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Storm Surges in German North Sea Estuaries and Climate Change – Investigating Impacts and Developing Adaptation Strategies

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ABSTRACT: As climate will change in this century and beyond, the German Ministry of Transport (BMVI) is interested in the effect of climate change on the waterways in the German North Sea estuaries and therefore initiated the project KLIWAS (www.kliwas.de). In order to find a strategy for adaptation to climate change it is important to understand today's situation and analyse the future situation under the influence of climate change. This concept will be presented by looking into storm surges in the German Bight. A sensitivity study is used to identify areas along the estuaries of Elbe, Jade-Weser and Ems, which are vulnerable in case of storm surges and climate change. In a second step the efficacy of several adaptation measures is investigated. Advantages and disadvantages of the adaptation measures can be identified. The results give the chance to develop an adaptation route for the waterways in the estuaries of Elbe, Jade-Weser and Ems in order to mitigate the problems caused by climate change.

Keywords: Storm surge scenario, Climate change, Sensitivity study, Hydrodynamic numerical model, Wind, Sea-level rise, River run off

1 INTRODUCTION

The German Ministry of Transport (BMVI) is interested in the effect of climate change on the waterways in e.g. the German North Sea estuaries and therefore initiated the project KLIWAS (www.kliwas.de). In order to find a strategy for adaptation to climate change it is important to understand today's situation and analyse the future situation under the influence of climate change. The impact of climate change for the estuaries is investigated, vulnerabilities can be identified and an adaptation strategy can be prepared.

This concept will be presented by looking into storm surges in the estuaries along the German Bight. Climate change is expected to cause a global sea-level rise as well as a local sea-level rise in the North Sea, an increase in winter precipitation over Europe that can induce higher river run off in the storm surge season, and an increase in wind speed. These possible consequences of climate change can influence the height of storm surges in the estuaries along the German Bight.

A sensitivity study is used to identify areas along the estuaries of Elbe, Jade-Weser and Ems, which are vulnerable in case of storm surges and climate change. In a second step the efficacy of several adaptation measures is investigated. Advantages and disadvantages of the adaptation measures can be identified. The results give the chance to develop an adaptation route for the waterways in the estuaries of Elbe, Jade-Weser and Ems in order to mitigate the problems caused by climate change.

2 SENSITIVITY STUDY: IMPACTS OF CLIMATE CHANGE

The height of a storm surge in an estuary is determined by the water level at the estuaries boundary to the North Sea, the river run off into the estuary and the wind field over the estuary. A sensitivity study on storm surges in times of climate change is used to investigate scenarios that are not intended to represent a full description of the future but highlight central elements of a possible future.

The scenarios are built based upon high historical storm surges, e.g. the storm surge of January 3rd, 1976 and the storm surge of November 1st, 2006. The sensitivity study investigates the influence of

- sea-level rise in the North Sea,
- increase of river run off Q into the estuary and
- increase of local wind speed over the estuary

on the highest water level HW along the estuaries during storm surge. The parameters mentioned are varied according to the knowledge about expected changes in a future climate (KLIWAS, 2011). The sea-level is increased by 25 cm, 80 cm and 115 cm. For the Elbe and Weser estuary a river run off of 2000 m^3/s, 3000 m^3/s and 4000 m^3/s and for the Ems estuary a river run off of 350 m^3/s, 700 m^3/s and 1200 m^3/s in addition to the measured value is considered. The wind speed is increased by 5 % and by 10 % over the estuaries.

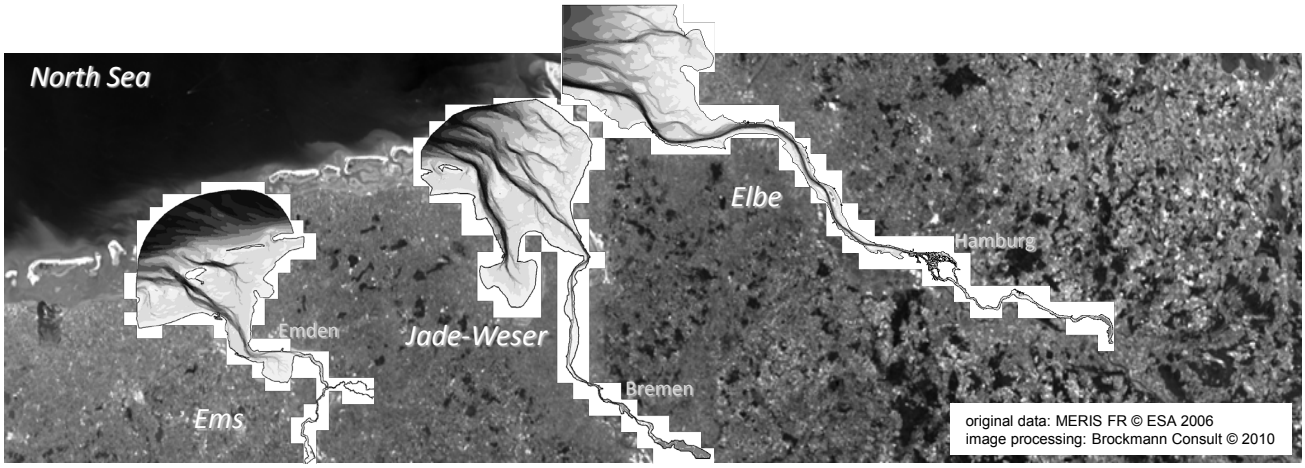

Figure 1. Schematic picture of the modelled area of the estuaries of Ems, Jade-Weser and Elbe in the German Bight.

The sensitivity is studied using hydrodynamic numerical models of the estuaries (UnTRIM, Casulli and Zanolli (1998) and BAW (2004)). The model domain covers the area of the estuary influenced by storm surges (Figure 1). The wind fields were provided by the German Meteorological Agency (DWD).

As a result of the sensitivity study an influence of the sea-level rise on the high water level, the low water level and the highest water level during storm surge HW can be found (Figure 2, right). The sea-level rise is also influencing the high water time. The highest water level during storm surge is reached earlier. Water levels higher as e.g. NHN + 3.00 m are lasting longer. An increase of the river run off (Figure 2, center) or the wind over the estuary (Figure 2, left) are influencing the same parameters but with different amounts of change in water level.

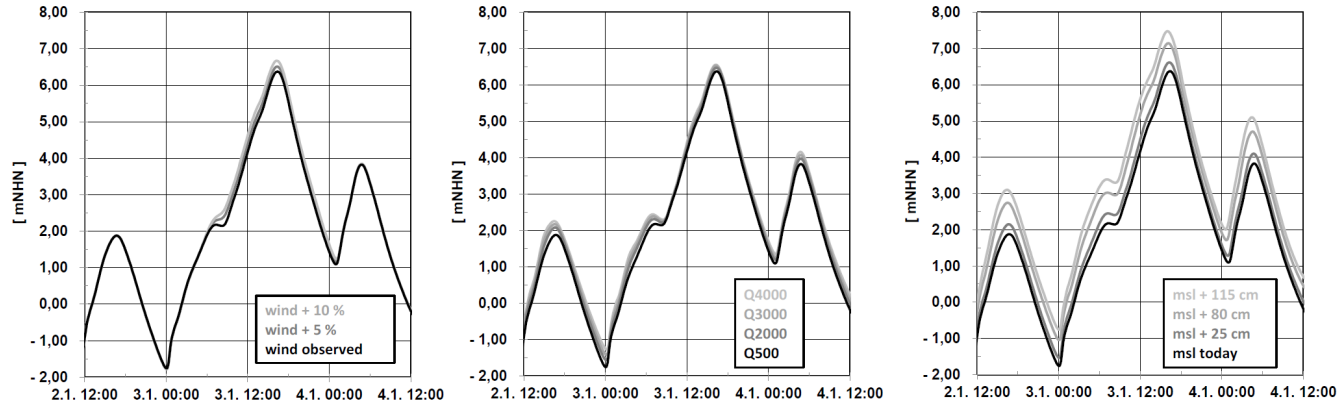

Figure 2. Time series of modelled water level in the Elbe estuary at Schulau (Elbe - km 640) for the scenarios "increase of local wind speed", "increase of river run off" and "sea-level rise".

The highest water level HW during storm surge is analysed along the whole estuaries of Elbe, Jade-Weser and Ems for the scenarios mentioned. As an example the results for the sea-level rise scenarios are shown in Figure 3. A sea-level rise in the North Sea affects the highest water level during storm surge along the whole estuaries even 100 km upstream of the mouth of the estuaries (Figure 3, black lines).

If the river run off is increasing in combination with a sea-level rise the highest water level during storm surge is increasing even more in the upper parts of the estuaries (Figure 3, grey lines).

As a result of this sensitivity study, in each estuary areas can be found where the water levels are influenced due to a change in the parameters sea-level rise, river run off or local wind. The local impact of global climate change on the water levels along an estuary can be identified (Schulte-Rentrop and Rudolph, 2012, Rudolph, 2014). It shows that today's challenges are likely to grow as a result of climate change (Seiffert and Hesser, 2014).

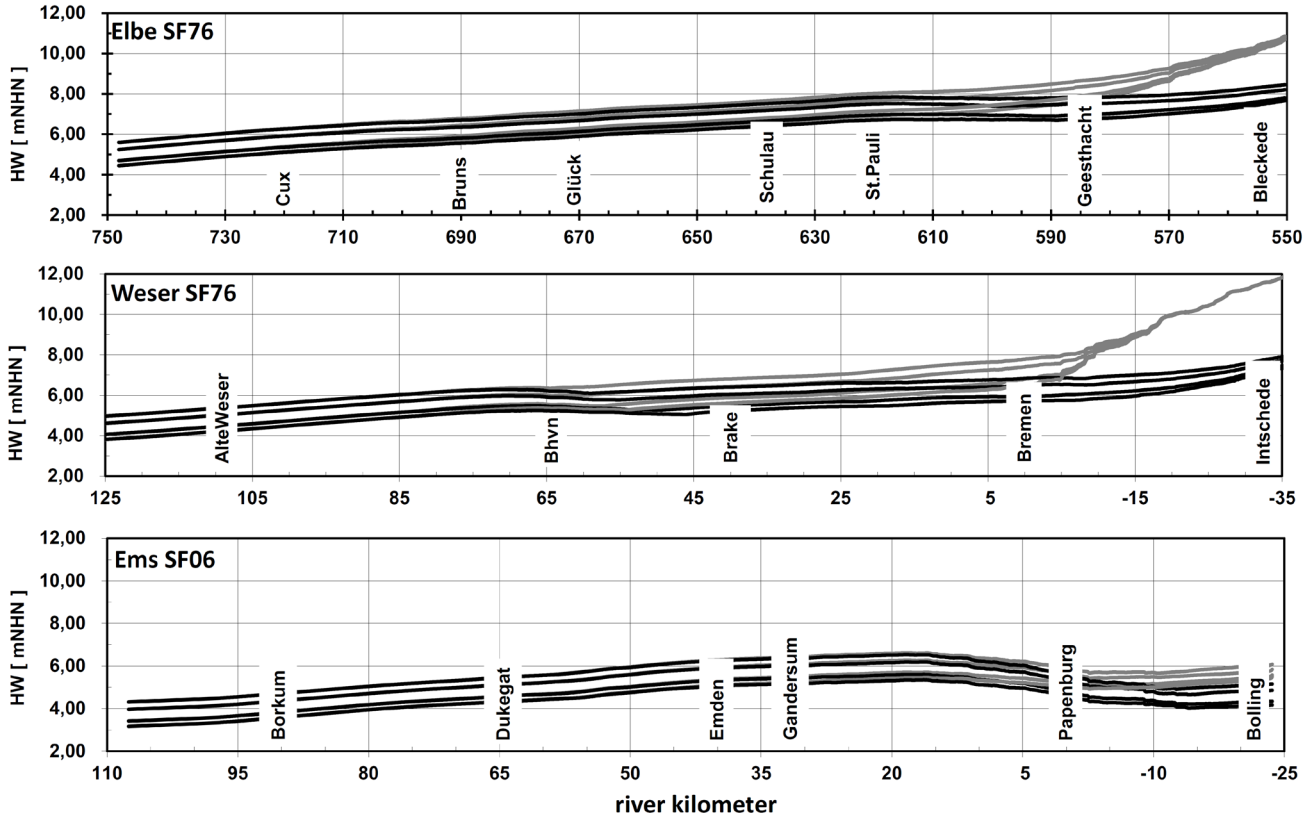

Figure 3. Sensitivity study sea-level rise in combination with increase of river run off: Highest water level during storm surge HW along the estuaries of Elbe (top), Weser (middle) and Ems (bottom) for a sea-level rise at the mouth of the estuaries of 25 cm, 80 cm and 115 cm. Black indicates a river run off for the Elbe of 500 m^3/s, Weser of 250 m^3/s and Ems of 32 m^3/s, grey indicates a river run off for Elbe and Weser of 3000 m^3/s and Ems of 700 m^3/s.

3 ADAPTATION MEASURES

In a second step the efficacy of several adaptation measures is investigated. As an alternative to increasing the dike height along the whole estuary, narrow the mouth of the estuary and storm surge barriers in the mouth of the estuary are investigated. Again a sensitivity study varying the parameters that might change in a future climate, such as sea-level rise or increase of river run off, is used to test the efficacy of the adaptation measures.

3.1 *Narrow the mouth of the estuary*

In order to narrow the mouth of the estuary several measures such as increasing an existing sandbank, building a new sandbank or building a dam (Seiffert and Hesser, 2014) are investigated. Figure 4 illustrates e.g. the position of a dam of NHN + 10 m height that is built in the area of Neufelder Sand as a narrowing measure for the Elbe estuary.

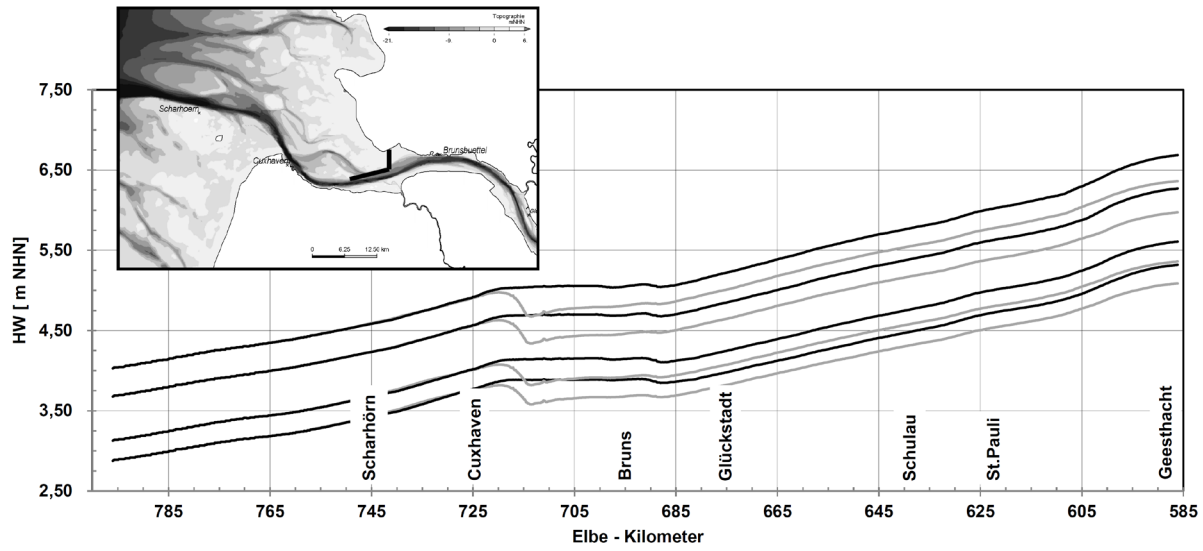

Figure 4. Highest water level along the Elbe estuary for storm surge scenario SF06 for today's mean sea-level and a sea-level rise of 25 cm, 80 cm and 115 cm in today's topography in black and with the narrowing measure dam in grey.

The highest water level during storm surge scenario SF06 with and without this narrowing measure is shown in Figure 4 for today's sea-level and a sea-level rise of 25 cm, 80 cm and 115 cm. The dam decreases the highest water level during storm surge upstream of the narrowing measure by about 20 cm in all scenarios investigated. But the effect of the sea-level rise can still be found along the whole estuary. Additional measures are needed to protect against storm surges and sea-level rise. In the area of the dam the current velocities in the fairway of the Elbe will change. It must be checked if this adaptation measure has side effects for the navigability of the Elbe fairway.

3.2 *Storm surge barrier*

Storm surge barriers are an appropriate measure to protect estuaries against storm surges. Since 2002 the Ems estuary upstream of Gandersum is protected by a storm surge barrier. In a sensitivity study this storm surge barrier is tested for sea-level rise scenarios in combination with river run off scenarios.

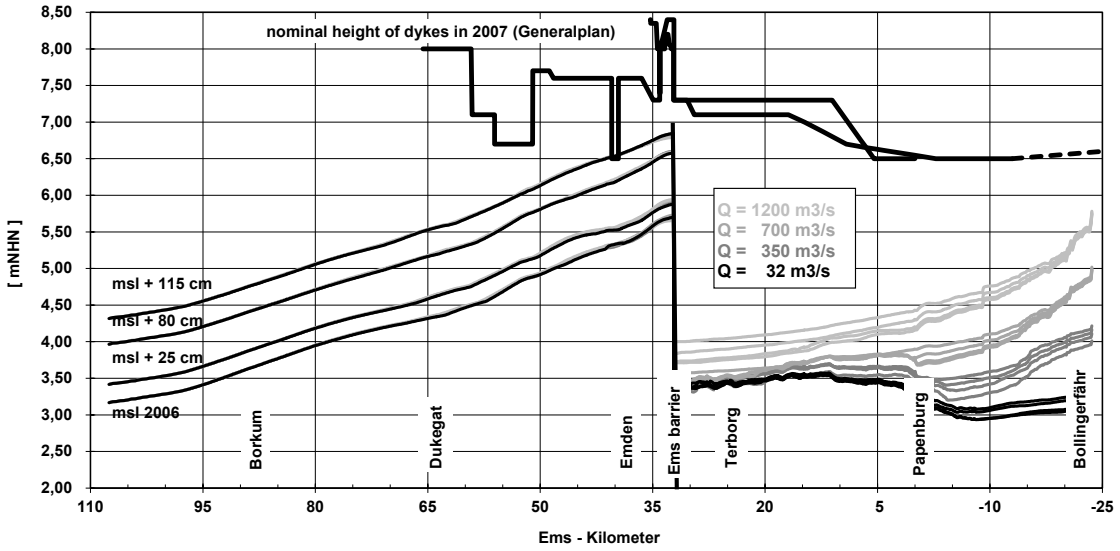

Figure 5. Highest water level along the Ems estuary with operated storm surge barrier for storm surge scenario SF06 with a river run off of 32 m^3/s for today's mean sea-level and a sea-level rise of 25 cm, 80 cm and 115 cm in today's topography in black. Combinations of sea-level rise scenarios with river run off scenarios Q are indicated in grey.

It shows, that upstream of the Ems barrier in the protected area no influence of a sea-level rise on the highest water level during storm surge can be observed (Figure 5, black lines). In this area the highest water level during storm surge is only influenced by the river run off (Figure 5, grey lines). Even for extremely high discharges of 1200 m^3/s (Figure 5, light grey lines) there is enough volume to store the discharge upstream of the barrier.

The barrier can only protect against storm surges of a certain height. It is possible to identify a sea-level rise scenario where the barrier will not give full protection anymore. It can be considered to operate the barrier differently or to adapt the barrier to different design water levels.

4 RESULTS

In order to develop a strategy for adaptation to climate change for the waterways in the German estuaries it is important to understand today's situation and to analyse the impacts of climate change. The impact of climate change on storm surges in the estuaries of Elbe, Weser and Ems is investigated using a sensitivity study. This study analyses the influence of sea-level rise at the mouth of the estuary, wind over the estuary and river run off.

The efficacy of the adaptation measures "narrow the mouth of the estuary" and "storm surge barrier" is investigated using again a sensitivity study. It shows, that to narrow the mouth of an estuary can reduce but not compensate the effect of a sea-level rise on the highest water levels during storm surge whereas a storm surge barrier protects an estuary against storm surges even in combination with sea-level rise. But both adaptation measures cause restrictions for the ships using the waterways in the estuaries.

The results of the sensitivity studies help to identify vulnerabilities of e. g. shore protection in each estuary due to climate change. Several adaptation measures are tested in a second sensitivity study. The advantages and disadvantages can be investigated. The results give a chance to develop an adaptation route (Lowe et al., 2009) for the waterways in the estuaries of Elbe, Jade-Weser and Ems in order to mitigate problems caused by climate change.

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