Clim. Past Discuss., 8, 3871–3900, 2012
www.clim-past-discuss.net/8/3871/2012/
doi:10.5194/cpd-8-3871-2012

Climate of the Past Discussions

Tree-ring based June–July mean temperature variations since the Little Ice Age in the Adamello-Presanella Group (Italian Central Alps)

A. Coppola[1], G. Leonelli[2], M. C. Salvatore[1], M. Pelfini[2], and C. Baroni[1]

[1]Dipartimento di Scienze della Terra, Università degli Studi di Pisa, Pisa, Italy
[2]Dipartimento di Scienze della Terra, Università degli Studi di Milano, Milan, Italy

Received: 19 July 2012 – Accepted: 1 August 2012 – Published: 20 August 2012

Correspondence to: A. Coppola (anna.coppola01@gmail.com)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Mountain climate is generally strongly conditioned by the site-specific topographic characteristics. Detailed reconstructions of climate parameters for pre-instrumental periods in these mountain areas, suffering of glacial retreat caused by recent global warming, are needed in the view of a better comprehension of the environmental dynamics. We present here the first reconstruction of early summer (June–July) mean temperature for the Adamello-Presanella Group (Central European Alps, 45°54′–46°19′ N; 10°21′–10°53′ E), one of the most glaciarized mountain Group of the Central Italian Alps. The reconstruction has been based on four larch tree-ring width chronologies derived from living trees sampled in four valleys surrounding the Group.

The reconstruction spans from 1596 to 2004 and accounts for about 35 % of the temperature variance. The statistical verification of the reconstruction demonstrates the positive skill of the tree-ring data set in tracking temperature variability, but a divergence is visible starting from about 1980 between actual and reconstructed temperature, which slightly underestimate instrumental data. An analysis of moving mean sensitivity over a time window of thirty years evidences a decrement of this parameter in recent times, which is likely related to the noticed divergence and indicates a recent more complacent response to climate of larch at the tree-line.

1 Introduction

In the large framework of the climate change detection and of the assessment of climate related impacts, mountain environments represent valuable study areas. The detection of climate changes in mountain environments, and in particular in the European Alps, involves detailed reconstructions of climate parameters for pre-instrumental periods, because the identification of long-term climate variation and past natural variability is a key issue for the understanding of recent climate dynamics within the natural climate variability (Houghton et al., 1990, 2001; Bradley and Jones, 1992; Bradley et al.,

CPD
8, 3871–3900, 2012

2003). In the Great Alpine Region (GAR), and in particular in high-elevation areas, instrumental climate-parameters records are scarce and extend back in time not more than few centuries. The analysis of proxy climate records becomes therefore essential for studying such climatically-impacted environments and their evolution (Beniston et al., 1997). The widely proven correlation between annual tree-ring growth and climate (e.g. Fritts, 1976) makes them an excellent source of palaeoclimatic information. Annually-resolved tree-ring chronologies actually are natural archives that have been widely used in mountain regions in Europe and in the Northern hemisphere for reconstructing past climate parameters, developing both site-specific and regional climate reconstructions (e.g. Büntgen et al., 2005, 2006; D'Arrigo et al., 2006; Esper et al., 2002; Frank et al., 2005; Frank and Esper, 2005a; Luckman and Wilson 2005; Larocque and Smith, 2005; Mann et al., 1998, 1999; Jacoby et al., 2000; Shiyatov et al., 1996). In recent years, considerable progresses have been made in central and eastern Asia and South America with the development of dendroclimatic studies and diverse tree-ring based climate reconstructions, in particular for China (Chen et al., 2012; Li et al., 2012; Fan et al., 2009; Fang et al., 2011, 2012), Mongolia (Liu et al., 2009; Bao et al., 2012), and for the Tibetan Plateau (Bräuning and Mantwill, 2004; Fan et al., 2010; Fang et al., 2010; Zhu et al., 2011), as well as for Chile and Argentina (e.g. Barichivich et al., 2009; Roig et al. 2001; Villalba, 1990; Villalba et al., 2003; Le Quesne et al., 2006, 2009). At the same time considerable advances have also been made in this research field in the southern side on the Mediterranean Basin, for example in northern Africa (Esper et al., 2007; Touchan et al., 2008, 2010) and in the Near East (Akkemik et al., 2005, 2007; Touchan et al., 2003, 2005).

In the European Alps, the abundance of temperature sensitive conifer species growing at the treeline (Schweingruber, 1996; Tessier et al., 1997; Carrer and Urbinati, 2004; Frank and Esper, 2005b; Pelfini et al., 2006; Leonelli and Pelfini, 2008) led to the development of several dendroclimatic studies and temperature reconstructions (e.g. Büntgen et al., 2005, 2006; Frank et al., 2005; Frank and Esper, 2005a; Corona et al., 2010, 2011). When performed on a regional scale these reconstructions usually

CPD
8, 3871–3900, 2012

include and average a large number of site chronologies reflecting peculiar and local climate characteristics. It is widely recognized that mountain climate, and also climate over central-western Alpine region, is strongly conditioned by the specific topographic characteristics and the peculiar environmental features of the different mountain areas (Beniston et al., 1994; Marinucci et al., 1995; Beniston, 2003, 2005; Leonelli et al., 2009). Therefore, the development of detailed climate reconstructions can help in understanding, at high resolution, how climate change have influenced the environmental dynamics in these climate-sensitive areas. In the Alpine region the dendroclimatic reconstructions have been mainly performed on the northern sector of the Alps and, at present, reconstructions that bring into focus the climate reconstruction for single mountain groups are not available yet.

We present here the first tree-ring based reconstruction of early summer (June-July) temperature for the Adamello-Presanella area, in the Italian Central Alps. Larch tree-ring growth at the treeline in the Adamello-Presanella Group is mainly driven by June temperature, although the strength and the stability of this relationship have varied over time (Coppola et al., 2012); the same paper identifies a more stable signal of seasonal parameters with respect to monthly parameters, with tree-ring width presenting a rather constant response over time to summer temperatures. In this work we intend to verify if the mentioned variation in sensitivity persists when it is examined in a seasonal transfer function mode (Hughes et al., 2011), performing a June-July (JJ) temperature reconstruction for the Adamello-Presanella area. The study area is characterized by one of the largest glacial system of the Italian Alps (CGI-CNR, 1959-1962; Ranzi et al., 2010) and, in the view of a better comprehension of glacial mechanism and dynamics, the reconstruction of climate parameters in pre-instrumental period in this area is a strategic issue.

2 Materials and methods

2.1 Study area

The Adamello-Presanella Group belongs to the central-southern sector of the Italian Central Alps (namely Rhetian Alps, 45°54′–46°19′ N; 10°21′–10°53′ E), covering an area of more than 1100 km^2. The area hosts approximately 100 glaciers (CGI-CNR, 1959–1962), primarily in the northern and central sectors of the Group, among which the Adamello Glacier (Ranzi et al., 2010), the widest of the whole Italian Alps, and the Lobbia Glacier, both high plateau glaciers which active fronts stand at the head of the valleys originating from the summit area (Baroni and Carton 1990, 1996; Baroni et al., 2004). The other glaciers are mainly located in small cirques and at the head of topographically protected valleys. The Adamello-Presanella Group shows a well-developed alpine glacial topography characterized by U-shaped valleys, sharp crests, cirques and horns. Valley floors show a longitudinal profile with overdeeppened hollows and steps of glacial shoulder (Riegel) representing inherited Pleistocene morphology, since the Holocene and presently affected by fluvial processes. Furthermore the steep slopes show evidence of widespread active mass wasting processes, underlined by debris flow channels and avalanche tracks, dissecting the upper portion of the slopes, and scree slope, talus, debris flow cones and rock fall at their foot. The sampling forest sites involved in this study are located at the top of four different glacial valleys surrounding the Group (Fig. 1). The vegetation characteristics in the four sampling sites are quite similar, and mainly consists in Norway spruce (*Picea abies* L.) woodlands that dominate the forest cover and that, above about 1800 m a.s.l., give way to open *Larix decidua* Mill.-*Picea abies* L. Karst mixed stands. In Val d'Avio and in Val di Fumo at approximately 2000 m a.s.l., Norway spruce is replaced by an open mixed association of larch and stone pine (*Pinus cembra* L.) (Andreis et al., 2004; Baroni et al., 2007).

CPD
8, 3871–3900, 2012

2.2 Tree-ring data and chronology development

This study is based on four European larch (*Larix decidua* Mill.) chronologies. As the main part of the alpine mountain environment, the investigated area is characterized by high geomorphological dynamics involving tree vegetation, that is subjected to diverse growing disturbance factors such as avalanches and mass wasting movements (Baroni et al., 2007; Gentili et al., 2010). Therefore, sampling procedures were conducted below the treeline selecting dominant and undisturbed trees without stem or crown anomalies potentially fading the climatic signal (e.g. Leonelli et al., 2011). The four tree-ring chronologies were obtained from core samples extracted by means of an increment borer and replicated within and between trees, following standard dendrochronological sampling procedures (Stokes and Smiley, 1968; Swetnam, 1985). Samples with evidences of mechanical disturbances or with time series shorter than 100 yr were discarded. Therefore, among about 70 sample trees, 57 trees have been used for the development of the four mean site chronologies. Tree-ring widths were measured to the nearest 0.01 mm by means of a LINTAB increment measuring table (RinnTech) and then visually and statistically (Fritts, 1976) cross-dated with the TSAPwin software (version 0.53; Rinn, 2005). The correct cross-dating was then checked using the program COFECHA (Holmes, 1983; Grissino-Mayer, 2001). The residual chronologies were calculated using the program ARSTANwin (Cook and Holmes, 1984; Cook, 1985) by applying a double detrending method. The wave-length of the spline was fixed at 67 % of the mean length of the series, with a 50 % frequency cut-off (Cook and Briffa, 1990) and the autocorrelation was removed from each series using an autoregressive model (Cook and Briffa, 1990). Individual indexed series were then computed into the mean site residual chronology by means of a bi-weight robust estimate of the mean (Cook, 1985). To assess the adequacy of the replication in the early years of the four chronologies we used the subsample signal strength (SSS) limiting our analysis to the period with SSS > 0.85 (Wigley et al., 1984). The four residual site chronologies (named PRS, AVI, FUM and PRL) have been then averaged to form a mean chronology (named ALL).

2.3 Climate data

The gridded HISTALP dataset (Auer et al., 2007, http://www.zamg.ac.at/histalp) was used in this study. We used gridded monthly and seasonal mean temperature anomaly records referring to the grid point 10° N, 46° E. Temperature anomalies span from 1760 to 2007 (247 yr; 2004–2011 release) and are referred to the 20th Century mean (1901–2000) (Auer et al., 2007).

2.4 Data processing

Climate-tree-ring-growth relationships of the four chronologies were evaluated by means of the standard correlation function (CF) and response function (RF) analysis (Fritts, 1976; see Coppola et al., 2012 for details).

To facilitate the comparison between the time series, tree-ring standardized residual indices and June-July (JJ) mean temperature values were scaled computing z-scores by subtraction of the mean and division by the standard deviation over their entire length, according to the formula:

$$z_i = (v_i - m)/\mathrm{std} \quad (1)$$

where v_i is the ring-width index or the temperature anomaly value, m is the mean and std the standard deviation of the entire series length. The resulting time series have zero mean and unit variance. The four ring-width chronologies were directly compared with the JJ mean temperature series.

To further delineate the response of our tree-ring dataset to climate we have checked the stability of mean sensitivity over time. Mean sensitivity (MS) is a measure of the year-to-year variation of tree-ring indexes, it is correlated to the series intercorrelation and depends on the species, on the climatic and site conditions, and on the number of samples (Fritts, 1976). It is a measure of the relative differences in width from one tree-ring to the next therefore it can be considered as an index of the limiting effects of climate on tree-rings and as a functional parameter in the assessment of the climatic severity of a site (Fritts, 1976). MS values usually range between 0.1 and 0.6 (Fritts and Schatz, 1975). Low MS values give evidence to a complacent response of trees to the climatic variability. MS was calculated here according to the formula:

$$\mathrm{MS}_x = \frac{1}{n-1} \sum_{t=1}^{t=n-1} \left| \frac{2\,(x_{t+1} - x_t)}{x_{t+1} + x_t} \right| \text{(Fritts, 1976)} \tag{2}$$

To evaluate the stability of this statistic over time in the ALL chronology, we calculated MS over a time window of 30 yr, progressively shifting the window of one year forward and reporting the mean value for each period.

Both climate (JJ temperature) and tree-ring (the ALL residual chronology) series were checked for normality (Kolmogorov-Smirnof test) and the direct relationship between the two series was verified by means of a linear regression and some related statistics.

As reported in Coppola et al. (2012), the CF and RF analysis results show that larch growth at the treeline is primarily driven by early summer (June-July) temperature. Moving Response Function (MRF) analyses allow detecting a weakening relationship between tree-ring width and June mean temperature in last decades, but an overall stability over time in the response of larch to summer (June to August) temperature. We have then chosen June-July mean temperature as the optimum climate predictand for the reconstruction.

The reconstruction model is a linear regression of June-July temperature on the ALL residual chronology (Fritts, 1976). Within the instrumental data time span (1760–2004) we chose a 120 yr time period to apply a transfer function analysis for obtaining the prediction equation. The chosen calibration/verification period is 1840–1959, and, as done by Jacoby et al. (2000), we decided to exclude the more recent time period from

CPD
8, 3871–3900, 2012

calibration/verification procedures, to avoid the inclusion of data from a period when a loss of thermal response with June mean temperature is visible (Coppola et al., 2012). Calibration and verification models were then stopped in 1960. The earliest period of the climate data series (1760–1839), was excluded as calibration/verification period because that data is based only on few meteorological stations.

Regression assumptions (Ostrom, 1990) were verified by the analysis of the residuals. Residuals were visually (histogram) and statistically (Anderson-Darling test) checked for normality and the lack of autocorrelation in the residuals was verified by means of Durbin-Watson statistic. The non-dependence of the residuals on the fitted values was also checked by means of a scatterplot (not shown). The existence of a long record of climate data allows to verify the stability of the transfer function over sufficiently long non-overlapping calibration and validation periods. To verify the stability of the regression model we have compared the estimated values against independent data not used in the calibration, using a split-sample procedure (Snee, 1977; Meko and Graybill, 1995; Touchan et al., 2003), dividing the full period (1840–1959) in two subsets (1840–1859 and 1900–1959), fitting the model to one part of the data and testing on the other part and replying the operation inverting the two calibration and verification periods. Several statistics were conducted to test the reliability of our split-sample calibration and verification procedure and the long-term reconstruction skills. Pearson's correlation between instrumental and reconstructed values was calculated in each phase of the calibration/verification procedure. The reduction of error statistic (RE) has been performed to measure the association between the series of actual values of monthly mean temperature and their estimates. The theoretical limits for RE values range from a maximum of +1 to minus infinity, but an RE value grater than 0 has to be considered as a positive skill (Fritts, 1976). Moreover, another statistical test was applied, the Coefficient of Efficiency (CE). The use of this statistic in Dendroclimatology was introduced by Briffa et al. (1988) and, as for RE, its theoretical limits range from +1 to minus infinity, any positive values indicating positive skill, a minus value indicates no agreement. It is a very rigorous test to pass if there are important differences

CPD
8, 3871–3900, 2012

between calibration and verification periods means, similar RE and CE values can be considered indicative of high stability of the calibration and verification periods data sets.

The full calibration period (1840–1959) was then used for the final reconstruction model and the verified transfer function was applied to the total extension of the ALL residual chronology (1596–2004) to produce the time series of reconstructed values. The June-July mean temperature reconstruction for the Adamello-Presanella Group for the 1596–2004 period was finally obtained.

3 Results and discussion

On comparing z-scores of the four ring-width chronologies and the ALL chronology with the JJ mean temperature anomalies series (Fig. 2), an increasing divergence between the two time series is visible for all the four chronologies in the most recent part of the entire time period. However, all the single chronologies show an increasing growth trend that is likely caused by the strong trend in the JJ instrumental temperature record. The analysis of mean sensitivity over a 30 yr time window performed on the ALL residual chronology, evidences a slight decreasing trend of this statistic starting from the first decades of the twentieth century and persisting until the most recent times (Fig. 3). This trend can be considered as a consequence of an increasing complacent response of the ALL residual chronology to the climatic variability and we think that it could be involved in the reduced capacity of the four tree-ring width chronologies in following the strong recent increasing temperature trend. Although these concerns, the verified normality and the checked direct relationship between the two time series (Figs. 4 and 5) and the statistical verification of the regression functions computed during the calibration/verification procedure (which however excludes from the analysis the most recent period) indicate positive skill of the reconstruction and the stability of the relationship over the halves of the chosen period (1840–1959). The correspondence between

CPD
8, 3871–3900, 2012

instrumental and reconstructed data is satisfying ($r = 0.60$ and $r = 0.62$ in the two calibration and verification periods: Fig. 6), and the JJ mean temperature reconstruction (Figs. 7–8) tracks the observed instrumental temperatures quite well ($r = 0.53$ over the entire overlapping period, 244 yr). The trend of the reconstructed JJ temperature over its entire extension goes clearly towards an increase of early summer mean temperatures. Looking in detail to the reconstructed series in the pre-instrumental period (1596–1760) (Fig. 8), relatively cool conditions are recorded during much of the 17th and early 18th centuries, with some decadal and multi decadal fluctuations. Relatively low temperatures are visible in the first part of the time series until about 1650, when an increase in JJ mean temperature follows until about 1680. Another reduction follows until about 1700 when a regular increment starts and reaches the mid 1700s, when a progressive decrease occurs, with an early summer cooling trend that continues until 1821. In this phase, a little fluctuation centred on 1750 is visible in our reconstruction. These findings are overall consistent with the results of other studies reporting reconstructed summer temperatures for the Alpine region (e.g. Büntgen et al., 2005, 2006; Corona, 2011), while the noticed slight reduction of temperatures in mid-1750s seems to be peculiar of our reconstructed series. The lowest recorded temperatures of the entire reconstruction are found in the 1813–1821 period. Actually, this decade is known as one of the coldest phases of the entire Little Ice Age (Bradley and Jones, 1993; Grove, 1988), characterized by the maximum Holocenic extension of Alpine glaciers (Oerlemans, 2001; Nicolussi and Patzelt, 2000; Holzhauser et al., 2005) that is also verified in the Adamello Group (Baroni and Carton, 1990, 1996). The 1813–1821 period corresponds to the Dalton minimum in solar activity (Wagner and Zorita, 2005; Wilson, 1998) and follows extensive volcanic activity, including the 1815 eruption of the Tambora, on the Indonesian Sumbawa Island (D'Arrigo and Jacoby, 1999; Sadler and Grattam, 1999; Crowley, 2000; Oppenheimer, 2003), resulting in a marked recrudescence of summer temperatures over the Northern Hemisphere (Briffa et al., 1998). The 1816 year, known as the "year without a summer" on global climate for the consequences of the Tambora eruption, does not reaches the absolute lower value JJ

CPD
8, 3871–3900, 2012

temperature in our reconstruction but is anyway among the lower values. In fact, the minimum value of the reconstructed temperature in this cold period corresponds to the year 1813 that also represents the lowest value of our entire reconstruction. The period after 1821 is characterized by an overall tendency to an increase in temperature, particularly evident after the 1850 that is in this sector of the Alps recognized as the end of the LIA (Baroni and Carton, 1990, 1996). Following the registered temperature, the JJ tree-ring based reconstructed temperature shows a post-LIA warming trend, with some minor fluctuations. Actually, the phase that follows the end of the LIA is clearly marked by a sharp rising of JJ temperatures, but the positive trend goes through a break in the early 1870s when a short relatively cool period centred on 1885–1890 takes place. After that, the rising trend starts again ceasing in correspondence of a relatively cool phase centred on about 1970s, which brings the reconstructed JJ mean temperatures to relative lower values. This recent reduction of early summer mean temperatures is well tracked and has been found in diverse reconstruction of summer temperatures reported for other sectors of the Alps (Büntgen et al., 2005, 2006; Corona et al., 2011), while is less apparent in the large scale tree-ring based summer temperature reconstructions (e.g. Briffa et al., 2001; D'arrigo et al., 2006). From this last relatively cool phase onwards, the JJ mean temperature rising trend appears constant, and goes on up to the end of the time series following the recent and persisting warming trend. In the most recent part of the time series, starting about from 1980, our reconstruction slightly underestimates actual JJ-temperatures values, showing some evidences of the well-known "divergence problem" (D'Arrigo et al., 2008), that has been largely reported in numerous studies (Büntgen et al., 2006; D'Arrigo et al., 2006; Jacoby et al., 2000; Wilmking et al., 2004; Wilson et al., 2007). As demonstrated in Büntgen et al. (2008), divergence is not a systematic issue at temperature-sensitive conifer sites and is likely to be addressed at a local level.

CPD
8, 3871–3900, 2012

4 Conclusions

The European larch tree-ring growth at the treeline in the glacial valleys surrounding the Adamello-Presanella Group is limited by early summer temperature. We have here performed the first attempt of a tree-ring based JJ mean temperature reconstruction for the Adamello-Presanella area, potentially useful also for glaciological models and reconstructions, being based in an Alpine region characterized by the presence of one of the largest alpine glacier of the Italian Alps.

The tree-ring based reconstruction of temperature record fits very well the JJ temperature reported in the HISTALP database since 1760 AD. The reconstructed data are therefore a tool also for climate reconstruction of pre-instrumental period. The actual temperature variations characterizing the LIA are well evident also in the reconstructed data, particularly the coldest years of the 19th Century (e.g. 1813, 1816 and 1821 AD).

The reconstructed temperature dataset records the recent warming trend of summer conditions starting from about 1970 and mostly, follows the measured instrumental trends. The proposed model slightly underestimates the actual early summer temperature in the recent period, but the correlation between the two datasets is good and the reconstruction statistically sound. The good potential showed by our tree-ring data set as a proxy climate of early summer temperature encourages an extension of the record further back in time improving sample replication in the earliest part of the chronologies.

Acknowledgements. The research was supported by the MIUR-PRIN 2008 project "Climate change effects on glaciers, permafrost and derived water resource. Quantification of the on-going variations in the Italian Alps, analysis of their impacts and modelling future projections," national coordinator C. Smiraglia, local coordinators P. R. Federici (Università di Pisa) and C. Smiraglia (Università di Milano).

References

Akkemik, Ü., Dağdeviren, N., and Aras, A.: A preliminary reconstruction (A.D. 1635–2000) of spring precipitation using oak tree rings in the western black sea region of Turkey, Int. J. Biometeorol., 49, 297–302, 2005.

Akkemik, Ü., D'Arrigo, R., Cherubini, P., Kose, N., and Jacoby, G. C.: Tree-rings reconstructions of precipitation and streamflow for north-western Turkey, Int. J. Climatol., 28, 173–183, doi:10.1002/joc.1522, 2008.

Andreis, C., Armiraglio, S., Bortolas, D., Broglia and A., and Caccianiga, M.: *Pinus cembra* L. nel settore sud-alpino lombardo, Natura Bresciana-Annuario del Museo Civico di Scienze Naturali di Brescia, 34, 19–39, 2004.

Auer, I., Böhm, R., Jurkovic, A., Lipa, W., Orlik, A., Potzmann, R., Schöner, W., Ungersböck, M., Matulla, C., Briffa, K., Jones, P., Efthymiadis, D., Brunetti, M., Nanni, T., Maugeri, M., Mercalli, L., Mestre, O., Moisselin, J.-M., Begert, M., Müller-Westermeier, G., Kveton, V., Bochnicek, O., Stastny, P., Lapin, M., Szalai, S., Szentimrey, T., Cegnar, T., Dolinar, M., Gajic-Capka, M., Zaninovic, K., Majstorovic, Z., and Nieplova, E.: HISTALP – historical instrumental climatological surface time series of the Greater Alpine Region, Int. J. Climatol., 27, 1–46, 2007.

Bao, G., Liu, Y., and Linderholm, H. W.: April–September mean maximum temperature inferred from Hailar pine (Pinus sylvestris var. mongolica) tree rings in the Hulunbuir region, Inner Mongolia, back to 1868 AD, Palaeogeogr. Palaeocli., 313/314, 162–172, doi:10.1016/j.palaeo.2011.10.017, 2012.

Barichivich, J., Sauchyn, D. J., and Lara, A.: Climate signals in high elevation tree-rings from the semiarid Andes of north-central Chile: Responses to regional and large-scale variability, Palaeogeogr. Palaeocli., 281, 320–333, 2009.

Baroni, C. and Carton, A.: Variazioni glaciali oloceniche nel Gruppo del M. Adamello, Memorie della Società Geologica Italiana, 45, 877–882, 1990.

Baroni, C. and Carton, A.: Geomorfologia dell'alta Val di Genova (Gruppo dell'Adamello Alpi Centrali), Geogr. Fis. Din. Quat., 19, 3–17, 1996.

Baroni, C., Carton, A., and Seppi, R.: Distribution and Behaviour of Rock Glaciers in the Adamello-Presanella Massif (Italian Alps), Permafrost Periglac., 15, 243–259, 2004.

Baroni, C., Armiraglio, S., Gentili, R., and Carton, A.: Landform-vegetation units for investigating the dynamics and geomorphologic evolution of alpine composite

debris cones (Valle dell'Avio, Adamello Group, Italy), Geomorphology, 84, 59–79, doi:10.1016/j.geomorph.2006.07.002, 2007.
Beniston, M.: Climatic change in mountain regions: a review of possible impacts, Climatic Change, 59, 5–31, 2003.
Beniston, M.: Mountain Climates and Climatic Change: An Overview of Processes Focusing on the European Alps, Pure Appl. Geophys., 162, 1587–1606, doi:10.1007/s00024-005-2684-9, 2005.
Beniston, M., Rebetez, M., Giorgi, F., and Marinucci, M. R.: Features of regional climate change in Switzerland, Theor. Appl. Climatol., 49, 135–159, 1994.
Beniston, M., Diaz, H. F., and Bradley, R. S.: Climatic Change at High Elevation Sites; A Review, Climatic Change, 36, 233–251, 1997.
Bradley, R. S. and Jones, P. D.: Climatic variations over the last 500 years, in: Climate Since AD 1500, Routledge, edited by: Bradley, R. S. and Jones, P. D., London, 649–665, 1992.
Bradley, R. S. and Jones P. D.: "Little Ice Age" summer temperature variations: their nature and relevance to recent global warming trends, The Holocene, 3–4, 367–376, 1993.
Bradley, R. S., Briffa, K. R., Cole, J., Hughes, M. K., and Osborn, T. J.: The climate of the last millennium, in: Paleoclimate, Global Change and the Future, edited by: Alverson, K. D., Bradley, R. S., and Pedersen, T. F., Springer, Berlin, 105–141, 2003.
Bräuning, A. and Mantwill, B.: Summer temperature and summer monsoon history on the Tibetan Plateau during the last 400 years recorded by tree rings, Geophys. Res. Lett., 31, L24205, doi:10.1029/2004GL020793, 2004.
Briffa, K. R., Jones, P. D., Pilcher, J. R., and Hughes, M. K.: Reconstructing Summer Temperatures in Northern Fennoscandinavia Back to A.D. 1700 Using Tree-Ring Data from Scots Pine, Arctic Alpine Res., 20, 385–394, 1988.
Briffa, K. R., Jones, P. D., Schweingruber, F. H., and Osborn, T. J.: Influence of volcanic eruptions on Northern Hemisphere summer temperature over the past 600 year, Nature, 393, 450–455, 1998.
Briffa, K. R., Osborn, T. J., Schweingruber, F. H., Harris, I. C., Jones, P. D., Shiyatov, S. G., and Vaganov, E. A.: Low-frequency temperature variations from a northern tree-ring density network, J. Geophys. Res., 106, 2929–2941, 2001.
Büntgen, U., Esper, J., Frank, D. C., Nicolussi, K., and Schmidhalter, M.: A 1052-year tree-ring proxy of Alpine summer temperatures, Clim. Dynam., 25, 141–153, 2005.

Büntgen, U., Frank, D. C., Nievergelt, D., and Esper, J.: Summer Temperature Variations in the European Alps, A.D. 755–2004, J. Climate, 19, 5606–5623, 2006.

Büntgen, U., Frank, D., Wilson, R., Carrer, M., Urbinati, C., and Esper, J.: Testing for tree-ring divergence in the European Alps, Global Change Biol., 14, 2443–2453, 2008.

Carrer, M. and Urbinati, C.: Age-dependent tree-ring growth responses to climate in Larix Decidua and *Pinus cembra*, Ecology, 85, 730–740, 2004.

Chen, F., Yuan, Y. J., Wei, W. S., Yu, S. L., Fan, Z. A., Zhang, R. B., Zhang, T. W., Li, Q., and Shang, H. M.: Temperature reconstruction from tree-ring maximum latewood density of Qinghai spruce in middle Hexi Corridor, China, Theor. Appl. Climatol., 107, 633–643, doi:10.1007/s00704-011-0512-y, 2012.

CGI-CNR (Comitato Glaciologico Italiano – Consiglio Nazionale delle Ricerche) 1959–1962 – Catasto dei Ghiacciai Italiani (Inventory of Italian glaciers), International Geophysical Year, 1957–1958, Comitato Glaciologico Italiano, Turin, Italy, Vol. 1–4, available at: http://www.glaciologia.it/i-ghiacciai-italiani/?lang=en (last access: 10 August 2012), 1959–1962.

Cook, E. R.: A time series analysis approach to tree-ring standardization, PhD thesis, University of Arizona, Arizona, 1985.

Cook, E. R. and Briffa, K. R.: A comparison of some tree-ring standardization methods, in: Methods of Dendrochronology, edited by: Cook, E. R. and Kairiukstis, L. A., Kluwer, Dordrecht, 104–123, 1990.

Cook, E. R. and Holmes, R. L.: Program ARSTAN user manual: laboratory of tree ring Research, University of Arizona, Tucson, 1984.

Coppola, A., Leonelli, G., Salvatore, M. C., Pelfini, M., and Baroni, C.: Weakening climatic signal since mid-20th century in European larch tree-ring chronologies at different altitudes from the Adamello-Presanella Massif (Italian Alps), Quaternary Res., 77, 344–354, doi:10.1016/j.yqres.2012.01.004, 2012.

Corona, C., Guiot, J., Edouard, J. L., Chalié, F., Büntgen, U., Nola, P., and Urbinati, C.: Millennium-long summer temperature variations in the European Alps as reconstructed from tree rings, Clim. Past, 6, 379–400, doi:10.5194/cp-6-379-2010, 2010.

Corona, C., Edouard, J.-L., Guibal, F., Guiot, J., Bernard, S., Thomas, A., and Denelle, N.: Long-term summer (AD751–2008) temperature fluctuation in the French Alps based on tree-ring data, Boreas, 40, 351–366, 2011.

Crowley, T. J.: Causes of climate change over the past 1000 years, Science, 289, 270–277, 2000.

D'Arrigo, R. and Jacoby, G. C.: Northern North American tree-ring evidence for regional temperature changes after major volcanic events, Climatic Change, 41, 1–15, 1999.

D'Arrigo, R., Wilson, R., and Jacoby, G.: On the long-term context for late 20th century warming, J. Geophys. Res., 111, D03103, doi:10.1029/2005JD006352, 2006.

D'Arrigo, R., Wilson, R., Liepert, B., and Cherubini, P.: On the "divergence problem" in northern forests: a review of the treering evidence and possible causes, Global Planet. Change, 60, 289–305, 2008.

Esper, J., Cook, E. R., and Schweingruber, F. H.: Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability, Science, 295, 2250–2253, 2002.

Esper, J., Frank, D., Büntgen, U., Verstege, A., and Luterbacher, J.: Long-term drought severity variations in Morocco, Geophys. Res. Lett., 34, L17702, doi:10.1029/2007GL030844, 2007.

Fan, Z. X., Bräuning, A., Yang, B., and Cao, K. F. Tree ring density-based summer temperature reconstruction for the central Hengduan Mountains in southern China, Glob. Planet. Change, 65, 1–11, doi:10.1016/j.gloplacha.2008.10.001, 2009.

Fan, Z. X., Bräuning, A., and Cao, K. F.: Tree ring recorded May–August temperature variations since A.D. 1585 in the Gaoligong Mountains, southeastern Tibetan Plateau, Paleogeogr. Paleocli., 296, 94–102, doi:10.1016/j.palaeo.2010.06.017, 2010.

Fang, K., Gou, X., Chen, F., Li, J., D'Arrigo, R., Cook, E., Yang, T., and Davi, N.: Reconstructed droughts for the southeastern Tibetan Plateau over the past 568 years and its linkages to the Pacific and Atlantic Ocean climate variability, Clim. Dynam., 35, 577–585, 2010.

Fang, K., Gou, X., Chen, F., Cook, E., Li, J., Buckley, B., and D'Arrigo, R.: Large-scale precipitation variability over Northwest China inferred from tree rings, J. Climate, 24, 3457–3468, 2011.

Fang, K., Gou, X., Chen, F., Davi, N., and Changzhi, L.: Spatiotemporal drought variability for central and eastern Asia over the past seven centuries derived from tree-ring based reconstructions, Quaternary Int., in press, doi:10.1016/j.quaint.2012.03.038, 2012.

Frank, D. and Esper, J.: Temperature reconstructions and comparison with instrumental data from a tree-ring network for the European Alps, Int. J. Climatol., 25, 1437–1454, 2005a.

Frank, D. and Esper, J.: Characterization and climate response patterns of a high elevation, multi-species tree-ring network in the European Alps, Dendrochronologia, 22, 107–121, 2005b.

Frank, D., Wilson, R., and Esper, J.: Synchronous variability changes in Alpine temperature and tree-ring data over the past two centuries, Boreas, 34, 498–505, 2005.

Fritts, H. C.: Tree Rings and Climate, Academic Press, New York, 1976.
Fritts, H. C. and Schatz, D. J.: Selecting and characterizing tree-ring chronologies for dendroclimatic analysis, Tree-Ring Bulletin, 35, 31–40, 1975.
Gentili, R., Armiraglio, S., Rossi, G., Sgorbati, S., and Baroni, C.: Floristic patterns, ecological gradients, and biodiversity in the channels (Central Alps, Italy), Flora, 205, 388–398, doi:10.1016/j.flora.2009.12.013, 2010.
Grissino-Mayer, H. D.: Evaluating crossdating accuracy: a manual and tutorial for the computer program COFECHA, Tree-Ring Res., 57, 205–221, 2001.
Grove, J. M.: The Little Ice Age, Routledge, London, 498 pp., 1988.
Holmes, R. L.: Computer-assisted quality control in tree-ring dating and measurement, Tree-Ring Bulletin, 43, 69–78, 1983.
Holzhauser, H., Magny, M., and Zumbühl, H. J.: Glacier and lake level variations in west-central Europe over the last 3500 years, The Holocene, 15, 789–801, 2005.
Houghton, J. T., Jenkins, G. J., and Ephraums, J. J. (Eds.): Climate Change: The IPCC Scientific Assessment ± Report of IPCC Working Group I, Cambridge University Press, Cambridge, 365 pp., 1990.
Houghton, J. T., Ding Y., Griggs, D. J., Noguer, M., van der Linden, P. J., and Xiaosu, D. (Eds.): Climate Change 2001: The Scientific Basis ± Contribution of Working Group I to the IPCC Third Assessment Report, Cambridge University Press, Cambridge, 944 pp., 2001.
Hughes, M. K.: Dendroclimatology in High-Resolution Paleoclimatology, in: Dendroclimatology: Progress and Prospects, edited by: Hughes, M. K., Swetnam, T. W., and Diaz, H. F.,Springer Verlag, 17–36, 2011.
Jacoby, G., Lovelius, N., Shumilov, O., Raspopov, O., Kurbainov, J., and Frank, D.: Long-term temperature trends and tree growth in the Taymir region of northern Siberia, Quaternary Res., 53, 312–318, 2000.
Larocque, S. J. and Smith, D. J.: A dendroclimatological reconstruction of climate since AD 1700 in the Mt. Waddington area, British Columbia Coast Mountains, Canada, Dendrochronologia, 22, 93–106, 2005.
Le Quesne, C., Stahle, D. W., Cleaveland, M. K., Therrell, M. D., Aravena, J. C., and Barichivich, J.: Ancient Austrocedrus Tree-Ring Chronologies Used to Reconstruct Central Chile Precipitation Variability from a.d. 1200 to 2000, J. Climate, 19, 5731–5744, doi:10.1175/JCLI3935.1, 2006.

CPD
8, 3871–3900, 2012

Tree-ring based June–July mean temperature variations

A. Coppola et al.

Le Quesne, C., Acuña, C., Boninsegna, J. A., Rivera, A., and Barichivich, J.: Long-term glacier variations in the Central Andes of Argentina and Chile, inferred from historical records and tree-ring reconstructed precipitation, Palaeogeogr. Palaeocli., 281, 334–344, 2009.
Leonelli, G. and Pelfini, M.: Influence of climate and climate anomalies on Norway spruce tree-ring growth at different altitudes and on glacier responses: examples from the Central Italian Alps, Geogr. Ann., 90 A, 75–86, 2008.
Leonelli, G., Pelfini, M., Battipaglia, G., and Cherubini, P.: Site-aspect influence on climate sensitivity over time of a high-altitude *Pinus cembra* tree-ring network, Climatic Change, 96, 185–201, doi:10.1007/s10584-009-9574-6, 2009.
Leonelli, G., Pelfini, M., Morra di Cella, U., and Garavaglia, V.: Climate Warming and the Recent Treeline Shift in the European Alps: The Role of Geomorphological Factors in High-Altitude Sites, Ambio, 40, 264–273, doi:10.1007/s13280-010-0096-2, 2011.
Li, Z. S., Zhang, Q. B., and Ma, K. P.: Tree-ring reconstruction of summer temperature for A.D. 1475-2003 in the central Hengduan Mountains, Northwestern Yunnan, China, Climatic Change, 110, 455–467, doi:10.1007/s10584-011-0111-z, 2012.
Liu, Y., Bao, G., Song, H. M., Cai, Q. F., and Sun, J. Y.: Precipitation reconstruction fromHailar pine (Pinus sylvestris var. mongolica) tree rings in the Hailar region, Inner Mongolia, China back to 1865 AD, Palaeogeogr. Palaeocli., 282, 81–87, 2009.
Luckman, B. H. and Wilson, R. J. S.: Summer temperatures in the Canadian Rockies during the last millennium: A revised record, Clim. Dynam., 24, 131–144, 2005.
Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., and Wanner, H.: European seasonal and annual temperature variability, trends, and extremes since 1500, Science, 303, 1499–1503, 2004.
Mann, M. E., Bradley, R. S., and Hughes, M. K.: Global-scale temperature patterns and climate forcing over the past six centuries, Nature, 392, 779–787, 1998.
Mann, M. E., Bradley, R., and Hughes, M.: NH temperatures during the past millennium: Inferences, uncertainties and limitations, Geophys. Res. Lett., 26, 759–762, 1999.
Marinucci, M. R., Giorgi, F., Beniston, M., Wild, M., Tschuck, P., and Bernasconi, A.: High Resolution Simulations of January and July Climate over the Western Alpine Region with a Nested Regional Modeling System, Theor. Appl. Climatol., 51, 119–138, 1995.
Meko, D. M. and Graybill, D. A.: Tree-ring reconstruction of Upper Gila River Discharge, Water Resour. Bull., 31, 605–616, 1995.

CPD
8, 3871–3900, 2012

Michaelsen, J.: Cross-validation in statistical climate forecast models, J. Clim. Appl. Meteorol., 26, 1589–1600, 1987
Nicolussi, K. and Patzelt, G.: Discovery of Early Holocene wood and peat on the forefield of the Pasterze Glacier, Eastern Alps, Austria, The Holocene, 10, 191–199, 2000.
Oerlemans, J.: Glaciers and Climate Change, Rotterdam, A. A. Balkema Publishers, 148 pp., 2001.
Oppenheimer, C.: Climatic, environmental and human consequences of the largest known historic eruption: Tambora volcano (Indonesia) 1815, Prog. Phys. Geog., 27, 230–259, 2003.
Ostrom Jr., C. W.: Time Series Analysis, Regression Techniques, 2nd Edn.: Quantitative Applications in the Social Sciences, Vol. 07-009, Newbury Park, Sage Publications, 1990.
Pelfini, M., Leonelli, G., and Santilli, M.: Climatic and Environmental Influences on Mountain Pine (Pinus Montana Miller) Growth in the Central ItalianAlps, Arct. Antarct. Alp. Res., 38, 614–623, 2006.
Ranzi, R., Grossi, G., Gitti, A., and Taschner, S.: Energy and mass balance of the mandrone glacier (Adamello, Central Alps), Geogr. Fis. Din. Quat., 33, 45–60, 2010.
Rinn, F.: TSAPWin – Time Series Analysis and Presentation for Dendrochronology and Related Applications, Version 0.53, User Reference, Heidelberg, 2005.
Roig, F. A., Le Quesne, C., Boninsegna, J. A., Briffa, K. R., Lara, A., Gruddk, H. Ê., Jones, P. D., and Villagra Ân, C.: Climate variability 50,000 years ago in mid-latitude Chile as reconstructed from treerings, Nature, 410, 567–570, doi:10.1038/35069040, 2001.
Sadler, J. P. and Grattan, J. P.: Volcanoes as agents of past environmental change, Global Planet. Change, 21, 181–196, 1999.
Schweingruber, F. H.: Tree rings and environment: dendroecology, Swiss Federal Institute for Forest, Snow and Landscape Research, Paul HauptVerlag, 609 pp., 1996,
Shiyatov, S. G., Mazepa, V. S., Vaganov, E. A., and Schweingruber, F. H.: Summer temperature variations reconstructed by tree-ring data at the polar timberline in Siberia, in: Tree Rings, Environment and Humanity: Proceedings of the International Conference, edited by: Dean, J. S., Meko, D. M., and Swetnam, T. W., Tucson, Arizona, 17–21 May 1994, 61–70, Radiocarbon, Tucson, 1996.
Snee, R. D.: Validation of regression models: methods and examples, Technometrics, 19, 415–428, 1997.
Stokes, M. A. and Smiley, T. L.: An Introduction to Tree-Ring Dating, University of Chicago Press, Chicago, IL, 1968.

CPD
8, 3871–3900, 2012

Tree-ring based June–July mean temperature variations

A. Coppola et al.

Swetnam, T. W.: Using dendrochronology to measure radial growth of defoliated trees, USDA Forest Service, Cooperative State Research Service, Agriculture Handbook No. 639, 1–39, 1985.
Tessier, L., Guibal, F., and Schweingruber, F. H.: Research strategies in dendroecology and dendroclimatology in mountain environments, Climatic Change, 36, 499–517, 1997.
Touchan, R., Garfin, G. M., Meko, D. M., Funkhouser, G., Erkan, N., Hughes, M. K., and Wallin, B. S.: Preliminary reconstructions of spring precipitation in southwestern Turkey from tree-ring width, Int. J. Climatol., 23, 157–171, 2003.
Touchan, R., Xoplaki, E., Funkhouser, G., Luterbacher, J., Hughes, M. K., Erkan, N., Akkemik, U., and Stephan, J.: Reconstructions of spring/summer precipitation for the eastern Mediterranean from tree-ring widths and its connection to large-scale atmospheric circulation, Clim. Dynam., 25, 75–98, 2005.
Touchan, R., Anchukaitis, K. J., Meko, D. M., Attalah, S., Baisan, C., and Aloui, A.: Long term context for recent drought in northwestern Africa, Geophys. Res. Lett., 35, L13705, doi:10.1029/2008GL034264, 2008.
Touchan, R., Anchukaitis, K. J., Meko, D. M., Sabir, M., Attalah, S., and Aloui, A.: Spatiotemporal drought variability in northwestern Africa over the last nine centuries, J. Clim. Dynam., 37/1–2, 237–252, doi:10.1007/s00382-010-0804-4, 2010.
Villalba, R.: Climatic fluctuations in Northern Patagonian during the last 1000 years as inferred from tree-rings records, Quaternary Res. 34, 346–60, 1990.
Villalba, R., Lara, A., Boninsegna, J. A., Masiokas, M., Delgado, S., Aravena, J. C., Roig, F. A., Schmelter, A., Wolodarsky, A., and Ripalta, A.: Large-scale temperature changes across the Southern Andes: 20th century variations in the context of the past 400 years, Climatic Change, 59, 177–232, 2003.
Wagner, S. and Zorita, E.: The influence of volcanic, solar and CO_2 forcing on the temperatures in the Dalton Minimum (1790–1830): a model study, Clim. Dynam., 25, 205–218, 2005.
Wigley, T. M. L., Briffa, K. R., and Jones, P. D.: On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology, J. Clim. Appl. Meteorol., 23, 201–213, 1984.
Wilmking, M., Juday, G., Barber, V., and Zald, H.: Recent climate warming forces contrasting growth responses of white spruce at treeline in Alaska through temperature thresholds, Glob. Change Biol., 10, 1724–1736, 2004.

Wilson, R. J. S., D'Arrigo, R., and Buckley, B.: Matter of divergence: tracking recent warming at hemispheric scales using tree-ring data, J. Geophys. Res.-A, 112, D17103, doi:10.1029/2006JD008318, 2007.
Wilson, R. M.: Volcanism, Cold Temperature, and Paucity of Sunspot Observing Days (1818–1858): A Connection? The Smithsonian/NASA Astrophysics Data System NASA/TP-1998–208592, 1998.
Zhu, H. F., Shao, X. M., Yin, Z. Y., and Huang, L.: Early summer temperature reconstruction in the eastern Tibetan plateau since ad 1440 using tree-ring width of Sabina tibetica, Theor. Appl. Climatol., 106, 45–53, doi:10.1007/s00704-011-0419-7, 2011.

CPD
8, 3871–3900, 2012

Tree-ring based June–July mean temperature variations

A. Coppola et al.

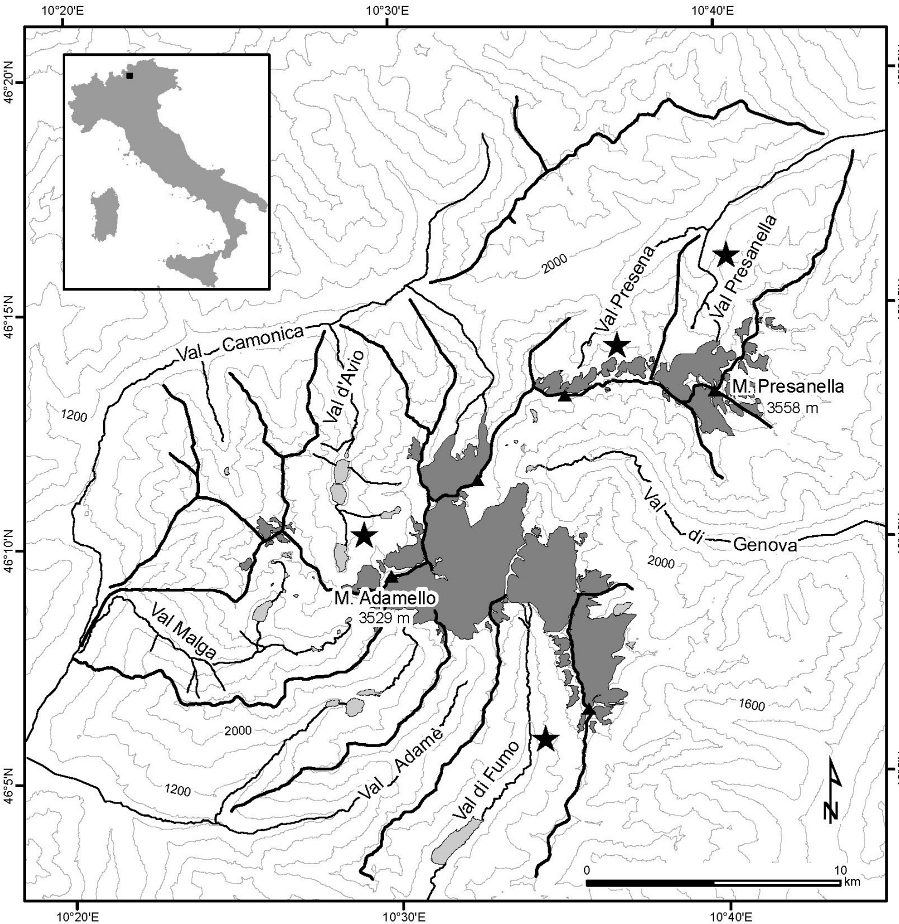

Fig. 1. Sketch map of the study area. Black asterisks indicate the location of the study sites.

CPD
8, 3871–3900, 2012

Tree-ring based June–July mean temperature variations

A. Coppola et al.

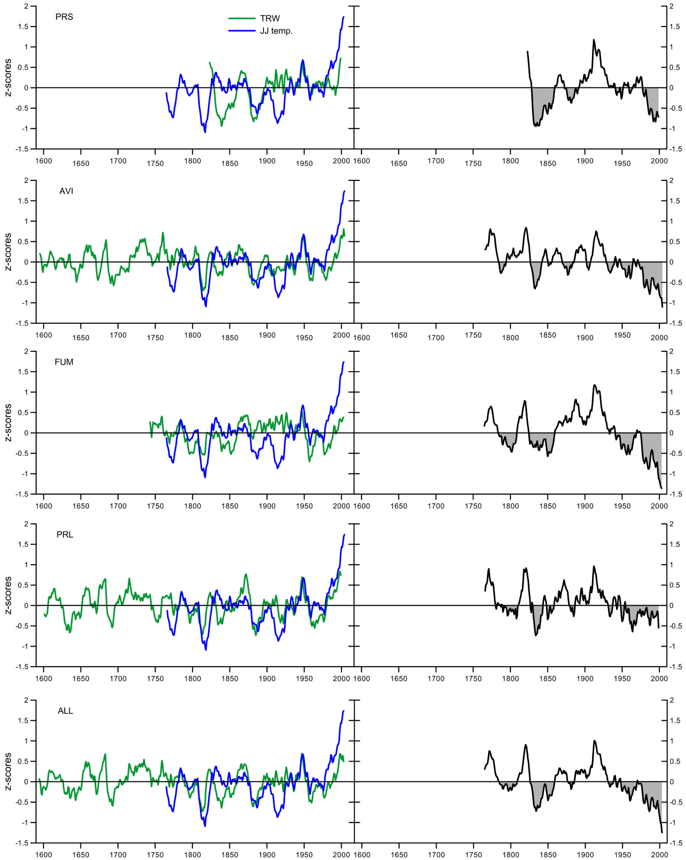

Fig. 2. *z*-scores derived from the four residual tree-ring width chronologies (green lines) and June-July mean temperature anomalies (°C wrt. 1901–2000) (blue lines). In the right side of the graphs are reported the difference series (growth minus temperature), negative values are shaded.

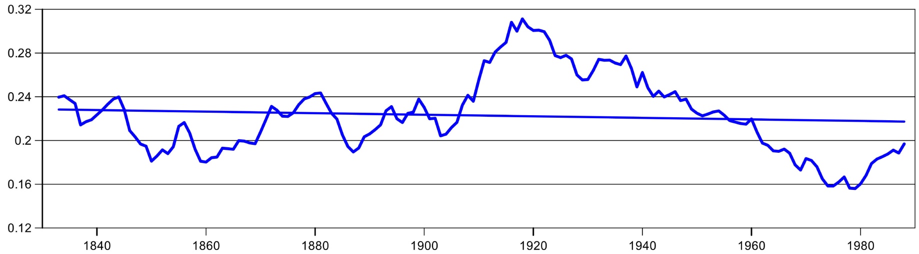

Fig. 3. Moving mean sensitivity, calculated over 30-yr time windows (see methods).

CPD
8, 3871–3900, 2012

Tree-ring based June–July mean temperature variations

A. Coppola et al.

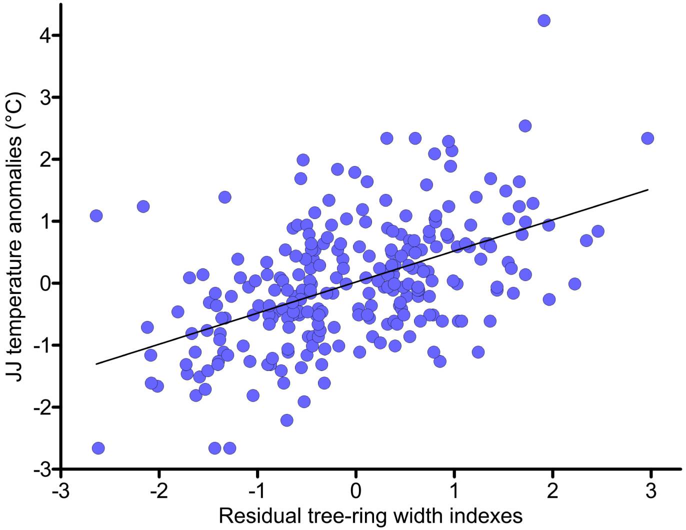

Fig. 4. Scatterplot of ALL residual tree ring width indexes against JJ temp anomalies.

CPD
8, 3871–3900, 2012

Tree-ring based June–July mean temperature variations

A. Coppola et al.

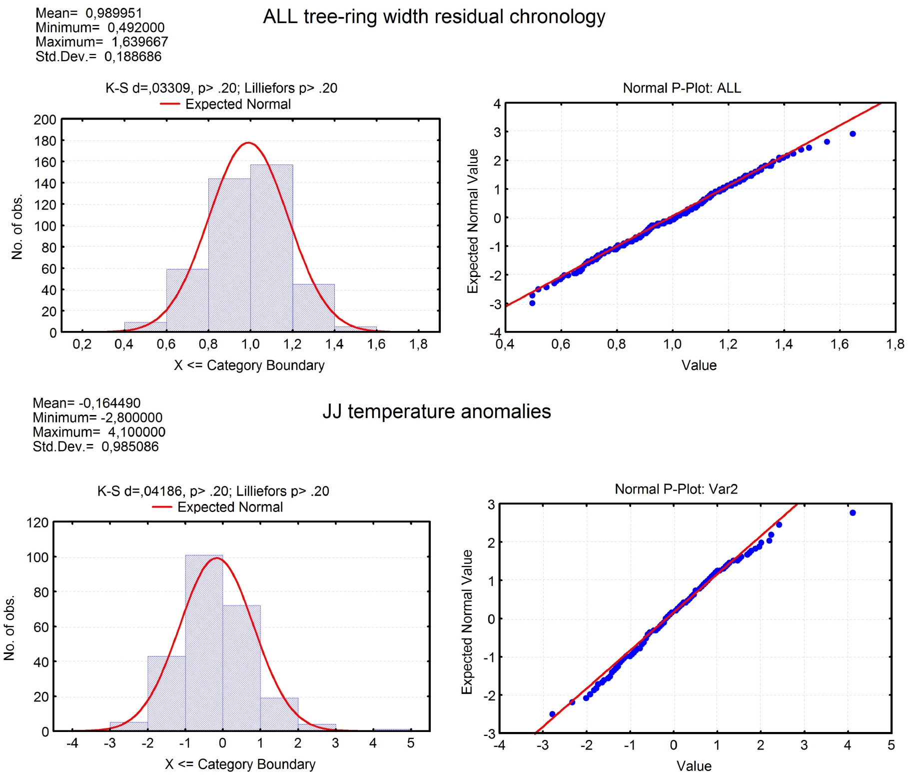

Fig. 5. Statistical characteristics of tree-ring data and June-July mean temperature anomalies.

CPD
8, 3871–3900, 2012

Tree-ring based June–July mean temperature variations

A. Coppola et al.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

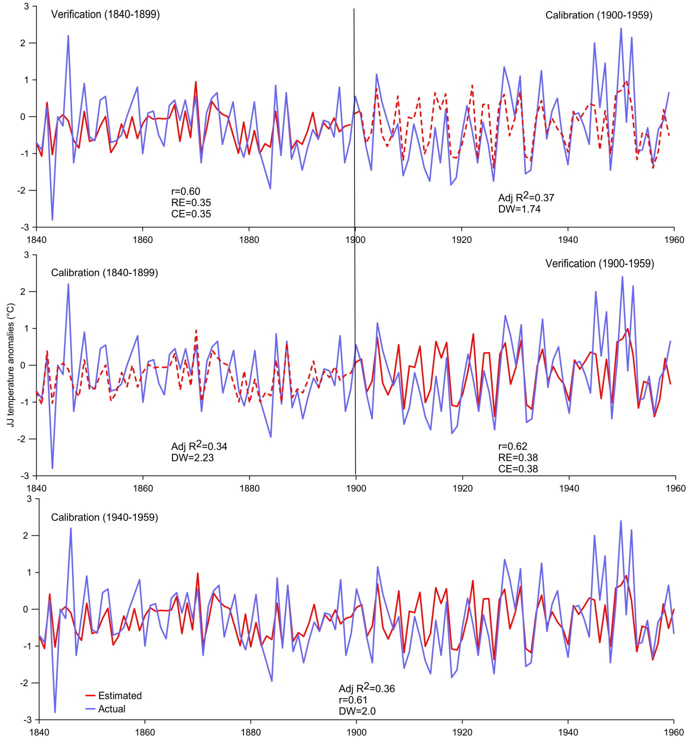

Fig. 6. Split sample procedure. Time series of the actual and reconstructed June-July mean temperature for the calibration and verification periods (1840–1960). All statistics are significant at the 0.05 level.

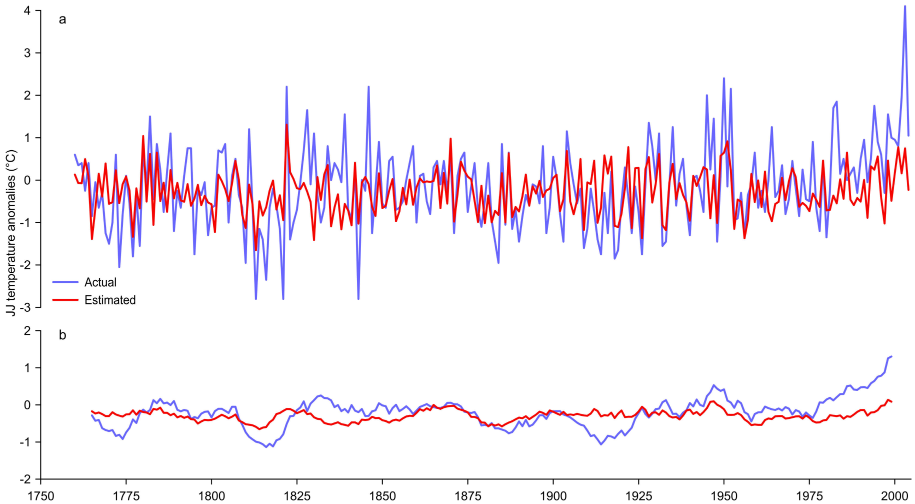

Fig. 7. (a) Actual and reconstructed June-July mean temperature over their entire overlapping period (1760–2004) ($r = 0.53$). **(b)** 11-yr moving averages of the two time series.

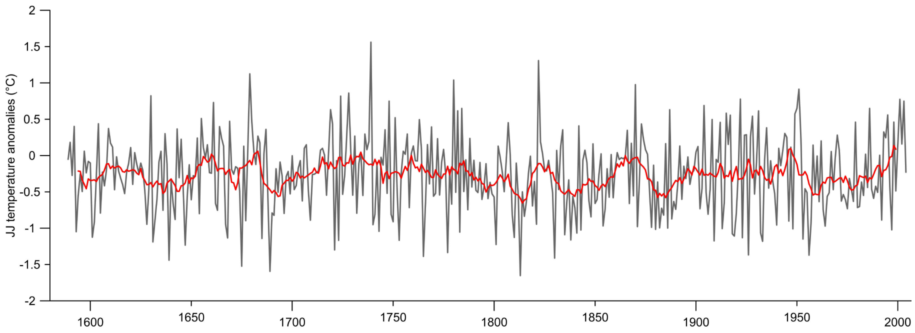

Fig. 8. Reconstructed June-July mean temperature. The red line is the 11-yr moving average.

CPD
8, 3871–3900, 2012