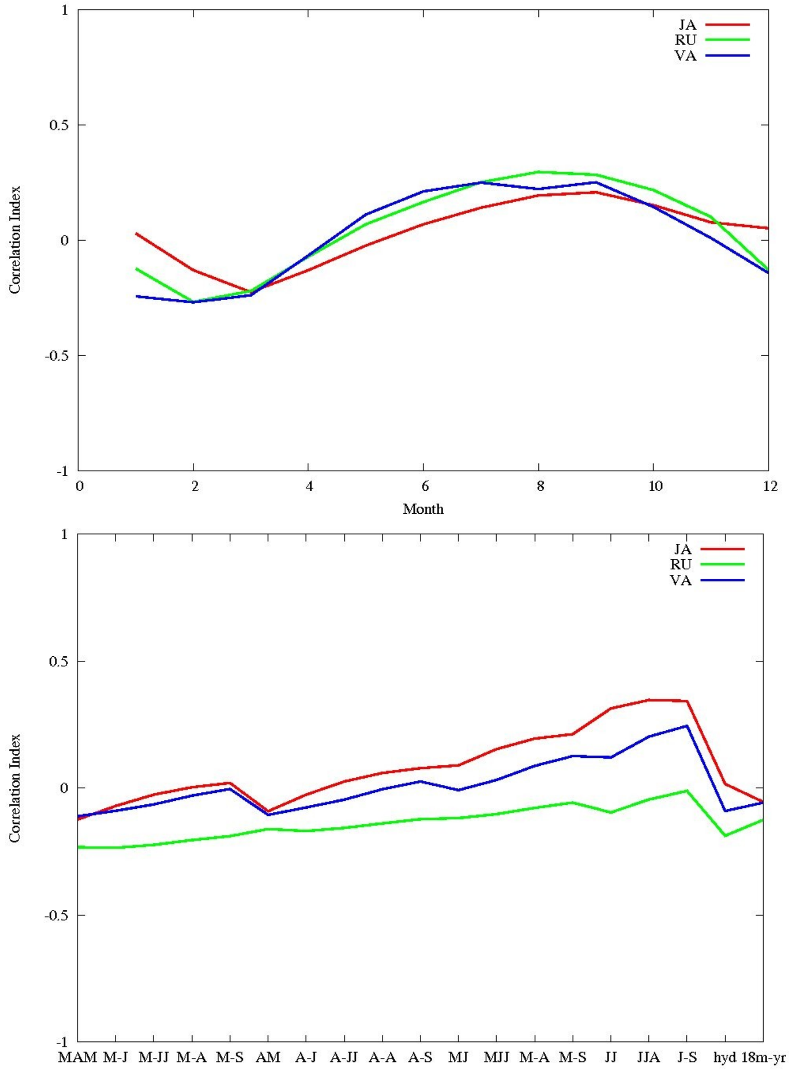


Figure 21. Correlation indexes between the chronologies and the monthly value of the water contributions to the reservoirs series (top) and between the chronologies and the different seasons considered as possible seasons of growth (bottom).

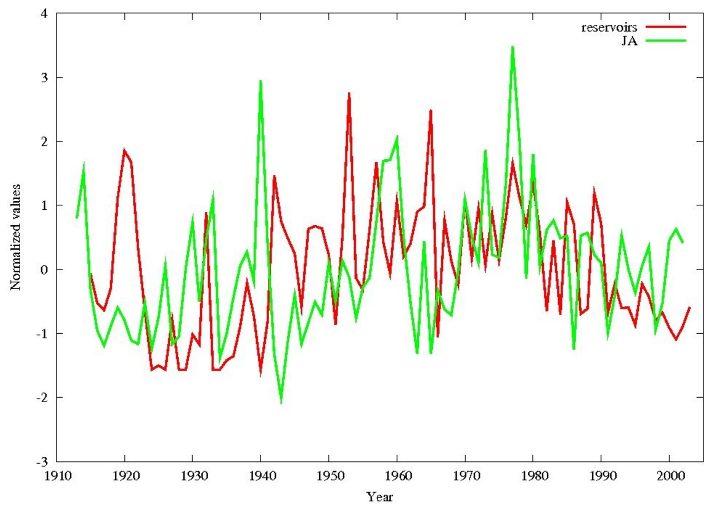


Figure 22. Mean water contribution to reservoirs series from Sierra de Guadarrama in June-August season and the chronology of Jarosa (JA).

3.3. Temperature variability

Figure 23 shows the distribution of available temperature series to compare with the chronologies: *Navacerrada (NVC), Rascafria (RSC), Embalse de Navacerrada 1 (EMB.NVC1), Embalse de Navacerrada 2 (EMB.NVC2) and San Lorenzo del Escorial (SLZ).*

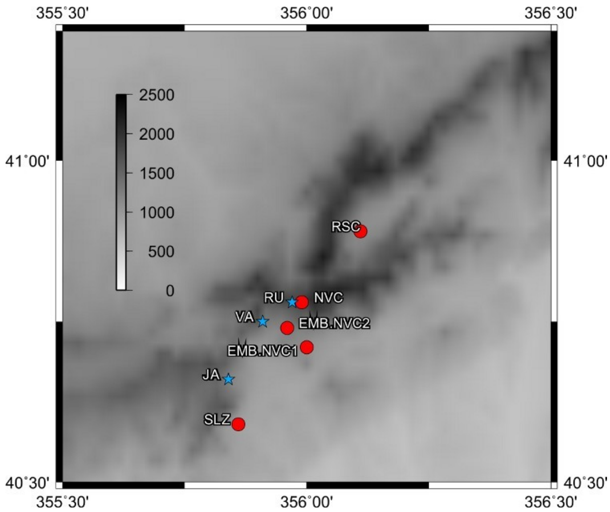
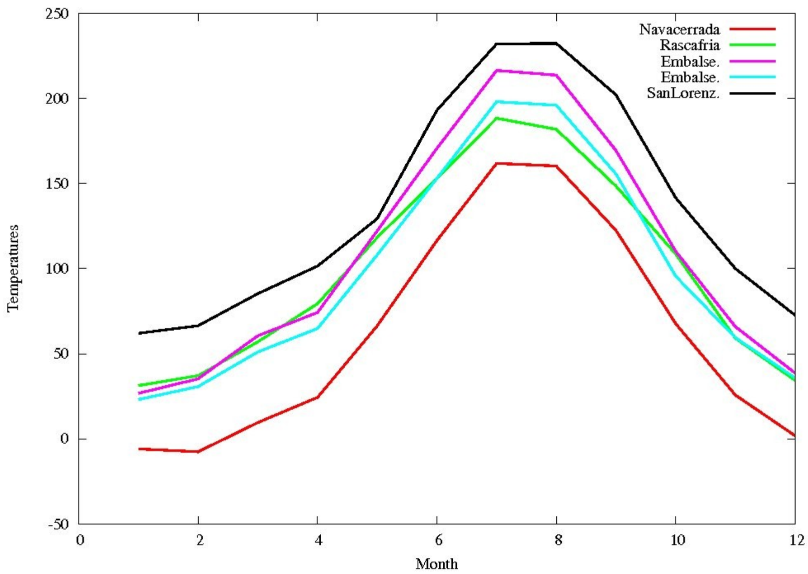


Figure 23. Temperature series (red circles) in the area of Sierra de Guadarrama and the JA, RU and VA chronologies (blue stars).

Figure 24 shows the annual cycle of the different temperature series in the area (top) and all the time series for May as an example (bottom). In this case, as occurred with the precipitation, the series show very similar behavior, that support the mean series of temperature as a good reference to compare with the TRW.



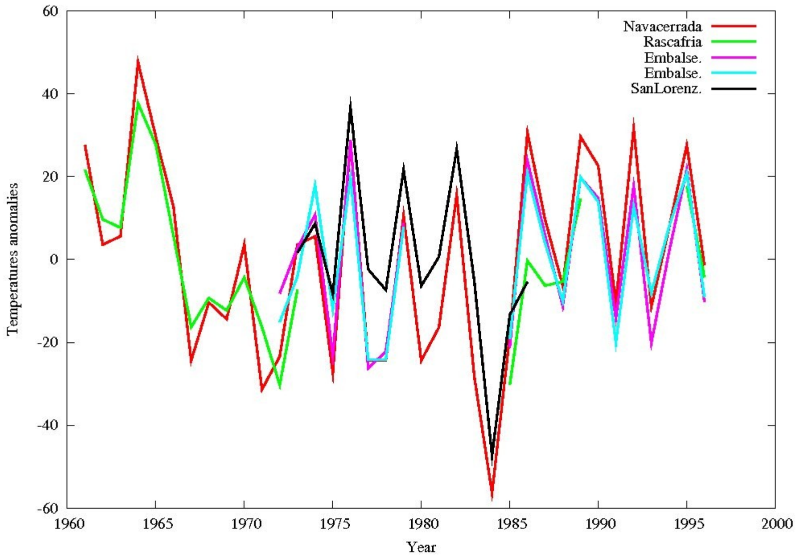
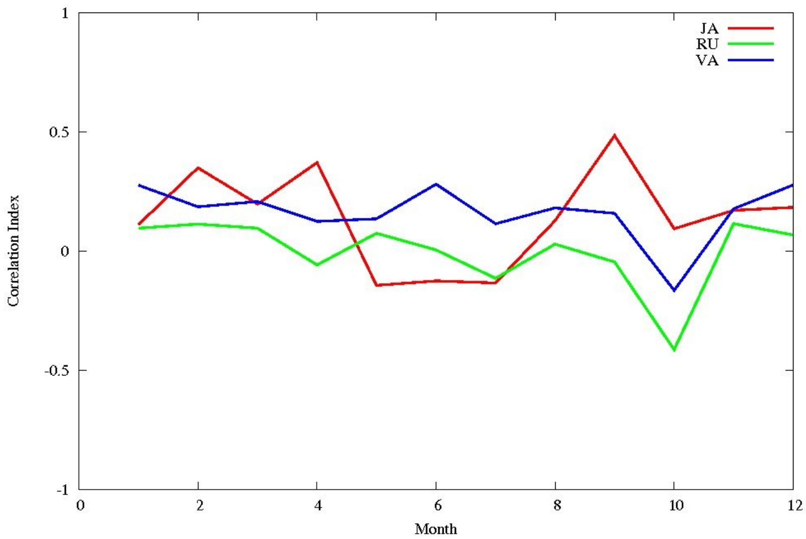


Figure 24. Annual cycle of temperature from some locations close to Sierra de Guadarrama (top) and the temporal evolution of the contribution of May (bottom).

Figure 25 shows the correlation values between the JA, RU and VA chronologies and different months (top) and seasons (bottom) of the mean temperature series of the area of Sierra de Guadarrama. The highest value is 0.48 and it corresponds to JA with the month of September (Figure 26). For the case of *Pinus sylvestris*, the highest value of 0.31 is provided by the JA chronology in the March-June season. Some months or seasons, as in the rest of climatic variables (3.1 and 3.2), seem to indicate a relation between the temperature and the TRW, but it is not strong enough to attribute the TRW to the temperature in any case.



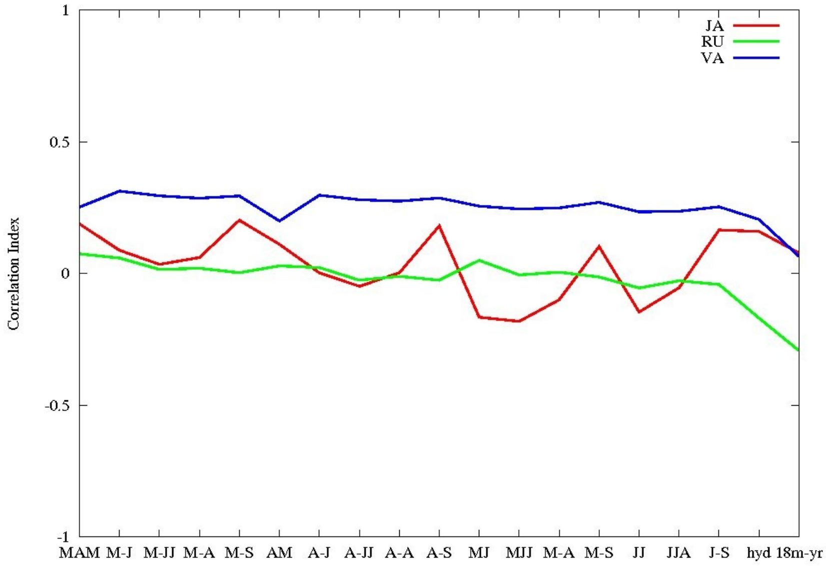


Figure 25. Correlation indexes between the chronologies and the monthly value of temperature series (top) and between the chronologies and the different seasons considered as possible seasons of growth (bottom).

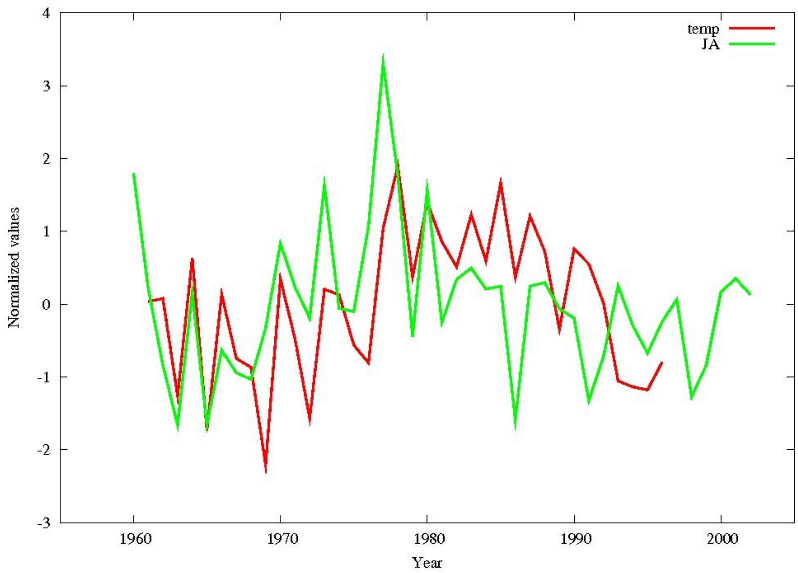


Figure 26. Mean temperature series from Sierra de Guadarrama in September and the chronology of Jarosa (JA).

4. Conclusions

The main result that we want to emphasize is that three new chronologies have been developed in the area of Sierra de Guadarrama, in Madrid. They offer around 450-years of chronology, from *Pinus sylvestris* and *nigra*. These chronologies have been studied in a context with 21 more existing chronologies, from which we have obtained an important TRW dataset of the area of Madrid.

The agreement between chronologies, particularly of the same species, has been shown. In the case of *Pinus nigra*, the agreement between the chronologies is important at any location (no matter about the altitude or the position). For the *Pinus sylevestris* the altitude played an important role, showing more similarity among the chronologies located at higher altitudes (above 1800 m asl) than in the lower ones. Between our two *Pinus sylvestris* chronologies this agreement is quantified with a correlation index above 0.8 for the 11-yr filter data. Comparing with the *Pinus nigra* site, although they are similar, the differences are more evident, and the correlation index with the other two sites is lower, around 0.6 for the last century. When all the chronologies are considered the correlation indexes are lower, but still is shown the similarity within the same specie and in a minor way with all the trees in the area. This agreement between the chronologies suggest that a similar mechanism has guided the growth response of the trees for the last 400 – 500 years.

Potential relationships to the climate have been studied, as precipitation, temperature and water contribution to the reservoirs in the area. Local and regional scale information has been compared to the TRW signal. Local observations have offered a better potential for the agreement between climate and chronologies, specially in the case of *Pinus nigra* sites, which offered a clearer response to precipitation than *sylvestris*.

However, the relation observed between climate and TRW in the area of Madrid, seems to show a really difficult climatic reconstruction frame. The response shown in this report of the trees to the climate factors studied doesn't offer yet links that are strong enough for reconstucting the climate in the area. At least not a pure reconstruction based in only one variable, the study of the relation between the TRW and a combination of the different climate variables including drought indexes is still open.
Also it is important to remark that this new dataset of chronologies offers a big potential for ecological studies, increasing the number of sites with 500-years trees in the center of the Iberian Peninsula.

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