Regional differences in winter sea-level variations in the Baltic Sea for the past 200 years

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1. Introduction

Estimations of future global sea-level from simulations with coarse-resolution global climate models mostly depend on large-scale processes, such as the heat-flux into the ocean, on changes in the ocean circulation and on the rate of melting of land-ice masses. In regions with complex coastlines, as the Baltic Sea, sea-level changes may additionally depend on other regional factors which are not properly represented in global models. In wintertime, inter-annual Baltic sea-level variations at its northern and eastern boundaries are influenced by the westerly winds, related to the sea-level-pressure (SLP) pattern of the North Atlantic Oscillation (NAO). Stronger westerlies in positive NAO phases cause higher sea-level in some areas of the Baltic Sea. Some studies indicate that the connection between individual Baltic stations and SLP may be heterogeneous in time and in space, concluding that other processes different from the wind-stress forcing are important for sea-level variability. For instance *Hünicke and Zorita* (2006) have suggested that precipitation and temperature may also contribute to sea-level variations, thus modulating the correlations between sea-level and the NAO. The question arises whether these local processes may significantly influence also sea-level variability at low-frequencies, i.e. multi-decadal, so that their contribution should be considered for future sea-level projections at local scales.

2. Methods

We present a statistical analysis of the relationships between Baltic sea-level and large-scale atmospheric forcing in the past 200 years, using winter means (December to February) of long gauge sea-level records (PSMSL) and gridded climate reconstructions of SLP, air-temperature and precipitation covering the European land area (*Luterbacher et al.*, 2002, 2004; *Pauling et al.*, 2006). These reconstructions coincide with corresponding observational records in their calibration period 1901-1990 (for precipitation 1901-1983) and did not include any sea-level information as predictors. We aim at confirming the heterogeneous regional response of sea-level to large-scale forcing at multi-decadal timescales and at identifying possible factors for this behavior. We consider each gauge station individually to ascertain whether the effect of large-scale factors may also vary regionally.

Our approach is based on statistical regression methods to hindcast sea-level variations, calibrated in the 20th century and validated in the 19th century, examining the skill of the different predictors. However, the processes responsible for regional winter sea-level variations for high-latitude semi-enclosed seas are complex, as sea-ice, precipitation, run-off, may affect sea-level, in some regions more strongly than in others. In this study the predictors considered are restricted to those for which long observations or reconstructions are available and which are potentially well simulated by coarse resolution models, so that its conclusions may be applied to the output of GCM simulations. In practice, these are SLP (an indicator of geostrophic wind), area-averaged precipitation and air-temperature.

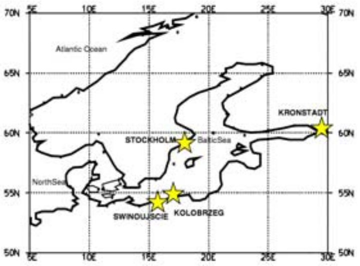

Figure 1. The location of the sea-level gauges

The trend in the sea-level records, caused by a combination of post-glacial land uplift and eustatic sea level change, is assumed to be linear and is eliminated by statistically estimating individually the linear trend and subtracting it. The analysis is then restricted to variations around the long-term linear trend. As we are interested in variability at decadal and longer timescales, all timeseries (sea-level and gridded climate reconstructions) were smoothed with an 11-year running mean filter.

3. Relationship between Baltic Sea level and large-scale gridded fields

In the 20th century, sea-level variations in the four stations used in this study evolve quite coherently, in the 19th century their agreement is less obvious, particularly between the Southern stations and the other two (Fig.2).

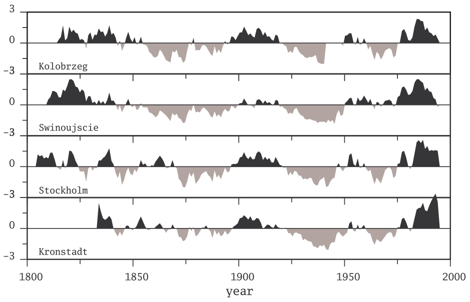

Figure 2. Relative winter mean (DJF) sea-level height in years 1800-2000: deviations from the 1900-1999 mean, linearly detrended, smoothed by a 11-year running-mean and standardized to unit standard deviation.

When decadally smoothed, the inter-station correlation exceeds 0.85 for all pairs in the 20th century, but in the 19th century the correlations between the southern stations and the rest falls about 0.5. A view of the possible external atmospheric forcings that may give rise to this behavior is presented in Fig.3.

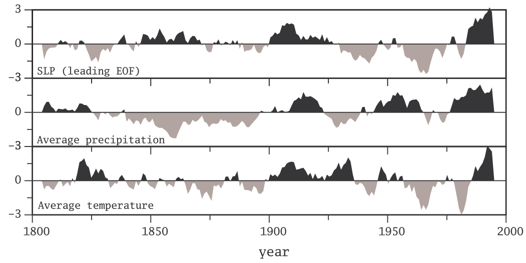

Figure 3. Timeseries of the leading winter SLP EOF in the North Atlantic-European sector, area average precipitation and area average temperature in the Baltic Sea region: deviations from the 1900-1999 mean, smoothed by a 11-year running mean and standardized to unit standard deviation (temperature has bee previously linearly detrended).

In the 20th century, all three time series behave coherently at decadal time scales, while in the 19th century they tend to diverge. Noteworthy are the large negative precipitation anomalies in the last decades of the 19th century, which is not matched by the SLP and temperature and suggests that these factors might force sea-level in a spatially heterogeneous way.

Thus, as a first predictor in a regression equation SLP is considered. The SLP field is previously decomposed in its Principal Components (PCs) to avoid co-linearity. In a second step we explore whether area-averaged precipitation could be a skillful predictor for the Southern sea-level stations (which show a low calibration and a very poor validation skill using SLP as predictor) Fig. 4 and Fig. 5 show the results. The skill of the regression was evaluated by the Reduction of Error statistics (RE, which adopts a value of unity for a perfect estimation and a value of zero foe a skill equal to climatology) and by the correlation coefficient (r) between observations and estimations, both evaluated in the validation period (indicated in the Figures).

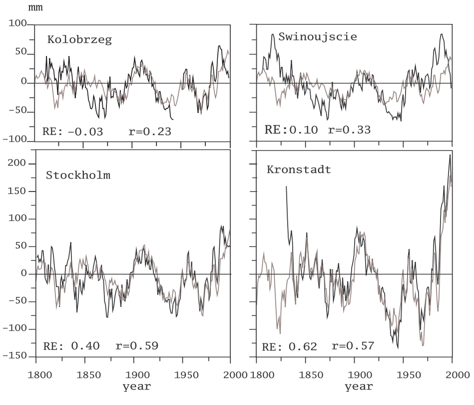

Figure 4. Decadally smoothed and linearly detrended observed sea-level and reconstructed sea-level (deviations from the 1900-1999 mean) using the SLP field as predictor.

In a third step winter air-temperature was used as a sole predictor, but the statistical model did not show any improvement relative to the SLP-only model.

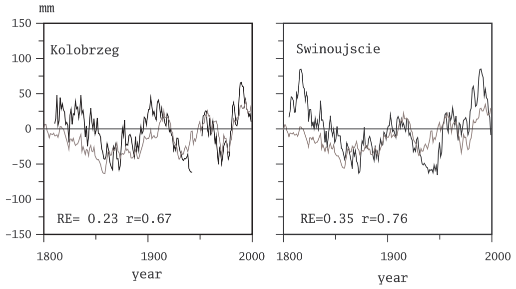

Figure 5. As in Figure 4, but for the southern Baltic stations only and using the area-average precipitation as predictor.

4. Summary and Conclusions

The study analyzes the spatial heterogeneity of sea-level records at decadal timescales and its possible physical origins. It is found that in regions with complex coastline structure, as in the Baltic Sea, sea-level records may show periods of homogenous behaviour, but also records of divergence. The explanation for this heterogeneity is found to be the heterogeneous influence of large-scale forcing factors, such as atmospheric circulation and precipitation.

Decadal sea-level variations in southwestern, central and eastern Baltic Sea tend to be less coherent in the 19 century than in the 20th. The evolution of the North Atlantic SLP, precipitation and air-temperature from gridded climate reconstructions has been considered to explain this behavior. The influence of these factors on sea-level varies for the different stations. In the central and eastern Baltic, sea-level variations are well described by SLP alone, whereas in the southern Baltic Sea area-averaged precipitation is a better predictor. The evolution of precipitation in the 19th century could explain the different behavior of the Southern Baltic stations. The effect of temperature variations may be contained in the SLP field or is less important for decadal sea-level variations. Depending on the evolution of these forcing factors in the past and future climate, regional sea-level variations might be affected by different physical mechanism and sea-level trends in different parts of one region may display some divergence. If SLP and precipitation trends diverge in future climates, e.g. due to humidity, sea-level trends in different parts of the Baltic Sea may also diverge. This may be relevant when trying to estimate past sea-level variations based on the average of a few long available records or when estimating future sea-level changes at regional scales.

References

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