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1    **Spring temperature variability over Turkey since 1800 CE reconstructed**

2    **from a broad network of tree-ring data**

3

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20    **Abstract**

21    The 20th century was marked by significant decreases in spring temperature ranges and increased

22    nighttime temperatures throughout Turkey. The meteorological observational period in Turkey,

23    which starts *ca.* 1929 CE, is too short for understanding long-term climatic variability. Hence,

24    the historical context of this gradual warming trend in spring temperatures is unclear. Here we

25    use a network of 23 tree-ring chronologies to provide a high-resolution spring (March–April)

26    temperature reconstruction over Turkey during the period 1800–2002. The reconstruction model

27    accounted for 67% (Adj. $R^2 = 0.64$, p $\leq$ 0.0001) of the instrumental temperature variance over the

28    full calibration period (1930–2002). During the pre-instrumental period (1800-1929) we captured

29    more cold events ($n = 23$) than warm ($n = 13$), and extreme cold and warm events were typically

30    of short duration (1–2 years). Compared to coeval reconstructions of precipitation in the region,

31    our results are similar with durations of extreme wet and dry events. The reconstruction is

32    punctuated by a temperature increase during the 20th century; yet extreme cold and warm events

33    during the 19th century seem to eclipse conditions during the 20th century. During the 19th

34    century, annual temperature ranges are more volatile and characterized by more short-term

35    fluctuations compared to the 20th century. During the period 1900–2002, our reconstruction

36    shows a gradual warming trend, which includes the period during which diurnal temperature

37    ranges decreased as a result of increased urbanization in Turkey.

38

39    KEYWORDS: Dendroclimatology, Climate reconstruction, *Pinus nigra,* Principle component

40    analysis, Spring temperature.

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## 1 Introduction

Significant decreases in spring diurnal temperature ranges (DTR) occurred throughout Turkey

from 1929 to 1999 (Turkes & Sumer 2004). This decrease in spring DTRs was characterized by

day-time temperatures that remained relatively constant while a significant increase in night-time

temperatures were recorded over western Turkey and were concentrated around urbanized and

rapidly-urbanizing cities. The historical context of this gradual warming trend in spring

temperatures is unclear as the high-quality meteorological records in Turkey, which start in

1929, are relatively short for understanding long-term climatic variability.

Tree rings have shown to provide useful information about the past climate of Turkey and were

used intensively during the last decade to reconstruct precipitation in the Aegean (Hughes et al.

2001, Griggs et al. 2007), Black Sea (Akkemik et al. 2005), Mediterranean regions (Touchan et

al. 2005a), as well as the Sivas (D'Arrigo & Cullen 2001), southwestern (Touchan et al. 2003,

Touchan et al. 2007), south-central (Akkemik & Aras 2005) and western Anatolian (Köse et al.

2011) regions of Turkey. These studies used tree rings to reconstruct precipitation because

available moisture is often found to be the most important limiting factor that influences radial

growth of many tree species in Turkey. These studies revealed past spring-summer precipitation,

and described past dry and wet events and their duration. Recently, Heinrich et al. (2013)

provided a winter-to-spring temperature proxy for Turkey from carbon isotopes within the

growth rings of *Juniperus excelsa* since AD 1125. Low-frequency temperature trends

corresponding to the Medieval Climatic Anomaly and Little Ice Age were identified in the

record, but the proxy failed to identify the recent warming trend during the 20th century. In this

64  study, we present a tree-ring based spring temperature reconstruction from Turkey and compare

65  our results to previous reconstructions of temperature and precipitation to provide a more

66  comprehensive understanding of climate conditions during the 19th and 20th centuries.

67

68  **2  Data and Methods**

69  2.1 Climate of the Study Area

70

71  The study area, which spans 36–42º N and 26–38º E, was based on the distribution of available

72  tree-ring chronologies. This vast area covers much of western Anatolia and includes the western

73  Black Sea, Marmara, and western Mediterranean regions. Much of this area is characterized by a

74  Mediterranean climate that is primarily controlled by polar and tropical air masses (Türkeş 1996,

75  Deniz et al. 2011). In winter, polar fronts from the Balkan Peninsula bring cold air that is

76  centered in the Mediterranean. Conversely, the dry, warm conditions in summer are dominated

77  by weak frontal systems and maritime effects. Moreover, the Azores high-pressure system in

78  summer and anticyclonic activity from the Siberian high-pressure system often cause below

79  normal precipitation and dry sub-humid conditions over the region (Türkeş 1999, Deniz et al.

80  2011). In this Mediterranean climate, annual mean temperature and precipitation range from 3.6

81  °C to 20.1 °C and from 295 to 2220 mm, respectively, both of which are strongly controlled by

82  elevation (Deniz et al. 2011).

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87    2.2 Development of tree-ring chronologies

88

89    To investigate past temperature conditions, we used a network of 23 tree-ring site chronologies

90    (Fig. 1). Fifteen chronologies were produced by previous investigations that focused on

91    reconstructing precipitation in the study area. In addition, we sampled eight new study sites and

92    developed tree-ring time series for these areas (Table 1). Increment cores were taken from living

93    *Pinus nigra* Arn. and *Pinus sylvestris* L. trees and cross-sections were taken from *Abies*

94    *nordmanniana* (Steven) Spach and *Picea orientalis* (L.) Link trees.

95

96    Samples were processed using standard dendrochronological techniques (Stokes & Smiley 1968,

97    Orvis & Grissino-Mayer 2002, Speer 2010).  Tree-ring widths were measured, then visually

98    crossdated using the list method (Yamaguchi 1991). We used the computer program COFECHA,

99    which uses segmented time-series correlation techniques, to statistically confirm our visual

100   crossdating (Holmes 1983, Grissino-Mayer 2001).  Crossdated tree-ring time series were then

101   standardized by fitting a 67% cubic smoothing spline with a 50% cutoff frequency to remove

102   non-climatic trends related to the age, size, and the effects of stand dynamics using the ARSTAN

103   program (Cook 1985, Cook et al. 1990a). These detrended series were then pre-whitened with

104   low-order autoregressive models to remove persistence not related to climatic variations. For

105   each chronology, the individual measured series were averaged to a single chronology by

106   computing the biweight robust means to reduce the influences of outliers (Cook et al. 1990b).

107   The mean sensitivity, which is a metric representing the year-to-year variation in ring width

108   (Fritts 1976), was calculated for each chronology and compared. The minimum sample depth for

109   each chronology was determined according to expressed population signal (EPS), which we used

110    as a guide for assessing the likely loss of reconstruction accuracy. Although arbitrary, we

111    required the commonly considered  threshold of EPS > 0.85 (Wigley et al. 1984; Briffa & Jones

112    1990).

113

114        2.3 Temperature reconstruction

115

116    We extracted monthly temperature and precipitation records from the climate dataset CRU TS

117    3.23 gridded at 0.5º intervals (Jones and Harris 2008) from KNMI Climate Explorer

118    (http://climexp.knmi.nl) for 36–42 ºN, 26–38 ºE. The period AD 1930–2002 was chosen for the

119    analysis because it maximized the number of station records within the study area.

120

121    First, the climate-growth relationships were investigated with response function analysis (RFA)

122    (Fritts 1976) for biological year from previous October to current October using the

123    DENDROCLIM2002 program (Biondi & Waikul 2004). This analysis is done to determine the

124    months during which the tree-growth is the most responsive to temperature. Second, the climate

125    reconstruction is performed by regression based on the principal component (PCs) of the 23

126    chronologies within the study area. The significant PCs were selected by stepwise regression.

127    The regression equation is calibrated on the common period (1930–2002) between robust

128    temperature time-series and the selected tree-ring series. Third, the final reconstruction is based

129    on bootstrap regression (Till and Guiot, 1990), the best method to assess the quality of the

130    regression and to calculate appropriate confidence intervals. It consists in randomly resampling

131    the calibration datasets to produce 1000 calibration equations based on a number of slightly

132    different datasets.

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133  The quality of the reconstruction is assessed by a number of standard statistics. The overall

134  quality of fit of reconstruction is evaluated based on the determination coefficient ($R^2$), which

135  expresses the percentage of variance explained by the model and the root mean squared error

136  (RMSE), which expresses the calibration error. This does not insure the quality of the

137  extrapolation which needs additional statistics based on independent observations, i.e.

138  observations not used by the calibration (verification data). They are provided by the

139  observations not resampled by the bootstrap process. The prediction RMSE (called RMSEP), the

140  reduction of error (RE) and the coefficient of efficiency (CE) are calculated on the verification

141  data and enable to test the predictive quality of the calibrated equations (Cook et al, 1994).

142  Traditionally, a positive RE or CE values means a statistically significant reconstruction model,

143  but bootstrap is much more interesting as it produces confidence intervals and finally we accept

144  the RE and CE which are significantly larger than zero, which is more constraining than being

145  just positive in mean. An early common period (1902–1929) is available for additional

146  verification, during which some climatic series are available but are not of sufficient quality to

147  insure an optimal calibration.

148

149  To identify the extreme March–April cold and warm events in the reconstruction, standard

150  deviation (SD) values were used.  Years one and two SD above and below the mean were

151  identified as warm, very warm, cold, and very cold years, respectively. Finally, as a way to

152  assess the spatial representation of our temperature reconstruction, we conducted a spatial field

153  correlation analysis between reconstructed values and the gridded CRU TS3.23 temperature field

154  (Jones and Harris 2008) for a broad region of the Mediterranean over the early common period

155  (1901–1929), and over the entire instrumental period (ca. 1901–2002).

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## 3 Results and Discussion

3.1 Tree-ring chronologies

In addition to 15 chronologies developed by previous studies, we produced six *P. nigra*, one *P. sylvestris*, one *A. nordmanniana / P. orientalis* chronologies for this study (Table 2). The Çorum district produced two *P. nigra* chronologies: one the longest (KAR; 627 years long) and the other the most sensitive to climate (SAH; mean sensitivity value of 0.25). Previous investigations of climate-tree growth relationships reported a mean sensitivity range of 0.13–0.25 for *P. nigra* in Turkey (Köse 2011, Akkemik et al. 2008). The KAR, SAH, and ERC chronologies (with mean sensitivity values from 0.22 to 0.25) were classified as very sensitive, and the SAV, HCR, and PAY chronologies (mean sensitivity values range 0.17–0.18) contained values characteristic of being sensitive to climate. The lowest mean sensitivity value was obtained for the ART *A. nordmanniana / P. orientalis* chronology. Nonetheless, this chronology retained a statistically significant temperature signal ($p < 0.05$).

3.2 March-April temperature reconstruction

RFA coefficients of May to August precipitation are positively correlated with most of the tree-ring series (Fig. 2) and among them, May and June coefficients are generally significant. The first principal component of the 23 chronologies, which explains 47% of the tree-growth variance, is highly correlated with May–August total precipitation, statistically ($r = 0.65$, $p \leq 0.001$) and visually (Fig. 3). The high correlation was expected given that numerous studies also found similar results in Turkey (Akkemik 2000a, Akkemik 2000b, Akkemik 2003, Akkemik et

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178     al. 2005, Akkemik & Aras 2005, Hughes et al. 2001, D'Arrigo & Cullen 2001, Touchan et al.

179     2003; Touchan et al. 2005a, Touchan et al. 2005b, Touchan et al. 2007, Köse et al. 2011).

180

181     The influence of temperature was not as strong as May–August precipitation on radial growth,

182     although generally positive in early spring (March and April) (Fig. 2). Conversely, the ART

183     chronology from northeastern Turkey contained a strong temperature signal, which was

184     significantly positive in March. In addition to this chronology, we also used the chronologies that

185     revealed the influence of precipitation, as well as temperature to reconstruct March–April

186     temperature.

187

188     The higher order PCs of the 23 chronologies are significantly correlated with the March–April

189     temperature and, by nature, are independent on the precipitation signal (Table 3). The best

190     selection for fit temperature are obtained with the $PC_3$, $PC_4$, $PC_5$, $PC_7$, $PC_9$, $PC_{10}$, $PC_{15}$, $PC_{17}$,

191     $PC_{21}$, which explains together 25% of the tree-ring chronologies. So the temperature signal

192     remains important in the tree-ring chronologies and can be reconstructed. The advantage to

193     separate both signals through orthogonal PCs enable to remove an unwanted noise for our

194     temperature reconstruction. Thus, $PC_1$ was not used as potential predictor of temperature because

195     it is largely dominated by precipitation (Table 3, Fig. 3). The last two PCs contain a too small

196     part of the total variance to be used in the regressions. However, even if Jolliffe (1982) and Hadi

197     & Ling (1998) claimed that certain PCs with small eigenvalues (even the last one), which are

198     commonly ignored by principal components regression methodology, may be related to the

199     independent variable, we must be cautious with that because they may be much more dominated

200     by noise than the first ones. So, the contribution of each PC to the regression sum of squares is

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201   also important for selection of PCs (Hadi & Ling 1998). The findings of Jolliffe (1982) and Hadi

202   & Ling (1998) provide a justification for using non-primary PCs, (*e.g*., of second and higher

203   order) in our regression, given that correlations with temperature may be over-powered by

204   affects from precipitation in our study area (Cook 2011, personal communication).

205

206   Using this method, the calibration and verification statistics indicated a statistically significant

207   reconstruction (Table 4, Fig. 4). The regression model for the calibration period was:

208

209   Eq. (1):  *TMP=7.53-2.94PC$_3$+4.02PC$_4$+2.50PC$_5$+2.77PC$_7$+2.73PC$_9$-2.67PC$_{10}$-*

210   *5.17PC$_{15}$+1.98PC$_{17}$-5.82PC$_{21}$*

211

212        The regression model accounted for 67% (Adj. $R^2$ = 0.64, $p \leq 0.0001$) of the actual temperature

213   variance over the calibration period (1930–2002). Also, actual and reconstructed March–April

214   temperature values had nearly identical trends during the period 1930–2002 (Fig. 4). Moreover, the tree-

215   ring chronologies successfully simulated both high frequency and warming trends in the temperature data

216   during this period. The reconstruction was more powerful at classifying warm events rather than cold

217   events. Over the last 73 years, eight of ten warm events in the instrumental data were also observed in

218   the reconstruction, while five of nine cold events were captured. Similarly, previous tree-ring based

219   precipitation reconstructions for Turkey (Köse et al. 2011; Akkemik et al. 2008) were generally

220   more successful in capturing dry years rather than wet years.

221

222   Our temperature reconstruction on the 1800–2002 period is obtained by bootstrap regression,

223   using 1000 iterations (Fig. 5). The confidence intervals are obtained from the range between the

224    2.5th and the 97.5th percentiles of the 1000 simulations. For the pre-instrumental period (1800–

225    1929), a total of 23 cold (1813, 1818, 1821, 1824, 1837, 1848, 1854, 1858, 1860, 1869, 1877–

226    1878, 1880–1881, 1883, 1897–1898, 1905–1907, 1911–1912, 1923) and 13 warm (1801–1802,

227    1807, 1845, 1853, 1866, 1872–1873, 1879, 1885, 1890, 1901, 1926) events were determined.

228    After comparing our results with event years obtained from May–June precipitation

229    reconstructions from western Anatolia (Köse et al. 2011), the cold years 1818, 1848, and 1897

230    appeared to coincide with wet years and 1881 was a very wet year for the entire region.

231    Furthermore, these years can be described as cold (in March–April) and wet (in May–June) for

232    western Anatolia.

233

234    Spatial correlation analysis revealed that our network-based temperature reconstruction was

235    representative of conditions across Turkey, as well as the broader Mediterranean region (Fig. 6).

236    During the period 1901–2002, estimated temperature values were highly significant ($r$ range 0.5–

237    0.6, $p < 0.01$) with instrumental conditions recorded from southern Ukraine to the west across

238    Romania, and from northern areas of Libya and Egypt to the east across Iraq. The strength of the

239    reconstruction model is evident in the broad spatial implications demonstrated by the

240    temperature record. Thus, we interpret warm and cold periods and extreme events within the

241    record with high confidence.

242

243    Among the warm periods in our reconstruction, conditions during the year 1879 were dry, 1895

244    wet, and 1901 very wet across the broad region of western Anatolia (Köse et al. 2011). Hence,

245    we defined 1879 as a warm (in March–April) and dry year (in May–June), and 1895 and 1901

246    were warm and wet years. In the years 1895 and 1901 the combination of a warm early spring

247    and a wet late spring-summer caused enhanced radial growth in Turkey, interpreted as longer

248    growing seasons without drought stress.

249

250    Of these event years, 1897 and 1898 were exceptionally cold and 1845, 1872 and 1873 were

251    exceptionally warm. During the last 200 years, our reconstruction suggests that the coldest year

252    was 1898 and the warmest year was 1873. The reconstructed extreme events also coincided with

253    accounts from historical records. Server (2008) recounted the winter of 1898 as characterized by

254    anomalously cold temperatures that persisted late into the spring season. A family, who brought

255    their livestock herds up into the plateau region in Kırşehir seeking food and water were suddenly

256    covered in snow on 11 March 1898. This account of a late spring freeze supports the

257    reconstruction record of spring temperatures across Turkey, and offers corroboration to the

258    quality of the reconstructed values.

259

260    Seyf (1985) reported that extreme summer temperature during the year 1873 resulted in

261    widespread crop failure and famine. Historical documents recorded an infamous drought-derived

262    famine that occurred in Anatolia from 1873 to 1874 (Quataert, 1996, Kuniholm, 1990), which

263    claimed the lives of 250,000 people and a large number of cattle and sheep (Faroqhi, 2009). This

264    drought caused widespread mortality of livestock and depopulation of rural areas through human

265    mortality, and migration of people from rural to urban areas. Further, the German traveler

266    Naumann (1893) reported a very dry and hot summer in Turkey during the year 1873 (Heinrich

267    et al, 2013). Conditions worsened when the international stock exchanges crashed in 1873,

268    marking the beginning of the "Great Depression" in the European economy (Zürcher, 2004). Our

269    temperature record suggests that dry conditions during the early 1870s were possibly exacerbated

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270    by warm spring temperatures that likely carried into summer. A similar pattern of intensified

271    drought by warm temperatures was demonstrated recently by Griffin and Anchukaitis (2014) for

272    the current drought in California, USA.

273

274    Extreme cold and warm events were usually one year long, and the longest extreme cold and

275    warm events were two and three years, respectively.  These results were similar with durations of

276    extreme wet and dry events in Turkey (Touchan et al. 2003, Touchan et al. 2005a, Touchan et al.

277    2005b, Touchan et al. 2007, Akkemik & Aras, 2005, Akkemik et al. 2005, Akkemik et al. 2008,

278    Köse et al. 2011). Moreover, seemingly innocuous short-term warm events, such as the 1807

279    event, were recorded across the Mediterranean and in high elevations of the European regions.

280    Casty et al. (2005) reported the year 1807 as being one of the warmest alpine summers in the

281    European Alps over the last 500 years. As such, a drought record from Nicault et al. (2008)

282    echoes this finding, as a broad region of the Mediterranean basin experienced drought

283    conditions.

284

285    Low frequency variability of our spring temperature reconstruction showed larger variability in

286    nineteenth century than twentieth century. Similar results observed on previous tree-ring based

287    precipitation reconstructions from Turkey (Touchan et al. 2003, D'Arrigo et al. 2001, Akkemik

288    and Aras 2005, Akkemik et al. 2005, Köse et al. 2011). Moreover, cold periods observed in our

289    reconstruction are generally appeared as generally wet in the precipitation reconstructions, while

290    warm periods generally correlated with dry periods (Fig. 7).

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292 Heinrich et al. (2013) analyzed winter-to-spring (January–May) air temperature variability in

293 Turkey since AD 1125 as revealed from a robust tree-ring carbon isotope record from *Juniperus*

294 *excelsa*. Although they offered a long-term perspective of temperature over Turkey, the

295 reconstruction model, which covered the period 1949–2006, explained 27% of the variance in

296 temperature since the year 1949. In this study, we provided a short-term perspective of

297 temperature fluctuation based on a robust model (calibrated and verified 1930–2002; Adj. $R^2 =$

298 0.64; $p \leq 0.0001$). Yet, the Heinrich et al. (2013) temperature record did not capture the 20th

299 century warming trend as found elsewhere (Wahl et al. 2010). However, their temperature trend

300 does agree with trend analyses conducted on meteorological data from Turkey and other areas in

301 the eastern Mediterranean region. The warming trend seen during our reconstruction calibration

302 period (1930–2002) was similar to the data shown by Wahl et al. (2010) across the region and

303 hemisphere. Further, the warming trends seen in our record agrees with data presented by Turkes

304 & Sumer (2004), of which they attributed to increased urbanization in Turkey. Considering long-

305 term changes in spring temperatures, the 19th century was characterized by more high-frequency

306 fluctuations compared to the 20th century, which was defined by more gradual changes and

307 includes the beginning of decreased DTRs in the region (Turkes & Sumer, 2004).

308

309 **4 Conclusions**

310

311 In this study, we used a broad network of tree-ring chronologies to provide the first tree-ring

312 based temperature reconstruction for Turkey and identified extreme cold and warm events during

313 the period 1800–1929 CE. Similar to the precipitation reconstructions against which we compare

314 our air temperature record, extreme cold and warm years were generally short in duration (one

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315    year) and rarely exceeded two-three years in duration. The coldest and warmest years over

316    western Anatolia were experienced during the 19th century, and the 20th century is marked by a

317    temperature increase.

318

319    Reconstructed temperatures for the 19th century suggest that more short-term fluctuations

320    occurred compared to the 20th century. The gradual warming trend shown by our reconstruction

321    calibration period (1930–2002) is coeval with decreases in spring DTRs. Given the results of

322    Turkes and Sumer (2004), the variations in short- and long-term temperature changes between

323    the 19th and 20th centuries might be related to increased urbanization in Turkey.

324

325    The study revealed the potential for reconstructing temperature in an area previously thought

326    impossible, especially given the strong precipitation signals displayed by most tree species

327    growing in the dry Mediterranean climate that characterizes broad areas of Turkey. Our

328    reconstruction only spans 205 years due to the shortness of the common interval for the

329    chronologies used in this study, but the possibility exists to extend our temperature

330    reconstruction further back in time by increasing the sample depth with more temperature-

331    sensitive trees, especially from northeastern Turkey. Thus future research will focus on

332    increasing the number of tree-ring sites across Turkey, and maximizing chronology length at

333    existing sites that would ultimately extend the reconstruction back in time.

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338     **Acknowledgements**

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452    Table 1. Site information for the new chronologies developed by this study in Turkey.

| Site name | Site code | Species | No. trees/ cores | Aspect | Elev. (m) | Lat. (N) | Long. (E) |
|---|---|---|---|---|---|---|---|
| Çorum, Kargı, Karakise kayalıkları | KAR | *Pinus nigra* | 22 / 38 | SW | 1522 | 41°11' | 34°28' |
| Çorum, Kargı, Şahinkayası mevkii | SAH | *P. nigra* | 12 / 21 | S | 1300 | 41°13' | 34°47' |
| Bilecik, Muratdere | ERC | *P. nigra* | 12 / 25 | SE | 1240 | 39°53' | 29°50' |
| Bolu, Yedigöller, Ayıkaya mevkii | BOL | *P. sylvestris* | 10 / 20 | SW | 1702 | 40°53' | 31°40' |
| Eskişehir, Mihalıççık, Savaş alanı mevkii | SAV | *P. nigra* | 10 / 18 | S | 1558 | 39°57' | 31°12' |
| Kayseri, Aladağlar milli parkı, Hacer ormanı | HCR | *P. nigra* | 18 / 33 | S | 1884 | 37°49' | 35°17' |
| Kahramanmaraş, Göksun, Payanburnu mevkii | PAY | *P. nigra* | 10 / 17 | S | 1367 | 37°52' | 36°21' |
| Artvin, Borçka, Balcı işletmesi | ART | *Abies nordmanniana Picea orientalis* | 23 / 45 | N | 1200– 2100 | 41°18' | 41°54' |

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455 Table 2. Summary statistics for the new chronologies developed by this study in Turkey.

| Site Code | Total chronology | | | Common interval | | |
|---|---|---|---|---|---|---|
| | Time span | 1st year (*EPS > 0.85) | Mean sensitivity | Time span | Mean correlations: among radii /between radii and mean | Variance explained by PC1 (%) |
| KAR | 1307–2003 | 1620 | 0.22 | 1740–1994 | 0.38 / 0.63 | 41 |
| SAH | 1663–2003 | 1738 | 0.25 | 1799–2000 | 0.42 / 0.67 | 45 |
| ERC | 1721–2008 | 1721 | 0.23 | 1837–2008 | 0.45 / 0.69 | 48 |
| BOL | 1752–2009 | 1801 | 0.18 | 1839–1994 | 0.32 / 0.60 | 36 |
| SAV | 1630–2005 | 1700 | 0.17 | 1775–2000 | 0.33 / 0.60 | 38 |
| HCR | 1532–2010 | 1704 | 0.18 | 1730–2010 | 0.38 / 0.63 | 40 |
| PAY | 1537–2010 | 1790 | 0.18 | 1880–2010 | 0.28 / 0.56 | 32 |
| ART | 1498–2007 | 1624 | 0.12 | 1739–1996 | 0.37 / 0.60 | 41 |

456 *EPS = Expressed Population Signal [Wigley et al., 1984]
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458    Table 3. Statistics from reconstruction model principal components analysis.

| | Explained variance | Correlation coefficients with | |
|---|---|---|---|
| | (%) | May–August PPT | March–April TMP |
| PC1 | 46.57 | –0.65 | –0.19 |
| PC2 | 7.86 | –0.07 | 0.15 |
| PC3* | 4.93 | 0.04 | –0.48 |
| PC4* | 4.68 | 0.11 | 0.17 |
| PC5* | 4.42 | –0.25 | 0.27 |
| PC6 | 3.73 | 0.15 | –0.14 |
| PC7* | 3.56 | 0.19 | 0.18 |
| PC8 | 2.87 | 0.26 | 0.01 |
| PC9* | 2.45 | 0.16 | 0.17 |
| PC10* | 2.21 | 0.14 | –0.08 |
| PC11 | 2.09 | –0.36 | –0.20 |
| PC12 | 1.80 | –0.12 | 0.05 |
| PC13 | 1.63 | –0.06 | 0.17 |
| PC14 | 1.55 | –0.14 | 0.06 |
| PC15* | 1.50 | –0.20 | –0.14 |
| PC16 | 1.31 | 0.04 | 0.08 |
| PC17* | 1.25 | 0.15 | 0.19 |
| PC18 | 1.14 | 0.13 | 0.02 |
| PC19 | 1.09 | 0.16 | –0.11 |
| PC20 | 0.95 | –0.15 | –0.01 |
| PC21* | 0.89 | 0.06 | –0.28 |
| PC22 | 0.85 | 0.44 | 0.10 |
| PC23 | 0.67 | –0.22 | –0.02 |

459    "*" indicates the PCs, which used in the
460    reconstruction as predictors

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468    Table 4. Calibration and verification statistics of bootstrap method (1000 iterations

469    applied) showing the mean values based on the 95% confidence interval (CI)

|  |  | Mean (95% CI) |
|---|---|---|
| Calibration | RMSE | 0.65 (0.52; 0.77) |
|  | $R^2$ | 0.73 (0.60; 0.83) |
| Verification | RE | 0.54 (0.15; 0.74) |
|  | CE | 0.51 (0.04; 0.72) |
|  | RMSEP | 0.88 (0.67; 1.09) |

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477    *RMSE* root mean squared error; $R^2$ coefficient of determination; *RE* reduction of error; *CE*

478    coefficient of efficiency; *RMSEP* root mean squared error prediction

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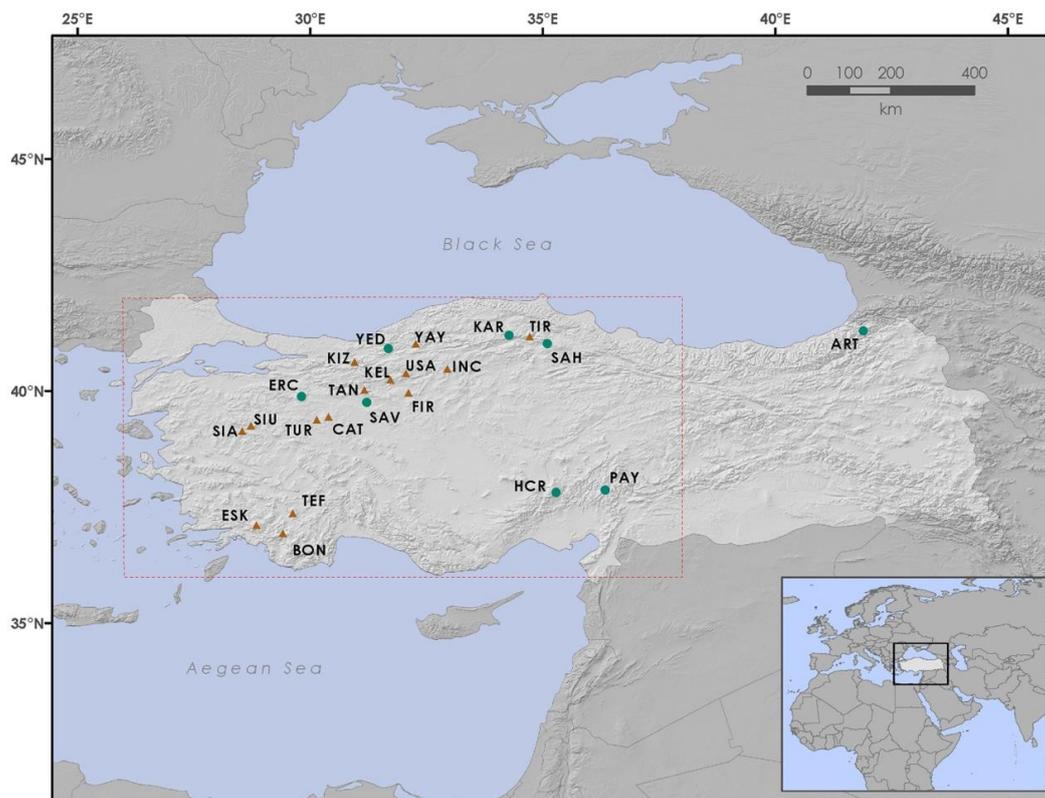
488 **Figure 1.** Tree-ring chronology sites in Turkey used to reconstruct temperature. Circles

489 represent the new sampling efforts from this study and the triangles represent previously-

490 published chronologies (YAY, SIA, SIU: Mutlu et al. 2011; TIR: Akkemik et al. 2008; TAN:

491 Köse et al. unpublished data; KIZ, ESK, TEF, BON, KEL, USA, FIR, TUR: Köse et al. 2011;

492 CAT, INC: Köse et al. 2005). The box (dashed line) represents the area for which the

493 temperature reconstruction was performed.

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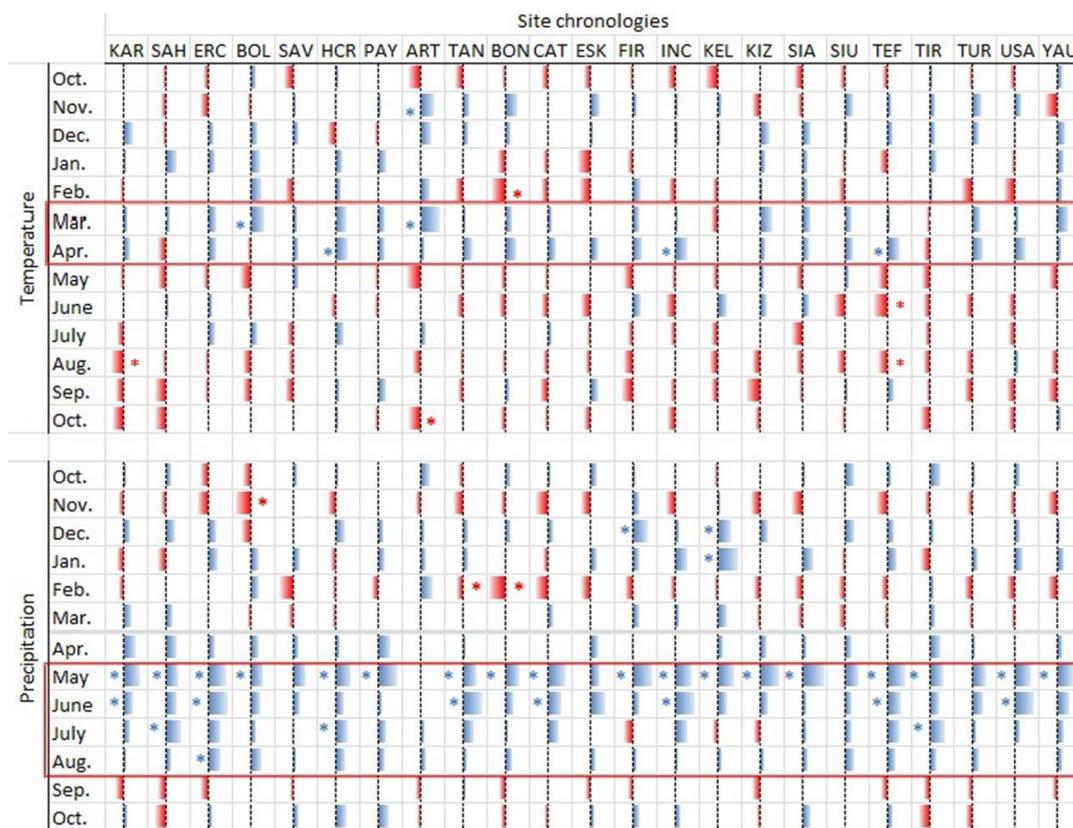
**Figure 2.** Summary of response function results of 23 chronologies. Red color represents

negative effects of climate variability on tree ring width; blue color represents positive effects of

climate variability on tree ring width. "*" indicates statistically significant response function

confidents ($p \leq 0.05$). Each response function includes 13 weights for average monthly

temperatures and 13 monthly precipitations from October of the prior year to October of current

year.

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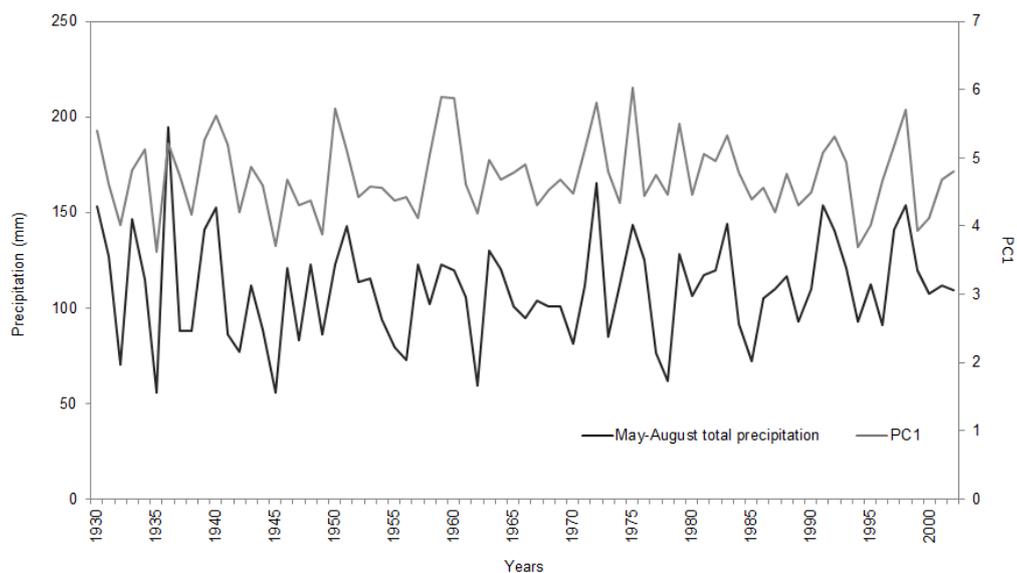
**Figure 3.** The comparison of May-August total precipitation (mm) and the first principal

component of 23 tree-ring chronologies.

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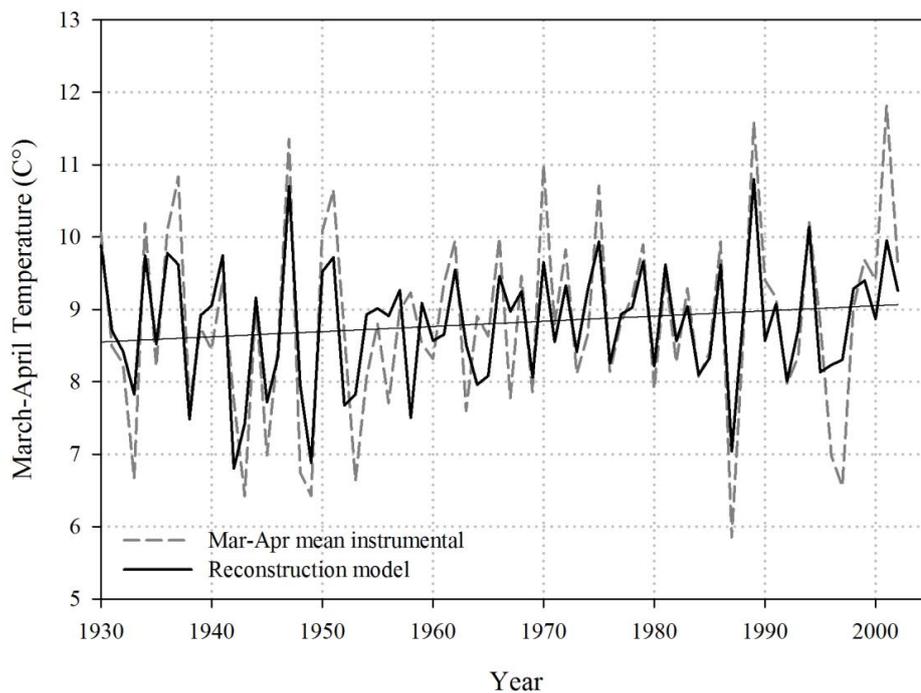
**Figure 4.** Actual (instrumental) and reconstructed March–April temperature (°C). Dashed lines

513  (dark grey) represent actual values and solid lines (black) represent reconstructed values shown

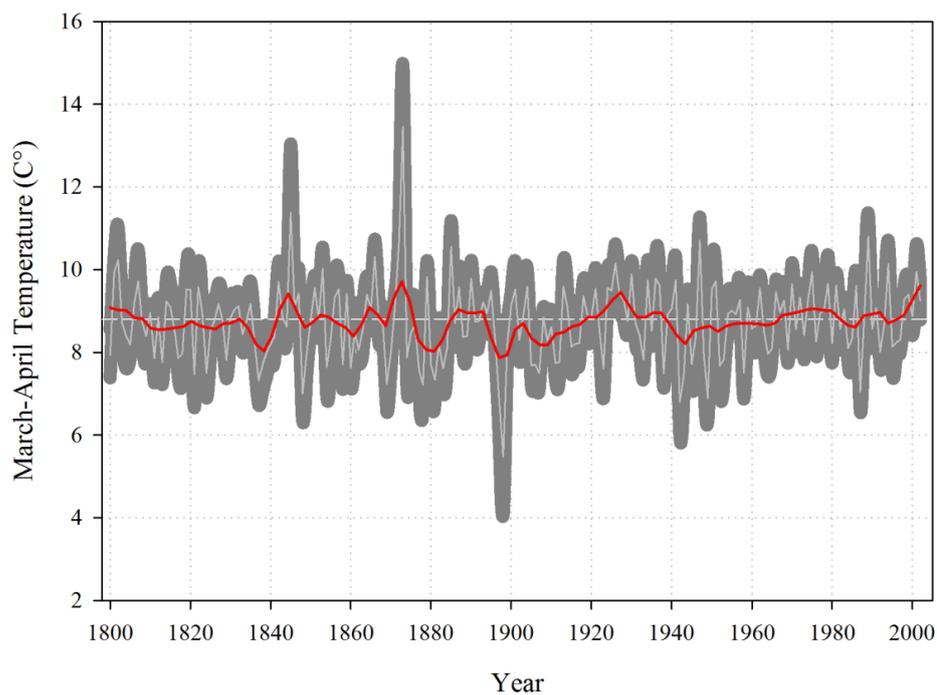514  with trend line (linear black line). Note: y-axes labels range 5–13 °C.

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**Figure 5.** March–April temperature reconstruction for Turkey for the period 1800–2002

CE. The central horizontal line (dashed white) shows the reconstructed long-term mean;

dark grey background denotes Monte Carlo ($n = 1000$) bootstrapped 95% confidence

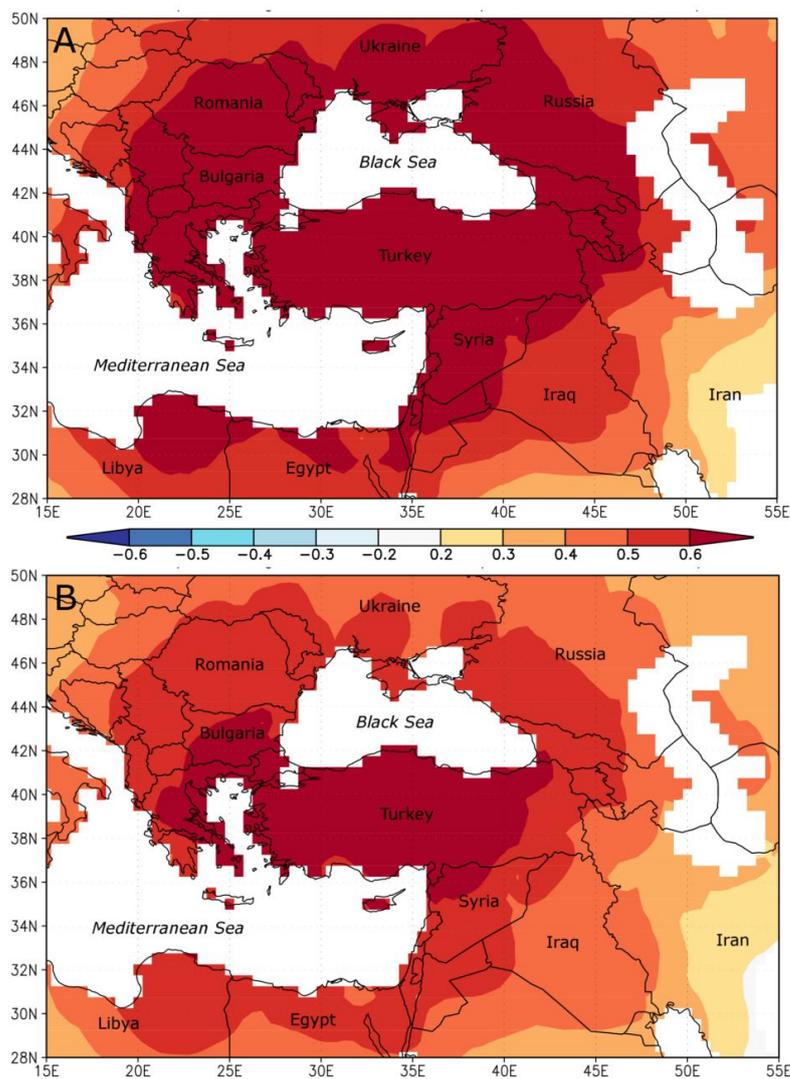limits; and the solid black line shows 13-year low-pass filter values. Note: y-axis labels

range 2–16 °C.

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**Figure 6.** Spatial correlation map for the March–April temperature reconstruction. Spatial

field correlation map showing statistical relationship between the temperature

reconstruction and the gridded temperature field at 0.5º intervals (CRU TS3.23; Jones and

Harris 2008) during the period 1930–2002 [A] and 1901–1929 [B] over the Mediterranean

region.
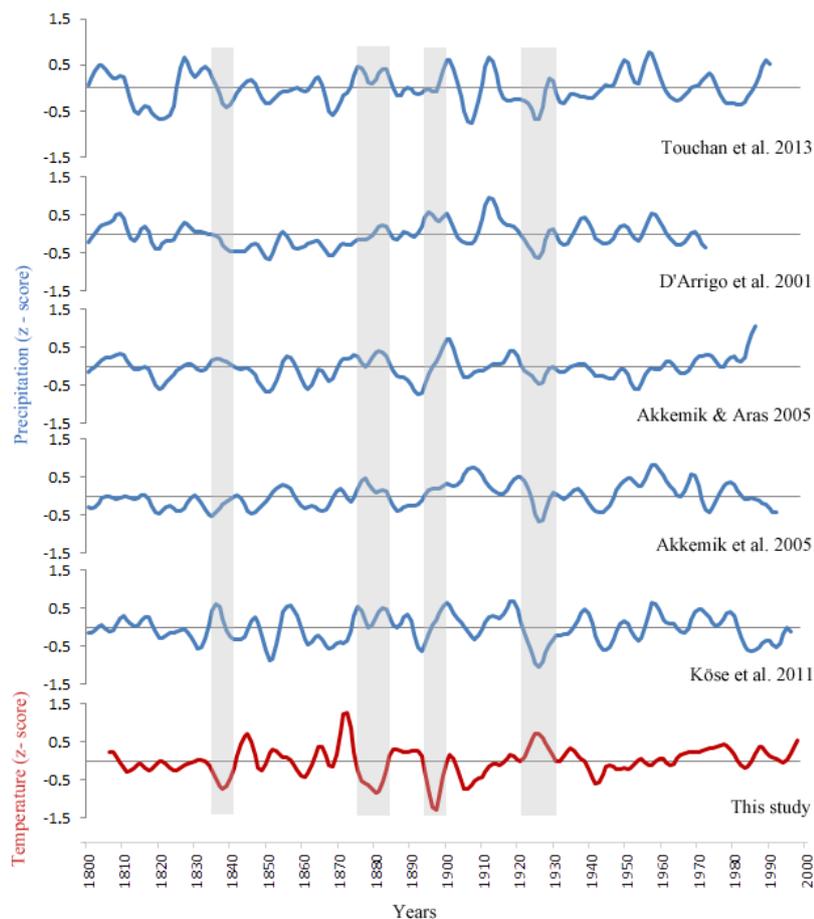
**Figure 7.** Low-frequency variability of previous tree-ring based precipitation

reconstructions from Turkey and spring temperature reconstruction. Each line shows 13-

year low-pass filter values. z-scores were used for comparison.