

Non-Stationarities in the Circulation-Climate-Relationship over the Baltic Sea and its Effects on Reconstructions of Climate Indices

Frederik Schenk (1), Daniel Hansson (2), Sebastian Wagner (1), Eduardo Zorita (1)

(1) GKSS Research Center Geesthacht, Institute for Coastal Research, Germany (frederik.schenk@gkss.de)

(2) Gothenburg University, Earth Sciences Centre, Ocean Climate Group, Sweden

1. Introduction

An important factor influencing the climate of the catchment area of the Baltic Sea is the North Atlantic Oscillation (NAO). The knowledge about this influence over the last centuries is of great importance reconstructing past terrestrial and oceanic climatic conditions. Bottom-up approaches are widely used to reconstruct the NAO from proxies reflecting the local near-surface climate. However, as we demonstrate in this study, localizations of proxies are partly inadequate for the large-scale influence distinct from the North Atlantic Ocean due to non-stationarities in the NAO-temperature relation.

In a first step of our approach we relate the NAO-index to the near-surface climate (i.e. temperature and sea-ice extent) of the Baltic region on monthly and seasonal basis. In a second and third step, we also use multi-proxy reconstructions and climate model simulations to investigate the NAO-climate relationship on longer time scales.

2. Characteristics of the climate of the Baltic sea

The Baltic Sea, including its coastal zone, covers a range of about 0.5 Mio. km² from 66° N to 53° N and 10°E to 30°E. In the winter half year (ONDJFM) the NAO explains more than one third of the monthly to seasonal interannual climate variability *Chen and Hellström* (1999) showed different spatial correlations between NAO and station temperature time series for Sweden. Although the whole Baltic region appears to be homogeneous with respect to changes in the strength of the NAO-influence during 20th century, our analysis yields that this is not the case previous to 1900.

3. Data

Because most recent reconstructions have already been subject of non-stationarities we concentrate our study mainly on long historical measurements and data from GCM simulations. The NAO-record is taken from *Jones et al.* (1997) for the period 1824–2000. It is based on the normalized (1951–80) SLP of Gibraltar minus Stykkisholmur/Iceland and updated until 2008 by *Osborn* (2006). Station temperature data are taken from *Jones and Moberg* (2003) and from the KNMI Operational Data Center (KODAC: <http://kodac.knmi.nl/kodac/>). Data for the max. sea-ice extent of the Baltic Sea (MIB) stem from *Seinä and Palosuo* (1996) for the period 1720–1995. They are updated by the Finish Institute of Marine Research till 2008 (FIMR: www.fimr.fi).

For studies of the last 500 years we used the gridded data set from multi-proxy reconstructions by *Luterbacher et al.* (2002) for the period 1500–1999. For the MIB data based on model simulations from *Hansson and Omstedt* (2007) for the period 1500–2001 are used. Comparisons with observations show high degree of trustworthiness on decadal and multi-decadal time scales.

For investigations of the last 1000 years we used the output of a control simulation and two externally forced (solar, volcanic and greenhouse gases) simulations from the comprehensive coupled atmosphere-ocean model Echo-G.

4. Methods

In our approach non-stationarities in the climate-circulation-relationship are detected and analyzed by changes of running correlations (Pearson correlation). Prior to analysis all time series were tested for serial autocorrelation and potential trends were removed. Because the running correlation analysis is based on sub-periods with window length of 30 years these sub-periods were de-trended, too.

5. Results (observations)

Running correlations (RC) between NAO and station-based temperatures show a high degree of non-stationarities for the Baltic region. Noteworthy are comparisons of the RC values of the 20th century with those of the 19th century for winter months (DJF). Accordingly, synchronous alterations since 1900 for the whole area and decreasing values in the 19th century for stations far in the north and east are evident. The divergence in the RC supports findings of *Jacobeit et al.* (1998) and *Lamb* (1985).

A hypothesis potentially suited to explain the physical mechanism controlling changes in RC is related to increased continental conditions during the Little Ice Age. This would also explain the spatial divergence of the RC previous to 1900. This results therefore questions the quality of proxy-reconstructions of circulation indices like the NAO from peripheral regions for the Little Ice Age. Periods of high or low levels in RC for both, the NAO-temperature as well as sea-ice correlations, do not appear to be systematically linked to the mean strength or variability of the NAO. This finding is in general agreement with results from *Slonosky* (1999) and with *Chen & Hellström* (1999). The authors also do not find any link between the degree in stationarity and anomalies of the NAO for Sweden.

6. Results (reconstructions)

The reconstructed SLP/NAO data sets by *Luterbacher et al.* (2002) include a high number of different proxies. In the following we used the historical MIB as representation of the near-surface winter climate of the Baltic Sea for RC with the NAO reconstructions.

Results indicate RC between winter-NAO (DJF) and MIB in the range of $0.3 < r < 0.8$ for the period 1720–1999. The non-stationarities of the reconstructed NAO with the modeled MIB of *Hansson and Omstedt* (2007) for the period 1500–2001 are in very good agreement with the historically observed MIB since 1720. Although the pattern of non-stationarities reflected by the reconstructed time series shows a similar amount of variability as the observations, interpretation is restricted by the question whether these non-stationarities are related to real climatic processes or to shortcomings in the reconstruction method. To analyze changes in the circulation-climate relationship on longer time scales we therefore used long simulations carried out with a coupled GCM.

7. Results (model studies)

Model studies with coupled GCMs for past climates are indispensable for our understanding of possible mechanisms of the climate system. This is because observations are not available and/or proxy-reconstructions are spatiotemporal too limited.

Results of RC for 1000 years show a high degree of non-stationarities between NAO and T-Baltic with correlation coefficients ranging between $0.0 < r < 0.8$ for winter (DJF). The amplitude of the RC and their temporal variability are similar in both, the control simulation and the two forced simulations (see fig. 1). In addition, non-stationarities in the simulations are in the same order like in observational studies of the last 175 years.

The agreement with respect to non-stationarities of the control/externally forced simulations and observations therefore suggest that non-stationarities are an internal climatic phenomenon. The results are in contradiction to findings by *Osborn et al.* (1999), who found lower variability in the RC in the control run compared to externally forced simulations with the GCM HadCM2.

References

Chen, D. & C. Hellström (1999), The influence of the North Atlantic Oscillation on the regional temperature variability in Sweden: spatial and temporal variations, *Tellus*, 51A, 505-516.

Hansson, D. & A. Omstedt (2007), Modelling the Baltic Sea ocean climate on centennial time scale: temperature and sea ice, *Clim. Dyn.*, 30, pp. 763-778.

Jacobeit, J., Beck, C. & A. Philipp (1998), Annual to decadal variability on climate in Europe; objectives and results of the German contribution to the European climate research project ADVICE. Würzburger Geographische Manuskripte, Heft 43, 88 pp., Würzburg.

Jones PD, Jonsson T and Wheeler D (1997), Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland, *Int. J. Climatol.*, 17, pp. 1433-1450.

Jones PD, Moberg A. 2003: Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. *J. Climate* 16: 206-223.

Lamb, H.H. (1985), The reconstruction of past climate during the historical period, *Ymer* (1985), 105, pp. 91-102.

8. Concluding remarks

Decadal running correlations between NAO and near-surface climate indices show a high degree of non-stationarities that are of the same order in observations, empirical reconstructions and in GCM simulations. The lack of link between clusters of high and low levels in RC with the strength or the variability of atmospheric circulation indicates on the one hand that non-stationarities are caused by internal chaotic variability.

On the other hand, in the case of decreasing values of RC during the 19th century in regions far to the north and east, also shifts to more continental conditions [associated to Little Ice Age type events] play an important role. The latter also points to a potential role of external forcing on the degree of stationarity.

Possible mechanisms causing these non-stationarities i.e. like the climatic shifts from the 19th to the 20th century are of great importance for future studies, because these episodes are shown to significantly lowering the level of RC over typical peripheral regions used for reconstructing the NAO.

Luterbacher, J., Xoplaki, E., Dietrich, D., Rickli, R., Jacobeit, J., Beck, C., Gyalistras, D., Schmutz, C. & H. Wanner (2002), Reconstruction of sea level pressure fields over Eastern North Atlantic and Europe back to 1500., *Clim. Dyn.* 18, pp. 545-561.

Osborn, T.J. (2006), Recent variations in the winter North Atlantic Oscillation, *Weather* 61, pp. 353-355.

Seinä, A. & E. Palusou (1996): The Classification of the Maximum Annual Extent of Ice Cover in the Baltic Sea 1720-1995 - Based on the material collected by Rirto Jurva (winters 1720-1940) and the Literaturverzeichnis 122 material of the Ice Service of the Finnish Institute of Marine Research (winters 1941-95) - Meri - Report Series of the Finnish Institute of Marine Research No. 27, 1996.

Slonosky, V.C., Jones, P.D. & T.D. Davies (2001), Atmospheric circulation and surface temperature in Europe from the 18th century to 1995, *Int. J. Climatol.*, 21, 63-75.

Zorita, E. & F. González-Rouco (2002), Are temperature-sensitive proxies adequate for the North Atlantic Oscillation reconstructions? *Geophys. Res. Lett.*, 29, pp. 1703-1706.

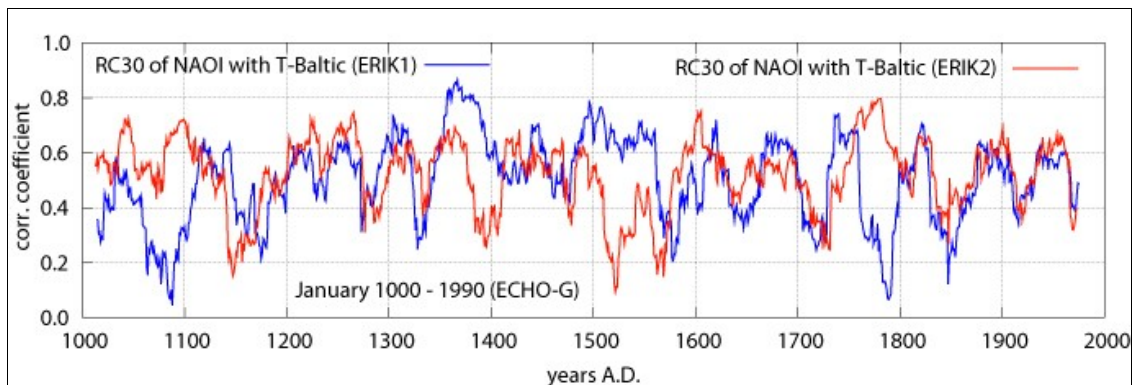


Fig. 1. Running correlations (RC30) of NAOI and T-Baltic calculated from two external forced simulations of the coupled GCM ECHO-G for January 1000-1990 A.D.