Contribution of regional climate drivers to future winter Baltic Sea-level changes: An application of statistical downscaling to the output of global climate model simulations

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1. Introduction

Present estimations of future global sea-level change are based on simulations with coarse-resolution global climate models (GCMs). The simulated sea-level changes mostly depend on the heat-flux into the ocean, on changes in the ocean circulation and on the rate of possible Greenland ice-sheet melting. A global average of sea-level rise, however, ensconces considerable regional variations, that may be caused by other processes that operate on regional and local scales.

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. Baltic 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 pattern of the North Atlantic Oscillation (NAO). However, the correlation between individual Baltic Sea level stations and SLP is heterogeneous in space (see Figure 1) and in time (range of 0.25 to 0.8 in wintertime for 1900 to 2000).

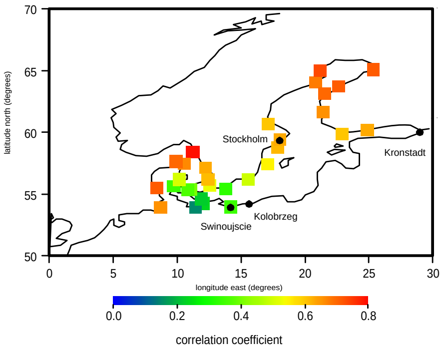

Figure 1 Correlation between winter mean (DJF) of NAO index and winter mean (linearly detrended) Baltic Sea level (obtained from PSMSL), 1900 to 1998. (adapted from Hünicke and Zorita, Tellus A, 2006). Sea level records for the 20th century are obtained from the Permanent Service for Mean Sea Level (PSMSL); the four longer time-series (up to 200 years; black dots) are obtained from Ekman (2003), Bogdanov et al. (2000) and TU Dresden.

In recent studies Hünicke and Zorita (2006, 2008) used several statistical approaches to investigate the influence of different atmospheric forcings on past and present Baltic Sea level with focus on multiyear to decadal timescales (in the context of anthropogenic climate change). Thereby, they restricted their study on those atmospheric forcing factors for which long term observations or reconstructions are available, and which are potentially well simulated by GCMs. Their results indicated that 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, decadal variations in the Southern Baltic Sea can be explained better by area-averaged precipitation. The establishment of these statistical relationships in the observational record allows an estimation of regional climate change by statistical means through the application of the statistical models to the corresponding output of GCM simulations.

2. Method

A statistical downscaling approach is applied to the output of different GCM simulations (Table 1; also see http://www-pcmdi.llnl.gov/ipcc/model_documentation/ipcc_model_documentation.htm) driven by SRES A2 future scenarios of greenhouse gas concentrations to estimate the contribution of changes in atmospheric circulation and in precipitation to regional future winter (December-January-February) sea-level changes in four Baltic gauges (Figure 1, black dots). The method is based on linear regression models, which establish a statistical relationship between Sea level as predictand (regional scale dependent variable) and large scale climate fields as predictors (independent variables).

Table 1 List of Global Climate Models.

Trends mm/year (95% confidence interval)	**Kolobrzeg**	**Swinoujscie**	**Stockholm**	**Kronstadt**
Global climate models	predictor precipitation		predictor sea-level pressure	
NCAR CCSM 3.0 (POP OGCM)	0.24 (±0.05)	0.21 (±0.05)	-0.19 (±0.21)	0.01 (±0.38)
NASA GISS Model E-R (Russell OGCM)	0.17 (±0.04)	0.14 (±0.03)	0.14 (±0.09)	0.13 (±0.17)
UKMO HadCM3	0.30 (±0.05)	0.26 (±0.04)	0.32 (±0.13)	0.29 (±0.26)
MPI ECHAM5	0.60 (±0.04)	0.52 (±0.04)	0.88 (±0.13)	1.25 (±0.26)
NOAA GFDL CM 2.1	0.62 (±0.05)	0.54 (±0.04)	1.24 (±0.18)	2.53 (±0.34)

Before applying the sea-level records to regression equations, we eliminate the contained trend caused by post-glacial land uplift and possibly by eustatic sea-level change by subtracting the linear long-term trend from each sea-level record. As the interest lies in the variability at decadal and longer timescales, all time-series were smoothed with an 11-year running mean filter.

For the central (Stockholm) and eastern (Kronstadt) Baltic Sea level stations, SLP was used as predictor. Therefore, the SLP field was decomposed to its principal components (PCs) to avoid co-linearity. Once the regression coefficients had been estimated by Least Mean Square-Error, the respective climate model time series associated with the leading SLP PCs were determined for the whole time-period (around 1860 to 2100, with minor changes depending on the climate model run used) by projecting the simulated SLP anomalies (deviations from the model 1900-1998 mean) onto the observational spatial eigenvectors of loadings from the PC analysis. The regression coefficients were calibrated in 1900-1999 by using gridded climatic data sets of SLP (Trenberth and

Paolino, 1980) and precipitation (Mitchell and Jones, 2005). For the sea-level stations in the Southern Baltic Sea (Swinoujscie and Kolobrzeg) catchments area-averaged precipitation was applied as predictor. Thereby, the precipitation time-series is treated the same as a single PC of the SLP field.

3. Results

Figure 2 shows the results of the regression analysis for the different GCM simulations. The estimated linear trends of the contribution of SLP and precipitation changes to future winter sea-level change are also given in Table 2, together with their 95% confidence interval.

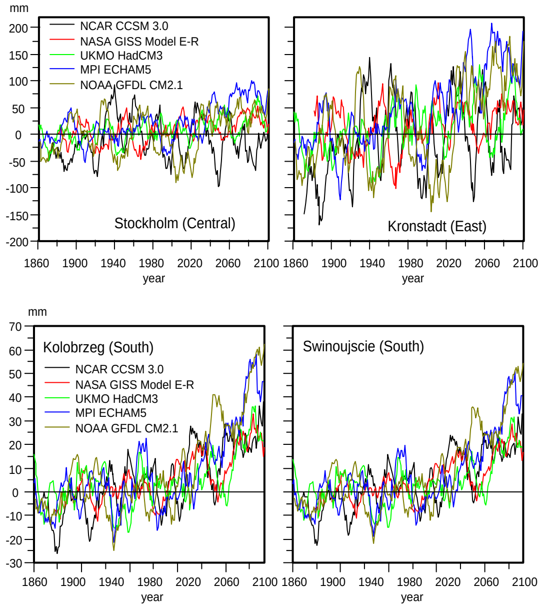

Figure 2 Estimations of the contribution of changes in atmospheric forcing to future winter sea-level change in the Baltic Sea based on regression between observed sea-level as predictand and SLP (upper panels) and area-averaged precipitation (lower panels) as predictor.

For the sea-level stations Stockholm and Kronstadt (predictand SLP PCs) the simulations with the UKMO HadCM3, MPI ECHAM5 and NOAA GFDL CM 2.1 climate models show a clear significant positive signal on sea-level rise. The strongest signal is obtained by applying the SLP output of the NOAA GFDL CM 2.1 simulation to the regression models (see Table 2 for more details). The ECHAM5 model also produces a much higher positive trend for Kronstadt than for Stockholm, but the values are lower. The HadCM3 model leads to positive trends, but much weaker and more similar between the two sea level stations. Whereas the NCAR model shows no significant trend for both sea level stations, the NASA model produces a minor upward trend for Stockholm. Considering all significant values, the mean estimate changes brought about by simulated changes in the SLP field are of the order of 1 mm/year for the investigated sea-level stations for the time period 2000 to 2100.

The estimation of the contribution of precipitation changes to future winter sea-level changes in the Southern Baltic Sea level stations Kolobrzeg and Swinoujscie (predictand area-averaged precipitation) shows a much more uniform result across the simulations. Similar to the findings using SLP as predictor, the strongest signal is reached by applying the precipitation output of the NOAA GFDL CM 2.1 simulation to the regression models. Thereby the 21st century trends reach values of 0.63 ±0.05 mm/year for Kolobrzeg and 0.54 ±0.04 mm/year (95% confidence interval) for Swinoujscie. Again, the ECHAM5 model delivers quite similar results. The lowest trends are estimated by using the precipitation output of the NASA GISS Model with values. The results for the NCAR and UKMO climate models are quite similar. For more details see Table 2.

Table 2 Estimated linear trends of the contribution of SLP and precipitation changes to future winter sea-level change (2000 to 2100), together with their 95% confidence interval.

Trends mm/year (95% confidence interval)	**Kolobrzeg**	**Swinoujscie**	**Stockholm**	**Kronstadt**
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4. Summary and Conclusions

A statistical downscaling approach is applied to the output of different global climate model simulations driven by SRES A2 future scenarios of greenhouse gas concentrations to estimate the contribution of changes in the atmospheric circulation and in precipitation to regional future winter sea-level changes. The method is based on observed statistical relationships between sea level as predictand and large-scale climate fields as predictors.

The results indicate that future trends in sea-level rise caused by these forcing are larger than the past variability. Using sea level pressure as predictor for the central and eastern Baltic Sea level stations, three climate models lead to 21st century future trends in the range of the order of 1 to 2 mm/year. Using precipitation as predictor for the stations in the Southern Baltic Coast all five models lead to significant trends with a range of the order of 0.4 mm/year. These numbers are smaller, but of the order of magnitude of the predicted future global sea level rise.

The findings qualitatively agree with the results of a dynamical downscaling approach by Meier et al. (2004).

Nevertheless, these estimations comprise only a partial contribution of selected large-scale regional predictors and an estimation of the total regional sea-level rise has to consider other regional factors such as the isostatic contribution to relative sea level changes or substantial changes in the sea-ice cover and global sea level rise.

References

Hünicke, B. and E. Zorita, Trends in the amplitude of Baltic Sea level annual cycle, *Tellus*, 60A, 154-164, 2008

Hünicke, B. and E. Zorita, Influence of temperature and precipitation on decadal Baltic Sea level variations in the 20th century, *Tellus*, 58A, 141-153, 2006

Hünicke, B., J. Luterbacher, A. Pauling and E. Zorita, Regional differences in winter sea-level variations in the Baltic Sea for the past 200 years, *Tellus*, 60A, 384-393, 2008

Meier, H.E.M et al., Simulated sea level in past and future climates of the Baltic Sea. *Clim Res*, 27, 59-75, 2004.