



Decadal sea-level changes in the Baltic Sea



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http://coast.gkss.de/staff/huenicke/pdfs/Poster_BSSC_0811.pdf

Introduction:

As a consequence of increasing concentrations of greenhouse gases in the atmosphere, the global rate of sea-level rise is expected to accelerate in the future. Some studies indicate that this acceleration has already been detected in the 20th century record of global sea-level rise (Merrifield et al., 2009) while others do not detect a significant change (Holgate, 2007; Houston and Dean, 2011). For regional planning agencies more important than the global number is, however, the regional acceleration.

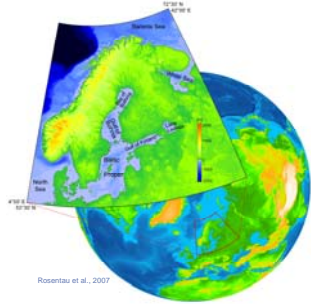


Fig.1 Location of the Baltic Sea Region and the Baltic Sea Area.

The Baltic Sea (Fig.1) is a region strongly influenced by isostatic rebound from the last deglaciation, with the Earth crust in the Northern Baltic rising at roughly 10 mm/year and in parts of the Southern Baltic sinking at about 1 mm/year. Time series of sea-level measured by coastal gauges thus display strong linear trends due to isostasy. The values of these trends form the basis for sea-level rise projections relevant to coastal protection, with an approximate estimate of possible sea-level rise caused by climate change added to the isostatic trends.

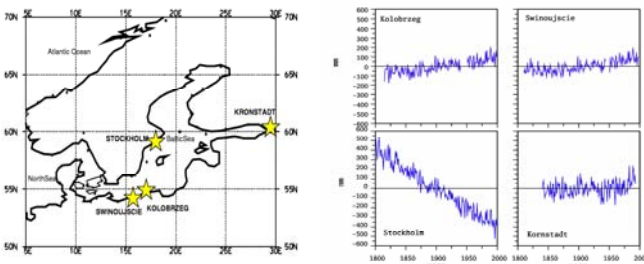


Fig.2 Annual mean sea-level in four gauge station in the Baltic Sea that report particularly long records: Swinoujscie (PSMSL), Kolobrzeg (PSMSL; before 1951 TU Dresden), Stockholm (Ekman, 2003) and Kronstadt (Bogdanov et al., 2000).

Deviations from a constant long-term trend, e.g. as an accelerating component, should be considered in future projections. The identification of a change in the long-term trend is hampered by other regional factors that cause variations in sea-level at multiple timescales, such as the North Atlantic Oscillation and other temperature and precipitation variations (e.g. Hünicke et al., 2008).

Methods:

Different statistical methods have been applied to identify changes in the rate of change. Method 1 is based on the estimation of multi-decadal linear trends, followed by the estimation of temporal changes in these trends (Fig.3). Method 2 attempts to fit the sea-level records to a linear and a quadratic, instead of only linear, trend over the whole observed period (Table 1, Fig.4-5). For the statistical significance of the presence of trends or acceleration, the structure of the regression residuals has to be taken into account. Here, a method based on bootstrapping of the residuals that conserves their serial correlation structure has been applied (Christiansen et al., 2010). As the possible acceleration signal is small, and the overall linear trend is heavily contaminated by the influence of isostatic adjustment, great care has to be put on the estimation of uncertainty ranges.

Results:

Following Method 1, preliminary results indicate that the present rates of sea-level rise are in general not unprecedented.

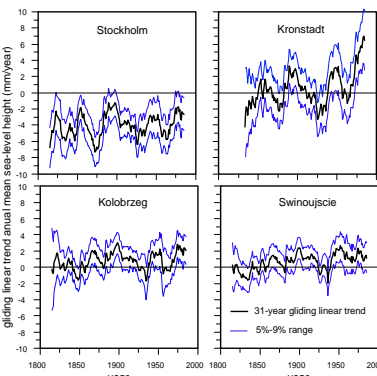


Fig.3 Gliding linear trends of selected sea-level records, estimated by linear fit in moving 31-year windows, together with the 5% and 9% uncertainty range. The abscissa of each data point indicates the centre of the 31-year window.

The interpretation of the Kronstadt gauge needs special caution because of possible data inhomogeneity due to peculiarities of observations in different epochs, methods of the series restoration, changes of its reference points, geodynamic and anthropogenic (technological) changes in the region (Bogdanov et al., 2000). The visible increase in the trend since 1950 can possibly be explained by a change of observation responsibilities and methods, respectively; but mostly due to the change in the level regime as a result of the construction (begin in 1978) of the complex of flood defence facilities (St. Petersburg dam).

Following Method 2, the estimated accelerations of annual sea-level in the Baltic Sea are all positive, and statistically significantly different from zero (Table 1). Also, the estimated magnitudes are all similar and they can be considered equal within the uncertainty ranges.

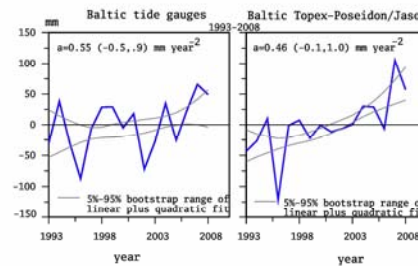
Table 1 Estimations of the acceleration in annual mean sea-level in four gauges in the Baltic Sea in the period 1800-2000. The last two columns indicate the 5% -95% uncertainty range.

unit: $10^{-2} \text{ mm/year}^2$	best estimate	5th	95th
Kolobrzeg	0.55	0.31	0.87
Swinoujscie	0.55	0.35	0.78
Stockholm	0.32	0.15	0.50
Kronstadt	0.46	0.24	0.69

This would be consistent with a climate influence in the last 200 years. An alternative interpretation, namely that the isostatic trend is slowing down, would not be consistent with the same sign of the acceleration for all four gauges, some located in sinking others in rising areas.

Preliminary results indicate that the present rates of sea-level rise are not unprecedented. The maximum rates were observed at the turn of the 19th century, and therefore an anthropogenic signal does not yet emerge. However, 200-year long records are best explained if a small acceleration of the rate is allowed for, which may be due to multiple causes.

The question arises as to how these findings compare with satellite data for the last few decades. For that purpose, all available tide gauge data which report between 1993 to 2008 were selected for the Baltic Sea Region (53N to 67N, 12E to 30E) from the PSMSL* RLR datasets. In addition, a combined satellite data set on a $1^\circ \times 1^\circ$ grid was downloaded from the CSIRO website: http://www.cmar.csiro.au/sealevel/sl_data_cmar.html for the same time period. For both datasets, each of the time-series (annual means) was fit to a linear and quadratic trend over the observed period. For the tide gauges as well for the satellite data, a positive acceleration of the annual mean sea-level averages could be detected (Fig.4).



*PSMSL = Permanent Service for Mean Sea Level (<http://www.psmsl.org/>)
RLR -> Revised Local Reference

Fig.4 Time-series of annual mean Baltic sea-level averages (1993-2008) derived from 24 tide gauges (left panel) and 77 grid points of combined satellite data (corrected for inverse barometer and GIA) of TOPEX/Poseidon, Jason-1 and Jason-2/OSTM sea level fields (right panel).

Within the satellite era (1993-today), available tide gauge readings cover most of the North and South-East Baltic coasts, whereas the satellite data cover the South and North-East Baltic open ocean. The spatially averaged acceleration is comparable in both data sets.

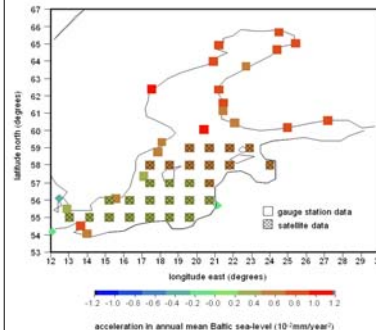


Fig.5 Acceleration values of annual mean Baltic sea-level averages derived from tide gauges and from satellite altimetry (1993-2008). (preliminary results)

Spatially resolved, the acceleration values range between 0.39 to 0.54 $10^{-2} \text{ mm/year}^2$ for the satellite data. For the tide gauge data, the range lies between -0.38 and 1.12 $10^{-2} \text{ mm/year}^2$ among the different stations, with a tendency to more positive values in the north and less positive values in the south. The same spatial gradient tendency is shown by the satellite data (Fig.5). It has to be kept in mind, that the satellite data do not provide measurements near the coast and thus are not directly comparable with the tide gauge data.

Outlook:

Future sea-level rise in the Baltic will be determined by several factors, some of them still poorly known, such as the dynamics of polar ice sheets. Many planning agencies broadly assume a continuation of the present linear trends, allowing for an additional 'climate contribution'. The estimation of an acceleration rate can contribute to improve these pragmatic estimations. A closer analysis of these first findings will be the focus of future research.

References: Bogdanov et al., 2000. Mean monthly series of sea level observations (1777-1993) at Kronstadt gauge. Reports of the Finnish Geodetic Institute 2000: 1, 34pp. Christiansen et al., 2010. A Surrogate Ensemble Study of Sea Level Reconstructions. J Climate 23, 4306-4326. Ekman, M., 2003. The world's longest sea level series and a winter oscillation index for Northern Europe 1774-2000. Small Publ Hist Geophys 12, 30pp. Holgate, S.J., 2007. On the decadal rates of sea-level change during the 20th century. Geophys Res Lett 34, L01602. Houston and Dean, 2011. Sea-Level acceleration Based on US Tide Gauges and Extensions of Previous Global-Gauge Analyses. J Coast Res, doi: 10.2112/JCOASTRES-D-10-00157.1 Hünicke et al., 2009. Regional differences in winter sea-level variations in the Baltic Sea for the past 200 years. Tellus 60A, 384-393. Merrifield et al., 2009. An anomalous recent acceleration of global sea level rise. J Climate 22, 5772-5781. Rosentau et al., 2007. Relative Sea level change in the Baltic Sea since the Littorina Transgression. Z geol Wiss 35, 3-16.