Surface temperature variability over Europe back to AD 1500 and its connection to the Northern Hemisphere; volcanic forcing and importance of multiproxy data for large-scale climate reconstructions

Jürg Luterbacher[1,2], Elena Xoplaki[1], E. Fischer[1], Andreas Pauling[1] and Heinz Wanner[1,2]

[1] Institute of Geography, University of Bern, Hallerstrasse 12, CH-3012 Bern, Switzerland,
email: juerg@giub.unibe.ch, Fax: ++ 41 31 631 85 11

[2] National Competence Center of Research in Climate, University of Bern, Bern, Switzerland

Annual, summer or growing season (April-September) resolved centuries-long surface temperature reconstructions have been made available for the Northern Hemisphere (NH) (e.g. Briffa and Osborn 2002 and references therein). They are based on natural proxy data or achieved through multi-proxy networks. These temperature estimates point to interannual-to-interdecadal temperature variability over the past millennium. However, they provide less information at the continental and seasonal scale. For instance, these NH reconstructions cannot resolve the degree and length for specific periods such as the 'Little Ice Age' cooling over Europe.

Here, we present seasonal surface temperature reconstructions at 0.5x0.5 degree resolution (60km x 60km) for European land areas back to AD 1500, statistically reconstructed using a combination of long instrumental series and historical documentary records. Principal component regression analysis has been used to derive the statistical relationships between the climate information for the last 500 years and the large-scale temperature fields. We applied different calibration/verification exercises within the twentieth century in order to obtain information on the spatio-temporal stability of the results and the quality of the estimations. For the final 500-year reconstructions, the statistical relationships obtained over the 1901-1995 century were then applied to the pre-1900 data. Error measures (RE statistics) will be discussed. Further, uncertainty ranges for the predicted European seasonal temperature are computed in terms of +/- 2 standard error using statistics from the final calibration period (1901-1995).

In order to obtain seasonal information on the temperature evolution over Europe, we averaged all the 5050 gridpoints to winter and summer time series and studied its variability over the last 500 years.

Cooler European winters were generally experienced throughout the sixteenth and seventeenth centuries with lowest values within the Maunder Minimum (1670-1700) (not shown). This period was dry in many European parts connected with strong advection of continental air from Russia. Winters were also cold from the mid eighteenth until the end of the nineteenth century. Warmer winters were experienced around 1530, 1730 and in parts of the twentieth century. The winter of 1709 was the coldest over the last 500 years with more than 3.5°C lower values compared to the long-term twentieth century mean. Figure 1 shows the spatial temperature anomaly pattern of this winter. It reveals negative departures of up to 5°C over Central and Eastern Europe, Southern Scandinavia as well as over Western Russia.

Anomalies of the order of minus 2°C are found over the remaining parts of Europe. Only over Iceland the reconstructions point to warmer conditions.

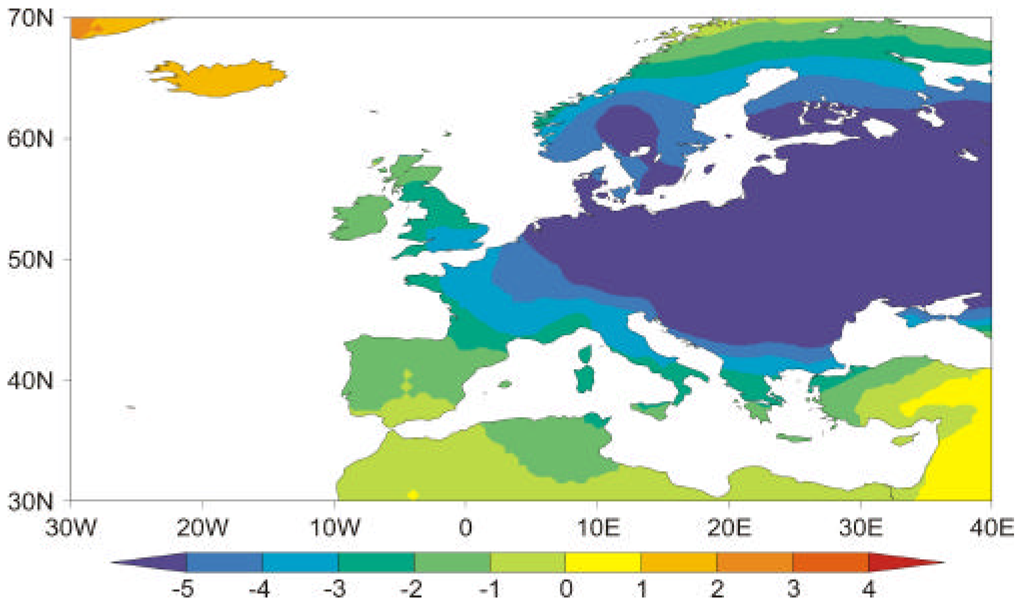

Figure 1: *European land temperature anomalies (reference period 1961-1990) for the very cold winter (DJF) 1709 (from Luterbacher et al. 2003).*

The warmest European winter was 1990 with around 2°C higher values in comparison with the 1901-1995 mean. Slightly warmer European summers were observed from around 1530 to 1570, from the 1750s to the mid-nineteenth century, around 1950 and at the end of the twentieth century. Cooler summer periods were prevalent around 1600, 1700 and 1900 (not shown). The warmest summer over the entire 500 year period was in 1811 with 1.5°C above normal temperature whereas 1902 was the coolest European summer with a similar departure compared to the 1901-1995 average.

The European land and the NH land temperatures at annual scale are highly correlated over the last 140 years of instrumental data and indicate an overall warming trend of around 1°C (depending on the season). However, for the pre-1860 periods, except for the mid-sixteenth century and the Maunder Minimum period, there is less agreement between European land and Northern Hemisphere temperature estimates (Figure 2). This might be attributed to uncertainties in the reconstructions, but could partly reflect different climate behavior at continental scale compared to the entire NH.

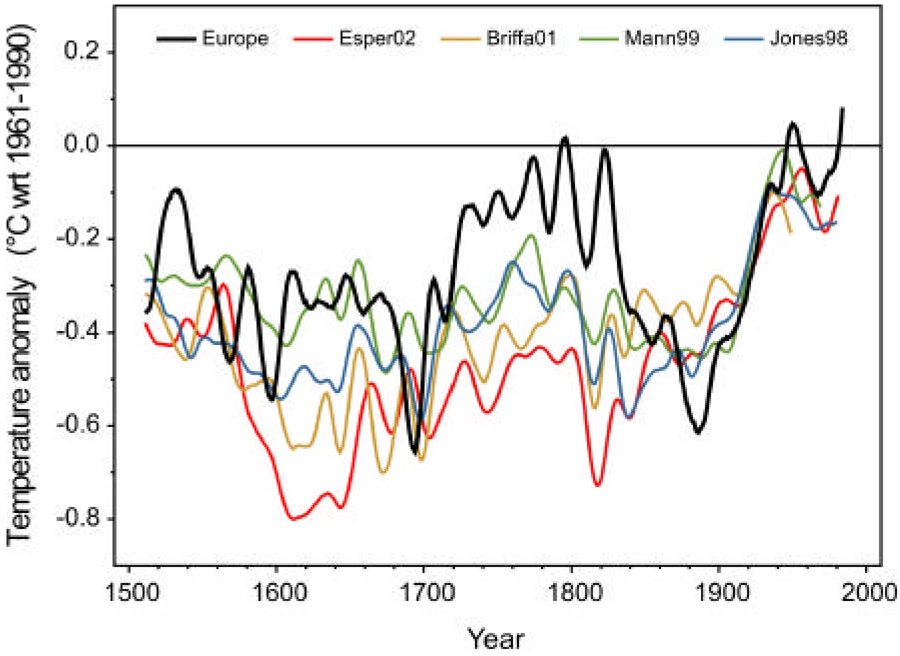

Figure 2: *Various estimates of large-scale Northern Hemisphere and European land temperature variations over the last 500 year, with reference to the average from 1961-1990 (Luterbacher et al. 2003). The Northern Hemisphere records were re-calibrated with linear regression against 1881-1960 mean annual temperature observations averaged over land areas north of 20°N (Briffa and Osborn, 2002). All time series are smoothed with a 30-year Gaussian filter (Luterbacher et al. 2003).*

The spatio-temporal highly resolved reconstructions offer extended insight in the European surface temperature response to volcanic eruptions. We calculated seasonal spatial temperature anomalies following sixteen major tropical volcanic eruptions over the last centuries. Superposed epoch analysis is performed to identify the mean climate response to large volcanic eruptions (Fischer et al. 2003).

The composite temperature field reveals negative anomalies for the two summers after an eruption, with a significant maximum cooling in the second summer (Figure 3, left panel). A very distinct cooling effect (up to 1.5°C) occurs in Northern Europe. Over the Mediterranean no effect can be noticed. The tropospheric summer cooling can be explained by radiative cooling due to scattering by stratospheric aerosols (Robock et al. 2000 and references therein). The composite temperature pattern in the second winter (Figure 3, right panel) after the eruptions indicates a strong warming, in particular in Northern Europe (more than 2°C) and somewhat cooler conditions over the Mediterranean. The warming is associated with a sea level pressure (SLP) pattern resembling a strong positive NAO mode (not shown). We assume that this reflects a dynamic response to the strengthening of the equator-to-pole temperature gradient in the lower stratosphere, caused by radiative heating of the aerosol layer in the tropics (Kirchner et al. 1999). An additional explanation could be a strengthened polar vortex through aerosol-induced tropospheric cooling in the subtropics (Stenchikov et al. 2002). The composite temperature fields of the first winter following the eruptions show similar although less pronounced patterns (not shown).

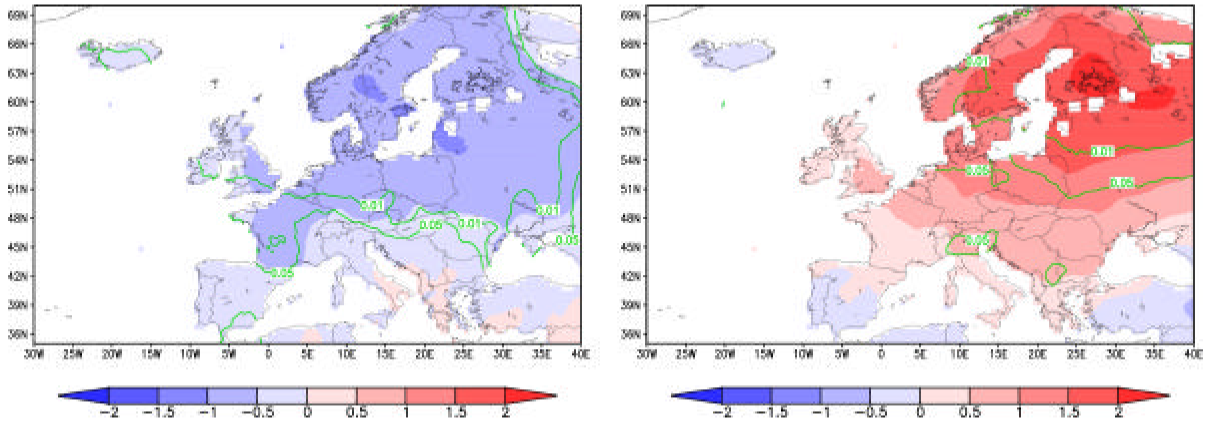

__Figure 3:__ Composite European land surface temperature anomaly field (°C, shaded) of the second summer (left panel) and second winter (right panel) following 16 selected major volcanic eruptions during the period 1500—1998. The green contours mark the statistical significance as p-values of the Wilcoxon Rank Sum Tests (from Fischer et al. 2003).

In the last part of the talk, we will address the question of the importance of natural and documentary proxies (tree-ring widths and densities, speleothem band width, ice core δ^{18}O and accumulation, coral δ^{18}O, varve thickness; temperature and precipitation indices) for European and North Atlantic boreal cold (October-March) and warm (April-September) temperature reconstructions (Pauling et al. 2003). We performed multiple regression, backward elimination and cross-validation techniques using a set of various natural and documentary predictors (Figure 4). This analysis was done for each grid point separately. We consider the last remaining predictor of the backward elimination procedure as the most important one for the grid point concerned.

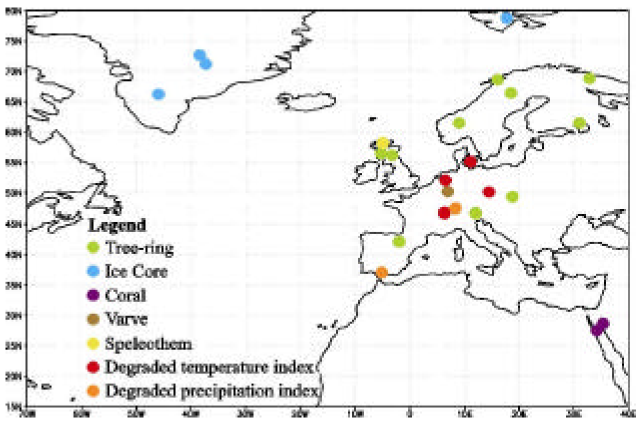

__Figure 4:__ Locations of the proxies. The spatial coverage of this map corresponds to the temperature grid used as predictand (from Pauling et al. 2003).

Figure 5 displays the distribution of the most important predictors for boreal winter (left panel) and boreal summer (right panel) temperature. For winter, documentary data are superior to natural proxies over large areas of continental Europe, whereas tree-ring data proved to be the strongest predictor for summer over the continent, and parts of the Atlantic.

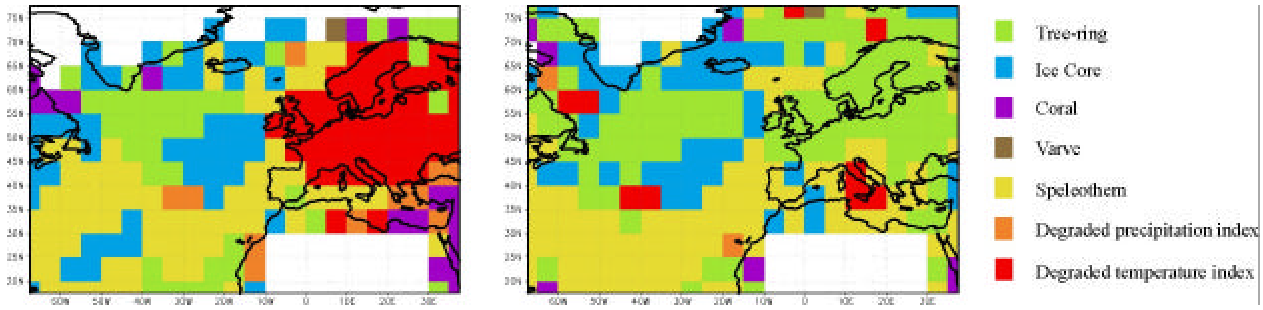

Figure 5: *Spatial distribution of the most important predictors for boreal winter (October to March) and summer temperature (April to September) determined from the predictor set depicted in Figure 1 through backward elimination. White areas indicate missing data (from Pauling et al. (2003).*

Ice cores are the most important predictors for the temperature in both seasons around Greenland (Pauling et al. 2003). For only a few grid points are the Red Sea corals the best predictor as they appear to represent mainly regional temperature conditions. The Scottish speleothem turned out to be valuable for large parts of the North Atlantic and adjacent land areas during both seasons. However, a number of calibration/verification exercises using data from the period 1871-1974 revealed that there are instabilities in the speleothem-temperature relationship whereas the importance of the tree-rings and the documentary indices remained stable over that time interval (Pauling et al. 2003).

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