Calibration trails using very long instrumental and proxy data

J. Esper[1], R. Niederer[1], J. Luterbacher[2,3], U. Büntgen[1] & D. Frank[1]

[1] *Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland*
[2] *National Centre of Competence in Research on Climate (NCCR) and Institute of Geography, University of Bern, 3012 Bern, Switzerland*
[3] *Oeschger Centre for Climate Change Research, University of Bern, 3012 Bern, Switzerland*
Email: esper@wsl.ch

Introduction

The European Alps are one of the few places that allow comparisons of natural climate proxies, such as tree-rings, with instrumental and documentary data over multiple centuries. Evidence from local and regional tree-ring analyses in the Alps clearly showed that tree-ring width (TRW) data from high elevation, near treeline environments contain substantial temperature signals (e.g., Büntgen et al. 2005, 2006, Carrer et al. 2007, Frank and Esper 2005a, 2005b, Frank et al. 2005). This sensitivity can be evaluated over longer timescales by comparison with instrumental temperature data recorded in higher elevation (>1,500 m asl) environments back to the early 19th century, and, due to the spatially homogenous temperature field, back to the mid 18th century using observational data from stations surrounding the Alps (Auer et al. 2007, Böhm et al. 2001, Casty et al. 2005, Frank et al. 2007a, Luterbacher et al. 2004). Further, the combination of such instrumental data with even older documentary evidence (Pfister 1999, Brázdil et al. 2005) allows an assessment of temporal coherence changes between tree-rings and combined instrumental and documentary data back to AD 1660. Such analyses are outlined here using TRW data from a set of *Pinus cembra* L. sampling sites from the Swiss Engadin, and calibrating these data against a gridded surface air temperature reconstruction integrating long-term instrumental and multi-proxy data (Luterbacher et al. 2004).

Material and methods

Tree-ring data and detrending

Core and disc samples from three high elevation (Tam, Muo, Sil) and one middle elevation (Cel) stone pine sites in the Swiss Engadin in the Central Alps were collected (Fig. 1).

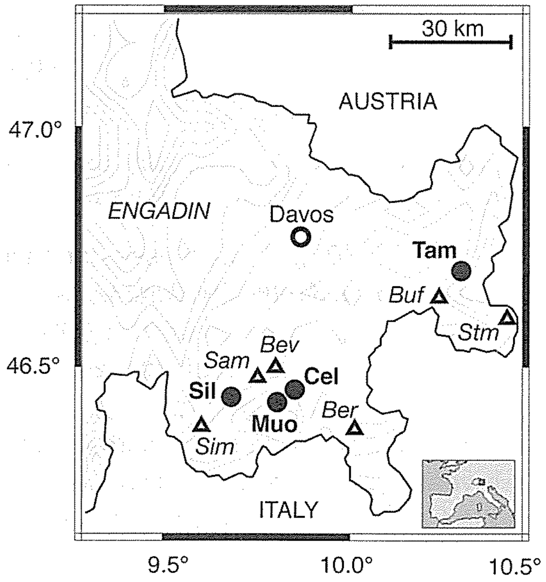

Figure 1: Tree-ring sampling sites (dots), and meteorological stations (triangles) in the Swiss Engadin south of Davos. Stations include Bernina Pass (Ber), Bever (Bev), Buffalora (Buf), Samedan (Sam), Sils Maria (Sil), Station Maria (Stm).

In total, 642 samples from 335 trees (Tab. 1) were processed, including TRW measurements, crossdating, and quality control (Esper and Gärtner 2001, Fritts 1976, Schweingruber 1983, Cook and Kairiukstis 1990). Mean segment and chronology lengths of the sites range from 125-206 years and AD 1564-1742, respectively. TRW data were detrended by taking residuals from 300-year cubic smoothing splines (Cook 1985) fitted to the power transformed (Cook and Peters 1997) measurement series. This procedure removes tree-age related trends (Bräker 1981), but emphasizes inter-annual to multi-decadal scale variance in the resulting index series (Cook et al. 1995, Esper et al. 2003).

Table 1: Sampling site and tree-ring data characteristics.

Site	Elevation [m asl]	Core sample number	Mean series length [yrs.]	Chronology period (> 4 series)
Muo	2,180	141	125	1682-2002
Tam	2,180	177	206	1564-2002
Sil	2,140	170	140	1660-2002
Cel	1,840	154	191	1742-2002

Site chronologies were calculated using the bi-weight robust mean, and the variance of these mean timeseries stabilized considering changes in sample replication and interseries correlation (Frank et al. 2007b).

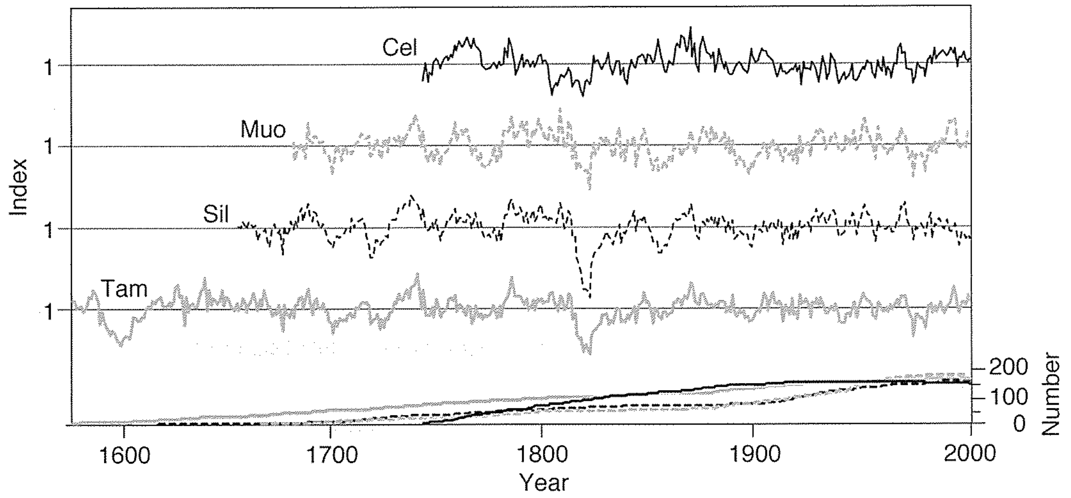

Figure 2: Spline detrended site chronologies from Cel, Muo, Sil, and Tam. Chronologies truncated at <5 series. Curves at the bottom show sample replication per site. Black curve is Cel, grey is Tam, dashed black is Sil, and dashed grey is Muo.

The site chronologies show common inter-annual to decadal scale (e.g., 1810s) variability (Fig. 2). Coherence between site chronologies ranges from r = 0.27 to 0.82 (mean = 0.55) calculated over the common 1741-2002 period (Tab. 2). Correlations of Cel (mean = 0.35) were lower than those of Muo (0.57), Sil (0.63), and Tam (0.65), indicating that this mid elevation site contains some different signals in comparison to the high elevation sites. Correlations do not decline back in time -- at least not back to 1701 as revealed in Table 2 -- indicating that inter-site coherence is fairly stable also during the less replicated early chronology periods (see replication curves at the bottom of Fig. 2). Interestingly, the chronology from Sil shows a negative trend over the most recent decade, a feature not revealed in any other site.

Table 2: Inter-site correlations over the 1741-2002, 1901-2002, 1801-1900, and 1701-1800 periods.

		1741-2002			
		Tam	Sil	Muo	Cel
1901-2002	Tam		0.82	0.72	0.41
	Sil	0.52		0.71	0.36
	Muo	0.73	0.60		0.27
	Cel	0.48	0.21	0.36	

		1801-1900			
		Tam	Sil	Muo	Cel
1701-1800	Tam		0.91	0.70	0.46
	Sil	0.84		0.73	0.38
	Muo	0.73	0.72		0.46
	Cel	—	—	—	

Instrumental and multi-proxy data

For comparison of tree-ring chronologies with instrumental and documentary data, we used the European scale gridded multi-proxy network from Luterbacher et al. (2004, hereafter abbreviated Lut04). For the grid points near the Swiss Engadin, this network contains information from regional long-term instrumental stations extending back to about 1760 (Auer et al. 2007), and temperature estimates derived from regional documentary evidence before that time back to 1500 (Luterbacher 2004, see Supporting Online Material).

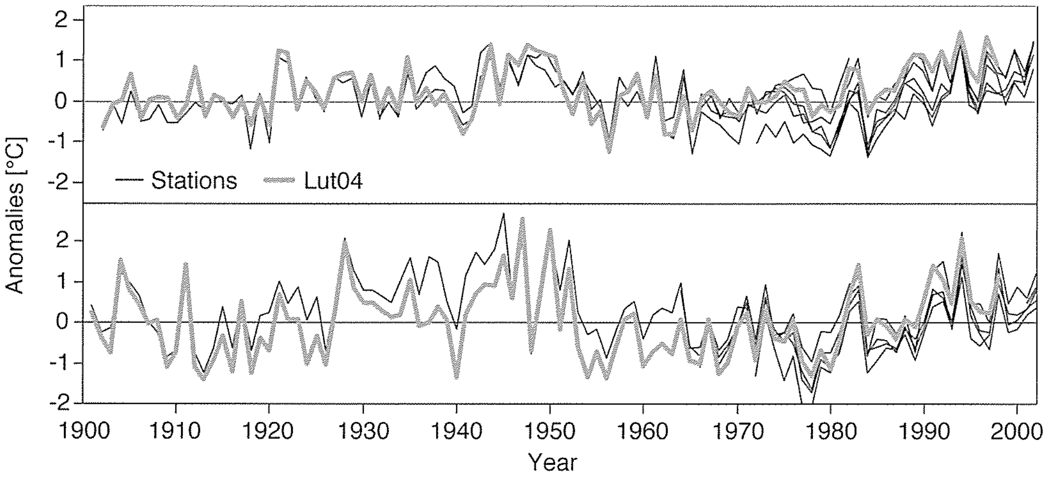

Figure 3: Temperature data from local observational stations and Lut04 since 1900. Top panel shows annual, bottom panel JJA temperatures. Thin black curves are the stations Ber, Bev, Buf, Sam, Sil, and Stm ranging from 1,390-2,256 m asl (see Fig. 1). Thick grey curve is Lut04. Series shown as anomalies with respect to the 1971-2000 period.

Correlations of Lut04 against local station data (see Fig. 1) range from 0.81-0.96 (mean = 0.90) for annual, and from 0.84-0.97 (mean = 0.93) for JJA temperatures, calculated over the 1970-2002 period. Visual comparison of the JJA and annual mean temperatures (Fig. 3) clearly demonstrates that Lut04 represents regional climate conditions as recorded in the six meteorological stations surrounding the tree sampling sites, and we used Lut04 for calibration trails over distinct periods and in a sliding window approach back to 1660.

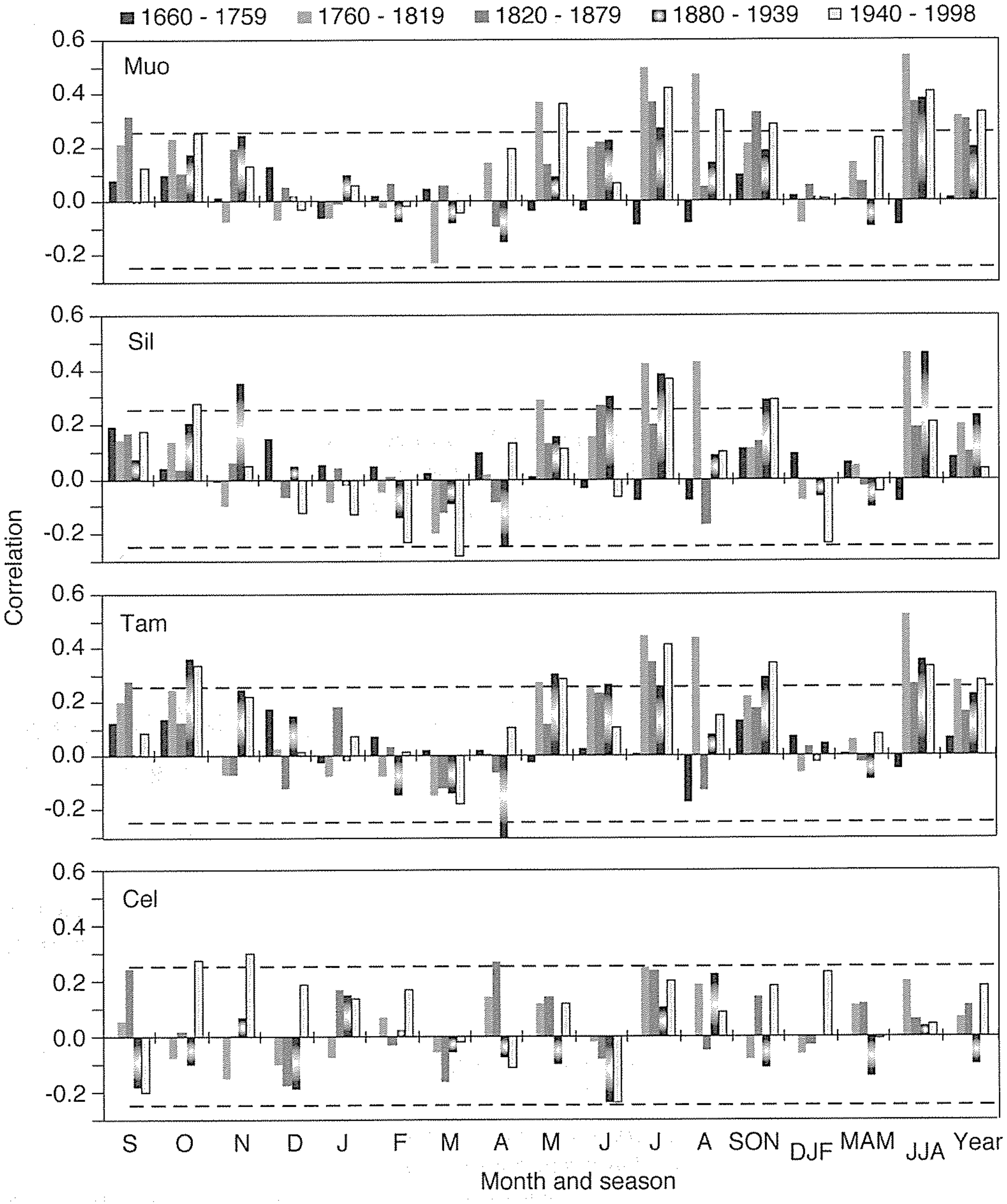

Figure 4: Monthly and seasonal correlations between four tree sites and Lut04 over the 1660-1759, 1760-1819, 1820-1879, 1880-1939, and 1940-1998 periods. Dashed curves approximate p<0.05.

Results

Climate response of the tree sites

The seasonal course and strength of climatic signals were quite similar between the three high elevation sites Muo, Sil, and Tam, but different in the mid elevation site Cel (Fig. 4). For the high elevation sites, significant correlations were found during some periods with previous year fall temperatures, and fairly strong responses for most of the current year summer months. Highest values were typically obtained for July and JJA mean temperatures. In comparison, the Cel sampling site from only about 300 m below the high elevation collections showed effectively no temperature signal, but was dominated by mixed impacts of cold/warm and wet/dry conditions (not shown).

Temporal variations in climate calibration

Comparison of the monthly and seasonal TRW versus Lut04 correlations over five distinct periods since 1660 indicated that the maximum sensitivity to July and mean JJA temperatures is largely stable back to 1760 at the high elevation sites (Fig. 4). The signal, however, disappeared over the early 1660-1759 period, during which both sample replication of the high elevation tree sites (especially Muo and Sil) declined considerably, and a change from early observational measurements towards estimates from documentary evidence in Lut04 occurred.

Computation of correlations between the tree sites and Lut04 JJA temperatures in a running 30-year window allowed further assessment of this temporal change, highlighting a strong decline in coherence including negative values in the pre-1760 period (Fig. 5). The course of correlation values was rather similar for all tree sites over the past 300+ years, adding some confidence to this analysis. The analysis, however, also indicated a drop in correlation during recent times in Sil, a feature that is likely related to the negative growth trend recorded at this site since the late 1980s.

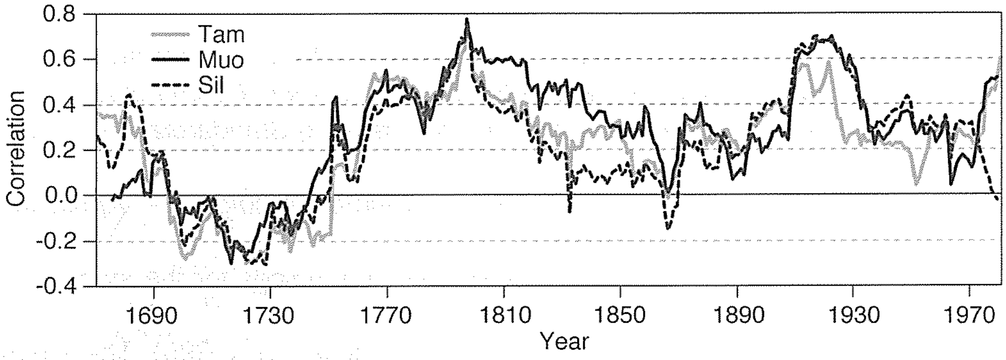

Figure 5: 30-year sliding window correlations of the Tam, Muo, and Sil site chronologies against mean JJA temperatures from Lut04.

Discussion

While our analyses revealed coherence between high elevation pine sites, between the Lut04 gridded and local station temperature data, and between the tree sites and regional temperatures as expressed by Lut04, calibration against early pre-1760 Lut04 data indicated no or even slightly negative correlations between tree growth and documentary evidence.

Our results are particularly robust over the past 2-3 centuries during which sample replication of the three treeline pine sites is rather high, but become less reliable before the 18th century when only the chronology from Tam is composed of a fairly high number of trees.

The loss of coherence between TRW and Lut04 data before 1760 either signifies that the climatic signal stored in the early, less replicated portions of the tree-ring chronologies diminished, and/or that the same signal weakened at the time the regional temperature measurements (e.g., Basel and Geneva temperature records started in the 1750s) were replaced with estimates derived from documentary evidence and measurements from more remote stations. Further research is needed to figure which of these alternatives is more important.

Acknowledgements

Supported by the EC project Millennium (Grant No. 017008), the SNSF through the National Centre for Competence in Climate Research (NCCR-Climate), and the Oeschger Centre for Climate Change Research.

References

Auer, I., and 31 Co-authors (2007): HISTALP – Historical instrumental climatological surface time series of the Greater Alpine Region. *International Journal of Climatology* 27: 17-46.

Böhm, R., Auer, I., Brunetti, M., Maugeri, M., Nanni, T., Schöner, W. (2001): Regional temperature variability in the European Alps: 1760-1998 from homogenized instrumental time series. *International Journal of Climatology* 21: 1779-1801.

Bräker, O.U. (1981): Der Alterstrend bei Jahrringdichten und Jahrringbreiten von Nadelhölzern und sein Ausgleich. *Mitteilungen der Forstlichen Bundesversuchsanstalt Wien* 142: 75-102.

Brázdil, R., Pfister, C., Wanner, H., von Storch, H., Luterbacher, J. (2005): Historical climatology in Europe – the state of the art. *Climatic Change* 70: 363-430.

Büntgen, U., Esper, J., Frank, D.C., Nicolussi, K., Schmidhalter, M. (2005): A 1052-year tree-ring proxy for Alpine summer temperatures. *Climate Dynamics* 25: 141-153.

Büntgen, U., Frank, D.C., Schmidhalter, M., Neuwirth, B., Seifert, M., Esper, J. (2006): Growth/climate response shift in a long subalpine spruce chronology. *Trees* 20: 99-110.

Carrer, M., Nola, P., Eduard, J.L., Motta, R., Urbinati, C. (2007): Regional variability of climate–growth relationships in *Pinus cembra* high elevation forests in the Alps. *Journal of Ecology* 95: 1072-1083.

Casty, C., Wanner, H., Luterbacher, J., Esper, J., Böhm, R. (2005): Temperature and precipitation variability in the European Alps since 1500. *International Journal of Climatology* 25: 1855-1880.

Cook, E.R. (1985): *A Time Series Analysis Approach to Tree-ring Standardization*. Lamont-Doherty Geological Observatory, New York.

Cook, E.R., Kairiukstis, L.A. (1990): *Methods of Dendrochronology – Applications in the Environmental Science*. Kluwer, Dordrecht.

Cook, E.R., Peters, K. (1997): Calculating unbiased tree-ring indices for the study of climatic and environmental change. *The Holocene* 7: 361-370.

Cook, E.R., Briffa, K.R., Meko, D.M., Graybill, D.A., Funkhouser, G. (1995): The `segment length curse´ in long tree-ring chronology development for palaeoclimatic studies. *The Holocene* 5: 229-237.

Esper, J., Gärtner, H. (2001): Interpretation of tree-ring chronologies. Erdkunde 55: 277-287.

Esper, J., Cook, E.R., Krusic, P.J., Peters, K., Schweingruber, F.H. (2003): Tests of the RCS method for preserving low-frequency variability in long tree-ring chronologies. *Tree-Ring Research* 59: 81-98.

Frank, D.C., Esper, J. (2005a): Characterization and climate response patterns of a high-elevation, multi-species tree-ring network for the European Alps. *Dendrochronologia* 22: 107-121.

Frank, D., Esper, J. (2005a): Temperature reconstructions and comparisons with instrumental data from a tree-ring network for the European Alps. *International Journal of Climatology* 25: 1437-1454.

Frank, D., Wilson, R.J.S., Esper, J. (2005): Synchronous variability changes in alpine temperature and tree-ring data over the last two centuries. *Boreas* 34: 498-505.

Frank, D.C., Büntgen, U., Böhm, R., Maugeri, M., Esper, J. (2007a): Warmer early instrumental measurements versus colder reconstructed temperatures: shooting at a moving target. *Quaternary Science Reviews*, in press.

Frank, D.C., Esper, J., Cook, E.R. (2007b): Adjustment for proxy number and coherence in a large-scale temperature reconstruction. *Geophysical Research Letters* 34, L16709.

Fritts, H.C. (1976): *Tree rings and climate.* Academic Press, New York.

Luterbacher, J., Dietrich, D., Xoplaki, E., Grosjean, M., Wanner, H. (2004): European seasonal and annual temperature variability, trends and extremes since 1500. *Science* 303: 1499-1503.

Pfister, C. (1999): Wetternachhersage: *500 Jahre Klimavariationen und Naturkatastrophen 1496-1995*. Haupt, Bern.

Schweingruber, F.H. (1983): *Der Jahrring: Standort, Methodik, Zeit und Klima in der Dendrochronologie*. Haupt, Bern.