

Atmospheric forcing of decadal Baltic Sea level variability in the last 200 years: A statistical analysis



Birgit Hünicke (birgit.huenicke@gkss.de), Institute for Coastal Research, Department of Paleoclimate, GKSS-Research Centre, Germany



<http://coast.gkss.de/staff/huenicke/>

ABSTRACT

The impact of different regional atmospheric factors on the past Baltic Sea level variations (200 years b.p.) are estimated by statistically analysing the relationship between Baltic Sea level records and observational and proxy-based reconstructed climatic data sets. The results indicate that Baltic Sea level variations on decadal and longer scales are strongly influenced by atmospheric forcings, but the influence of different large-scale forcing factors on sea level vary geographically. While the decadal sea level variations in the northern and eastern Baltic gauges are strongly influenced by the atmospheric circulation, the decadal variations in the southern Baltic Sea can be (statistically) better explained by area-averaged precipitation.

Keywords: regional sea-level variability, atmospheric forcing, climate reconstructions, statistical analysis

Introduction

The Baltic Sea is one of the largest brackish seas in the world and with its complex coastline and bathymetry a clear example of a complex coupled ocean-atmosphere-land system. Sea level variations at inter-annual to decadal timescales are generally believed to be caused essentially by variations in wind forcing, in particular (although not exclusive) by the Sea level pressure (SLP) pattern of the North Atlantic Oscillation (NAO).

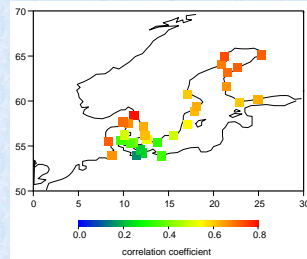


Fig.2 Correlation between winter mean (DJF) of NAO index and winter mean (linearly detrended) Baltic Sea level, 1900 to 1998. (Hünicke and Zorita, Tellus A, 2006). Sea level records are obtained from the Permanent Service of Mean Sea Level (PSMSL).

However, the correlation between individual Baltic Sea level stations and SLP is heterogeneous in space (Fig.2) and in time (with a range of 0.25 to 0.8 in wintertime for 1900-2000). In this study it is statistically estimated to what extent other regional climate factors contribute to the spatially heterogeneous Baltic Sea level variations around the isostatic trend (Fig.3) at multi-decadal timescales.

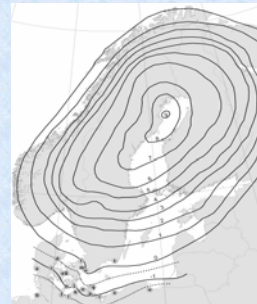


Fig.3 Map of vertical crustal movement relative to the sea level (mm/year) (Ekman, 1996; Rosentau et al., 2007)

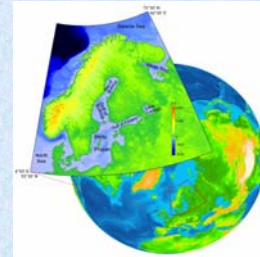
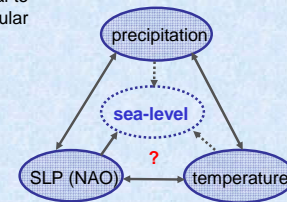


Fig.1 Location of the Baltic Sea Region and the Baltic Sea Area (Rosentau et al., 2007)



Approach

Identification and quantification of contribution of different atmospheric factors, restricted to those that are potentially well simulated by coarse resolution models. The timescales of interest are decadal, since future climate change will presumably evolve at these slow timescales.

Strategy I Statistical downscaling approach

Application of linear regression models (transfer functions) to establish statistical relationships between Sea-level (sl) as predictand (regional scale dependend variable) and large scale climate fields (pc) as predictors (independent variables)

$$SL(t) = \sum_{i=1,N} a_i pc_i(t) + SLR(t)$$

where pc_i is the i^{th} PC, a_i is the corresponding regression coefficient, N the number of PCs included in the regression and SLR are the sea-level residuals. The parameters a_i are calibrated by testing different time periods in 1800-2000 (eg. 1950-2000).

The sea-level records contain a trend which is caused by a combination of postglacial land uplift and eustatic sea-level change. (see Fig.3). On the time scales of our analysis this trend can be assumed to be linear and is eliminated by substrating the linear trend from each sea-level record.

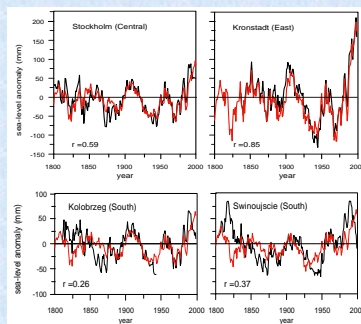


Fig.4 Decadally smoothed and linearly detrended observed (black line) sea level and reconstructed (red line) sea level deviations from the 1900 to 1999 mean, using the SLP field (upper panels) and area-averaged precipitation (lower panels) as predictors. The decadal correlation r between observations and reconstructions in the 19th century is indicated in each panel. (adapted from Hünicke et al., 2008). The long sea level records are obtained from the PSMSL, Ekman (2003), Boogdanov et al. (2000) and TU Dresden.

Strategy II Trend analysis

Baltic Sea level shows a mean annual cycle (min early spring, max winter). The amplitude (max -min) ranges between 10-30cm and increased in the 20th century by ~ 0.8 mm/year. The magnitude of the trends is almost spatially uniform (Fig.5).

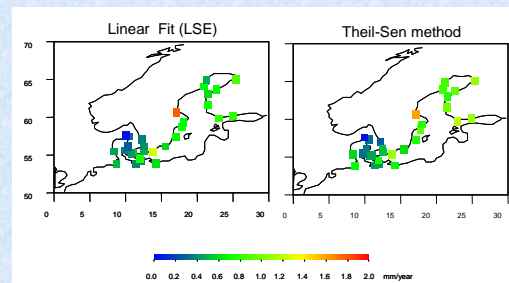


Fig.5 Trends in the amplitude of the sea-level annual cycle winter minus spring in the Baltic Sea estimated in the 20th century by a least-square-error linear fit and by the non-parametric Theil-Sen method (adapted from Hünicke and Zorita, 2008)

Several hypotheses are proposed to explain these centennial trends on the winter minus spring sea level: wind (through the SLP field), the barometric effect, temperature and precipitation. By elimination of three of the working hypothesis, seasonal Baltic precipitation remains a plausible candidate. For the other three, either the sign or magnitude of the trend makes them unlikely the sole explanation.

The approach is independent of the isostatic trend contained in the sea-level record, as the analysis focuses on monthly differences.

Conclusion

The analysis of the statistical relationships between sea-level and climatic datasets yield a clearer picture of the main climatic factors responsible for sea-level variations at decadal and centennial timescales. This is essential to understand the future regional sea-level changes under global climate change. The results indicate that the influence of the analysed atmospheric forcings vary geographically. Northern and eastern are strongly influenced by the atmospheric circulation (SLP), southern Baltic variations can be (statistically) better explained by area-averaged precipitation. Establishing these statistical relationships in the observational record also allows an estimation of regional climate change by statistical means through the application of the transfer functions to corresponding output of global climate model simulations (Hünicke, 2009). The presented estimations comprise only a partial contribution of the selected large scale regional factors and an estimation of the total regional sea-level rise has to consider other factors such as the isostatic contribution to relative sea-level changes and substantial changes in sea-ice cover and global sea-level rise.

References: ***Hünicke, B. (2009) Contribution of regional climate drivers to future winter sea-level changes in the Baltic Sea estimated by statistical methods and simulations of climate models. *Int. J. Earth Sciences (in minor revisions)* ***Hünicke, B., Luterbacher, J., Pauling, A. and Zorita, E. 2008. Regional differences in winter sea-level variations in the Baltic Sea for the past 200 years. *Tellus 60A* (2), 384-393. ***Hünicke, B. and Zorita, E. 2008. Trends in the amplitude of Baltic Sea level annual cycle. *Tellus 60A* (1), 154-164. ***Hünicke, B. and Zorita, E. 2006. Influence of temperature and precipitation on decadal Baltic Sea level variations in the 20th century. *Tellus 58A* (1), 141-153.