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Tree-ring reconstructions of May–June precipitation for western Anatolia

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ABSTRACT

In this study, we aim to examine past dry and wet events for the western Anatolia, performing local and spatial reconstructions. 17 new black pine site chronologies were developed, May–June precipitation time series were reconstructed for four localities, and the first spatial May–June precipitation reconstruction was achieved for western Anatolia. The long-term local May–June precipitation reconstructions contain mostly one-year and, less commonly, two-year drought events. The longest consecutive dry period (AD 1925–1928) in the reconstructed time series for Kütahya lasted four years. Spatial reconstructions revealed that between AD 1786 and 1930 the extreme dry years for all of western Anatolia were AD 1887, 1893, 1794 and 1740. The driest year during the 215-year-long period under consideration was 1887. The wettest years for the entire western Anatolia were determined to be AD 1835, 1876, 1881 and 1901. There is a big overlap between agricultural famine years and dry years as determined from reconstructions. In this context, our study provides a basis for understanding agricultural drought and better management of regional water resources.

Introduction

Long-term systematic observations are necessary to understand natural variability of climate, determine human impacts of on the climate system, parameterize the main processes required in models and verify model simulations (Türkeş et al., 2002). Instrumental records span only a tiny fraction of the Earth's climatic history and provide inadequate perspective on climatic variation and evolution. A longer perspective on climatic variability can be obtained by the study of natural phenomena that are climate-dependent, and that incorporate a measure of this dependency into their structure (Bradley and Eddy, 1991). Tree-rings as proxy records incorporate their precise dating to calendar years, which allows them to be compared directly with instrumental records. They also represent the most geographically widespread records capable of yielding annually resolved time series over the past several centuries (Touchan et al., 2003, 2005a).

Natural systems and human activities in Turkey are frequently at risk due to the lack of sufficient and regular water during the year, even though Turkey is relatively water-rich. (Türkeş, 1998). The mean annual precipitation in Turkey is 644 mm (DMI, 2010) and this value is lower for central Anatolia (400 mm) (Bozkurt and Sen, 2009). There is a high year-to-year variability and high seasonality in rainfall. On the other hand, activities in countries with a lower rainfall variability and seasonality do not suffer as much from the irregularities of the climate. Historically, sufficient and timely rainfall in autumn and spring months is vital to agricultural activities over most of Turkey. With high population growth and rapid urbanization, communities in Turkey now have to use water resources more rationally throughout the year by planning their water requirements (Türkeş, 1998). Therefore, understanding the nature of climate variability is of great practical importance in Anatolia.

The first dendroclimatological study in Turkey was conducted in 1937 by Gassner and Christiansen-Weniger (1942); they determined wet and dry years around Ankara for the first half of 20th century using tree rings of black pine. Comprehensive studies started only in the 21st century: reconstructions were developed, and climate history (dry and wet years) of Anatolia was documented (D'Arrigo and Cullen, 2001; Hughes et al., 2001; Touchan et al., 2003, 2005a,b, 2007; Akkemik and Aras, 2005; Akkemik et al., 2005, 2008; Griggs et al., 2007). These studies aimed mainly at reconstructing spring–summer precipitation, because late spring–summer precipitation is the factor most limiting the growth of tree rings in this region. Dry years indicated in the historical records were also found as dry years in the precipitation reconstructions.

Although the above studies revealed past dry and wet years for many regions of Anatolia, a spatial reconstruction for precipitation in Anatolia has not been attempted. For example, AD 1887 was an extremely dry year in Anatolia, but its spatial extent and severity for different regions within Anatolia were unclear. The goals of the present study are to: (1) describe a new tree-ring data network that is climatically significant for western Anatolia; (2) perform local precipitation reconstructions for meteorological stations that have long-term records, and then describe past dry and wet events; and (3)

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develop spatial precipitation reconstructions in order to examine past dry and wet events for the region as a whole.

Site description

The study area is bounded by 36°–42° N latitude and 26°–34° E longitude, so it is principally western Anatolia including the western Black Sea, Marmara, and western Mediterranean regions, including the western part of Central Anatolia. Because we do not have enough tree-ring data there, the coastal parts of Anatolia are excluded from the study area. Since old forests are generally located at elevations greater than 1000 m, the best dendroclimatological reconstructions are for inland sections of Anatolia.

The climate of Anatolia is largely Mediterranean, with impacts from both higher latitude (temperate to subpolar) and lower latitude (tropical and subtropical) air masses (e.g. Türkeş, 1996; Cullen and deMenocal, 2000). Anatolia, a peninsula in the eastern Mediterranean, is surrounded by Black Sea in the north, Aegean Sea in the west and the Mediterranean Sea in the south. The terrain of the peninsula is quite complex, and together with its surroundings it show some remarkable contrasting features in topology, land–sea boundary and landscape. The coastal areas demonstrate the characteristics of Mediterranean climate with some variations while the interior plateau indicates the attributes of the continental climate (Bozkurt and Sen, 2009).

Turkey has been divided into seven climatological regions (Çölaşan, 1960), four of which are in the study area (Mediterranean, central Anatolian, Black Sea and Marmara regions). The regions are topographically defined and have very different climatic regimes. Along the southern coast of Turkey (also called the “Mediterranean region”) the summers are arid and the winters are mild and wet. The annual mean temperature in this area is 16°C with mean annual precipitation of 726 mm. Most of the precipitation occurs during the winter. The contribution of the summer precipitation to this sum is only 6%. The “Black Sea type” climate dominates the region to the north of the mountains that align parallel to the Black Sea coast. The northern part of the Marmara region is also characterized under this climate type, which is very wet with none of the above-mentioned regions suffering from the lack of the water supply. Annual mean temperature is 13°C and mean annual precipitation is 843 mm. In this region the contribution of the summer precipitations to the mean annual sum is 19%. The “Marmara type” climate governs the Marmara and northern Aegean regions. The winters in these regions are less mild than the Mediterranean region and the summers are not as wet as the Black Sea region. Annual mean temperature is 14°C and mean annual precipitation is 595 mm most of which occur during winters. The contribution by the summer precipitations is 12%. Finally, central Anatolia is cold during the winters and hot during the summers. Annual mean temperature is 11°C. The mean annual precipitation of 414 mm is the lowest of all Turkish regions. Most precipitation is recorded during springs. The region is arid during the summers and the contribution of the summer precipitations is 15% (Sensoy et al., 2010).

In western Anatolia, the forests that have potential for dendroclimatological research are located in the higher altitudes of the mountains. Due to thousands of years of human activity, the lower parts of the mountains are covered by damaged and young forests. The main tree species that are both useful to tree-ring-based reconstructions and may attain ages of more than 300 yr, are black pine (*Pinus nigra* Arn. subsp. *pallasiana*), oak (*Quercus* sp.), oriental beech (*Fagus orientalis* Lipsky.), juniper (*Juniperus excelsa* Bieb. and *J. foetidissima* Willd.) and Taurus cedar (*Cedrus libani* A. Rich.). Of these trees, black pine grows naturally in all regions except the inner steppe of western Anatolia. Oak and oriental beech grow in Black Sea region, and cedar and old juniper trees grow in the Mediterranean region (Mayer and Aksoy, 1998). Tree rings of black pine are sensitive to climate, especially when they are located on the south slopes (Akkemik and Cherubini, 2003; Touchan et al., 2003, 2005b; Akkemik and Aras, 2005; Köse et al., 2005).

Material and methods

Tree-ring data and chronology development

P. nigra is widely distributed throughout the mountains of the Black Sea, Aegean and Mediterranean regions. In Anatolia it can also grow in steppes. Because it produces rings sensitive to climate, this species was selected in this study as the basis for climate proxies. Seventeen tree-ring sites were sampled in the Karabük, Bolu, Kastamonu, Afyon, Denizli, Burdur, Ankara and Eskişehir districts of western Anatolia (Table 1 and Fig. 1). Increment cores were taken from living black pine trees. Samples were fine-sanded and cross-

Table 1
Site information.

Site name	Site code	City	Species	No. of trees/cores	Aspect	Elevation (m)	Latitude (N)	Longitude (E)	Time span	Total no of years
Dikmen, Avdan Yaylası	AVD	Karabük	*Pinus nigra*	11/21	S	1560	41.04	32.46	1575–2003	429
Dikmen, Kapaklı Tepe	KAP	Karabük	*P. nigra*	11/21	SW	1508	41.02	32.43	1630–2003	374
Merkez, Küçükyayla	KUC	Karabük	*P. nigra*	10/20	SW	1096	41.13	32.34	1683–2003	321
Mengen, Yalakkuz Eğriova Yaylası yolu	YAL	Bolu	*P. nigra*	22/42	S	1380	41.00	32.22	1431–2005	575
Mudurnu, Gürse, Kızaklı Yaylası	KIZ	Bolu	*P. nigra*	20/40	S	1400	40.37	30.57	1665–2005	341
Küre, Yaralıgöz Mevkii, PınarözüKöyü yakını	YAR	Kastamonu	*P. nigra*	11/21	N	1160	41.45	34.01	1833–2004	172
Akdağ	AKD	Afyon	*P. nigra*	36/72	S	1776	38.21	29.56	1643–2004	363
Honaz Dağı	HON	Denizli	*P. nigra*	18/34	S	1420	37.43	29.17	1561–2004	444
Eskere, Sandras Dağı, Kartal Gölü	ESK	Denizli	*P. nigra*	27/50	S	1792	37.06	28.51	1163–2004	842
Tefenni, İkizce	TEF	Burdur	*P. nigra*	26/47	S	1800	37.22	29.38	1274–2004	731
İbecik, Havut, Boncuk Tepe altı	BON	Burdur	*P. nigra*	26/44	S	1535	36.56	29.25	1284–2004	721
Keltepe	KEL	Ankara	*P. nigra*	20/40	S	1500	40.14	31.44	1713–2004	292
Tekke Dağı	TEK	Ankara	*P. nigra*	16/29	S	1535	40.15	31.58	1787–2004	218
Uşakgöl Ormanı	USA	Ankara	*P. nigra*	12/21	S	1721	40.19	31.55	1762–2004	243
Mihalıçç8ık, Beşpınar, Akarca Pınarı	AKA	Eskişehir	*P. nigra*	16/32	SE	1686	39.56	31.19	1642–2003	362
Fırınlık Kalesi	FIR	Eskişehir	*P. nigra*	11/22	SW	1553	39.58	31.07	1744–2003	260
Seyitgazi/Küçük Türkmen Baba	TUR	Eskişehir	*P. nigra*	12/26	SE	1723	39.26	30.23	1732–2003	272

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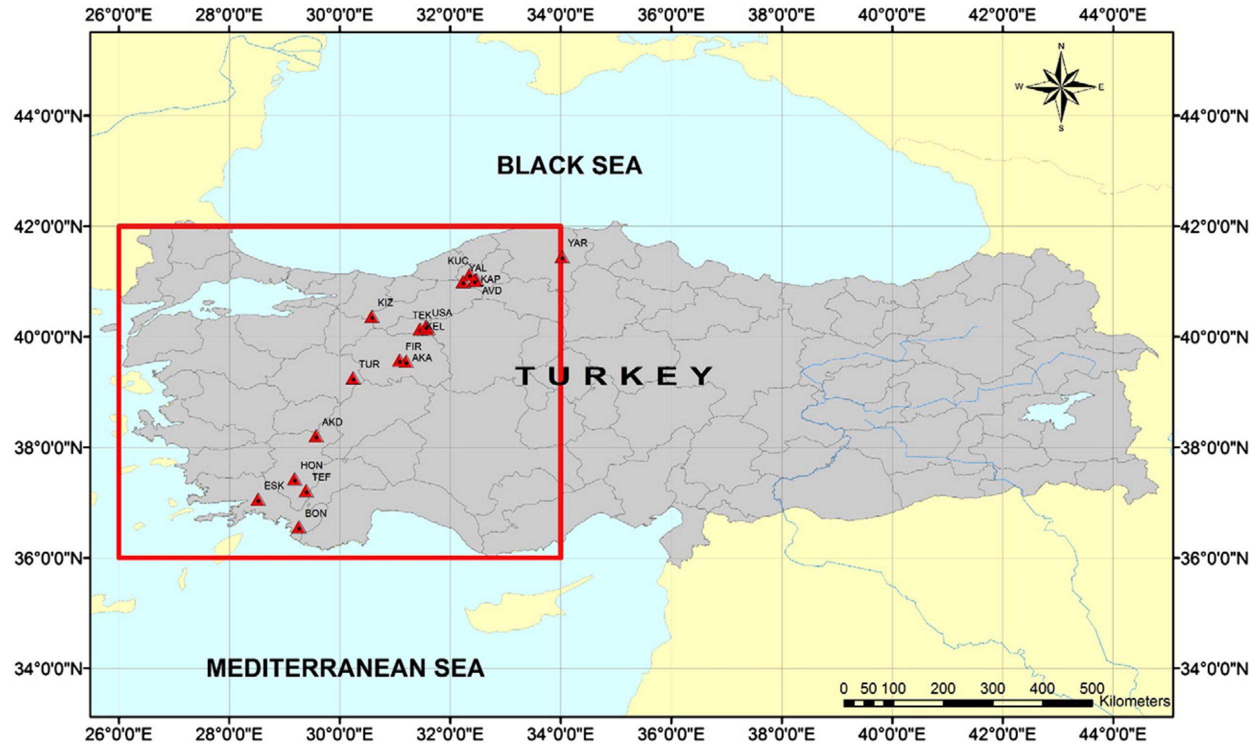

Figure 1. Locations of tree-ring sites (filled triangles). Box represents the area for which the dendroclimatologic reconstructions were performed.

dated using standard dendrochronological techniques (Swetnam, 1985; Stokes and Smiley, 1996). The width of each annual ring on the cores and cross-sections was measured to the nearest 0.01 mm. The program COFECHA was used to test the accuracy of raw measurements of each site (Holmes, 1983). COFECHA uses segmented time-series correlation techniques to assess the quality of crossdating in measurement series (Grissino-Mayer, 2001).

Each ring width series was standardized by means of a negative exponential or linear regression to remove non-climatic trends related to the age, size, and the effects of stand dynamics (Fritts, 1976; Cook et al., 1990a). The detrended series was then pre-whitened with low-order autoregressive models to remove persistence not related to climatic variations. The individual indices were combined into single averaged chronologies for each site using a bi-weight robust estimate of the mean (Cook et al., 1990b). These analyses were performed using the ARSTAN program (Cook, 1985; Grissino-Mayer et al., 1996).

Some of the above-mentioned sampled 17 tree-ring chronologies were used for local reconstructions of climate. In the spatial reconstructions, the YAR and TEK chronologies, which are shorter than 215 yr, were not used. In addition to the remaining 15 new chronologies for Western Anatolia, 16 site chronologies built by different researchers in the study area were also used for the spatial reconstructions (Table 2).

Climate data

Three types of climate datasets were used for this study:

(1) Monthly precipitation and temperature records extracted from the high-resolution climate dataset CRU TS 2.1 gridded at 0.5° intervals (Mitchel et al., 2004) for 36–42° N, 26–34° E. These data were used in evaluating the climate–tree growth relationship.
(2) Monthly May–June precipitation data from the meteorological stations having the longest records (AD 1931–2005) in the study area were used in the local reconstructions (Göktürk, 2005).
(3) Monthly May–June precipitation records CRU TS 2.1. The period AD 1930–2000 was chosen for the spatio-temporal analysis because it maximizes the number of station records within this region. Data for the land areas within the study region include 245 of 320 total grid points.

Precipitation reconstructions

Response function analysis (Fritts, 1976) was used to identify the relationship between the tree-ring indices and monthly gridded temperature and precipitation. Analyses were performed using the DENDROCLIM2002 program (Biondi and Waikul, 2004). Response function analysis identified May–June total precipitation as the most appropriate seasonal predictors for reconstructions.

Local reconstructions

The precipitation reconstructions were calibrated on the basis of total May–June precipitation values recorded at the meteorological stations having the longest records. Following this approach, separate reconstructions for the Afyon, Kütahya, Eskişehir and Isparta meteorological stations were developed. The minimum sample depth (the number of trees for each site chronology) has been decided according to subsample signal strength (SSS). We required the SSS to be greater than 0.85. The sub-sample signal strength (SSS) is a function of the sample size and the correlations between individual trees. SSS is a guide to assessing the likely loss of reconstruction accuracy, when the chronology is formed from a limited number of series (Briffa and Jones, 1990).

Different chronology sets were transformed to uncorrelated predictors by projecting them onto their principle components (PCs). The first PCs of chronology sets were used as predictors for the reconstructions. Calibration equations were then applied to the

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Table 2
Information about the chronologies from previous studies.

Site name	Site code	Species	Time span	Latitude (N)	Longitude (E)	Elevation (m)	References
Kazdağları, Gürgen Dağı, Dalak Suyu	IDAU	*Pinus nigra*	1778–2000	39°47′	26°33′	1300	Dağdeviren (2002)
Karabük-Keltepe Ormanı	2PS	*P. sylvestris*	1750–2000	41°05′	32°28′	1700	Akkemik et al. (2008)
Bolu-Aladağ-Ardıçtepe Ormanı	1PN	*P. nigra*	1675–2000	40°34′	31°29′	1450	Akkemik et al. (2008)
Katran Dağı	KAT	*Cedrus libani*	1695–2000	37°23′	30°36′	1469	Touchan et al. (2005a)[a]
Dumanlıdağ ve Göller	DUDP	*Pinus brutia*	1730–2000	37°24′	30°38′	1156	Touchan et al. (2005a)[a]
Göller	GOLJ	*Juniperus excelsa*	1157–2000	37°05′	30°31′	1047	Touchan et al. (2005a)[a]
Kozlu Pınarı	KOPP	*P. nigra*	1590–2000	36°39′	32°12′	1633	Touchan et al. (2005a)[a]
Su Batan	SUBJ	*J. excelsa*	1251–2000	37°25′	30°18′	1862	Touchan et al. (2005a)[a]
Aziziye	AZY	*P. nigra*	1776–2000	37°25′	30°17′	1601	Touchan et al. (2005a)[a]
Yellic Beli	YEBC	*C. libani*	1630–2000	36°39′	32°11′	1723	Touchan et al. (2005a)[a]
Elmalı	EJUE	*J. excelsa*	1339–2000	36°36′	30°01′	1853	Touchan et al. (2005a)[a]
Elmalı	ECELI	*C. libani*	1452–2000	36°36′	30°01′	1937	Touchan et al. (2005a)[a]
Kızılcahamam, Kasımlar Yaylası	KAS	*P. sylvestris*	1757–2002	40.4316	32.3781	1735	Köse et al. (2005)
Kızılcahamam, Soğuksu Milliparkı, İncegeçiş M.	INC	*P. nigra*	1674–2002	40.2659′	32.3540	1633	Köse et al. (2005)
Eskişehir, Kırka, Gövemce Mevkii	GOV	*P. nigra*	1710–2002	39.4186	30.3940	1617	Köse et al. (2005)
Eskişehir, Çatalçam M.	CAT	*P. nigra*	1734–2002	39.4391	30.3995	1612	Köse et al. (2005)

[a] Obtained from International Tree Ring Data Bank (ITRDB).

precipitation data for the period of instrumental data in order to maximize the number of observations and the degrees of freedom used to calculate model significance in the final regression. In order to verify the model stability, a split-sample procedure that divided the full period into two subsets of equal length was used (Meko and Graybill, 1995; Touchan et al., 2003, 2005a,b, 2007). Reduction of error (RE) statistics was used to tests whether or not our reconstructions were statistically significant. This test gives a "pass" if the RE value is positive. Correlation coefficients and sign test were used as additional comparisons between actual and estimated values (Fritts, 1976). The resulting models for the full period were then used to calculate reconstructions.

Analysis of extreme dry and wet events

To identify the extreme May–June dry and wet events, standard deviation (SD) values were used. Years 1 and 2 SD above/below the mean were identified as wet, very wet/dry and very dry years, respectively. This method gave valuable and comparable results to previously obtained dry and wet years of Anatolia (D'Arrigo and Cullen, 2001; Akkemik and Aras, 2005; Akkemik et al., 2005; Touchan et al., 2005a).

Spatial reconstructions

We followed a multi-step mathematical strategy to relate the precipitation variability in western Anatolia to the chronologies of a total of 31 sites (e.g. Fritts, 1976). Our aim in this procedure was to transform the chronology information into 'the deviation from the mean' information or, in other words, to perform a reconstruction of 'precipitation anomaly'.

For calibration purposes we obtained precipitation data from CRU TS 2.1 (Mitchel et al., 2004), organized on a 0.5° grid for the period 1901–2000. We transformed this dataset into the netCDF format (Unidata, 2010) and extracted the May–June precipitation data for our study area. In Turkey, instrumentally reliable meteorological observations started in 1930; therefore we limited our station reconstructions period to AD 1930–2000.

For each grid cell, we calculated May–June mean and standard deviation for the period between AD 1930–2000 and we subtracted the mean from each data and divided by the standard deviation in order to standardize the data. We then applied principle component analysis (PCA) to the standardized precipitation data (71×245 precipitation standard deviation values) and examined the eigenspectrum. We found that the first ten principal components explained 86% of the precipitation variance. Following Fritts (1976) we chose these first ten principal eigenvectors as our basis and projected the precipitation data between AD 1930 and 2000 onto these ten principal components.

We used the common AD 1786–2000 periods of 31 local chronologies for the reconstructions. We applied PCA also to these data and kept the first ten principal components explaining the 76% of the variance (following Fritts, 1976). We later projected the chronologies onto these principal components.

After these procedures we obtained a 71×10 'filtered' grid precipitation data matrix and a 71×10 "filtered" tree-ring chronology data matrix. We applied canonical correlation analysis (CCA) to relate these two matrices (Fritts, 1976; Guiot, 1990).

The CCA led to ten canonical pairs out of which we selected the first eight pairs (with correlation coefficients 0.78, 0.68, 0.50, 0.40, 0.38, 0.30, 0.26, and 0.13.). This corresponds to a low-pass spatial filter in a sense. We then reconstructed a 215-yr-long precipitation anomaly record for the 245 grid points using these eight canonical pairs and plotted them on maps. The significance of this reconstruction was tested through a Student's *t*-test using the difference between the calculated and observed values for the observational period of 71 yr.

Results

Tree-ring chronologies

The lengths of the seventeen chronologies range from 172 yr (AD 1833–2004) to 842 yr (AD 1163–2004) (Table 3). Due to higher between/within-tree correlations and a higher mean sensitivity in the residual chronologies than in the standard chronologies, we selected the residual chronologies for further reconstructions. Residual chronologies have also stronger high-frequency climate signal, because autocorrelations are eliminated depending upon prior growth. Statistical analyses of each residual chronology are summarized in Table 3. The mean correlation among individual radii at each site representing the strength of their common signal ranges from 0.27 to 0.41. Correlation among all cores tends to be low since it reflects the responses of the individual trees to their environmental conditions. Other authors have come to the same conclusion: Touchan et al. (2005a,b) found mean correlations among individual radii in the range of 0.31–0.37 for black pines in Turkey; Akkemik and Aras (2005), for the same species, estimated a value of 0.22. The correlation between site chronologies reflecting the common signal and individual radii values tends to be high (in the range of 0.53 to 0.67). For the same species Akkemik and Aras (2005) found a value of 0.49.

Table 3
Summary statistics for the 17 chronologies for the ARSTAN program.

Site name	Site code	No. of trees/cores	Total chronology					Common interval		
			Standard deviation	Skewness	Kurtosis	1st year SSS[a] > 0.85	Mean sensitivity	Time span	Mean correlation among radii/radii versus mean	Explained variance PC1 (%)
Dikmen. Avdan Yaylası	AVD	11/21	0.18	0.34	0.54	1653	0.20	1686–1957	0.38/0.64	42.98
Dikmen. Kapaklı Tepe	KAP	11/21	0.21	0.14	0.03	1662	0.23	1712–2002	0.41/0.67	47.59
Merkez. Küçükyayla	KUC	10/20	0.17	0.11	0.14	1774	0.20	1811–2003	0.35/0.62	40.83
Mengen. Yalakkuz Eğriova Yaylası yolu	YAL	22/42	0.17	0.20	0.07	1628	0.19	1736–1997	0.30/0.56	32.81
Mudurnu. Gürse. Kızaklı Yaylası	KIZ	20/40	0.16	0.18	1.10	1729	0.17	1841–2005	0.36/0.61	38.59
Küre. Yaralıgöz Mevkii. PınarözüKöyü yakını	YAR	11/21	0.18	0.59	0.72	1847	0.21	1894–2004	0.36/0.64	42.84
Akdağ	AKD	36/72	0.18	0.60	1.29	1673	0.20	1784–2004	0.40/0.63	42.75
Honaz Dağı	HON	18/34	0.22	0.61	2.20	1685	0.25	1803–1997	0.35/0.61	38.63
Eskere. Sandras Dağı. Kartal Gölü	ESK	27/50	0.13	0.17	0.60	1267	0.14	1534–2003	0.27/0.53	30.47
Tefenni. İkizce	TEF	26/47	0.19	0.48	0.83	1632	0.21	1752–2004	0.38/0.63	41.32
İbecik. Havut. Boncuk Tepe altı	BON	26/44	0.12	−0.05	0.25	1459	0.13	1701–2003	0.27/0.54	32.62
Keltepe	KEL	20/40	0.16	−0.35	1.08	1759	0.19	1795–1999	0.37/0.62	39.80
Tekke Dağı	TEK	16/29	0.18	0.10	−0.19	1823	0.21	1890–2000	0.31/0.57	34.80
Uşakgöl Ormanı	USA	12/21	0.20	0.39	1.28	1817	0.23	1896–2004	0.33/0.61	39.18
Mihalıççık. Beşpınar. Akarca Pınarı	AKA	16/32	0.20	0.09	0.90	1756	0.22	1833–2003	0.38/0.64	41.59
Fırınlık Kalesi	FIR	11/22	0.19	0.11	0.23	1766	0.22	1839–2003	0.36/0.62	39.95
Seyitgazi/Küçük Türkmen Baba	TUR	12/26	0.16	0.19	0.34	1813	0.18	1872–1999	0.31/0.57	36.73

[a] SSS is Subsample Signal Strength (Wigley et al., 1984).

Response function results

The response function results show that precipitation, more than temperature, influences tree-ring widths of *P. nigra* Arn. (Table 4). The response functions that represent the effect of the precipitation on the tree-ring widths are positive and significant in May in almost all regions. In June, the significance is less but is still positive. This result revealed that the most important factor affecting tree-ring width of black pine was May–June precipitation in western Anatolia. Therefore, for the total precipitation we decided to do the reconstructions for May and June only.

Local reconstructions

Only four meteorological stations having long-term (AD 1931–2005) records could be used in this study to reconstruct May–June precipitation. Here we give a short list of details of the reconstructions for each station.

Table 4
Summary of response function results.

	Temperature													Precipitation												
	O	N	D	J	F	M	A	M	J	J	A	S	O	O	N	D	J	F	M	A	**M**	**J**	J	A	S	O
AVD	-	-	+	+	-	+	+	-	-	+	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	-
KAP	-	-	+	+	+	+	+	-	-	+	-	-	-	-	-	-	+	-	+	+	+	+	+	+	-	-
KUC	+	-	-	-	+	+	-	-	+	-	-	-	-	-	-	+	-	-	+	+	+	+	-	+	+	-
YAL	-	-	+	+	+	+	+	-	+	+	-	-	+	-	-	+	+	-	+	+	+	+	-	+	-	-
KIZ	-	-	+	+	+	+	+	+	+	-	-	-	-	-	-	+	+	-	-	+	+	+	-	+	-	-
YAR	-	+	-	-	-	+	+	-	+	-	-	+	-	-	-	+	-	+	+	+	+	+	+	+	+	-
AKD	-	+	-	+	-	+	+	-	-	+	+	-	-	+	-	+	+	-	+	-	+	+	+	+	+	+
HON	+	-	+	+	+	+	+	-	-	-	-	+	+	-	-	+	+	+	-	+	+	-	+	+	-	+
ESK	-	+	+	-	-	+	+	-	-	-	-	+	-	+	-	-	+	-	-	+	+	+	-	+	-	+
TEF	-	+	+	-	+	+	+	-	-	+	-	+	-	+	-	+	+	-	-	-	+	+	+	+	-	+
BON	-	+	+	-	-	+	+	-	-	-	-	+	-	+	-	+	-	-	-	-	+	+	+	+	-	-
KEL	-	+	-	-	-	-	-	-	+	-	-	-	-	-	+	+	+	-	+	+	+	+	-	+	+	+
TEK	-	-	-	-	+	+	+	-	-	-	-	+	-	-	-	+	+	-	+	-	+	+	+	+	-	+
USA	-	+	-	-	-	+	+	-	-	-	+	-	-	+	-	+	+	-	-	-	+	+	+	+	-	+
AKA	-	+	-	-	-	+	+	-	-	+	+	-	-	-	+	+	-	-	-	+	+	+	+	+	+	+
FIR	-	-	-	-	+	+	+	-	+	-	-	-	-	-	+	+	+	-	+	-	+	+	-	+	-	+
TUR	-	+	+	-	-	+	+	-	-	-	-	-	-	+	-	-	+	-	+	-	+	+	+	+	-	-

"+" represents positive effects of climate variability on tree ring width; "−" represents negative effects of climate variability on tree ring width; gray filled boxes represent significant response function results. Each response function includes 13 weights for average monthly temperatures and 13 monthly precipitations from October (O) of the prior year to October of current year. The circle represents the most important factor affecting tree-ring widths.

Table 5
Results of the statistical calibrations and cross-validation between May–June precipitation and tree growth for reconstructions.

Calibration period			Verification period	Constant and coefficient	Adj. R^2	F	RE	Calibration		Verification	
								ST	P	ST	P
AFYON	1685–2004	1930–1967	1968–2004	−190.4 132.1	0.39	24.22 $p \le 0.0001$	0.43	$26^{+}/11^{-}$ $p \le 0.05$	0.63 $p \le 0.001$	$28^{+}/9^{-}$ $p \le 0.01$	0.66 $p \le 0.001$
		1968–2004	1930–1967	−142.2 101.4	0.42	27.53 $p \le 0.0001$	0.40	$28^{+}/9^{-}$ $p \le 0.01$	0.66 $p \le 0.001$	$26^{+}/11^{-}$ $p \le 0.05$	0.63 $p \le 0.001$
		1930–2004		−185.1 125.8	0.41	52.18 $p \le 0.0001$		$54^{+}/20^{-}$ $p \le 0.01$	0.65 $p \le 0.001$		
KUTAHYA	1823–2004	1930–1967	1968–2004	−138.8 118.6	0.35	20.66 $p \le 0.0001$	0.46	$28^{+}/9^{-}$ $p \le 0.01$	0.60 $p \le 0.001$	$29^{+}/8^{-}$ $p \le 0.01$	0.80 $p \le 0.001$
		1968–2004	1930–1967	−180.1 133.3	0.63	61.76 $p \le 0.0001$	0.47	$29^{+}/8^{-}$ $p \le 0.01$	0.80 $p \le 0.001$	$28^{+}/9^{-}$ $p \le 0.01$	0.60 $p \le 0.001$
		1930–2004		−161.9 127.2	0.46	64.10 $p \le 0.0001$		$57^{+}/17^{-}$ $p \le 0.01$	0.68 $p \le 0.001$		
	1632–1822	1930–1967	1968–2004	−106.5 144.5	0.35	21.01 $p \le 0.0001$	0.36	$27^{+}/10^{-}$ $p \le 0.01$	0.61 $p \le 0.001$	$27^{+}/10^{-}$ $p \le 0.01$	0.68 $p \le 0.001$
		1968–2004	1930–1967	−154.8 166.0	0.47	30.41 $p \le 0.0001$	0.36	$27^{+}/10^{-}$ $p \le 0.01$	0.68 $p \le 0.001$	$27^{+}/10^{-}$ $p \le 0.01$	0.61 $p \le 0.001$
		1930–2004		−124.6 151.1	0.37	45.28 $p \le 0.0001$		$54^{+}/20^{-}$ $p \le 0.01$	0.62 $p \le 0.001$		
ESKISEHIR	1756–2003	1930–1966	1967–2003	−81.12 73.75	0.31	17.08 $p \le 0.0005$	0.29	$28^{+}/8^{-}$ $p \le 0.01$	0.58 $p \le 0.001$	$28^{+}/9^{-}$ $p \le 0.01$	0.55 $p \le 0.001$
		1967–2003	1930–1966	−147.3 96.05	0.28	15.09 $p \le 0.0005$	0.30	$28^{+}/9^{-}$ $p \le 0.01$	0.55 $p \le 0.001$	$28^{+}/8^{-}$ $p \le 0.01$	0.58 $p \le 0.001$
		1930–2003		−105.8 81.13	0.29	31.27 $p \le 0.0001$		$56^{+}/17^{-}$ $p \le 0.01$	0.55 $p \le 0.001$		
	1673–1755	1930–1966	1967–2003	−80.81 82.16	0.32	18.02 $p \le 0.0002$	0.29	$28^{+}/8^{-}$ $p \le 0.01$	0.58 $p \le 0.001$	$30^{+}/7^{-}$ $p \le 0.01$	0.51 $p \le 0.01$
		1967–2003	1930–1966	−121.4 94.47	0.24	11.47 $p \le 0.002$	0.29	$30^{+}/7^{-}$ $p \le 0.01$	0.51 $p \le 0.01$	$28^{+}/8^{-}$ $p \le 0.01$	0.58 $p \le 0.001$
		1930–2003		−98.19 86.83	0.29	30.20 $p \le 0.0001$		$58^{+}/15^{-}$ $p \le 0.01$	0.55 $p \le 0.001$		
ISPARTA	1759–2004	1931–1967	1968–2004	−271.8 184.5	0.50	37.52 $p \le 0.0001$	0.42	$27^{+}/9^{-}$ $p \le 0.01$	0.72 $p \le 0.001$	$26^{+}/11^{-}$ $p \le 0.05$	0.55 $p \le 0.001$
		1968–2004	1931–1967	−136.6 110	0.28	15.08 $p \le 0.0004$	0.40	$26^{+}/11^{-}$ $p \le 0.05$	0.55 $p \le 0.001$	$27^{+}/9^{-}$ $p \le 0.01$	0.72 $p \le 0.001$
		1931–2004		−216.7 154.1	0.42	54.13 $p \le 0.0001$		$53^{+}/20^{-}$ $p \le 0.01$	0.66 $p \le 0.001$		
	1459–1758	1931–1967	1968–2004	−188.1 200.6	0.28	14.66 $p \le 0.0005$	0.25	$26^{+}/10^{-}$ $p \le 0.05$	0.54 $p \le 0.001$	$26^{+}/11^{-}$ $p \le 0.05$	0.47 $p \le 0.01$
		1968–2004	1931–1967	−92.43 121.2	0.20	9.85 $p \le 0.004$	0.24	$26^{+}/11^{-}$ $p \le 0.05$	0.47 $p \le 0.01$	$26^{+}/10^{-}$ $p \le 0.05$	0.54 $p \le 0.001$
		1931–2004		−144 163.9	0.25	24.91 $p \le 0.0001$		$52^{+}/21^{-}$ $p \le 0.05$	0.51 $p \le 0.001$		

May–June precipitation of Afyon meteorological station was obtained from the first PC of AKD, HON, ESK, TEF and BON site chronologies, and explains 60% of total variance. The final regression statistics were found significant at the 95% confidence level (Table 5). Because of the similarity and strength of the derived calibration equations and verification tests, the full calibration period (AD 1930–2004) was used for reconstruction (Fig. 2), covering the period AD 1685–2004 (Fig. 3).

Two separate reconstructions were developed to accommodate the varying chronology lengths for May–June precipitation of Kütahya meteorological station. The first reconstruction uses YAL, TEF, KEL and TEK site chronologies, with a common interval AD 1823–2004; the second uses just YAL and TEF chronologies with a common interval AD 1632–1822. The first PC of the chronologies explains 60% and 66% of total variance respectively. Because of the similarity and strength of the derived calibration equations and verification tests, the full calibration period (AD 1930–2004) was used for reconstruction (Table 5, Figs. 2 and 3).

Two separate reconstructions were developed to accommodate the varying chronology length for May–June precipitation of Eskişehir meteorological station. The first uses the AVD, KAP, AKD, TEF and AKA site chronologies, with a common interval AD 1756–2003; the second uses just the AVD, KAP, AKD and TEF chronologies, with a common interval AD 1673–1755. The first PC of the chronologies explains 63% and 64% of total variance respectively. Because of the similarity and strength of the derived calibration equations and verification tests, the full calibration period (AD 1930–2003) was used for reconstruction (Table 5, Figs. 2 and 3).

Two separate reconstructions were developed to accommodate the varying chronology length for May–June precipitation of Isparta meteorological station. The first uses the ESK, TEF, BON and KEL site chronologies, with a common interval AD 1759–2004; the second uses just the ESK and BON chronologies, with a common interval 1459–1758. The first PC of the chronologies explains 63% and 64% of total variance respectively. Because of the similarity and strength of the derived calibration equations and verification tests, the full calibration period (AD 1930–2004) was used for reconstruction (Table 5, Figs. 2 and 3).

Extreme dry and wet events

Around Afyon, for the period between AD 1685 and 1929 a total of 35 dry (−) and 37 wet (+) events with standard values exceeding standard deviations ±1 (dry/wet) and ±2 (very dry/very wet) have been determined. Of these years, AD 1693, 1725, 1840, 1852, 1887 and 1893 were exceptionally dry. Dry durations were usually 1 yr long (there were 23 such dry years) but in AD 1715–1716, 1725–1726, 1793–1794, 1851–1852, 1867–1868 and 1893–1894 we see dry

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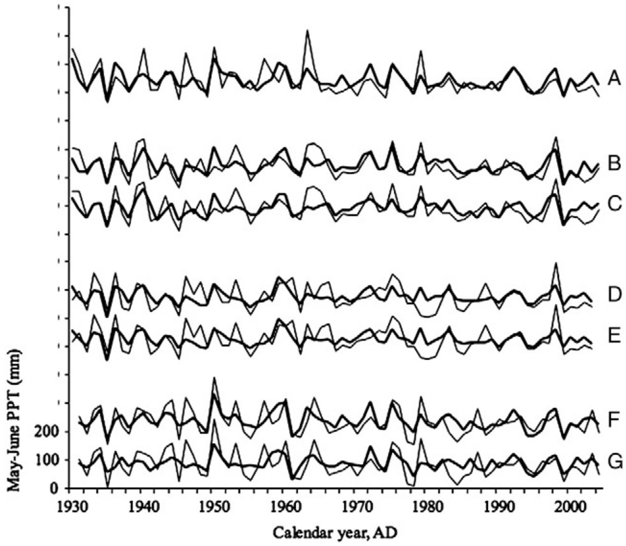

Figure 2. Comparison of actual (thin line) and reconstructed (bold line) May–June precipitation (ppt). Curves offset for clarity. A—Afyon meteorological station reconstruction (AD 1685–2004) based on five chronologies; B, C—Kütahya meteorological station reconstructions (for the periods AD 1823–2004 and AD 1632–1822) and based on four and two chronologies respectively; D, E—Eskişehir meteorological station reconstructions (for the periods AD 1756–2003 and AD 1673–1755) and based on five and four chronologies respectively; F, G—Isparta meteorological station reconstructions (for the periods AD 1759–2004 and AD 1459–1758) and based on four and two chronologies respectively.

periods persisting 2 yr. The years AD 1717, 1744, 1755, 1788, 1876 and 1919 were very wet years. The very wet periods also were mostly one year-long (29 wet years) but in AD 1736–1737, 1770–1771, 1835–1836 and 1919–1920 we find longer wet periods.

Around Kütahya, for the period between AD 1632 and 1929 a total of 43 dry (−) and 42 wet (+) years with values exceeding ±1 (dry/wet) and ±2 (very dry/very wet) standard deviations were determined. Of these years, AD 1840, 1852, 1873, 1887, 1893 and 1909 were exceptionally dry. Dry durations were usually 1 yr long (there were 31 such dry years) but in AD 1715–1716, 1851–1852, 1867–1868 and 1893–1894 they were 2 yr long. The years AD 1640, 1643, 1744, 1855, 1876 and 1919 were very wet years. The very wet periods were mostly one year long (31 wet years) but in AD 1642–1643, 1770–1771, 1919–1920 they were 2 yr long, and in AD 1835–1836–1837 they were 3 yr-long. The longest dry period was 4 yr long (AD 1925–1928).

Around Eskişehir, for the period between AD 1673 and 1929 a total of 40 dry (−) and 43 wet (+) years with values exceeding ±1 (dry/wet) and ±2 (very dry/very wet) standard deviations were determined. Of these years, AD 1840, 1852, 1873, 1887 and 1893 were exceptionally dry. Dry durations were usually 1 yr long (there were 28 such dry years) but in AD 1715–1716, 1789–1790, 1819–1820, 1867–1868 and 1878–1879, 1927–1928 they were 2 yr long. The years AD 1700, 1717, 1744, 1788, 1829, 1876 and 1885 were very wet years. The very wet periods were mostly one year long (31 wet years) but in AD 1770–1771, 1900–1901, 1919–1920 they were 2 yr long, and in AD 1727–1728–1729 and 1835–1836–1837, they were 3 yr long.

Around Isparta, for the period between AD 1459 and 1929 a total of 71 dry (−) and 70 wet (+) years with values exceeding ±1 (dry/wet) and ±2 (very dry/very wet) standard deviations were determined. Of these years, AD 1561, 1567, 1607, 1693, 1819, 1840, 1852, 1887, 1893 and 1916 were exceptionally dry. Dry durations were usually 1 yr long (there were 37 such dry years) but in AD 1511–1512, 1607–1608, 1610–1611, 1623–1624, 1702–1703, 1715–1716, 1725–1726, 1763–1764, 1789–1790, 1793–1794, 1801–1802, 1819–1820, 1851–1852, 1867–1868, 1870–1871, 1893–1894, 1927–1928 they lasted for 2 yr. The years AD 1605, 1717, 1744, 1780, 1788, 1818, 1876 and 1885 were very wet years. They were mostly one year-long (43 wet years) but in AD 1554–1555, 1605–1606, 1620–1621, 1681–1682, 1709–1710, 1727–1728, 1737–1739, 1770–1771, 1817–1818, 1835–1836, 1884–

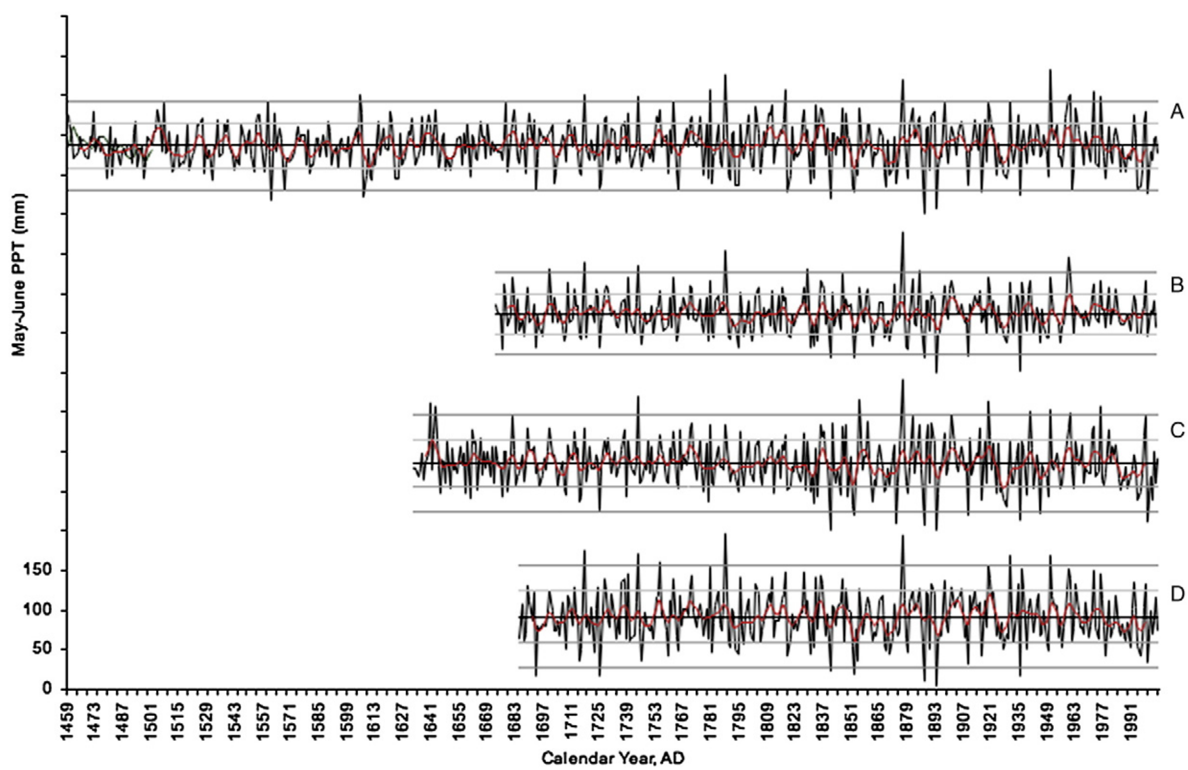

Figure 3. May–June precipitation (ppt) reconstructions of Isparta (A), Eskişehir (B), Kütahya (C), Afyon (D) meteorological stations. Central horizontal lines show the mean of estimated values; inner horizontal lines show the border of one standard deviation; outer horizontal lines two standard deviation from the mean; and red lines show 13-yr low-pass filter values. Curves offset for clarity.

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Table 6
Dry and wet years obtained from May to June precipitation reconstructions. To qualify, at least three of the stations were determined to be either dry or a wet year.

Dry years

Years	Afyon	Kütahya	Eskişehir	Isparta	References
1650		X		X	11, 13
1660		X		X	9, 13, 16 1, 2, 3, 17
1693	XX		X	XX	10, 11
1715	X	X	X	X	9, 10, 11
1716	X	X	X	X	10, 13, 11
1725	XX	X	X	X	9, 10, 13, 11, 4, 17
1746	X		X	X	9, 10, 13, 11
1764	X	X		X	
1779		X	X	X	10, 13, 11
1790	X		X	X	10, 11
1794	X	X	X	X	15
1819	X	X	X	XX	8, 10, 11
1830	X	X	X	X	
1832	X	X	X	X	
1840	XX	XX	XX	XX	8, 10, 15, 13, 11
1851	X	X		X	
1852	XX	XX	XX	XX	10, 15, 13, 11
1867	X	X	X	X	8
1868	X	X	X	X	10, 11
1870	X		X	X	15
1879	X	X	X	X	15
1887	XX	XX	XX	XX	6, 8, 9, 10, 15, 13, 14, 11, 6, 17
1893	XX	XX	XX	XX	8, 10, 15, 11
1894	X	X		X	
1909	X	XX		X	8, 10, 15
1916	X	X		XX	8, 14
1927	X	X	X	X	9, 10, 13, 11, 12, 1,17
1928		X	X	X	8, 9, 10, 15, 13, 14, 11, 12, 1, 17

Wet years

Years	Afyon	Kütahya	Eskişehir	Isparta	References
1643		XX		X	9
1665		X		X	9, 11, 13
1681		X	X	X	11, 13
1689	X	X	X		9, 10, 11, 13
1700	X	X	XX		
1712	X	X	X		
1717	XX	X	XX	XX	10, 11
1727	X		X	X	9, 10, 11, 13
1737	X	X		X	
1739	X		X	X	
1744	XX	XX	XX	XX	10, 11, 13
1755	XX	X	X	X	10, 11, 12, 13
1762	X	X	X	X	8, 15
1770	X	X	X	X	10
1771	X	X	X	X	9, 10, 11, 13
1780	X	X	X	XX	8, 10, 11, 15
1788	XX	X	XX	XX	10, 11, 15, 13
1795	X	X		X	
1818	X	X		XX	10
1827	X	X	X	X	10, 11, 13
1835	X	X	X	X	15
1836	X	X	X	X	
1846	X	X	X	X	8, 15
1848	X	X		X	
1855	X	XX	X	X	8
1876	XX	XX	XX	XX	8, 10, 11, 15
1881	X	X	X	X	8, 9, 15, 14
1885	X	X	XX	X	8, 10, 11, 15
1891	X	X	X	X	
1897	X	X	X	X	10, 11, 15, 14, 13
1901	X	X	X		8, 9, 10, 11, 15, 14, 13
1919	XX	XX	X		8, 10, 11, 14, 13
1920	X	X	X	X	15

X: dry/wet, XX: very dry/very wet, 1: Kadioğlu (2001), 2: Zachariadou (1999), 3: Purgstall (1983), 4: Panzac (1985), 5: Quataert (1968), 6: Ottoman Archive, 7: Afkhami (1998), 8: Akkemik and Cherubini (2003), 9: Akkemik et al. (2005), 10: Akkemik and Aras (2005), 11: Touchan et al. (2003), 12: Touchan et al. (2005b), 13: D'Arrigo and Cullen (2001), 14: Hughes et al. (2001), 15: Köse et al. (2005), 16: Kuniholm (1999), 17: Touchan et al. (2007).

1885, 1891–1892 they were 2 yr long, and in AD 1809–1810–1811 they were 3 yr long.

Spatial reconstructions

For the reconstructions of Afyon, Kütahya, Eskişehir and Isparta meteorological stations, we list the years for which at least three of the stations were observed to be either dry or wet (Table 6). We determined 28 dry and 33 wet years based on four local reconstructions for western Anatolia. These meteorological stations are close (within 225 km) to each other. Therefore the dry and wet years determined by local reconstructions do not necessarily reflect the precipitation characteristics of western Anatolia as a whole. To generalize these findings, we perform spatial precipitation reconstruction. For the last 215 yr (AD 1786–2000), a period common for 31 chronologies, we spatially reconstructed the deviation of May–June precipitation from the mean. The calculated values were found to be statistically significant at the 95% confidence level for each grid cell. The maps given in Figures 4 and 5 are for the years that were found to be either dry (AD 1790, 1794, 1819, 1830, 1832, 1840, 1851–52, 1867–68, 1870, 1879, 1887, 1893–94, 1909, 1916, and 1927–28) or wet (AD 1762, 1770–71, 1780, 1788, 1795, 1827, 1835–36, 1846, 1848, 1855, 1876, 1881, 1885, 1891, 1897, 1901, and 1919–20). Within each grid cell, the color represents the precipitation deviation from the mean.

Discussion

Previous dendroclimatological studies in Anatolia showed that the most important factor limiting tree-ring growth is the precipitation during the vegetation period (Akkemik, 2000a,b,c, 2003; D'Arrigo and Cullen, 2001; Hughes et al., 2001; Touchan et al., 2003, 2005a,b, 2007; Akkemik and Aras, 2005; Akkemik et al., 2005; Köse et al., 2005). The results obtained in this study confirm this and shows that the most rapid ring growth occurs during May and June. This is probably due to the fact that sampled sites were selected mostly under Central Anatolia and Mediterranean climate, which have a summer drought.

It has been observed that the reconstructions are better at detecting dry years. For some of the extreme wet years, there are large discrepancies between the reconstructions and station data. To understand the causes of these discrepancies, standard deviations of May–June daily precipitation time series for AD 1950–2003 were plotted (Fig. 6). It can be observed that for those years in which tree-rings failed to respond (e.g. AD 1998, 1973, 1963 and 1960) rainfall was irregular. Intense rainfall resulted in surface runoff that was non-beneficial to trees.

The long-term May–June precipitation reconstructions for Afyon, Kütahya, Eskişehir and Isparta meteorological stations display mainly one-year, and rarely two-year drought events. The longest consecutive dry period was determined for Kütahya and was 4 yr long (AD 1925–1928).

Touchan (2005a) determined May–June the standardized precipitation index (SPI) for a region that also includes western Anatolia and found that the longest consecutive dry periods there were 2 yr long. On the other hand, Touchan et al. (2005b) did total precipitation reconstructions of May–August for the period between AD 1400 and 2000. In this reconstruction they determined 26 dry periods of 2 yr, eight lasting 3 yr, two lasting 4 yr and one lasting 5 yr.

AD 1840, 1852, 1887, 1893 were very dry years (below 2 standard deviations) for all meteorological stations. These years were

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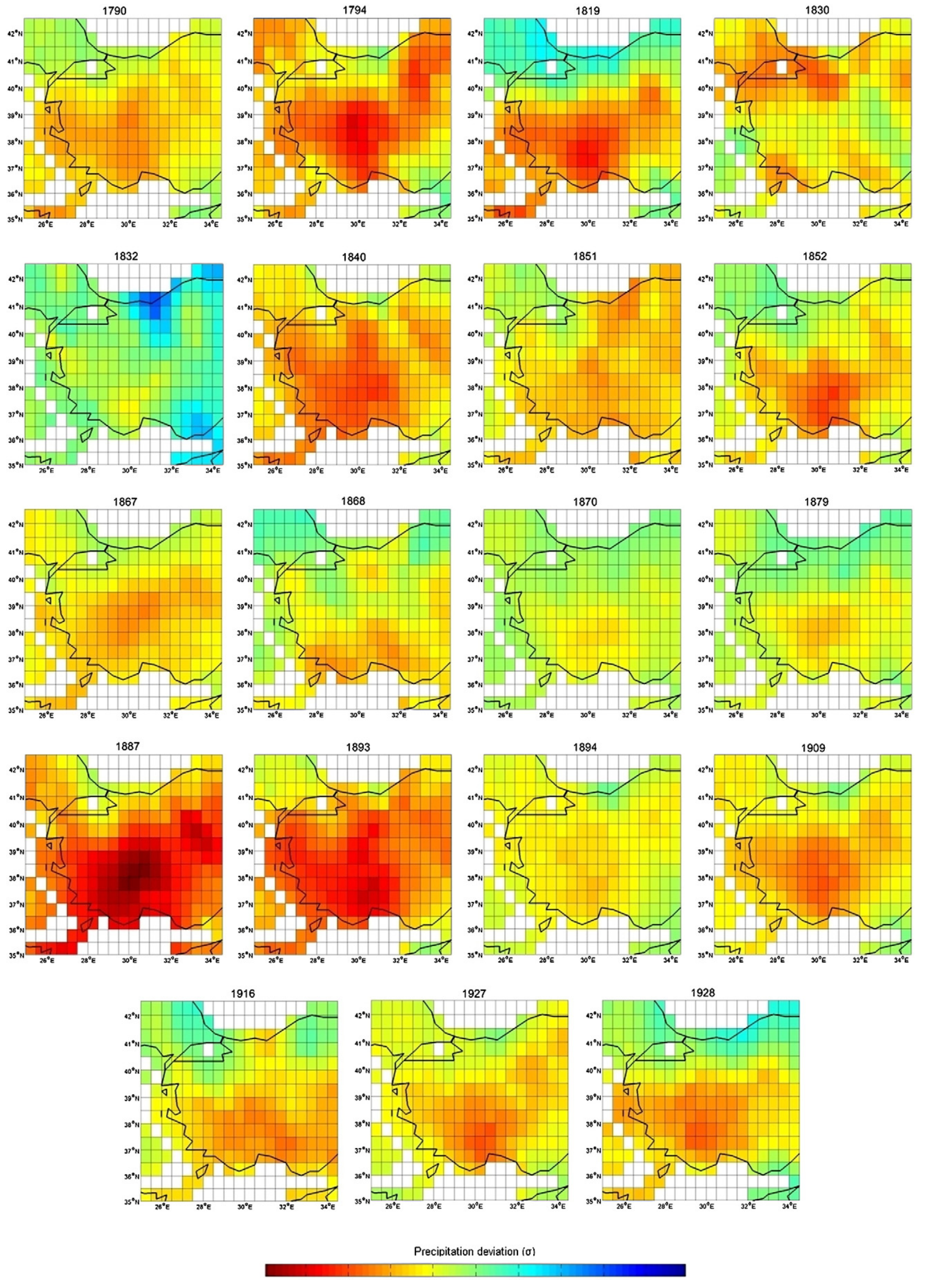

Figure 4. Deviation about the mean of precipitation for dry years in western Anatolia obtained from spatial reconstructions. The calculated values were found to be statistically significant at the 0.95% confidence level for each grid cells.

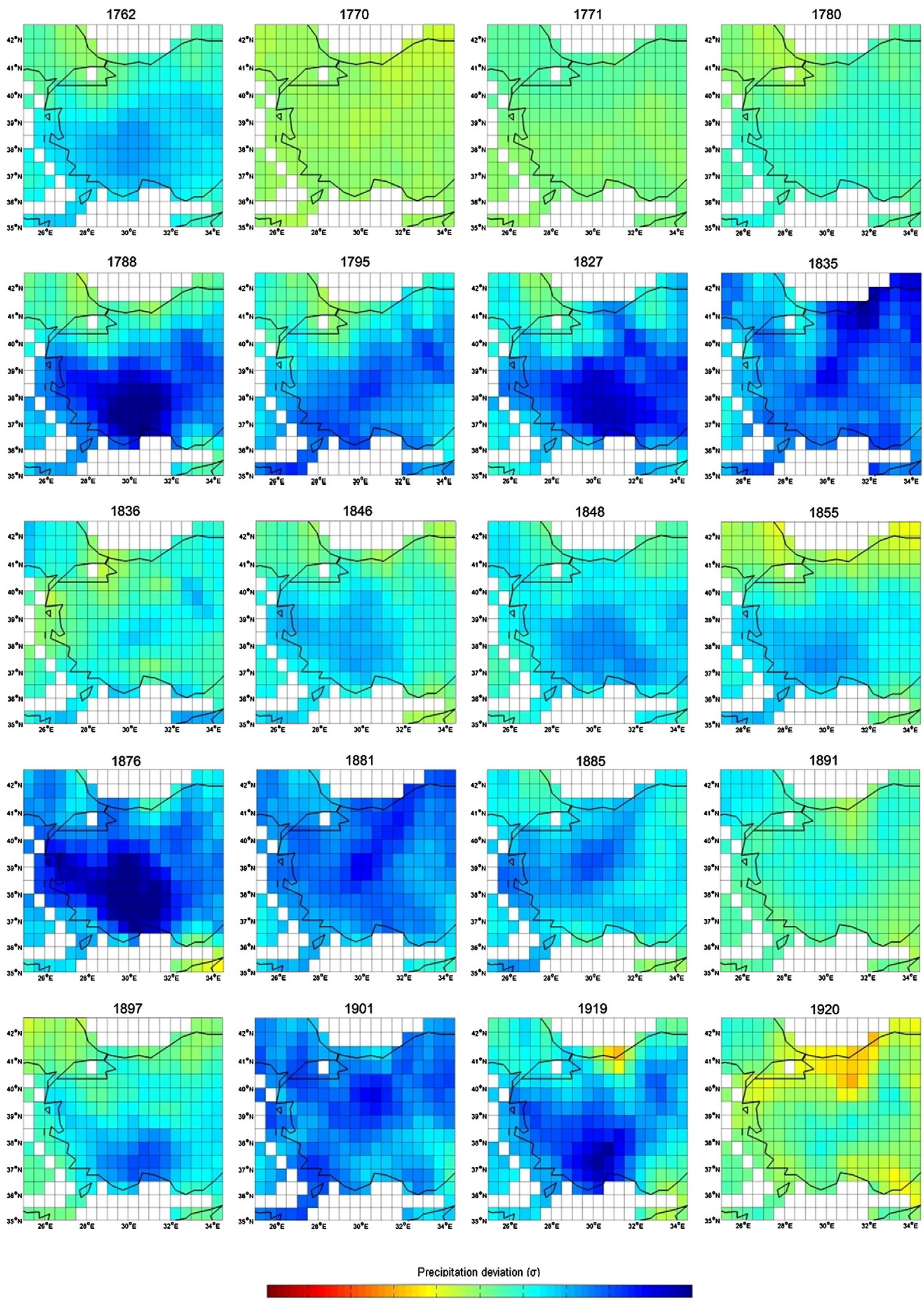

Figure 5. Deviation about the mean of precipitation for wet years in western Anatolia obtained from spatial reconstructions. The calculated values were found to be statistically significant for at the 0.95% confidence level 245 grid cells.

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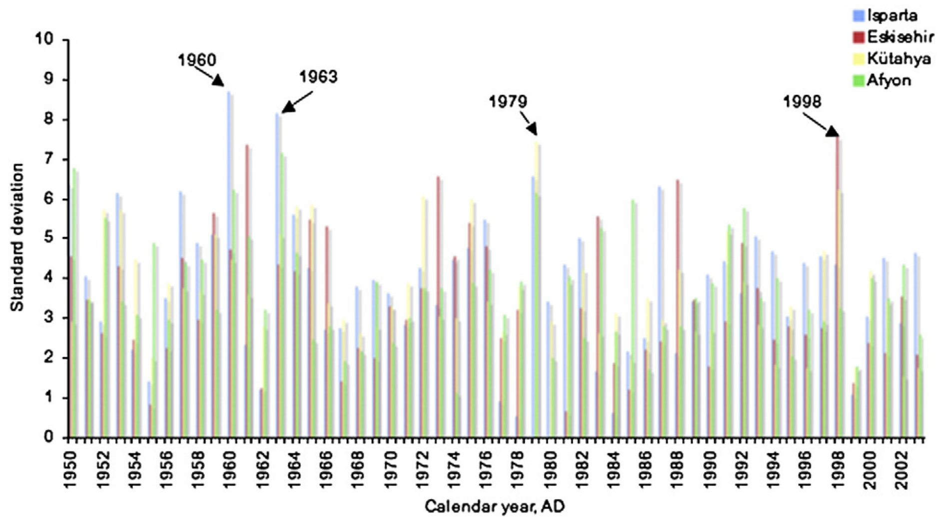

Figure 6. Standard deviations of May–June daily precipitation time series for AD 1950–2003.

mentioned as dry years also in previous studies (D'Arrigo and Cullen, 2001; Hughes et al., 2001; Akkemik and Cherubini, 2003; Touchan et al., 2003, 2005a,b, 2007; Akkemik and Aras, 2005; Akkemik et al., 2005; Köse et al., 2005; Griggs et al., 2007). Historical records about some of the dry years are given in Table 6.

Some historical records for Anatolia and neighboring countries corroborate the occurrence of major droughts and famine events. In AD 1660, which was a dry year in the Kütahya and Isparta reconstructions, catastrophic fires and famine were reported in Anatolia (Purgstall, 1983). This year was found also to have an extremely dry summer in the reconstructions developed by Touchan et al. (2005a,b, 2007). Panzac (1985) reported major droughts in Anatolia and Syria in the period AD 1725–26. Afyon and Isparta reconstructions show this period as an extremely dry interval. In AD 1887, great drought and famine were reported in Anatolia in Ottoman Archives. This year was shown as a very dry year in all the reconstructions and precipitations were below 2 SD of the mean.

Purgstall (1983) reported a sustained famine in Anatolia from AD 1925 to AD 1928. The Kütahya reconstruction shows four years of drought for the same period. This event was also detected in previous studies (Touchan et al., 2003, 2005b, 2007; Akkemik and Aras, 2005; Akkemik et al., 2005), but with a duration of two years. The fact that the reconstruction for Kütahya station was able to 'catch' this four-year event is an indication of the performance of our procedures and data.

This extremely dry period detected in the Kütahya reconstruction was also observed in the gridded CRU dataset. With the exception of 1925 (101 mm), the other years, AD 1926 (with 49 mm), 1927 (with 40 mm) and 1928 (with 31 mm) are below one standard deviation. It can easily be observed that 1928 experienced the most serious drought with 31 mm of precipitation. Similarly, all other station and spatial reconstructions show the greatest anomaly for this year.

With spatial reconstructions, spatial extent and severity of dry and wet years in western Anatolia, which founded by local reconstructions, were figured out. AD 1790, 1794, 1830, 1840, 1851, 1867, 1887, 1893, 1894, 1909 and 1927 were dry years in western Anatolia. The first years of the 2-yr dry periods of AD 1851–1852, 1893–1894 and 1927–1928 were determined to be drier than the second years. In the years AD 1819, 1868, 1870, 1879, 1916 and 1928 the drought was more severe in the inner and southern parts of the western Anatolia. AD 1832 was less dry compared to the other years (Fig. 4).

Among these dry years, in AD 1794, 1840, 1887 and 1893 the drought was exceptionally strong in spatial reconstructions (Fig. 4). Local reconstructions agree with these. These years were also determined as dry years by previous dendroclimatological studies (D'Arrigo and Cullen, 2001; Hughes et al., 2001; Akkemik and Cherubini, 2003; Touchan et al., 2003, 2005a,b, 2007; Akkemik and Aras, 2005; Akkemik et al., 2005; Köse et al., 2005; Griggs et al., 2007). Differently from local reconstructions and previous studies, spatial reconstructions showed that drought was severe in these years and affected the whole western Anatolia. Of these years, AD 1887 was found as the driest year during the last 215-year-long period. This year was also reported as a major famine year in whole land of Ottoman Empire by Gül (2009) because of severe drought.

The years AD 1788, 1795, 1827, 1835, 1876, 1881, and 1901 were wet for the entire western Anatolia. For the years AD 1836, 1846, 1848, 1855, 1891 and 1897 the precipitation standard deviation has smaller values compared to the other years. AD 1919 was a dry year in south-western Anatolia but the deviation of the precipitation in the north was above average. In AD 1920 the inner regions were wet but the standard deviations were low (Fig. 5).

Droughts are among the most serious problems for the Turkish agriculture (Korkmaz, 2009). According to the Drought Action Plan published by the Ministry of Agriculture and Rural Affairs, precipitation for the period from the cultivation (October of the previous year) until the completion of the development of the plant (June) is extremely important for plant growth (Tarım ve K.yişleri Bakanlığı, T.C., 2008). Cereals constitute 75% of the agricultural production of Turkey; wheat itself constitutes 68% (Miran, 2005). Wheat productivity depends on spring, especially April–May, precipitation (Korkmaz, 2009; Kadioğlu and Acar, 2010). As stated above, there is a big overlap between agricultural famine years and dry years as determined from reconstructions. In this context, we believe that results of our study will constitute a basis for understanding agricultural drought and better management of regional water resources.

Conclusions

In this study, May–June precipitation reconstructions were performed for four meteorological stations using 17 new site chronologies and first spatial May–June precipitation reconstruction was performed for western Anatolia. The spatial reconstruction that resulted from this study enabled us to determine the strength of the dry and wet years and the regions in Anatolia associated with them. The results show that the extreme dry and extreme wet years usually covered the entire western Anatolia. The very dry years in western Anatolia, for the reconstructed period (AD 1786–1930), were AD 1887, 1893, 1794 and 1740. The driest year during this 215-year-long period was AD 1887. This is also confirmed by the documents in the Ottoman archives and other reconstructions. In the instrumental

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period (AD 1931–2005) the very dry year in western Anatolia is AD 1935 (note that this is not indicated in any of the graphics given in the text). Between AD 1786 and 1930, the very wet years in western Anatolia were AD 1835, 1876, 1881 and 1901. In the Ottoman archives there is no reference to any of those years as being very wet, probably due to the fact that the Ottoman archives usually mention only catastrophes such as fires, earthquakes and famines.

It is clear that dendroclimatology is a powerful approach for reconstructing the climate history of Anatolia. The quality and reliability of the findings can be further improved by more detailed sampling in the future. In this spatial reconstruction study we could only go back as far as 215 yr due to the shortness of the chronologies at hand. We wish to extend this both temporally and spatially in future work. It is our hope that these findings can assist other 'historical' studies investigating the human–environment interactions and technology evolution in Anatolia.

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