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# Multi-archive summer temperature reconstruction for the European Alps, AD1053–1996

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## Abstract

We present a multi-archive, multi-proxy summer temperature reconstruction for the European Alps covering the period AD 1053–1996 using tree-ring and lake sediment data. The new reconstruction is based on nine different calibration approaches and errors were estimated conservatively. Summer temperatures of the last millennium are characterised by two warm (AD 1053–1171 and 1823–1996) and two cold phases (AD 1172–1379 and 1573–1822). Highest pre-industrial summer temperatures of the 12th century were 0.3 °C warmer than the 20th century mean but 0.35 °C colder than proxy derived temperatures at the end of the 20th century. The lowest temperatures at the end of the 16th century were ~1 °C lower than the 20th century mean.

## Highlights

► Multi-archive summer temperature reconstruction for the European Alps. ► Highest JJA temperatures 1000–2000 AD occurred at the end of the 20th century. ► Sensitivity analysis suggests higher uncertainties prior to 1400. ► We therefore can't conclude on how unprecedented current temperatures are. ► Sensitivity analysis highlights importance of data included.

## Introduction

To assess the anthropogenic fingerprint of recent climate change, detailed insight into the evolution of pre-industrial (natural) climate during the last millennium is essential (Hegerl et al., 2011). While attention has focussed mainly on hemispheric-scale annual temperature reconstructions for the last 1000 years (e.g. Moberg et al., 2005, Frank et al., 2007a, Mann et al., 2008), regional scale and seasonally-resolved information is required to critically test the ability of General Circulation Models (GCM) to reconstruct the

climate of the past, and therefore to assess their reliability for predicting the climate of the future (e.g. McCarroll, 2010, Yamazaki etal., 2011). Spatial and seasonal variation in response to natural and anthropogenic forcing is also key to defining the sensitivity of the climate system to rising levels of greenhouse gases and to predicting the ecological, social and economic consequences of future climate change (Frank etal., 2010).

In the recent past a number of reconstructions of summer temperature for the Greater Alpine region (GAR) have been presented. Climate field reconstructions are available for the last 500 years (e.g. Luterbacher etal., 2004, Casty etal., 2005). Reconstructions based on documentary data covering the last 500 or 1000 years were presented recently (Glaser and Riemann, 2009; Dobrovolný etal., 2010). Further, several tree-ring based reconstructions (e.g. Büntgen etal., 2005, Büntgen etal., 2006, Büntgen etal., 2011, Corona etal., 2010, Corona etal., 2011) and high-resolution quantitative reconstructions from lake sediments (e.g. Larocque-Tobler etal., 2010, Trachsel etal., 2010) are available, and parts of the GAR are covered by the multi-proxy reconstruction of Guiot etal. (2005).

Reconstructions covering small areas are usually based on only one type of climate proxy, which makes them prone to proxy-specific restrictions such as the 'observational bias' of documentary data (Brázdil etal., 2005, Brázdil etal., 2010), the 'segment-length curse' of tree rings (Cook etal., 1995) or dating uncertainties of lake sediments. A multi-archive climate reconstruction is potentially less affected by these limitations and may provide a less biased understanding of pre-industrial climate evolution.

In this study, we present a multi-archive summer temperature reconstruction for the Greater Alpine Region spanning the period AD 1053–1996. The reconstruction is based on a set of climate proxies from lake sediments and tree-rings. Estimates of uncertainty are essential for detection and attribution studies (e.g. Hegerl etal., 2006) as well as data-model comparison (e.g. Graham etal., 2007). Here we use sensitivity analysis, thereby including uncertainty due to differences between the proxies during the reconstruction period (e.g. Moberg etal., 2005) as well as the uncertainties due to calibration (e.g. Rutherford etal., 2005). Our sensitivity analysis involves excluding (i) specific frequency bands of proxy time series (sensu Moberg etal., 2005), (ii) proxies that inherit an associated dating uncertainty and (iii) proxy series at random. We compare our reconstructions with tree-ring (Büntgen etal., 2011) and independent documentary-based reconstructions on a regional scale (Glaser and Riemann, 2009, Dobrovolný etal., 2010) and with multi-proxy reconstructions on hemispheric scale (e.g. Frank etal., 2007a, Hegerl etal., 2007, Mann etal., 2008).

## Section snippets

### Data

From the large number of datasets produced within the European Union project Millennium (http://www.ncdc.noaa.gov/paleo/pubs/millennium/millennium.html↗), we chose in total eight tree-ring and lake sediment based proxies from four different locations in the Greater Alpine Region (Table1, Fig.1). Proxy time series were selected according to their length (they should at least cover the period back to 1200) and their sensitivity to summer (JJA) temperatures in the calibration period (AD…

### Data

Fig.2(a–h) shows filtered versions of all the proxy time series used in this study. In the following, we briefly introduce the proxy series on which incomplete information is available in peer-reviewed journals.

The Tyrol-mxd data set (Esper et al., 2007, Fig. 2b) was developed using a total number of 227 P*icea abies* samples from living trees and relict wood spanning the period 1053–2003 with a minimum replication of 4 samples. The mean inter-series correlation is always higher than $r$=0.53.…

## Reconstructions

The Greater Alpine region represents a relatively small portion of the Northern Hemisphere extra-tropics. Still, there is general agreement between five northern hemisphere reconstructions and the reconstruction presented in this study, which does not include any proxy data used in the Northern Hemisphere reconstructions (Fig. 7a). Reconstructions indicate warmer conditions at the beginning of the last millennium, a subsequent cooling with coldest temperatures mostly in the 17th century and a…

## Conclusions

In this study we presented a multi-archive reconstruction of summer temperature for the European Alps covering the last millennium based on nine different calibration approaches and conservative, but not all-embracing error estimation. Warmest summers 0.3 °C warmer than the 20th century mean occurred between 1050 and 1200. These temperatures were, however, 0.35 °C lower than temperatures in the last decade of the 20th century, though uncertainties during the early period of our reconstruction…

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