Source: Elferts D, Brumelis G, Gärtner H, Helle G, Schleser G (eds.) (2008) TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 6: Proceedings of the DENDROSYMPOSIUM 2007, May 3rd – 6th 2007, Riga, Latvia. GFZ Potsdam, Scientific Technical Report STR 08/05, Potsdam, p. 51 - 56.

# Contrasting long-term drought signals in proxy records from northwestern Europe and the Mediterranean

**V. Trouet & J. Esper**

*Swiss Federal Research Institute WSL, 8903 Birmensdorf, Switzerland*
*Email: trouet@wsl.ch*

## Introduction

The Mediterranean region (including northern Africa) has in recent decades been subject to a distinctly decreasing precipitation trend, starting in the 1970s (Dünkeloh and Jacobeit 2003, Xoplaki et al. 2004, Luterbacher et al. 2006). A trend towards wetter winters occurred over the same time period in northwestern Europe (Jones and Conway 1997, Kiely 1999, Mills 2005). Winter precipitation in both regions is closely linked to hemispheric circulation patterns (e.g., Xoplaki et al. 2004, Pauling and Paeth 2007) and to the North Atlantic Oscillation (NAO) in particular (Hurrell 1995). Positive NAO winters are characterized by a deeper than normal trough over Iceland and a higher than normal ridge over the Azores (Fig. 1a), resulting in an anomalously strong westerly flow, wet conditions over northwestern Europe, and dry conditions in the Mediterranean. During negative NAO phases, precipitation patterns are effectively inverted, and the subtropical High, Icelandic Low, and westerly flow are weak (Fig. 1b). The NAO pattern shows a large amount of interannual variance, but is also variable on decennial time-scales (Van Loon and Rodgers 1978, Hurrell 1995).

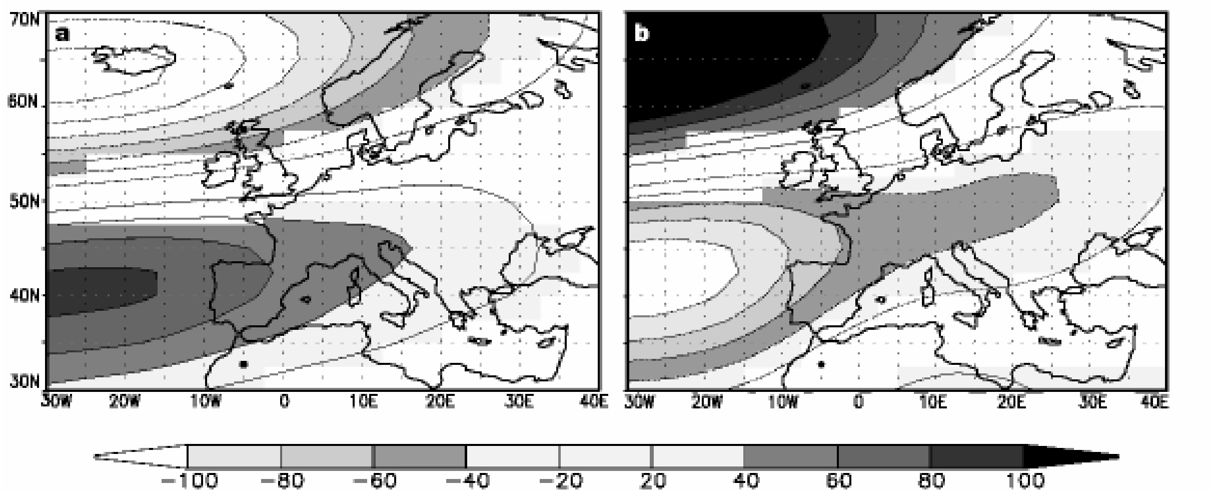


*Figure 1: Anomaly (from the 1948-2000 average) composites of January-March 500 hPA patterns of the five highest (a) and the five lowest (b) NAOI years (1949-2000). Positive anomalies are indicated by full lines, negative anomalies by dashed lines. Shaded areas reflect significant (p<0.1) differences, calculated using a Student's t-test. The locations of the two proxy records from Scotland and Morocco are marked by black dots.*

The co-occurrence of opposing trends in winter precipitation anomalies in northern versus southern Europe in recent decades has been ascribed to the concomitant dominance of positive winter NAO modes (Hurrell 1995, Hurrell and Van Loon 1997, Dünkeloh and Jacobeit 2003). To put the recent multi-decadal precipitation trend in a historical context, long-term analysis of regional precipitation variability is needed. The use of proxy climatic data provides a mean to extend precipitation records back in time and thus to analyse past precipitation anomalies (e.g., Luterbacher et al. 2006).

In this paper, we combine a millennium-long speleothem-based precipitation proxy from Scotland (Proctor et al. 2000) with a tree-ring based drought reconstruction from Morocco (Esper et al. in press). The location of the two proxies in core regions of the European/NW-African precipitation dipole, and near the centers of action of the NAO (Fig. 1), allows for testing the temporal stability of spatial climate patterns and the prevailing hemispheric circulation patterns controlling them.

## Data

*The Morocco drought reconstruction*

A 953-year long (1049-2002) tree-ring chronology was developed based on ring-width data from 178 *Cedrus Atlantica* trees from the Atlas Mountains in Morocco (Esper et al. in press). A combination of Regional Curve Standardization (Esper et al. 2003a), regular normalization (Esper et al. 2003b), and individual standardization (Fritts 1976) was applied to preserve multi-decadal and multi-centennial variability. This tree-ring chronology was used in a linear regression model to reconstruct February-June Palmer Drought Severity Index (PDSI; Palmer 1965) variability. PDSI is a standardized measure of surface moisture conditions with limited seasonality. The resulting reconstruction is therefore a good representation of winter drought conditions. The decreasing precipitation trend since the 1970s, as recorded in regional observational station data (Knippertz et al. 2004), is fully retained in the reconstruction (Fig. 2).

*The Scotland precipitation reconstruction*

An actively growing stalagmite from a cave in NW Scotland provided a 1100-year long (900-1993) precipitation proxy (Proctor et al. 2000). The continuous, annual luminescent bands formed by organic matter in the stalagmite, allowed for precise determination of growth rate variations. Growth rates were found to be controlled by precipitation variability, and annual band width data were used to reconstruct winter precipitation over the last millennium. The resulting reconstruction proved to be highly sensitive to multi-decadal variations in NAO over the instrumental period (1865-1990; Proctor et al. 2000).

*Large-scale geopotential height patterns*

For the instrumental period, we used an extended version of the traditional winter NAO index, which is defined as the normalized pressure difference between the Azores and Iceland (Hurrell 1995). This extended version of the index (back to 1824) was developed by including data from Gibraltar and Stykkisholmur (Jones et al. 1997).

To investigate long-term associations of the proxy records with atmospheric circulation patterns, we applied composite map analysis. This non-linear method captures the possible asymmetric character of the associations (Rimbu et al. 2006). We used reconstructed (1659-2001) fields of monthly 500 hPA geopotential height, developed by Luterbacher et al. (2002). The years of most positive (95$^{th}$ percentile) and most negative (5$^{th}$ percentile) difference in precipitation between Scotland and Morocco were identified and the respective geopotential height data averaged for these sets of extreme years. The significance of the differences in composite climatic conditions between extreme years was determined using a Student’s t-test (Brown and Hall 1999).

## Results

The contrasting moisture conditions since the 1970s in northwestern Europe (wet) and northwestern Africa (dry) are reflected in the drought reconstructions from Scotland and Morocco (Fig. 2).

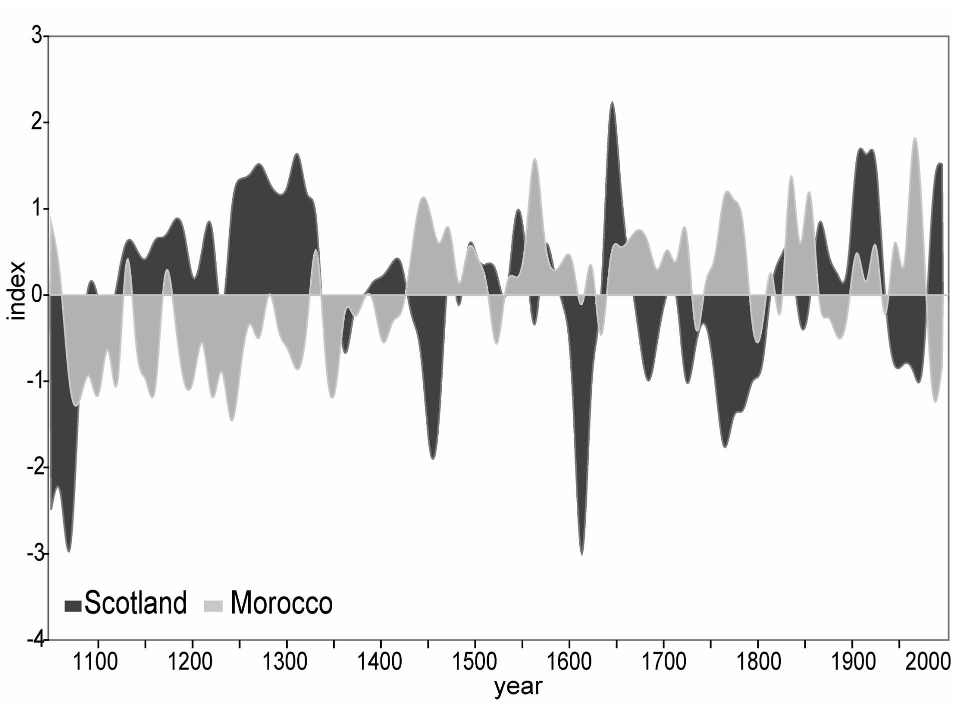


*Figure 2: Decadal scale variance in Morocco PDSI and Scotland precipitation. Series were computed from 10-year, non-overlapping averages, and then smoothed using a cubic spline for presentation (unsmoothed values used in correlation analysis).*

Multi-decadal variations of both reconstructions are characterized by quasi-regular occurrences of contrasting conditions over the last millennium. Contrasting moisture conditions were particularly strong during the Medieval Warm Period (MWP; 1000-1350), the 18th century and since the 1940s (Fig.2). The reconstructions contain substantial multi-decadal scale variability that was shown to correlate negatively (r=-0.26; p<0.05) using sequential 10-year non-overlapping means.
The NAO influence on the contrasting precipitation regimes was investigated by calculating the difference between the standardized, decadally smoothed Scotland and Morocco time series. This residual series (MSres) was then correlated with the NAOI over the instrumental period (1824-1993), revealing rather strong and positive correlations (r=0.75, p<0.01; Fig. 3).

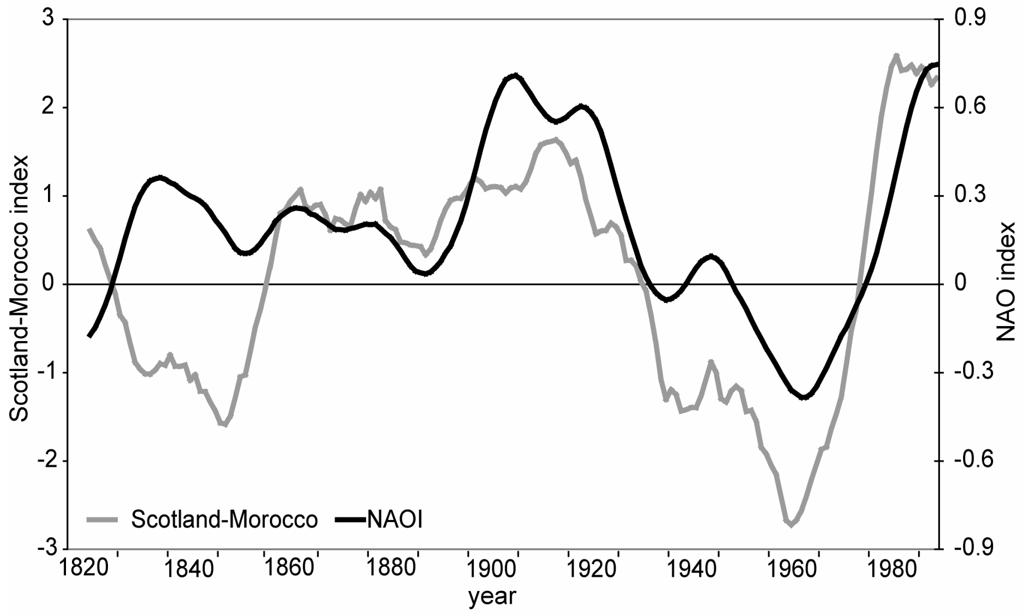


*Figure 3: Interdecadal variation in MSres and NAOI. Series were standardized and smoothed using a 10-year moving average.*

Positive MSres values correspond to positive NAO phases, and vice versa. While MSres followed the NAOI closely from 1850 onwards, substantial differences were found over the 1824-1850 period during which the Gibraltar/Stykkisholmur series showed higher values.

The reconstructed (1659-2001) geopotential height fields (Luterbacher et al. 2002) provide a test bed to study NAO influence on precipitation patterns over longer time-scales. Reconstructed geopotential height anomalies during the most positive MSres years (Fig. 4a) closely reproduce positive NAO geopotential height patterns over Europe, as derived from observational pressure data (1949-2000; Fig. 1a). The Icelandic Low is deeper than usual and a strong ridge prevails over the Azores and the whole Mediterranean. Reverse geopotential height conditions characterize strongly negative MSres years (Fig. 4b), as was the case in the late 18th century, when a consistent anomalously high Icelandic Low resulted in a reduced pressure gradient between the Icelandic Low and the Azores High (typical for a negative NAO phase; Fig. 1b) and weakened westerlies across the North Atlantic (Fig. 4b). During this period drier and cooler than normal winter conditions prevailed over northwestern Europe, while warmer and wetter winters occurred in the Mediterranean (Fig. 2).

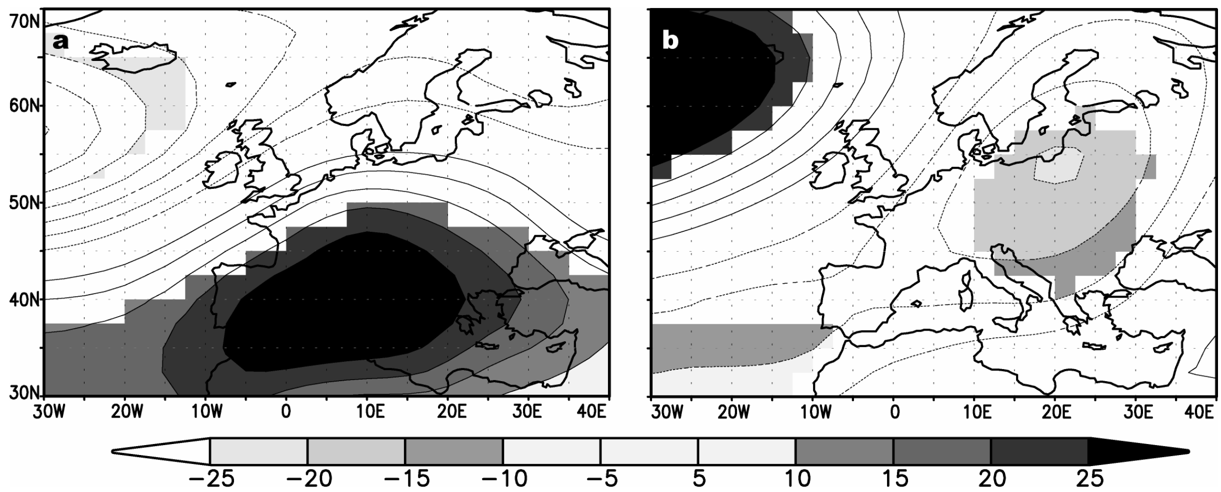


*Figure 4: Anomaly (from the 1659-2000 average) composites of January-March 500 hPA patterns of the 5% highest (a) and the 5% lowest (b) values in MSres. Positive anomalies are indicated by full lines, negative anomalies by dashed lines. Shaded areas reflect significant (p<0.1) differences, calculated using a t-test.*

## Discussion

Combination of two drought-sensitive, millennium-long climate proxies from western Europe and northwestern Africa revealed potential to reconstruct extreme, decadal scale NAO phases over the past millennium.

The decadal resolution of the speleothem record from Scotland restricts our analysis to a multi-decadal time-scale, which corresponds to the dominant frequency domain of the NAO (6-10 years; Hurrell and Van Loon 1997). A combination of the two proxies, which are located near the prevailing centers of action of this dipole, closely reflects the decadal scale NAO variability over most of the instrumental period (Fig. 3). This association was weak, however, over the early observational data period (1824-1850).

The proxy combination shows a strong moisture contrast between Scotland and Morocco since the 1970s, corresponding to the concomitant highly positive NAO phase. Additionally, the high index phase from the turn of the 20th century until the 1930s (Hurrell 1996) and the minimum in the 1960s (Hurrell and Van Loon 1997) are well captured in the proxy record. Periods of contrasting moisture conditions over Europe were also associated with NAO-like geopotential height patterns over longer time-periods (Fig. 4).

Our results indicate that the strong moisture contrast between Scotland and Morocco since the 1970s is not exceptional within the millennium-long context provided by the reconstructions (Fig. 2) and multi-decadal and multi-centennial contrasting periods have occurred regularly over the last millennium. Reconstructed precipitation over Scotland was consistently high through much of the MWP, whereas several periods of low precipitation occurred during the subsequent Little Ice Age (LIA; ca. 1500-1850). The Morocco proxy record, in contrast, is characterized by persistent medieval drought and LIA moistening. The MWP-LIA fluctuations in the isotopic signature of a speleothem in the central Alps (Mangini et al. 2005), suggest changes in the strength of winter westerlies across northern Europe, associated with a NAO phase shift (Graham et al. 2007). The centennial-scale moisture fluctuations resulting from this shift, as well as the contrasting moisture conditions in recent decades, co-occurred with moisture anomalies around the globe (Hoerling and Kumar 2003, Cook et al. 2007, Seager et al. 2007). The global character of this centennial-scale hydroclimatic variability implies forcing by fluctuating global ocean-atmosphere states (Seager et al. 2007). A persistently positive NAO in the Medieval period could be teleconnected with prevailing La Niña-like conditions in the tropical Pacific (Graham et al. 2007), which in turn could arise as a result of positive radiative forcing and reduced volcanic activity (Cook et al. 2007). Model simulations further suggest that a switch in radiative forcing could be a contributing factor in the long-term shift in NAO phase between the MWP and the LIA (Shindell et al. 2003).

Our combined millennium-long proxy record reflects extreme NAO phases accurately on a multi-decadal to multi-centennial time-scale. By combining two drought proxies with opposite long-term trends, we link long-term fluctuations in European winter precipitation patterns to variations in large-scale circulation, which may help to improve our understanding of the climate system, its natural variability, and its forcing factors.

**Acknowledgements**

We thank A. Baker for providing data and helpful suggestions. Supported by the EC project Millennium (Grant No. 017008), and the SNSF through the National Centre for Competence in Climate Research (NCCR-Climate).

**References**

Brown, T. J., Hall, B. L. (1999): The use of t-values in climatological composite analyses. *Journal of Climate*: 2941-2944.

Cook, E. R., Seager, R., Cane, M.A., Stahle, D.W. (2007): North American droughts: reconstructions, causes and consequences. *Earth Science Reviews*: 93-134.

Dünkeloh, A., Jacobeit, J. (2003): Circulation dynamics of Mediterranean precipitation variability 1948-1998. *International Journal of Climatology*: 1843-1866.

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

Esper J., Shiyatov, S. G., Mazepa, V. S., Wilson, R. J. S., Graybill, D. A., Funkhouser, G. (2003b): Temperature-sensitive Tien Shan tree ring chronologies show multi-centennial growth trends. *Climate Dynamics*: 699-706.

Esper, J., Frank, D., Büntgen, U., Verstege, A., Luterbacher, J., Xoplaki, E. (in press): Long-term drought severity variations in Morocco. *Geophysical Research Letters* .

Graham, N., Hughes, M.K., Ammann, C.M., Cobb. K.M., Hoerling, M.P., Kennett, J.P., Rein, B., Stott, L., Wigand, P.E., Xu, T. (2007): Tropical Pacific-Mid latitude teleconnections in Medieval times. *Climatic Change*: 241-285.

Hoerling, M. P., Kumar, A. (2003): The perfect ocean for drought. *Science*: 691-694.

Hurrell, J. W. (1995): Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. *Science*: 676-679.

Hurrell, J. W. (1996): Influence of variations in extratropical wintertime teleconnections on Northern Hemisphere temperature. *Geophysical Research Letters*: 665-668.
Hurrell, J. W., Van Loon, H. (1997): Decadal variations in climate associated with the North Atlantic Oscillation. *Climatic Change*: 301-326.
Jones, P. D., Conway, D. (1997): Precipitation in the British Isles: an analysis of area average data updated to 1995. *International Journal of Climatology*: 427-438.
Jones, P. D., Jónsson, T., Wheeler, D. (1997): Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. *International Journal of Climatology*: 1433-1450.
Knippertz, P., M. Christoph, and P. Speth (2004): Long-term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climates. *Meteorological and Atmospheric Physics*: 67–88.
Kiely, G. (1999): Climate change in Ireland from precipitation and streamflow observations. *Advances in water resources*: 141-151.
Luterbacher, J., and 48 coauthors (2006): Mediterranean climate variability over the last centuries: A review, in *The Mediterranean Climate*, edited by P. Lionello et al., pp. 27-148, Elsevier, Amsterdam.
Mangini, A., Spötl, C., Verdes, P. (2005): Reconstruction of temperature in the Central Alps during the past 2000 yr from a d18O stalagmite record. *Earth and Planetary Science Letters*: 741-751.
Mills, T. C. (2005): Modelling precipitation trends in England and wales *Meteorological applications*: 169-176.
Palmer, W. C. (1965): Meteorological drought. *Research Paper 45*, 58 pp., U.S. Dept. of Commerce, Washington.
Pauling, A., Paeth, H. (2007): On the variability of return periods of European winter precipitation extremes over the last three centuries. *Climate of the Past*: 65-76.
Proctor, C. J., Baker, A., Barnes, W.L., Gilmour, M.A. (2000): A thousand year speleothem proxy record of North Atlantic climate from Scotland. *Climate Dynamics*: 815-820.
Rimbu, N., Felis, T., Lohmann, G., Patzold, J. (2006): Winter and summer climate patterns in the European-Middle East during recent centureis as documented in a morthern Red Sea coral record. *The Holocene*: 321-330.
Seager, R., Graham, N., Herweijer, C., Gordon, A.L., Kushnir, Y., Cook, E. (2007): Blueprints for Medieval hydroclimate. *Quaternary Science Reviews*.
Shindell, D. T., Schmidt, G.A., Miller, R.L., Mann, M.E. (2003): Volcanic and solar forcing of climate change during the pre-Industrial period. *Journal of Climate*: 4094-4107.
Van Loon, H., Rodgers, J.C. (1978): The seesaw in winter temperatures between Greenland and northern Europe. Part I: general description. *Monthly Weather Review*: 296-310.
Xoplaki, E., J.F. González-Rouco, J. Luterbacher, and H. Wanner (2004): Wet season Mediterranean precipitation variability: influence of large-scale dynamics and predictability. *Climate Dynamics*: 63-78.