Tree-ring reconstruction of Crimean drought and lake chronology correction

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[1] The first verifiable reconstruction of spring (April–July) precipitation is presented for Crimea, Ukraine. It is derived from Crimean pine (*Pinus hamata*) ring-width data spanning A.D. 1620–2002. The reconstruction accounts for 37% of the variance in observed precipitation over 1896–1988. Most droughts recorded in Crimean historical documents in the 17th–19th centuries coincide with below-average reconstructed precipitation in the concurrent or following year. An 11-year filtered version of the reconstruction correlates with an annually-laminated sediment-thickness record from Saki Lake (4188 years in length), once this record is shifted backward by 15 years. The offset may be explained by anthropogenic changes at the lake in the late 19th century. The significant relationship between the lake sediments and reconstruction suggests that the lake record is also a moisture indicator. If so, the wettest period of the past 1500 years ($\sim$AD1050–1250) broadly coincides with the "Medieval Warm Period" (MWP) in Crimea. **Citation:** Solomina, O., N. Davi, R. D'Arrigo, and G. Jacoby (2005), Tree-ring reconstruction of Crimean drought and lake chronology correction, *Geophys. Res. Lett.*, *32*, L19704, doi:10.1029/2005GL023335.

1. Introduction

[2] Crimea is a densely populated, topographically diverse peninsula on the northern coast of the Black Sea in Ukraine (Figure 1). Human settlement extends back to Paleolithic times. Lack of water, due to a dry climate and limestone bedrock drainage, is a main factor limiting human development. Climate is temperate in the interior and Mediterranean on the southern coast. Plains and steppe vegetation occupy the north, where temperate air masses originate from eastern Europe. The North Atlantic Oscillation [*Cullen and deMenocal*, 2000] and East Atlantic-Western Russia teleconnection pattern [*Barnston and Livezey*, 1987; *Luterbacher et al.*, 1999] are known to impact climate in this general region. Occurrence of frequent drought in Ukraine may involve intrusion of cold air masses from the north or west and formation of large anticyclones behind these fronts, which can create dry, hot conditions (P. Kovalenko et al., unpublished report, available at http://iranrivers.com/electronic_library/paper/drought/50DOC.pdf). Southern Crimea is one of the areas of Ukraine with greatest risk for drought.

[3] In Southern Crimea, three parallel mountain ranges act as barriers to cold air masses from the north. The Black Sea moderates the continental climate: severe frosts are rare, fall is warmer than spring, and seasonality is moderate. Freezing temperatures and snow cover are typical at the Aj-Petri summit (1180 m; Figure 1) from December to March. Maximum precipitation in interior Crimea (Simferopol') occurs in early summer, and in winter on the southernmost mountain range (Aj-Petri) and southern coast. Precipitation at the highest elevations of Aj-Petri is more than twice as high (up to 1000 mm/yr) as in Yalta and Simferopol' due to orographic effects.

[4] Beyond the above description, the climatic history of the region is poorly known. Yet, knowledge of climate variations in Crimea may have practical use for hydrological management. There is potential to extract paleoclimatic information from historical documents and natural archives, such as tree rings and lake sediments. Below, we describe a *Pinus hamata D.Sosn* chronology (1620–2002) from Aj-Petri, Crimea, which we use to develop the first verifiable dendroclimatic reconstruction for this region.

2. Data and Analysis

2.1. Aj-Petri Pine (APP) Tree-Ring Chronology

[5] Core samples were collected from 22 living trees and 5 logs on the south slope of Aj-Petri (800–1100 m). Samples were processed using standard procedures [*Cook*, 1985; *Cook and Kairiukstis*, 1990; *Holmes*, 1994]. Average series intercorrelation among all samples is 0.536 and mean sensitivity is 0.3. The Expressed Population Statistic (EPS), an indicator of chronology reliability, remains above 0.85 (a generally accepted cutoff [*Cook and Kairiukstis*, 1990]) from the mid-1700s to 2002. EPS declines prior to the mid-1700s as sample size decreases. To preserve low-frequency variability we used conservative (negative exponential and straight line curve fits) detrending [*Cook and Kairiukstis*, 1990]. The final chronology, based on 29 samples from 17 trees, extends from 1620–2002. Due to the low sample size early in the record, the chronology should be interpreted with caution prior to $\sim$1700.

2.2. Meteorological Data

[6] Monthly precipitation data for the Aj-Petri meteorological station (1896–1988) was obtained from the Global Historic Climate Network [*Vose et al.*, 1992]. Three years of missing data (1942–1944) were estimated (Dendrochronological Program Library; http://www.ltrr.Arizona.edu/pub/dpl). The station is located on top of Aj-Petri Mountain, adjacent to the tree-ring sampling site (44.47°N, 34.07°E; Figure 1). Trees were sampled in close proximity to the meteorological station due to high spatial variability of precipitation in this mountainous region. No trend in pre-

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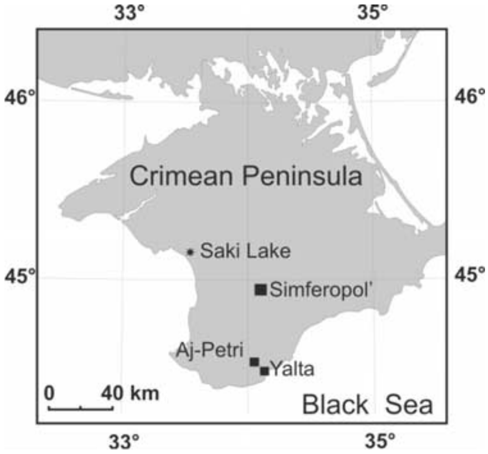

Figure 1. Map of Crimea, Ukraine, showing tree-ring sampling site (at Aj-Petri), meteorological stations, and location of Saki Lake.

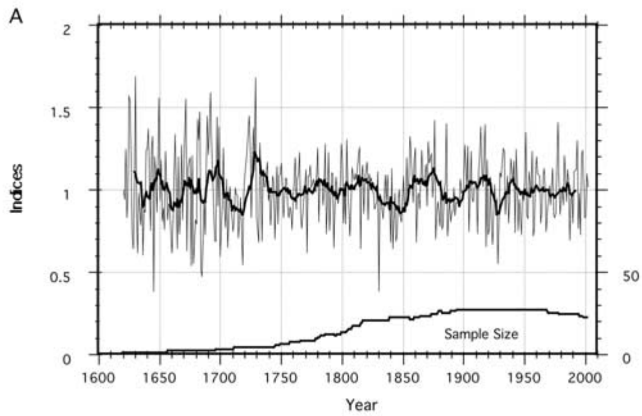

Figure 2. APP chronology with 11-year running mean smoothing and sample depth.

cipitation is evident at Aj-Petri (1896 to 1988). However, since the 1830s the annual sum of precipitation has increased at Simferopol' by ~100 mm.

3. Climate Analyses and Precipitation Reconstruction

[7] The APP chronology showed the strongest relationship with April-July precipitation at Aj-Petri ($r = 0.61$; $p = 0.01$; DF = 93) over 1896–1988. Positive correlations in spring-early summer are typical for chronologies from Mediterranean climates [*Hughes et al.*, 2001] and reflect the importance of moisture supply during this period of active growth. APP shows negative correlations with growing season temperatures, especially from July–September, likely reflecting the negative effects of summer evapotranspiration [*Tranquillini*, 1979]. In contrast, positive winter-spring temperature correlations indicate that warm winters and springs contribute to growth.

[8] Linear regression was used to develop a reconstruction of April–July precipitation from 1620–1988 for Aj-Petri. One outlier year, 1949 (exceeding 3 sigma at 521 mm per year: mean = 243 mm), was replaced with the monthly mean, which improved the model. The final climate/tree growth model accounts for 37% of the variance over 1896–1988, and demonstrates valid calibration and verification statistics typically used to evaluate dendroclimatic reconstructions (Table 1, Figures 2 and 3) [*Cook and Kairiukstis*, 1990]. The reconstruction is more sensitive to drought than to wetter conditions, as observed elsewhere [*Fritts*, 1976]. One explanation is that brief but intense episodes of summer rainfall can run off the steep slope of Aj-Petri and fail to penetrate the soil. This rainfall is not very useful for tree growth and can have deleterious effects due to soil erosion.

4. Precipitation Reconstruction and Saki Lake Sediment Record

[9] Perhaps the only other high-resolution climatic proxy series available for Crimea is a sediment record for Saki Lake (Figure 1) [*Schostakovich*, 1934]. These sediments are annually laminated, with lighter layers deposited in winter and darker layers in summer. Saki Lake is about 150 km from our tree site at Aj-Petri. It is now separated from the sea by a dam 0.5 km wide and up to 5 m high. It is believed that the lake was formed ca. 8000 years ago due to transgression of the Black Sea [*Schwets*, 1978]. A layer of black to gray clay sediments (27 m thick) has accumulated on the bottom of the lake. The lake once accumulated water from several rivers. However, following construction of two main dams in 1895, inflow has been limited to precipitation and seawater transported by an artificial channel. Annual precipitation sum does not exceed 300–400 mm, and precipitation occurs in the first half of summer. River and wind transport provide the greatest contribution to sediments on the bottom of the lake. Products of wind transport accumulate mainly in summer, whereas intensity of river erosion corresponds to that of precipitation. The period of snow and ice cover is brief. Snowmelt influx is another possible contributor to the lake's sediment.

[10] In 1931, *Shostakovich* [1934] cored the bottom of Saki Lake and obtained 7 m of sediments with undisturbed structure. He measured the annual layer thickness of the uppermost 5.2 m. The lower portion of the core included

Table 1. Calibration and Verification Statistics for Aj-Petri Pine Reconstruction[a]

	1896–1941 Calibration	1942–1988 Verification	1945–1988 Calibration	1896–1941 Verification
Adjusted r^2	0.472	—	0.279	—
RE	0.484	0.435	0.295	0.401
Sign test	$28^+/6^-$ (0.001)	$36^+/9^-$ (0.001)	$30^+/15^-$ (0.001)	$33^+/15^-$ (0.01)
P	0.696 (0.001)	0.662 (0.001)	0.544 (0.001)	0.670 (0.001)

[a]Adjusted r^2 is the variance accounted for by the calibration model, adjusted for degrees of freedom; RE is the reduction of error statistic, and P is the Pearson correlation coefficient [*Cook and Kairiukstis*, 1990]. Levels of significance are indicated in parentheses.

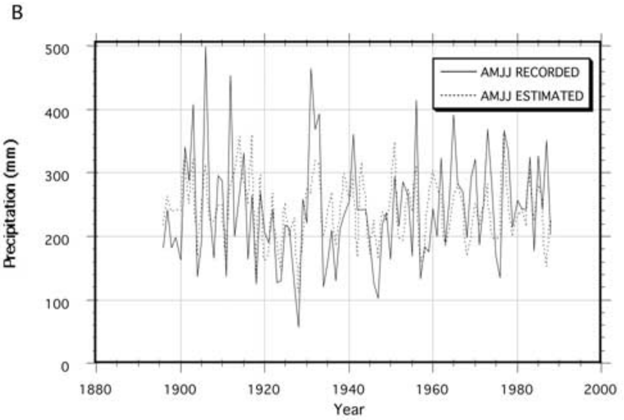

Figure 3. Recorded (solid line) and estimated (dashed line) April–July precipitation for 1900–1988 calibration period. Correlation between the two series is 0.63.

salt and gypsum lenses and was not usable for dating. According to Shostakovich, the uppermost layer dates to 1894, the last year before the dam construction in 1895 which dramatically changed the hydrological regime of the lake. He concluded that layer thickness depended mostly on annual precipitation, although this could not be proven directly due to lack of instrumental observations at the time.

[11] Initial comparison of the lake sediment thickness with our reconstruction did not reveal any similarities. However, smoothing both records using 11-year running means (Figure 4a) demonstrated a common signal, particularly after the Saki Lake series was shifted backward by 15 years (Figure 4b). Following this adjustment, there is a significant correlation between the two series ($R^2 = 0.33$) for 1637–1873. The earliest 17 years of the APP chronology, represented by only one sample, were eliminated. Comparison of historical records to the shifted lake series indicated that the lake's hydrological regime was probably disturbed before dam construction in 1895. In 1885 a channel was constructed which connected the lake with the sea. There is other evidence, though less dramatic, of human activity in the Saki basin, which has been used for recreation since the 1830's. These disturbances may have lead to the destruction of several uppermost layers, resulting in misdating at the end of the lake record. However, the earlier record is valid with the 15-year shift, indicating that Shostakovich's conclusions about annual layering are correct.

[12] Comparison of our reconstruction with historical records [*Veselovsky*, 1857; *Buchinsky*, 1953; *Borisov*, 1956] reveals that reconstructed values exceeding one standard deviation (SD) coincide with major historical droughts in 1687, 1833–1834, 1845, and 1882 (the 1806 reconstructed value, following the drought of 1805 [*Borisov*, 1956], is low but not over 1 SD). The extremely wet summers recorded in the historical documents are not as well captured by the reconstruction for reasons noted earlier.

[13] According to the smoothed reconstruction, the driest periods occurred in 1653–1684, 1703–1719, 1824–1852, 1879–1897 and 1920–1933. The latter period and part of the previous one overlap with the instrumental data and are in agreement with these observations. Reconstructed precipitation was near-average with relatively few extreme values from ~ the middle 1700s to early 1800s. In this respect this period resembles the 20th century (after ~1920). The historical data do not mention any drought between 1687 and 1805. On the contrary, at least two episodes of relatively wet climate were indicated: 1. in 1764, when it was noted that there was sufficient water and grass for people and animals in Crimea; and 2. in the late 18th century, when it was noted that both the Salgir and Karasu rivers were full of water, which is unusual.

[14] The reconstruction shows two periods of large variability in April–July precipitation: in the 1650s–1720s and 1820–1920s (although the former period is less reliable due to low sample depth; smoothed values in Figure 2). The reconstruction also shows, as noted, two periods of moderate values during much of the 18th century and the 20th century (after the 1920s). The above trends, however, are not apparent in the lake sediment record. The Saki chronology is generally more variable than the tree-ring reconstruction, and likely contains a somewhat different seasonal precipitation signal. The 1050s–1250s were extremely wet at Saki Lake, and overall humidity appears higher than during the instrumental period (Figure 5). This interval partly coincides with the "Medieval Warm Period" (e.g. ~AD 900–1240 [*Grove and Switzur*, 1994]). If the lacustrine series is influenced by a similar climatic signal as our chronology then we can conclude that the climate between the 1050s–1250s in Crimea was warmer in winter, but cooler and wetter in summer.

5. Conclusions

[15] 1. A species of pine is found to have considerable potential for dendroclimatic studies in Crimea.

[16] 2. A tree-ring reconstruction of April–July precipitation, spanning AD 1620–2002, has been presented. It accounts for 37% of the variance of observed AMJJ precipitation over 1896–1988. It also shows a significant positive correlation with February–March temperature and a significant negative correlation with August–September temperature.

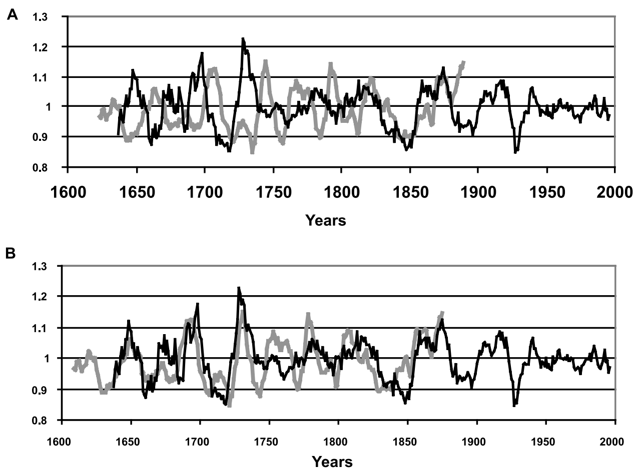

Figure 4. (A) Comparison of original Saki Lake sediment chronology (gray) and APP reconstruction (black), both smoothed with the 11-year running mean. (B) Saki chronology shifted backwards by 15 years.

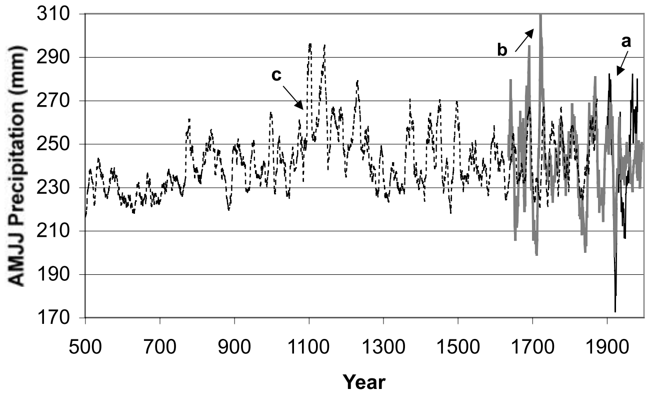

Figure 5. (a) Sum of AMJJ precipitation measured at Aj-Petri, black line. (b) AMJJ reconstruction, (gray line). (c) Eleven-year running mean of Saki lake chronology for past 1,500 years (dashed line).

[17] 2. Most major droughts described in Crimean historical documents in the 17th–19th centuries coincide with reconstructed drought during the current or following year.

[18] 3. The tree-ring reconstruction correlates significantly (R^2 = 0.33 for the common period 1635–1897) with a sediment record from Saki Lake [*Schostakovich*, 1934] after an 11year-filter was applied to both records and the Saki record is corrected for a 15-year offset. We have corrected its dating, and calibrated these records against the meteorological observations using the Crimean tree-ring record.

[19] 4. According to the corrected lake record, the wettest period of the past 1500 years in Crimea occurred between ~the 1050s and 1250s. These dates broadly coincide with the approximate period of the MWP, AD 900–1240 [*Grove and Switzur*, 1994]. The Medieval "anomaly" in Crimea between AD 1050s and 1250s was likely characterized by warmer winters, but cooler, wetter summers.

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