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Impact of Sea Level Change on Inner Coastal Waters of the Baltic Sea

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ABSTRACT: As a consequence of global warming a rise of the mean sea level (MSL) is expected in the Western Baltic Sea. This fact may have practical consequences to long term planning and use of infrastructure and coastal protection measures. Especially sensitive to an MSL rise are inner coastal waters like the Schlei estuary and the Bodden coast. The intention of this study was to give a qualitative and quantitative view of the changes of water level variability due to a given MSL change for these regions. Nested model simulations with a Baltic Sea model and a high resolution estuary model were performed to estimate the effect of a given constant rise of sea level at the Skagerak on short term water level variability. The results show significant rise of variability range in conjunction with the rising of MSL, induced by a volume change of the water body of the inner waters and its relation to the size of inflow section area. The numerical effect of too coarse grid resolution leads to an overestimation of the impact of MSL rise and approves the use of high resolution models for quantitative predictions. Nevertheless, the presented model results show a significant change in water level variability of the Schlei area in addition to MSL rise. Therefor practical impacts on infrastructure management can result.

Keywords: Sea level rise, Inner coastal waters, Western Baltic, Sea level Variability, Climate impact

1 INTRODUCTION

As a consequence of global warming a sea level rise of several decimeters is considered to be likely in the region of the Western Baltic Sea. In shallow waters the MSL change can change the volume of a water body in order of several ten percent of its absolute value. In context of local hydrodynamic situation this may have significant impacts on the behavior of environment.

1.1 *Description of inner coastal waters*

Inner coastal waters in the context of this article are nearly enclosed coastal basins with a narrow outflow section towards the open Baltic Sea. Their average depth is shallow and in relation to their outflow sections they cover a large area. The exchange of water between the Baltic Sea and the inner waters is limited by their outflow section and causes a damping of the short term water level variability inside these waters. On the other hand dependent on the basin size short frequency standing waves can be generated due to wind forcing.

Inner coastal waters of the Western Baltic can be classified into three classes:

1. Elongated chain of basins, connected to each other with a narrow channel with low freshwater input,
2. enclosed basin with one or multiple narrow channels to the open sea with low freshwater input,
3. enclosed basin with one or multiple narrow channels to the open sea with high freshwater inflow.

The first class is represented by the Schlei estuary. A member of the second class is the Bay of Greifswald, a member of the third the Szczecin Lagoon. The influence of freshwater inflow in the third class is an additional damping of the Baltic Sea influence on variability of the water level, to reduce the salinity significantly and to grow the influence of landward input of tracers.

The inner coastal waters have in common, that a large area has very shallow average water depth. Only narrow channels connect them to the sea. Some of the channels are maintained to a certain depth to provide safe navigation to vessels, which are expected to enter them.

1.2 *Intention of the study*

The inner coastal waters are important regions for economic, ecologic and recreational purposes. They link the hinterland to the open sea as waterways, providing ports for regional traffic and medium sized shipyards are located there. Due to their protected location they are important ecosystems with a high diversity of life. Their natural beauty attracts people to use them as recreational places both at the coastline and on the water. A sea level change has influence on the behavior of the sea level variability and on the exchange of properties of the water body of the inner waters with the Baltic Sea.

1.3 *The Schlei estuary*

The Schlei estuary is an inlet extending about 40 kilometers from the mouth at Schleimünde to the town Schleswig. Its geomorphological creation was in the Weichsel ice age, caused by the extending glaciers. In the mid ages the Schlei was an important waterway connection to the North Sea with only a land bridge of about 16 kilometers width dividing it from the Treene, a small river flowing into the Eider. Viking town Haitabu near Schleswig still documents its historic importance (WIKIPEDIA 2014). The waterway is nowadays still used by water tourism as well as small fishery and touristic vessels. The hinterland is characterized by intensive agriculture. The diffusive freshwater input to the Schlei by small creeks imports also a significant nutrient load into the water.

2 PHYSICAL DESCRIPTION

2.1 *Geometry and bathymetry*

The Schlei estuary has several basins, which are connected to each other with narrow channels. The flooded area at MSL is about 52.5 km2 and the water volume at MSL is 0.126 km3. The water depths related to MSL range from several centimeters in the shallow areas up to 15 meters in the channels. As shown in Figure 1, the estuary is dominated by water depths less than 3 meters MSL.

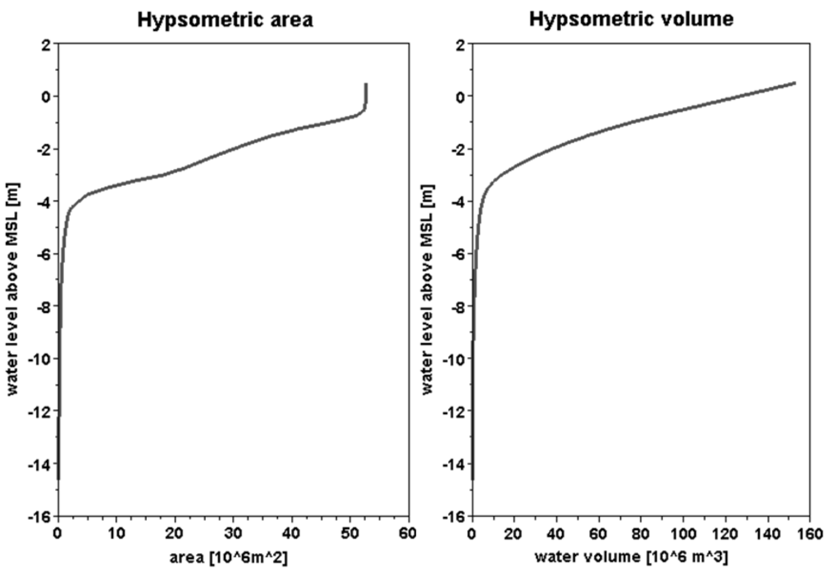

Figure 1. hypsometric area and volume of the Schlei estuary.

2.2 *Sea level variations in the Western Baltic and the Schlei*

Sea level variations in the Western Baltic are caused by different forces. The most important one is the wind induced setup during periods of strong storms. Typically easterly to northeasterly winds rise the water level, southwesterly to westerly winds induce a lowering of the water level. During a sudden change of the wind direction the Baltic Sea generates standing basin waves (seiches). These seiches can intensify the effect of wind setup. The typical period of such variations is 27 or 36 hours. Further sources of variability are the semidiurnal tides with about 0.2 meters of amplitude local wind setup and fjord seiches with a few centimeters of range.

The sea level variations, which are triggered by the oscillations of the Baltic Sea, are damped slightly by the relation of the entry channels cross section area to the water volume of the estuary. The damping is a result of frictional forces and turbulence in the channels connections between the basins of the Schlei.

2.3 *Salinity distribution*

The salinity in the Schlei estuary decreases about 6 PSU, comparing the value of the mouth at Schleimünde to the value at Schleswig (LANU-SH 2001). Due to the low freshwater input the salinity at Schleswig is still considerably high. There is no clear mixing zone between freshwater and salt water, because there are many very small input sources distributed around the Schlei.

3 MODEL CONFIGURATION

The numerical model code used is the UNTRIM code, Version 2007. A description of the general numerical background can be found in (CASULLI und LANG 2004). UNTRIM is a finite volume code which is operating on unstructured orthogonal grids. Two models were used in this study:

1. A model of the whole Baltic Sea, which has a low resolution in the inner and a medium resolution of the coastal structures (Figure 2). This model is driven with water levels of gauge Smögen, a constant salinity at the boundary and wind fields from the German Weather Service forecast model.
2. A high resolution model of the Schlei estuary, which has a sufficient resolution of the bathymetry (Figure 2). This model is driven at the seaward boundary by time series calculated by the Baltic Sea model and the same meteorological fields.

Both models are part of a model tool kit of the Baltic sea which has been developed for consulting tasks for the fairway management authorities, as described in (SEIß 2012).

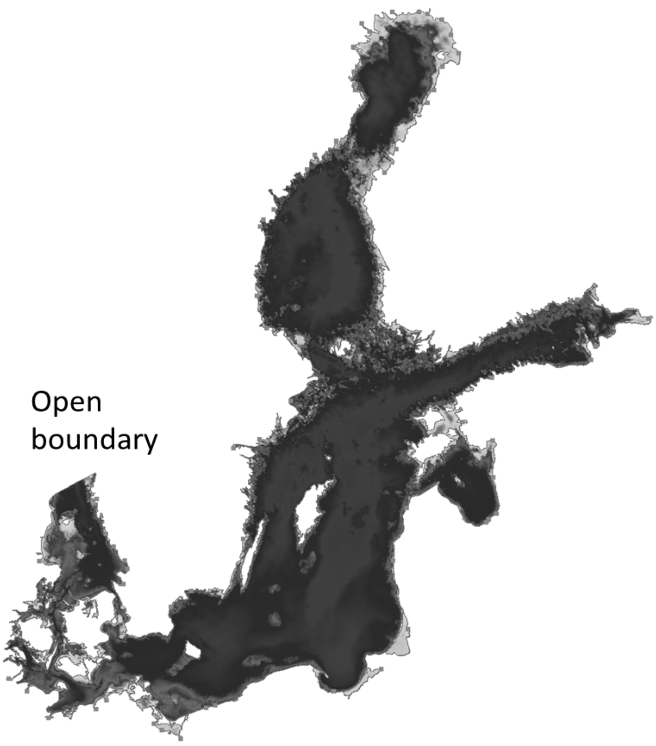

Figure 2. Model area and bathymetry of the Baltic Sea model.

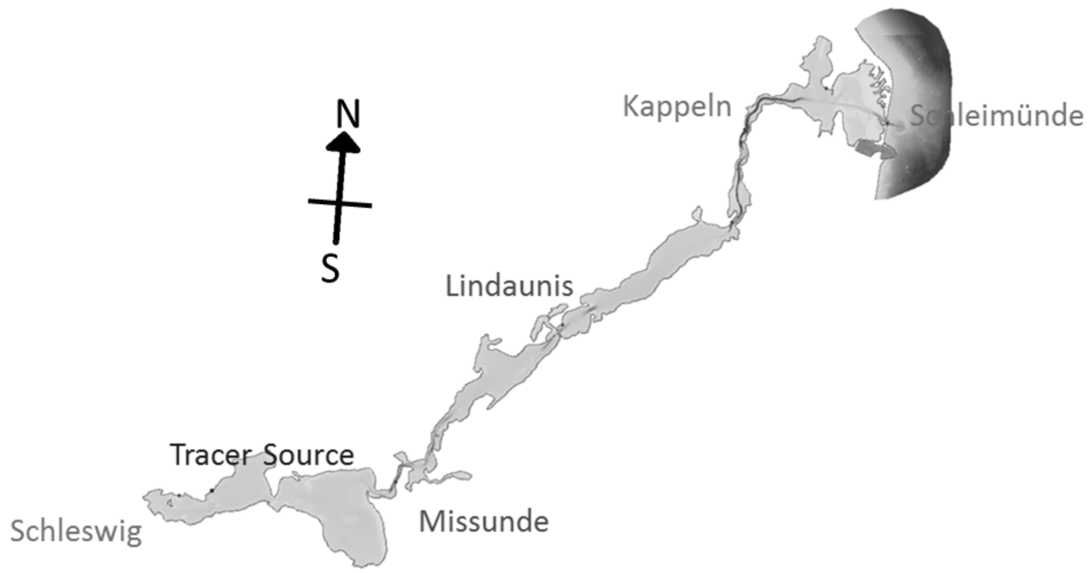

Figure 3. Model area and bathymetry of the fine resolution Schlei model.

The model simulations include hydrodynamics forced by wind and tides without waves.

3.1 *Sensitivity experiments*

Sea level change due to global warming is a slow process if it is compared to the time scales of dominant physical processes in the Schlei estuary. Therefor the reaction of the system on a changing MSL can be assumed as instantaneous. There is no need to know exactly, when a distinct MSL value is reached but how the system reacts on it in its short term dynamical behavior.

Throughout this article we compare an assumed specific MSL rise with the nowadays existing situation. Here we choose a fictive value of 0.8 m sea level rise (a value which may be representative for end of the century or even later).

Four simulations were done for the period of two months (October – November 2006):

1. Present state MSL with the Baltic Sea model (ACT).
2. Present state MSL plus 0.8 m with the Baltic Sea model (MSL+80)
3. Present state MSL with the Schlei model (ACTfine)
4. Present state MSL plus 0.8 m with the Schlei model (MSL+80fine)

3.2 *Simulated Scenario*

As the simulated time period for the four simulations we choose the months October and November 2006. During this period we observed a combination of low water event and high water event, which was initiated by the storm "Britta" between 01.11. and 03.11.2006. Westerly to north-westerly storm pulled the water into the central Baltic basin which resulted in a lowering of the water level of 0.5 m in the Western Baltic. After the turning of wind direction towards north, the water masses returned to the Western Baltic as a seiche. Additional setup occurred through the actual wind stress. The highest measured water levels reached 1.76 m above MSL in Kiel-Holtenau (Figure 4) and 1.77 in Lübeck. The event shows the typical range for short term variations of the water level in the Western Baltic. Meteorological boundary conditions were taken from the 24 hour prediction of the German Weather Service as hourly fields.

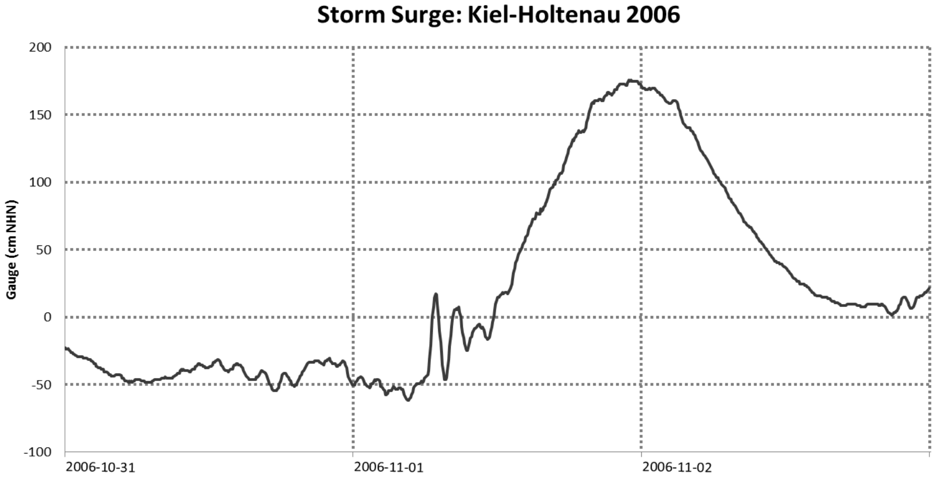

Figure 4. Evaluation of water level at Kiel-Holtenau gauge during event "Britta".

4 ANALYSIS OF RESULTS

The model produces the physical variables water level, currents, salinity, temperature and tracer concentration in as synoptic fields equidistant time steps. These raw data must be further analyzed to condense the information.

One obvious indicator of variability of the water level is the difference between the maximum and minimum water level. We use the software tool LZKWF (BAW 2013) to analyze the model results. This procedure leads to the following derived characteristic quantities:

- Minimum water level reached during analyzed time period NW
- Maximum water level reached during analyzed time period HW
- Average water level of the analyzed time period MW
- Difference between minimum and maximum water level reached during analyzed time period HW-NW

The difference of these quantities is calculated between the simulation MSL+80 and ACT as well as MSl+80fine and ACTfine to get the effect of sea level rise on them.

5 RESULTS

5.1 *Change of water level variability*

The difference HW-NW is used as indicator for the short term (several hours to days) variablility of the water level. The change of this quantity from ACT to MSL+80 is depicted in Figure 5.

The coarse resolution model here shows a positive difference in this quantity up to 0.75 m. This means that in addition to the MSL rise of 0.80 m we would expect much greater water level variability in the Schlei caused by this MSL rise. From a qualitative point of view the result seems to be plausible. The cross sectional area of the narrow connection to the Baltic Sea becomes wider and the frictional forces at the bottom reduce drastically in the shallow parts of the estuary. Nevertheless, there are doubts on the quantitative effect, which can result from a numerical overestimation of these effects. The Baltic Sea itself shows only changes of less than 0.05 m.

The fine resolution Schlei model, which can resolve the bathymetry more accurate, confirms this assumtion. Figure 6 shows the same quantity as a comparison for ACTfine and MSL+80fine. In this model configuration we find only a rise of HW-NW of up to 0.25 m. This is still a considerable effect, which can lead to practical consequences on the management of infrastructure and the ecosystem.

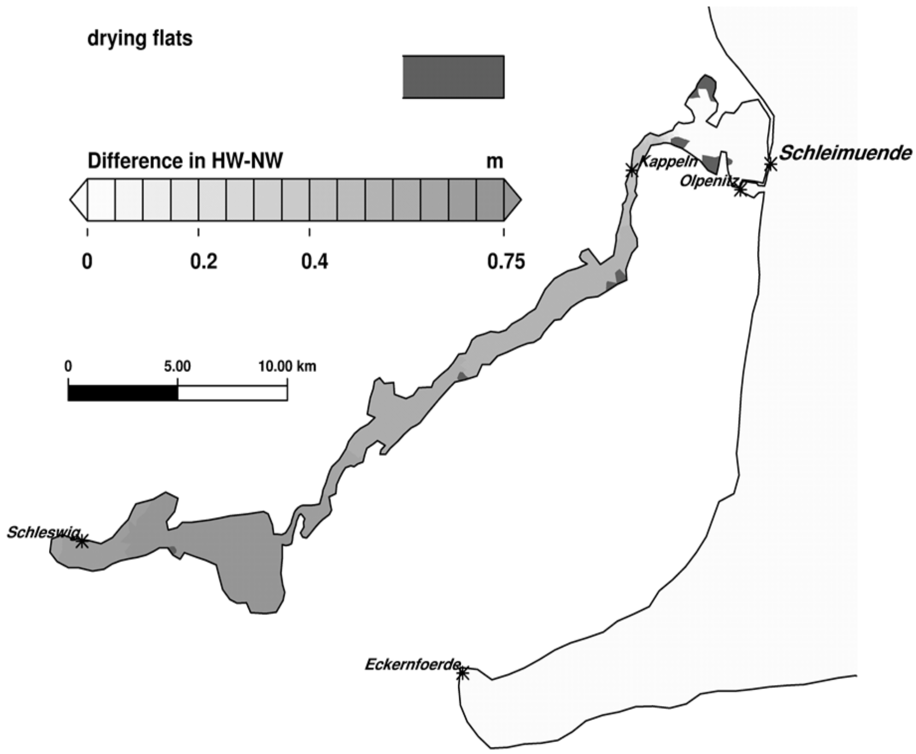

Figure 5. Difference of the quantity HW-NW, comparing MSL+80 with ACT.

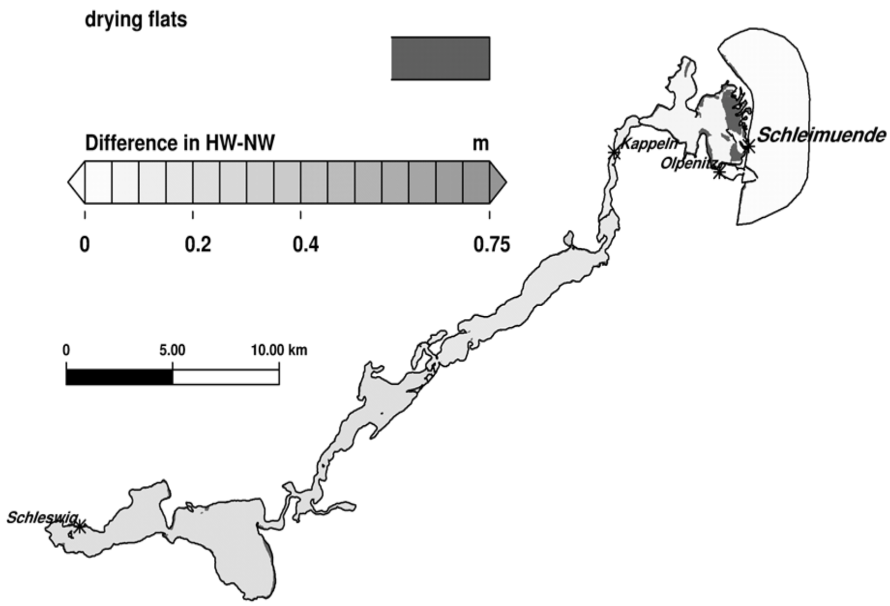

Figure 6. Difference of the quantity HW-NW, comparing MSL+80fine with ACTfine.

6 PRACTICAL CONSEQUENCES

As a result of MSL rise we expect the following effects on the water level in inner coastal waters of the Western Baltic Sea like the Schlei area:

- The mean sea level rise at the Kattegat entry will be transported to the inner coastal waters in the same quantity.
- The range of water level increases dependent on the changes of the cross sectional area, the volume and frictional behavior of the inner coastal waters.

The rise of MSL itself and the decrease of frictional forces (bottom stress) reduce the need of dredging fairways and allow usage of them to vessels with higher draft. Smaller boats, which have to use the dredged fairway because of their draft nowadays, eventually after a significant sea level rise are able to use also the area outside the fairway to navigate.

On the other hand, the MSL rise and its increasing variability induce the need of adaption of economically relevant infrastructure like quays and marinas.

Larger water volume of the inner coastal waters and wider cross sectional areas change the mixing relation between Baltic Sea water and freshwater inflow to a more marine environment.

7 CONCLUSION

The change of MSL and its effect on the inner coastal waters of the Western Baltic Sea has been subject of this study. With two models of different horizontal resolution it was shown, that the numerical effect of resolution can have strong influence on the quantitative but not the qualitative results. Numerical effects justify the need to use high resolution models, which are able to sufficiently resolve the bathymetry and the main current sheers of the considered area.

Two results are evaluated from model results: a mean sea level signal occurring at the Kattegat entry of the Baltic Sea is transported into the whole Basin without too much change on the behavior of the short term variability (seiches, tides). But the change in the variability of water level in inner coastal waters like the Schlei estuary can be significant and reach several decimeters.

Mean sea level change as well as significant changes of the water level variability have practical consequences on planning and management of infrastructure as well as the mixing behavior of the estuary. The influences may be positive or negative, dependent on the need for adaption measures e.g. for navigational purposes.

NOTATION

MSL	mean sea level
ACT	model run of the coarse Baltic Sea model with nowadays MSL
MSL+80	model run of the coarse Baltic Sea model with sea level rise of 0.8m
ACTfine	model run of the fine resolution Schlei model with nowadays MSL
MSL+80fine	model run of the fine resolution Schlei model with sea level rise of 0.8m

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