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RECONSTRUCTION (1689–1994 AD) OF APRIL–AUGUST PRECIPITATION IN THE SOUTHERN PART OF CENTRAL TURKEY

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ABSTRACT

A reconstruction of April–August precipitation (1689–1994) was developed for the region by using *Pinus nigra* tree rings. A linear regression was performed using the residual chronology, composed of at least nine trees (SSS>0.85). Within this reconstructed period, dry years were distributed generally as 1 year (23 times), rarely 2 years (four times) and very rarely 3 years (one time). According to the results, dry events of 3 years' duration were seen only once (1745–47) in the reconstruction period, and wet events were seen twice (1727–29 and 1900–02). Events of 2 years' duration occurred during all three centuries: 1725–26, 1796–97, 1819–20, 1862–63 and 1927–28 (dry years), and 1770–71, 1901–02 (wet years). In accordance with other studies, the years 1693, 1725, 1819, 1868, 1878, 1887 and 1893, which were below two standard deviations, were determined as the driest years in the eastern Mediterranean basin. The distribution of dry and wet periods over time was irregular, and the time between two dry periods was not less than 6 years. There was a significant negative correlation between concurrent April–August North Atlantic oscillation and instrumental precipitation, but it was lower with reconstructed April–August precipitation and nonsignificant. The present results could be useful in the planning and management of water resources and agricultural activities in the region. Copyright © 2005 Royal Meteorological Society.

KEY WORDS: drought; reconstruction; precipitation; dendroclimatology; tree rings; eastern Mediterranean; central Turkey; *Pinus nigra*

1. INTRODUCTION

In spite of recent dendroclimatological studies that have been carried out in Turkey and neighbouring countries (Kuniholm, 1996; Hughes *et al.* 2001; D'Arrigo and Cullen, 2001; Touchan *et al.* 1999, 2003; Dalfes *et al.*, 2003), much work remains to be done. Recent studies (Bolle, 2003; Cherubini *et al.*, 2003) show that long data sets for the past climate are necessary to develop information on long-term drought for the Mediterranean basin. Chronologies sensitive to precipitation are very useful for developing a good understanding of the ongoing desertification process in the Mediterranean basin (Cherubini *et al.*, 2003).

Owing to the absence of long climatic records, information on the variability of water resources in this region (e.g. likelihood of droughts, their duration, distribution and severity) is very scarce (D'Arrigo and Cullen, 2001). This has implications for the planning and management of water resources and, as a result, for the political and economic stability of Turkey and its neighbours.

The high-quality instrumental records in Turkey start with the development of the State Meteorology Service in 1929. Over the last several years, several studies on climate variability, the effects of the North Atlantic oscillation (NAO), and El Niño/La Niña events in Turkey have been performed (Cullen and deMenocal, 2000; Karaca *et al.*, 2000; Kahya and Karabörk, 2001; Türkes and Erlat, 2003; Unal *et al.*, 2003). The data

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from these studies show that, during positive NAO years, Turkey experience significantly cooler and drier conditions, whereas warmer and wetter conditions dominate during negative phases of the NAO.

In the Mediterranean region, *Pinus nigra* Arn. is one of the principal tree species, which grow naturally at higher altitudes (Mayer and Aksoy, 1998). This species has proven to be very useful for dendroclimatic reconstruction purposes, because it produces tree rings that are sensitive to precipitation (Liphschitz *et al.*, 1979; Akkemik, 1997, 2000). Then, *P. nigra* was selected for use in the reconstruction process. The purpose of the present study was to reconstruct precipitation in the southern part of central Turkey and to understand the nature of drought.

2. DESCRIPTION OF THE REGION

Turkey has been separated into seven major geographic regions, i.e. the Mediterranean, Aegean, Marmara, Black Sea, central Anatolia, eastern Anatolia and the southeastern Anatolian region (Atalay, 1994). The major mountain chains present are in the northern and southern regions, and they are generally parallel to the coast. The mountains in the north are the Northern Anatolia Mountains and the mountains to the south are the Taurus Mountains. These mountain chains are separated from each other by wide plain areas, which are located over the central part of Anatolia.

Mountain ranges extend in an east–west direction parallel to the north and south coasts, and they are a principal factor in determining ecological conditions. The mountain ranges running parallel to the Black and Mediterranean Seas create a barrier for rain clouds moving inland, resulting in abundant rainfall on the mountain slopes facing the coast (Atalay, 1994). Along the Mediterranean coast, precipitation occurs mostly during the winter period. The south-facing slopes of the Taurus Mountains get high precipitation, whereas the slopes facing the inland parts of the mountains receive less precipitation because of the rain-shadow effect of the mountain ranges (Atalay, 1994). The mean annual total precipitation for this region is above 800 mm. In central Anatolia, as a result of being protected from the moisture-bearing air masses, the range of mean annual precipitation totals is between 350 and 500 mm (Kahya and Karabörk, 2001).

As indicated in Türkes (1996a), the Atlantic Ocean and the Mediterranean Sea are the major sources of moist air masses that cause precipitation during late autumn, winter and early spring over Turkey. The NAO predominantly governs these mid-latitude storms from the Atlantic. Cullen and deManocal (2000) found that precipitation in the entire Mediterranean sector, extending from Portugal and Morocco through to Turkey, is negatively correlated with the NAO.

Türkes (1996a) also stated that the main geographical controls on precipitation variability in Turkey are (1) the continental seas (the Mediterranean, Black and Caspian Seas), which provide natural passages for frontal cyclones; and (2) a west–east-oriented mountain range where the forced orographic ascent of air masses promotes heavy rainfall along windward slopes and loss of moisture content resulting from adiabatic 'drying' upon descent on the leeward side. Based on cluster analysis, the climate type of the region is that of the central Anatolian climate type with low precipitation (Unal *et al.*, 2003).

3. DATA AND METHODS

3.1. Tree-ring data

The sampling area is located in the upper and northern part of the Western Taurus Mountains of the Mediterranean region of Turkey (Figure 1). The dominant tree in the two sampling sites is *P. nigra*. Their maximum age is approximately 500 years (Table I). The dominant rock type is limestone and the soil is red–brown. Mixed tree species are *Cedrus libani* A. Rich., *Abies cilicica* Carr., *Juniperus foetidissima* Willd. and *Juniperus excelca* Bieb. Detailed information for the sites is given in Akkemik (1997, 2000) and relevant details are summarized in Table I.

The samples, collected in 1995, are reanalysed here for dendroclimatic reconstruction. They were also used in our previous studies (Akkemik, 1997, 2000). Tree-ring widths were measured to the nearest 0.01 mm.

Figure 1. Locations of tree-ring sites (■) and the Konya district, from where meteorological records were taken. Because the tree-ring sites are very near to each other, they were shown as one area on the map

Table I. Site information for Cevizli and Alanya (Antalya, Turkey), summarized from Akkemik (1997, 2000)

Site	Site code	Elevation (m)	Coordinates	Number of trees	Number of cores	Time span (years)	Total no of years
Antalya, Cevizli, Herse	CEVI	1700	37°20′N 31°44′E	11	20	1568–1994	426
Antalya, Alanya, Tasatan çukuru	ALAN	1250	36°44′N 32°22′E	10	19	1575–1994	419

Each ring-width series was standardized with a negative exponential function and linear regression to remove non-climatic trends due to age, size, and the effect of stand dynamics (Fritts, 1976). A modified negative exponential curve of the form

$$Y = A\exp(-Bt) + D$$

is fit to the data set. In this study, the residual version of the chronology was used. Grissino-Mayer *et al.* (1996) state that the residual version is produced in the same manner as the standard version, but in this case the series are residuals from autoregressive modelling of the detrended measurement series. The residuals from individual cores of the sites CEVI and ALAN were then combined into a master chronology using a bi-weight robust estimate of the mean (Cook *et al.*, 1990a,b). All analyses were performed using the ARSTAN program (Cook, 1985; Grissino-Mayer *et al.*, 1996).

3.2. *Climatic data*

The climatic data were obtained from the State Meteorology Service. Because the sites sampled are located at upper elevations on north-facing slopes, their environment differs from the typical Mediterranean climate. According to the cluster analysis of Unal *et al.* (2003), the area sampled is climatically similar to the central Anatolian region. Climate data from six meteorological stations were used in the initial analysis. Data begin in the year 1930 at Konya and Antalya, and in the year 1961 at Karaman, Eregli, Karapinar and Alanya. For this reason, the data for Konya and Antalya were sufficient for dendroclimatological reconstruction. Correlation coefficients between April and August precipitation of the six stations and the tree-ring chronology are given below. Because Antalya and Alanya experience the typical Mediterranean climate conditions, correlation coefficients were lower. Based on the results of both data lengths and correlations, we selected the data for the Konya station:

Antalya	Konya	Alanya	Karaman	Eregli	Karapinar
0.26	0.62	0.44	0.49	0.48	0.58

Therefore, the monthly total precipitation of the Konya district, located in the southern part of central Turkey (Figure 1), was used in the dendroclimatic reconstruction. Mean annual precipitation and mean temperature of the Konya Meteorology Station were 322 mm and 11.0 °C respectively.

3.3. Dendroclimatological reconstruction

As a preliminary step, the relationship between tree-ring indices and monthly precipitation was investigated with simple correlation analysis. Monthly correlation coefficient plots identified April–August precipitation as the most appropriate predictand for reconstruction. Therefore, based on correlation and graphical comparisons, April–August precipitation totals were selected as the appropriate season for reconstruction.

Wigley *et al.* (1984) derived an equation that describes the variance in common between a t'-core subsample and the t-core chronology, assuming that there is only one core per tree. Where multiple cores are available, r_{eff} should be used, and t' and t become the number of trees in the subsample and reference chronologies respectively. They define a quantity, the subsample signal strength (SSS; Briffa and Jones, 1990), as

$$\text{SSS} = \frac{t'\,[1 + (t-1)r_{\text{eff}}]}{t\left[1 + (t'-1)r_{\text{eff}}\right]}$$

Because an unequal number of cores per tree were averaged, in this equation r_{eff} was used. The SSS, which is computed from data on sample size and between-tree correlation, is a guide to assessing the likely loss of reconstruction accuracy, which occurs when the chronology is made up of too few series (Wigley *et al.*, 1984). In the current study, SSS > 0.85 corresponded to a minimum sample depth of nine trees and allowed for reconstruction for the period AD 1689 to 1994. Regression (Touchan *et al.*, 1999) and analysis of variance (ANOVA) were used to develop the reconstruction.

Initially, the period 1931–64 was used for calibration and the period 1965–94 was used for verification. Following this, the period 1965–94 was used for calibration and the period 1931–64 was used for verification.

The reduction of error (RE) statistic provides a highly sensitive measure of reliability. RE should assume a central role in the verification procedure. The equation used to calculate RE is defined as follows (Fritts *et al.*, 1990):

$$\text{RE} = 1 - \frac{\sum (y_i - y_t)^2}{\sum (y_i - \hat{y})^2} \quad i = 1, \ldots, n$$

where y_i is one of n observed values, y_t is the estimate, and $\hat{y}$ is the mean of the observed values for those climatic data used to calibrate the regression equation (not the average value of the independent data) (Blasing *et al.*, 1981). The theoretical limits for the values of the RE statistic range from a maximum of +1, which indicates perfect agreement, to minus infinity. This is a very rigorous statistic, and any positive value in RE indicates there is some useful information in the reconstruction (Fritts *et al.*, 1990). Correlation coefficients and adjusted R^2 were used as additional comparisons between the actual and estimated values.

The reconstruction was compared with previous dendroclimatological studies (Kuniholm, 1996; D'Arrigo and Cullen, 2001; Hughes *et al.*, 2001; Touchan *et al.*, 2003) to identify common regional dry and wet years. Türkes (1996b) suggested three limiting values to find dry and wet years for Turkey. The calculation method is a well-known normalization formula:

$$Z_i = \frac{X_i - \overline{X}}{s}$$

where Z_i are normalized values, X_i are climatic data in the year i, $\overline{X}$ is the mean of the climatic data, and s is the standard deviation. The limiting values given by Türkes (1996b) are $\pm 1.30 \geqslant Z_i \geqslant \pm 0.86$ for slightly dry or wet years (m±); $\pm 1.75 \geqslant Z_i \geqslant \pm 1.31$ for moderately dry or wet years (vm±); $Z_i \geqslant \pm 1.76$ for extreme dry or wet years (ex±)

Numerous moderate and extreme dry and wet years were identified. These moderate and extremely dry and wet years were compared with those of other dendroclimatic studies (Kuniholm, 1996; D'Arrigo and Cullen, 2001; Hughes *et al.*, 2001; Touchan *et al.*, 2003).

The 13-year low-pass filter method (Fritts, 1976) was also used to find periodic changes in the actual and estimated precipitation data.

The NAO index (which is defined as the difference between the normalized mean winter sea-level pressure anomalies at locations representative of the Azores high and the Icelandic low) is the dominant mode of winter climate variability in the North Atlantic region, ranging from central North America to Europe and into large parts of northern Asia (Türkes and Erlat, 2003). In correlation analysis, monthly and annual NAO data (http://www.cru.uea.ac.uk/cru/data/nao.htm) were used to investigate links between the state of the Atlantic ocean–atmosphere system and precipitation in the southeastern part of central Turkey.

4. RESULTS AND DISCUSSION

4.1. Chronology

A tree-ring chronology 426 years in length, from 1568 to 1994, was constructed using the ARSTAN program (Figure 2). The statistical composition of the series is given in Table II. As given in Table II, the average correlations within trees (0.471, $p \leqslant 0.001$) and radii with master (0.485, $p \leqslant 0.001$), and the signal-to-noise ratio (5.074) were high.

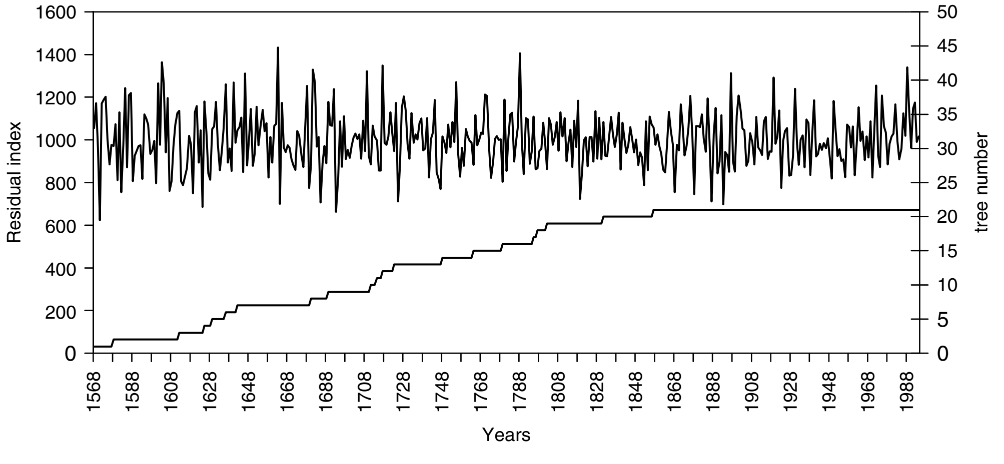

Figure 2. The residual chronology covering the years 1568–1994, and the number of trees

Table II. Summary statistics for the residual chronology from ARSTAN

Chronology type	Residual
Chronology time span	1568–1994
Total no of years	426
Mean	0.9952
Median	0.9947
Mean sensitivity	0.1380
Standard deviation	0.1261
Skewness	0.3084
Kurtosis	0.4543
Autocorrelation order 1	−0.0105
Common interval time span 1802 to 1994 19 trees, 30 radii	
Mean correlations:	
Among all radii	0.217
Within trees	0.471
Radii versus mean	0.485
Signal-to-noise ratio	5.074
Agreement with population chronology	0.835
Variance in first eigenvector (%)	25.12
Chron common interval mean	0.994
Chron common interval std dev	0.113

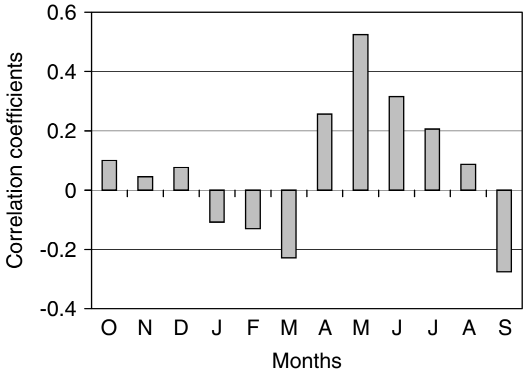

Figure 3. Correlation coefficients between the residual chronology and monthly total precipitation from October of the previous year to September of the current year. Horizontal lines indicate confidence levels at $p \leqslant 0.05$, $p \leqslant 0.01$ and $p \leqslant 0.001$

4.2. *Dendroclimatic reconstruction*

The correlation coefficients between the residual chronology and monthly climatic data between 1931 and 1994 revealed that the precipitation was significantly positively correlated from April to August (Figure 3). This result shows that low precipitation in these months limits tree-ring growth in *P. nigra*. A visual comparison of the residual chronology and total April–August precipitation was also performed (Figure 4). The Pearson correlation coefficient between the two series was 0.62 ($p \leqslant 0.001$). This result indicates that April–August precipitation was the most appropriate predictand for reconstruction.

The SSS showed that 1689 should be the first year of the reconstruction. Therefore, the time period covered by the reconstruction was from 1689 to 1994. Total instrumental data for April–August from 1931 to 1994 was the predictand, and the residual chronology was the predictor used to develop the reconstruction. The regression results are given in Table III. According to the results of ANOVA, in the first model the adjusted

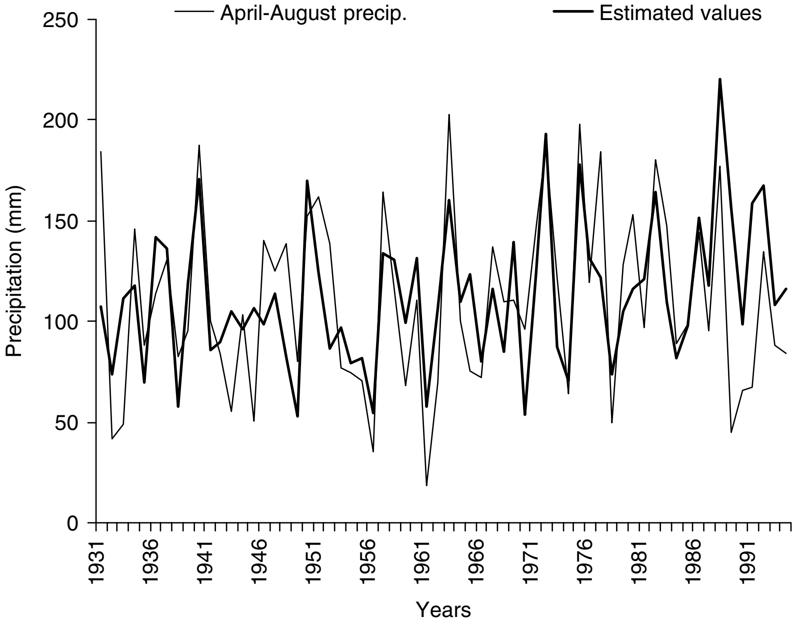

Figure 4. Actual and estimated April–August precipitation

Table III. Results of the calibration between April–August precipitation and tree-ring chronology of *P. nigra* yielded from linear regressions

Calibration period	Verification period	Constant and coefficients	Adj. R^2	F	RE	Pearson correlation	
						Calibration period	Verification period
1931–64	1965–94	−211.098 0.322203	0.43	26.241 ($p \leqslant 0.001$)	0.38	0.67 ($p \leqslant 0.001$)	0.57 ($p \leqslant 0.001$)
1965–94	1931–64	−96.8034 0.205157	0.30	13.299 ($p \leqslant 0.001$)	0.38	0.57 ($p \leqslant 0.001$)	0.67 ($p \leqslant 0.001$)

R^2 and F values were 0.43 and 26.241 ($p \leqslant 0.001$) respectively, with an RE value of 0.38. Any positive value of the RE statistic indicates there is some information in the reconstruction. Therefore, the first model was selected for reconstruction. The equation of this model was

$$y_r = -211.098 + 0.322X$$

The estimated values are given in Figure 5. As used by D'Arrigo and Cullen (2001), the values outside the inner horizontal lines (one standard deviation) are considered as 'dry' and 'wet' years, and those beyond the outer horizontal lines (two standard deviations) were extremely dry and extremely wet years. In our study, dry and wet years generally occurred as individual years, sometimes as two consecutive years, and once as 3 years (Table IV).

A very high similarity was observed on comparing the previous dendroclimatological studies of the years, which are considered as dry or wet (Kuniholm, 1996; D'Arrigo and Cullen, 2001; Hughes *et al.*, 2001; Touchan *et al.*, 2003).

Based on limiting values for dry and wet years (Türkes, 1996b), a classification was made (Table IV). As an instance, in Table IV, the year 1693 (ex−)* was an extreme negative year (ex−) (a driest year) and it

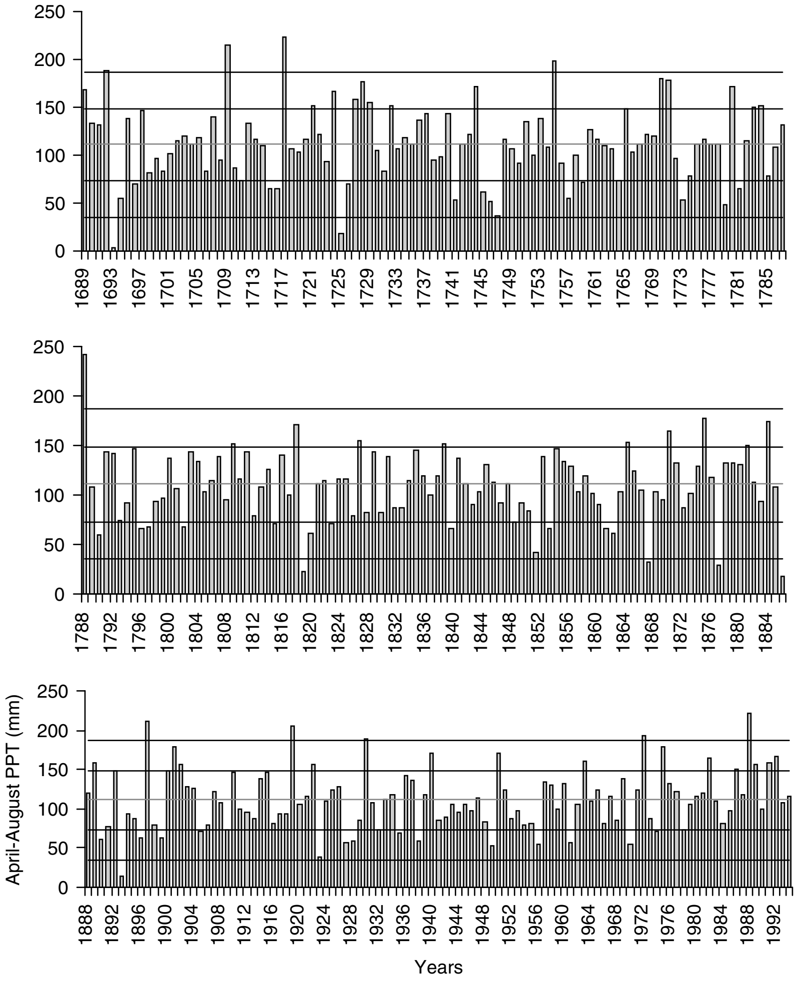

Figure 5. Estimated (bar) from 1689 to 1994 AD April–August precipitation. Inner horizontal lines (dotted) indicate the limits of one standard deviation, and outer ones (line) indicate the limits of two standard deviations

was considered as a dry year by one previous reconstruction (*). Based on Türkes' (1996b) limiting values, with the exception of the years explained in Table IV, the years 1737, 1740, 1765, 1783–84, 1791–92, 1795, 1803, 1811, 1829, 1835, 1855, 1892, 1900 and 1915 could be interpreted as wet years. On the other hand, the years 1774, 1785, 1793, 1826, 1849, 1891, 1898 and 1906 should be considered as dry years. Because none of these years exceeded one standard deviation, they were not included in Table IV. The years 1812–13, 1851, 1873–74, 1895 and 1916, which were identified by D'Arrigo and Cullen (2001) and Touchan *et al.* (2003) as dry years, were below the mean in this present study, but they did not exceed a one standard deviation threshold.

Our results showed that dry (1745–47) and wet (1727–29 and 1900–02) events with 3 years' duration were seen during the 18th and 20th centuries. Dry events of 2 years' duration occurred during all three centuries: 1725–26, 1796–97, 1819–20, 1862–63 and 1927–28 and 2-year wet events occurred in 1770–71. As also stated by Touchan *et al.* (2003), drought events of more then 3 years were very rare and occurred only once during the period 1476–79.

The 13-year low-pass filter values were highly similar in both actual and estimated precipitation data (Figure 6). The correlation coefficient between them was 0.69 ($p \leqslant 0.001$). Based on this strong

Table IV. Dry and wet years for the period 1689–1930, and comparison with previous studies carried out in Turkey (Kuniholm, 1996; D'Arrigo and Cullen, 2001; Hughes *et al.*, 2001; Touchan *et al.*, 2003). The symbol (*) indicates that this year was identified by at least one previous study, (**) by at least two and (***) by at least three previous studies. (ex±) indicates extreme, (vm±) moderate, and (m±) slight event years. The event years were dry (−) and wet (+) years. Italics show the driest years

Driest years (below 2SD)	Dry years (below 1SD)	Wet years (over 1SD)	Wettest years (over 2SD)
1693 (ex−)*	_1693 (ex−)_*–1694(vm−)*	1689 (vm+)**	1692 (ex+)*
1725 (ex−)**	1696 (m−)**	1721 (m+)	1709 (ex+)**
1819 (ex−)*	1715(m−)*–1716(m−)*	1724 (vm+)*	1717 (ex+)*
1868 (ex−)*	_1725 (ex−)_*–1726(m−)**	1727(m+)*–1728(vm+)*–1729(m+)	1755 (ex+)*
1878 (ex−)	1741 (vm−)*	1732(m+)	1788 (ex+)*
1887 (ex−)****	1745(m−)–1746(vm−)**–1747(ex−)	1744 (vm+)**	1897 (ex+)***
1893 (ex−)*	1757 (vm−)**	1765 (m+)	1919 (ex+)***
	1759 (m−)**	1770(ex+)–1771(ex+)*	1930 (ex+)***
	1773 (vm−)	1780 (vm+)*	
	1779 (vm−)*	1809 (m+)*	
	1781 (m−)*	1818 (vm+)	
	1790 (vm−)*	1827 (m+)*	
	1796(m−)*–1797(m−)*	1839 (m+)	
	1802 (m−)	1865 (m+)*	
	1815 (m−)*	1871 (m+)	
	_1819 (ex−)_*–1820(vm−)*	1876 (vm+)*	
	1823 (m−)*	1882 (m+)*	
	1840 (m−)*	1885 (vm+)*	
	1852 (ex−)**	1889 (m+)*	
	1854 (m−)*	1892 (m+)*	
	1862(m−)*–1863(m−)*	1900(m+)–1901(vm+)***–1902(m+)	
	1890 (vm−)****	1922 (m+)	
	1896 (vm−)		
	1899 (vm−)		
	1905 (m−)*		
	1909 (m−)*		
	1923 (ex−)*		
	1927(vm−)*–1928(vm−)***		

covariability, a plot showing the variation with 13-year duration in precipitation is shown in Figure 7. The distribution of dry and wet periods was irregular, and the time between two dry periods was not less than 6 years.

The correlation between the NAO, which is traditionally defined as the normalized pressure difference between a station on the Azores and one on Iceland, and April–August precipitation is significantly negative ($r = -0.37^{**}$). Türkes and Erlat (2003) also found a negative relationship between the Turkish precipitation series and the NAO index. However, the correlation between reconstructed April–August precipitation and NAO was not significant. In another study, Cullen and deMenocal (2000) investigated the regional extent of the NAO over the eastern Mediterranean sector and concentrated on the impacts of the NAO in terms of temperature, precipitation and the discharge of the Tigris–Euphrates in Turkey. They found that, during positive NAO years, Turkey experiences significantly cooler and drier conditions, whereas warmer and wetter conditions dominate during negative phases of the NAO, due to the more zonal trajectories of Atlantic heat and moisture. On the contrary, Touchan *et al.* (2003) found no significant correlation between May–June instrumental precipitation and the NAO.

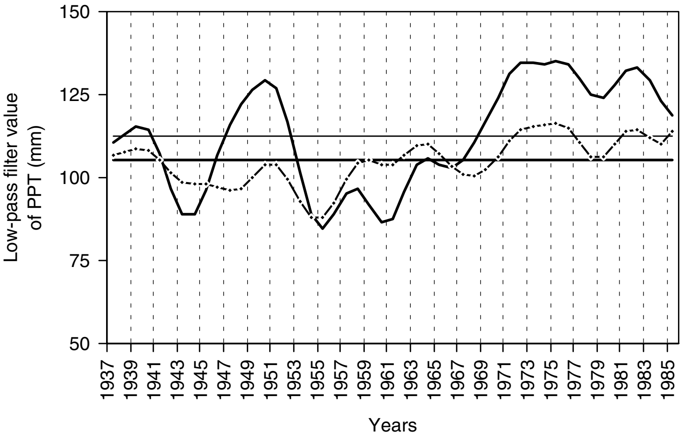

Figure 6. The 13-years' duration low-pass filter values for both actual and estimated April–August precipitation. Strong covariability can clearly be seen

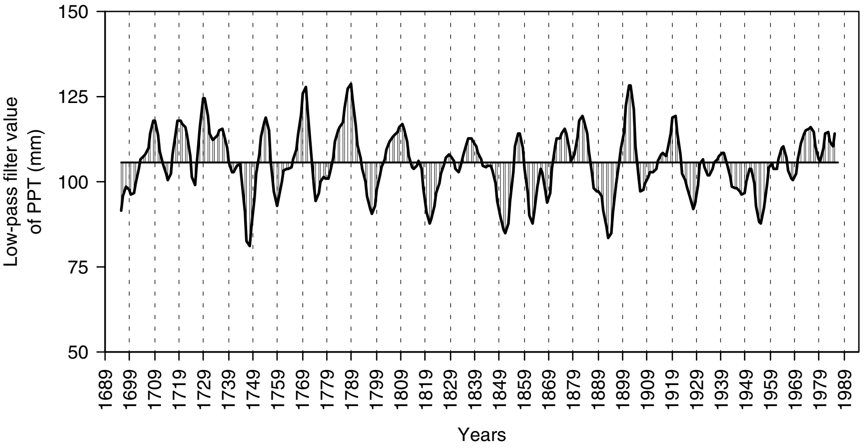

Figure 7. The 13-years' duration low-pass filter for April–August precipitation. The changes were irregular, and the time between two dry periods was never less than 6 years

5. CONCLUSIONS

With this study, a precipitation reconstruction for the southern part of central Anatolia was developed. The earlier reconstructions (D'Arrigo and Cullen, 2001; Touchan *et al.*, 2003) and our study showed that droughts of more than 3 years in duration have not occurred during the last three centuries. Touchan *et al.* (2003) in a longer chronology found that the longest period of drought, which occurred only once during the past six centuries were the years between 1476 and 1479. Compared with previous studies (Kuniholm, 1996; D'Arrigo and Cullen, 2001; Hughes *et al.*, 2001; Touchan *et al.*, 2003), our data also demonstrate a high relationship in dry and wet years. Based on the Ottoman Records, Kadıoglu (2001) showed that a severe drought occurred in Anatolia during the years 1873–74 and 1925–28. Our results also showed these drought periods as having 2 years' durations (1873–74, and 1927–28) and where the year 1887 was one of the driest years in the reconstructed series. Furthermore, the year 1890, which was a dry year in the reconstructed series, is documented as a very dry year, which caused a serious cholera outbreak in Iran (Afkhami, 1998). In Figure 7, the years 1890 and 1925–28 were clearly seen as extreme dry years.

Our data further show that, under stressed conditions, *P. nigra* trees produce tree rings that are sensitive to precipitation in the Mediterranean part of Turkey and might be very useful in dendroclimatological studies. The present results give us some important data on dry and wet years and their durations in the region. As stated by Cherubini *et al.* (2003) and Dalfes *et al.* (2003), the nature of drought is of paramount importance for the Mediterranean region. These results might be useful for future planning purposes.

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REFERENCES

Afkhami A. 1998. Disease and water supply: the case of cholera in 19th century Iran. In *Transformations of Middle Eastern Natural Environments: Legacies and Lessons*, Coppock J, Miller J (eds). *Yale University Bulletin Series* No. 103. Yale University Press: New Haven, CT: 206–220.

Akkemik Ü. 1997. Dendrochronological studies on *Pinus nigra* Arn and *Abies cilicica* Carr in western Mediterranean region of Turkey. PhD thesis, University of Istanbul, Faculty of Forestry (in Turkish).

Akkemik Ü. 2000. Dendrochronological investigations in two monumental *Pinus nigra* Arn stands near Antalya (Turkey). In *Proceedings of the International Scientific Conference — 75 Years University Forestry Education in Bulgaria*, 15–16 June 2000, Sofia, Bulgaria; 179–187.

Atalay I. 1994. *Türkiye Vejetasyon Cografyasi (Vegetation geography of Turkey).* Ege Universitesi Basimevi: Izmir.

Blasing TJ, Duvick DN, West DC. 1981. Dendroclimatic calibration and verification using regionally averaged and single station precipitation data. *Tree-Ring Bulletin* **41**: 37–43.

Bolle HJ. 2003. Mediterranean drought observed from space. *AVEC workshop, Variablility of European Ecosystems Facing an Increasing Drought Risk. Abstract Book*: 4.

Briffa K, Jones PD. 1990. Basic chronology statistics and assessment. In *Methods of Dendrochronology: Applications in the Environmental Sciences*, Cook E, Kairiukstis LA (eds). Kluwer Academic Publishers: Boston; 137–152.

Cherubini P, Tognetti R, D'Arrigo R, Gartner BL, Akkemik Ü, Solomina O. 2003. Tree-ring evidence of past droughts at mediterranean and mesic sites. *AVEC workshop, Variablility of European Ecosystems Facing an Increasing Drought Risk. Abstract Book*: 5–6.

Cook E. 1985. A time series analysis approach to tree-ring standardization. Unpublished PhD dissertation, University of Arizona, Tucson.

Cook E, Briffa K, Shiyatov S, Mazepa V. 1990a. Tree-ring standardization and growth-trend estimation. In *Methods of Dendrochronology: Applications in the Environmental Sciences*, Cook E, Kairiukstis LA (eds). Kluwer Academic Publishers: Boston; 104–122.

Cook E, Shiyatov S, Mazepa V. 1990b. Estimation of the mean chronology. In *Methods of Dendrochronology: Applications in the Environmental Sciences*, Cook E, Kairiukstis LA (eds). Kluwer Academic Publishers: Boston; 123–132.

Cullen HM, deMenocal PB. 2000. North Atlantic influence on Tigris–Euphrates streamflow. *International Journal of Climatology* **20**: 853–863.

Dalfes HN, D'Arrigo R, Cullen H, Jacoby G, Önol B. 2003. Hydrometeorological variability of eastern Anatolia: recent results from dendroclimatological reconstructions. In *AVEC-Workshop, Variability of European Ecosystems Facing an Increasing Drought Risk. Abstract Book*; 7–8.

D'Arrigo R, Cullen HM. 2001. A 350-year (AD 1628–1980) reconstruction of Turkish precipitation. *Dendrochronologia* **19**(2): 169–177.

Fritts HC. 1976. *Tree-Rings and Climate*. Kluwer Academic Publishers: New York.

Fritts HC, Guiot J, Gordon GA, Schweingruber FH. 1990. Methods of calibration, verification, and reconstruction. In *Methods of Dendrochronology: Applications in the Environmental Sciences*, Cook E, Kairiukstis LA (eds). Kluwer Academic Publishers: Boston; 163–217.

Grissino-Mayer HD, Holmes RL, Fritts HC. 1996. *The International Tree-Ring Data Bank Program Library Version 2.0 User's Manual*. Laboratory of Tree-Ring Research, The University of Arizona: Tucson, AZ.

Hughes MK, Kuniholm PI, Garfin GM, Latini C, Eischeid J. 2001. Aegean tree-ring signature years explained. *Tree-Ring Research* **57**(1): 67–73.

Kadıoglu M. 192001. *Bildiğiniz Havaların Sonu — Küresel İklim Değişimi ve Türkiye*. Güncel Yayınları: Istanbul (in Turkish).

Kahya E, Karabörk MC. 2001. The analysis of El Niño and La Niña signals in streamflows of Turkey. *International Journal of Climatology* **21**: 1231–1250.

Karaca M, Deniz A, Tayanç M. 2000. Cyclone track variability over Turkey in association with regional climate. *International Journal of Climatology* **20**: 1225–1236.

Kuniholm PI. 1996. Long tree-ring chronologies for the eastern Mediterranean. *Archaeometry 1994. Proceedings of the 29th International Symposium on Archaeometry*, Ankara, Turkey; 401–409.

Liphschitz N, Lew-Yadun S, Waisel Y. 1979. Dendrochronological investigations in the Mediterranean basin — *Pinus nigra* of south Anatolia (Turkey). *La-Yaaran, The Journal of the Israel Forestry Association* **26**(1–2): 1–10.

Mayer H, Aksoy H. 1998. Türkiye ormanları (Turkey forests). Publication of Ministry of Forestry, No. 38 (in Turkish).

Touchan R, Meko D, Hughes MK. 1999. A 396-year reconstruction of precipitation in southern Jordan. *Journal of the American Water Resources Association* **35**(1): 49–59.

Touchan R, Garfin GM, Meko DM, Funkhouser G, Erkan N, Hughes MK, Wallin BS. 2003. Preliminary reconstructions of spring precipitation in southwestern Turkey from tree-ring width. *International Journal of Climatology* **23**: 157–171.

Türkes M. 1996a. Spatial and temporal analysis of annual rainfall variations in Turkey. *International Journal of Climatology* **16**: 1057–1076.

Türkes M. 1996b. Meteorological drought in Turkey: a historical perspective, 1930–93. *Drought Network News* **8**: 17–21.

Türkes M, Erlat E. 192003. Türkiye'de Kuzey Atlantik Salınımı ile bağlantılı yağış değişiklikleri ve değişebilirliği. *III. Atmoafer Bilimleri Sempozyumu*, 19–21 March 2003, Istanbul, Turkey. Proceedings; 318–333 (in Turkish).

Unal Y, Kindap T, Karaca M. 2003. Redefining the climate zones of Turkey using cluster analysis. *International Journal of Climatology* **23**: 1045–1055.

Wigley TML, Briffa K, Jones PD. 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. *Journal of Climate and Applied Meteorology* **23**: 201–213.