

**Surface temperature variability over Europe back to AD 1500 and its connection to the Northern Hemisphere; implications of volcanic eruptions on surface temperature and the importance of proxies for large-scale climate reconstructions**

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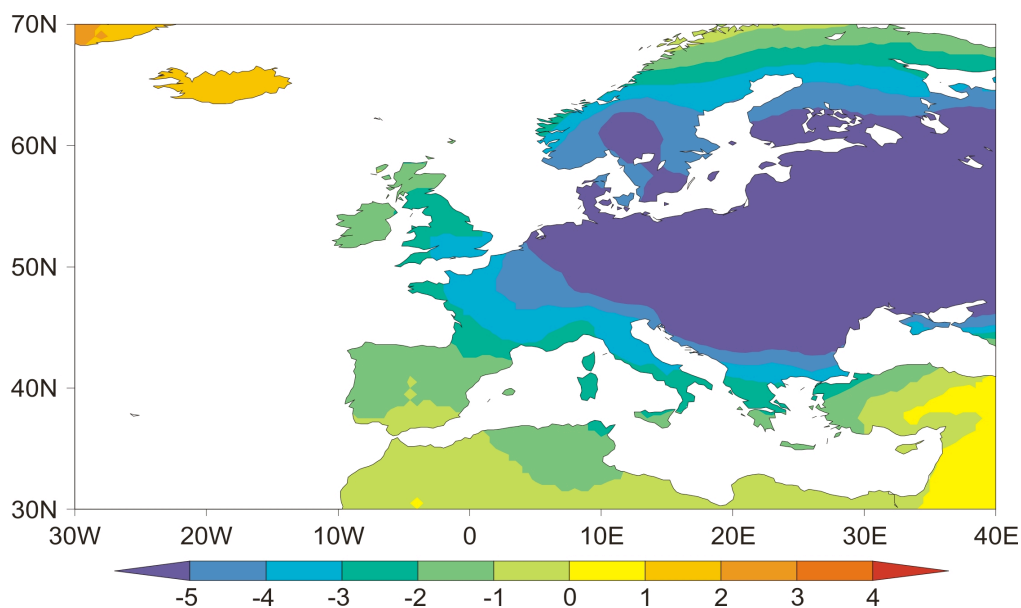
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Annual, summer or growing season (April-September) resolved centuries-long surface temperature reconstructions have been made available for the Northern Hemisphere (NH) (e.g. Briffa and Osborn 2002 and references therein). They are based on natural proxy data or achieved through multi-proxy networks. These 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 0.5 x 0.5 degree resolution (60 km x 60 km) 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 calibration period were then applied to the pre-1900 data. Error measures (RE statistics) will be discussed. Further, uncertainty ranges for the reconstructed European seasonal temperature are given by the +/- 2 standard error which was derived from the calibration period.

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

Cooler European winters were generally experienced in parts of the sixteenth and seventeenth centuries with lowest values within the Maunder Minimum (1670-1700) (not shown). This period was dry in many parts of Europe 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 lower than 3.5°C values compared to the long-term twentieth century mean. Figure 1 shows the spatial temperature anomaly pattern of this exceptional winter. It reveals negative departures of more than 5°C over Central and Eastern Europe, Southern Scandinavia as well as over Western Russia. Negative anomalies of the order of 2°C are found over the remaining parts of Europe. Only over Iceland the reconstructions point to warmer conditions.

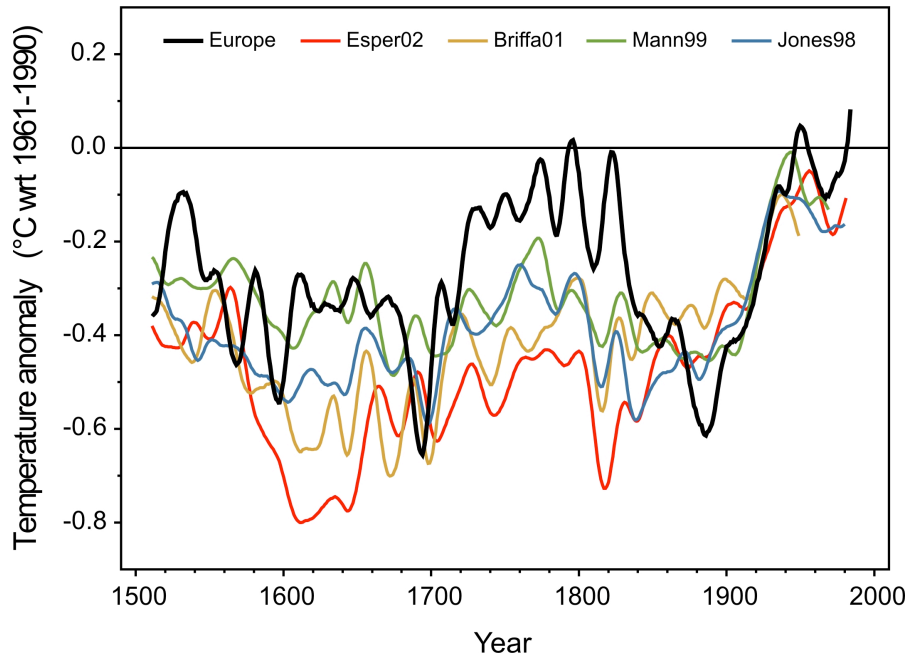


**Figure 1:** European land temperature anomalies (in °C wrt 1961-1990) for the very cold winter (DJF) 1709 (from Luterbacher et al. 2003).

The warmest European winter was 1990 with around 2°C higher values in comparison to 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 overall European 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, but negative departure compared to the 1901-1995 average.

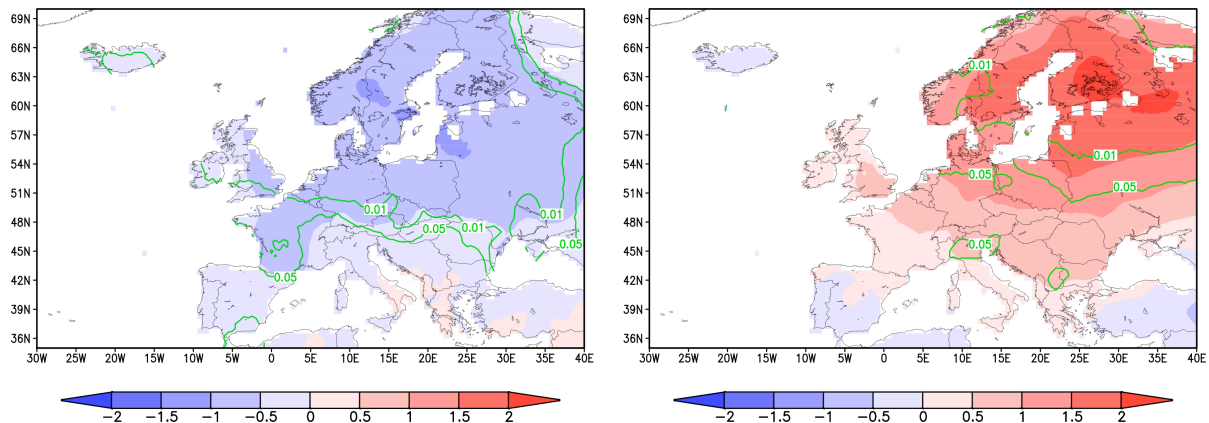
The European and the NH land temperatures, at annual scale, are highly correlated over the last 140 years of instrumental data and indicate an overall warming trend of around 1°C (depending on the season). However, for the pre-1860 periods, except for the mid-sixteenth century and the Maunder Minimum, there is less agreement between European land and NH temperature estimates (Figure 2). This could be attributed to uncertainties in the reconstructions, but also could partly reflect different decoupling and 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 years, with reference to the mean from 1961-1990 (Luterbacher et al. 2003). The Northern Hemisphere records were re-calibrated with linear regression against the 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).

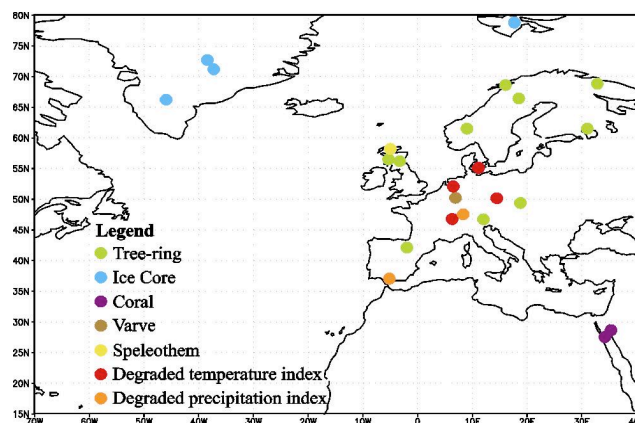
The spatio-temporal highly resolved reconstructions offer extended insight in the European surface temperature response to volcanic eruptions. We calculated seasonal spatial temperature anomalies following sixteen major tropical volcanic eruptions over the last centuries. Superposed epoch analysis is 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 significant 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 an eruption indicates a strong warming, in particular over 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 field of the first winter following an eruption shows a similar although less pronounced pattern (not shown).



**Figure 3:** Composite European land surface temperature anomaly field ( $^{\circ}\text{C}$ , shaded) of the second summer (left panel) and second winter (right panel) following sixteen 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).

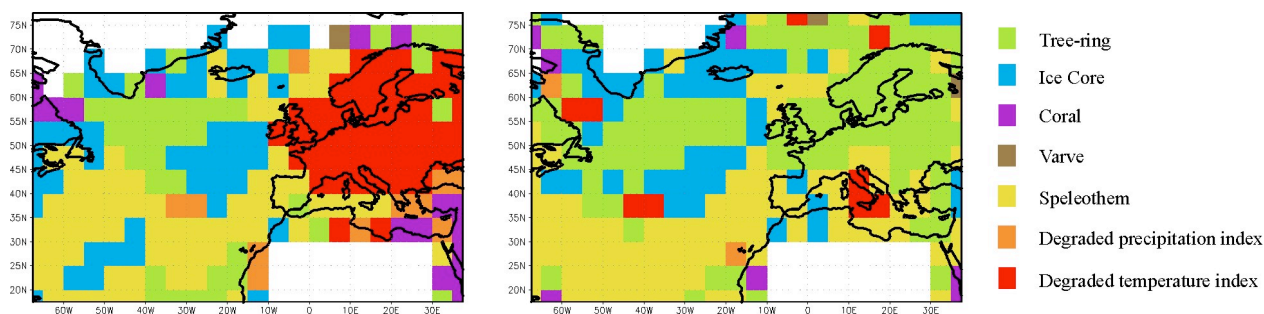
In the last part of the talk, we will address the question of the importance of natural and documentary proxies (tree-ring widths and densities, speleothem band width, ice core  $\delta^{18}\text{O}$  and accumulation, coral  $\delta^{18}\text{O}$ , varve thickness; temperature and precipitation indices) 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). The 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 (not shown).



**Figure 4:** Locations of 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; left panel) and summer temperature (April to September; right panel) 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. The Red Sea corals are only for a few grid points 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).

## References:

- Briffa, K.R. and T.J. Osborn, 2002: Blowing Hot and Cold. *Science*, 295, 2227-2228.
- Fischer, E., and coauthors, 2003: Seasonal European temperature response to major tropical volcanic eruptions over the last 500 years. In preparation.
- Kirchner, I., G. L. Stenchikov, H. F. Graf, A. Robock, and J. C. Antuña, 1999: Climate model simulation of winter warming and summer cooling following the 1991 Mount Pinatubo volcanic eruption. *J. Geophys. Res.*, 104 (D16), 19039-19055.
- Luterbacher, J. and coauthors, 2003: European temperature variability over the last 500 years- uncertainties, extremes and trends. Submitted.
- Pauling, A., J. Luterbacher, and H. Wanner, 2003: Evaluation of Proxies for European and North Atlantic Temperature Field Reconstructions, *Geophys. Res. Lett.*, in press.
- Robock, A., 2000: Volcanic eruptions and climate. *Rev. Geophys.*, 38, 191-219.
- Stenchikov, G. I., A. Robock, V. Ramaswamy, M. D. Schwarzkopf, K. Hamilton, and S. Ramachandran, 2002: Arctic Oscillation response to the 1991 Mount Pinatubo eruption: Effects of volcanic aerosols and ozone depletion. *J. Geophys. Res.*, doi: 10.1029/2002JD002090.