What do we know about sea-level change in the Baltic Sea?

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1. Background

Sea-level change is becoming an issue of increasing importance, especially in the context of anthropogenic global climate change. In addition, it is also closely linked to studies of solid earth processes and geodetic science. The possible impact of sea-level rise on the coast (see Figure 1) and the associated costs for coastal protection is of great interest to governmental bodies and the public.

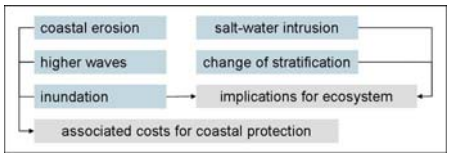

Figure 1. Possible impacts of sea-level rise.

The understanding of sea-level rise and variability on a global scale is nowadays the focus of many research studies worldwide and was one of the key topics of the IPCC Fourth Assessment Report (AR4). However, sea-level changes are not uniform over the globe. Considerable regional variations that may be caused by regional and local-scale processes are not captured in the global averaging of sea level.

2. Understanding global sea level change

The two main reasons for sea-level rise are thermal expansion of ocean waters and the increase in the ocean mass from land-based sources of ice (Figure 2).

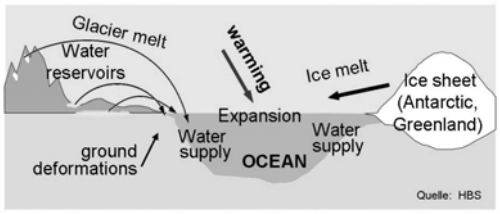

Figure 2. Main factors causes sea-level rise.

Both factors are significantly affected by global warming. For the 20th century, tide gauge measurements show an increase in mean global sea-level rise of around 1.7 mm/year, whereas satellite-altimeter observations since 1993 report values in the range of 3.1 ±0.4 mm/year *(Church et al., 2008).*
Climate projections of the IPCC AR4 (2007) under different scenarios of atmospheric greenhouse concentrations foresee a estimated rise of 18-59cm for the end of the 21st century. About ¾th of this increase will be mainly caused by thermal expansion of the oceanic water volume. However, the effect of increasing ice sheet discharge (melting, but also flow) is still highly uncertain. We can expect that sea-level will continue to rise with at least the same rates as seen in the 20th century, but higher rates are more likely.

3. What effects Baltic Sea-level Change?

The changes in mean Baltic Sea level can be seen as the sum of global, regional and local effects. Regional effects include a) thermo- and halosteric effects (which can reach, according to *Skovgaard Madsen,2009,* similar magnitudes at basin-scale) b) general changes in wind, surface pressure and ocean currents and c) gravitational effects, whereas land uplift and wind effects, increasing freshwater input and higher increase in temperatures than open ocean can account for local effects.

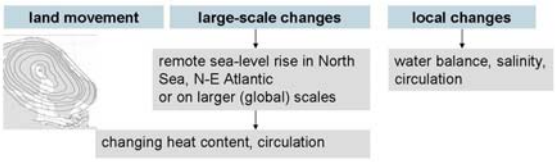

Figure 3. Main factors affecting long-term Baltic Sea level.

Land Movement: The Baltic Sea is a region strongly influenced by the effect of the glacial isostatic adjustment (GIA) with the Earth crust in the Northern Baltic rising at roughly 9 mm/year (resulting in a negative trend in sea-level) and in parts of the Southern Baltic sinking at about 1 mm/year (resulting in a slight positive trend) *(e.g. Rosentau et al., 2007)* However, these values are based on local observations of long-term relative sea-level trends, presenting the position of sea-level with respect to land and therefore include both: the signal related to vertical crustal movements and the absolute sea-level change. On timescales up to 200 years, the trend caused by post-glacial land-movement can be assumed to be approximately linear. Currently, new geodetic techniques such as GPS are applied to measure the rates of vertical movements (e.g. ongoing research projects in Denmark and Germany) and allow for comparison with results of GIA models and corrections out of geological data.

***Climate influence*:** Baltic Sea level variations at inter-annual to decadal timescales are generally believed to be caused essentially by variations in the North Atlantic Oscillation (NAO) index. The NAO influences sea level not just through the influence on zonal winds, but also through direct pressure and steric effects. However, the correlation between individual Baltic Sea level stations and the 20th century winter NAO index is heterogeneous in space and in time. Although the NAO is the dominant SLP large-scale pattern of the North Atlantic, it explains (on average) only 32% of the total variability of sea level at inter-annual timescales *(Kauker & Meier, 2003).* Thus, the estimation of the full amount of variability which can be explained by the atmospheric circulation has to consider the whole SLP field of the North Atlantic –West European region. Especially for the south-western Baltic coast, other atmospheric forcing factors seem to be more relevant. Statistical analyses (e.g. *Hünicke et al., 2008*) found a relation between long-term Baltic Sea level variations and precipitation changes for Southern Baltic Sea level

records. As on timescales larger than 1 month, the Baltic Sea acts like an open basin (*Samuelsson & Stigebrandt, 1996)*, this relation cannot be explained by the direct volume effect, but possibly due to changes in water density due to changed salinity.

4. Tide gauge records

The understanding of climatic future trends of sea level on regional scales presumes the understanding of the decadal variability in the observational period. Thus, long time-series of sea level are required. Fortunately, the Baltic Sea Area is one of the most investigated sea-level sites of the world. Many of the available sea-level time-series can be obtained through the webpage of the Permanent Service for Mean Sea level (PSMSL)[1]. In addition, historical sea-level time-series are available due to different sources, e.g. via publications for Stockholm (1774-2000; *Ekman, 2003*) Kronstadt (1816-1999; *Bogdanov et al., 2000*) and Travemünde (since 1826; *Jenssen & Töppe, 1986*), but also from national institutions. Interestingly, significant differences seem to exist in the datasets, depending on the data source *(Dimke & Fröhle, 2009).*

5. Satellite Altimetry

Since 1993, high-quality satellite-altimeter observations of sea levels allow for more accurate estimates of globally averaged and regional sea-level change *(Cazenave et al., 2008)*, although the satellite data of coastal areas is still not applicable without special treatment. For the open ocean the trend in Baltic Sea level rise is found to be very likely higher than the global mean, but also higher than the North Sea trend (*Skovgaard Madsen, 2009).*

6. Is Baltic Sea Level rise accelerating?

At global scales, acceleration in sea-level rise has already been detected in the 20th century *(Merrifield & Merrifield, 2009*), while other studies do not detect a significant change *(Holgate, 2007)*. For regional planning agencies more important than the global number is, however, the change in the rate at regional scales. According to the *BACC Report*, the eustatic increase of sea level was found to accelerate at many Baltic Sea tide gauge stations at the end of the 20th century (e.g. *Ekman, 2003; Johansson et al., 2004; Suursaar & Kullas, 2006*). Also the recent Sea level Report by SMHI, which put together sea-level information from 23 Swedish gauges, quotes an acceleration in the average sea-level rise of about 3cm/century since 1980 (average rate 1886-1980: 1.5 mm/year). However, according to engineers, in sea-level observations of the southwestern Baltic coastline (e.g. record Warnemünde) no significant acceleration is evident. The question arises if the different findings can be attributed to different methods used to identify the changes in the sea-level time-series.

7. Summary

An overview of the available knowledge about mean sea-level variability and change in the Baltic Sea Region is presented, as regional sea-level rise appears more and more to be a major issue with high relevance for stakeholders and planning authorities, but also the public in large. A number of new studies about mean sea-level change have been published since the conclusion of the *BACC report* (2006). Thus, the presented work tries to provide an overview of the state-of-the art of Baltic sea-level research outlining not just regional information, but also looking from the global perspective. As sea-level change is a wide range topic, the focus will be placed on answering selected questions of high relevance, such as: What drives global sea-level change in general and what specifically effects Baltic Sea level change? Are satellite-altimeter observations currently useful for the study of Baltic Sea level variability? Are there new efforts being made in the development of advanced geodetic techniques for measuring vertical land movement at tide gauges? Which sea-level data is available for the Baltic Sea Community and which of the data has been quality controlled by peer-reviewed scientific studies? Which studies about **Baltic sea-level projections** exist up-to-date, as they are a priority for coastal engineers and planning authorities *(Hünicke & Storch, 2009)*. What is known? What is very likely? What is still uncertain? How convinced is the BALTEX community that the Baltic is experiencing a) more gradual impacts of sea-level rise due to climatic change and b) a sea-level rise that poses a very serious threat to the Baltic Sea? *(Bray & Storch, 2009).*

[1] http://www.pol.ac.uk/psmsl/

References

BACC Author Team. Assessment of Climate Change for the Baltic Sea, *Springer*, Berlin, Heidelberg, 2008.

Bray, D & H von Storch, An introspective look at BACC: SURBACC2009, *BALTEX Newsletter* 13, 2009.

Bogdanov et al., Mean monthly series of sea level observations (1777-1993) at the Kronstadt gauge, *Reports of the Finnish Geodetic Institute* 2000: 1, 34pp, 2000.

Cazenave, A, et al., Present-day sea level rise: A synthesis. Comptes Rendus Geosciences 340(11), 761-770, 2008.

Church J, et al., Understanding global sea levels: past, present and future, *Sustain Sci* 3 (1), 9-22, 2008.

Dimke, S & F Fröhle, Measured sea level rise at the Baltic Sea coast of Mecklenburg -Vorpommern and implications for the design of coastal structures, *Proceedings of the International Conference on Climate Change*, 25-28 May 2009, University of Szczecin, Poland, ISSN 1681-6471.2009.

Ekman, M, The world's longest sea level series and a winter oscillation index for Northern Europe 1774-2000, *Small Publ Hist Geophys* 12, 30pp, 2003.

Holgate, SJ, On the decadal rates of sea-level change during the 20th century, *Geophys Res Lett* 34, L01602, 2007.

Hünicke, B & H von Storch, What is known about sea-level change in the Baltic Sea? *BALTEX Newsletter* 13, 2009.

Hünicke B, et al., Regional differences in winter sea-level variations in the Baltic Sea for the past 200 years, *Tellus* 60A, 384-393, 2008.

Jensen, J & A Töppe, Composition and Evaluation of Original Records of the Gauge at Travemünde/ Baltic Sea since 1826. (in german). *Deutsche Gewässerkundliche Mitteilungen* DGM 30, 4, 99-107, 1986.

Johansson M, et al., Scenarios for sea level on the Finnish coast. Boreal Env Res 9:153-166, 2004.

Kauker, F & MHB Meier, Modeling decadal variability of the Baltic Sea: 1. Reconstructing atmopsheric surface data for the period 1902-1998. *J Geophys Res* 108 (C8), 2003.

Merrifield MA & ST Merrifield, An anomalous recent acceleration of global sea level rise, *J Climate* 22, 2009.

Rosentau et al., Relative Sea level change in the Baltic Sea since the Littorina Transgression, Z geol Wiss 35, 3-16, 2007.

Samuelsson, M & A, Stigebrandt, Main characteristics of the long-term sea level variability in the Baltic Sea, *Tellus* 48A, 673-683, 1996.

Suursaar, Ü & T Kullas, Influence of wind climate changes and the mean sea level and current regime in the coastal waters of west Estonia, Baltic Sea, *Oceanologia* 48 (3), 361-383, 2006.

Skovgaard Madsen, K, Recent and future climatic changes in temperature, salinity, and sea level of the North Sea and the Baltic Sea, *PhD Thesis*, Planet and Geophysics, Niels Bohr Institute, University of Copenhagen, 2009.