The influence of regional climate change on the local wave climate and the longshore sediment transport at the German Baltic Sea Coast

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1. Introduction

Sediment-transport processes along the coast are one of the main forces for the morphological development of the coastline. The processes are influenced by the meteorological (wind) and hydrodynamical conditions (e.g. currents, waves and water levels) at the coast and can be divided into two groups: i) long-term processes for average conditions and ii) short-term processes for extreme events.

The average wind- and wave conditions at a mean sea-level are effecting long-term morphologic changes of the coastline like e.g. coastal erosion and deposition (longshore transport). The changes may also have consequences for the maintenance of shipways within coastal areas.
On the other hand side, under storm conditions, short-term extreme water levels and waves can have significantly effects on e.g. the erosion of a sandy beach or artificial flood-protection dune (crossshore transport).

Aim of this paper is the presentation of a method to estimate possible consequences of climate change on the morphological development of sandy coasts and on the functional design of coastal protection measures. This is exemplarily done at some locations of the German Baltic Sea. Possible changes of the average wind- and wave conditions within the study area are known from previous investigations.

In this study future changes of the average wind conditions (near-surface average wind velocities and directions) on the basis of regional climate change scenarios will be discussed for selected locations along the German Baltic Sea coast.
On the basis of the changes in wind conditions, the changes of the average wave conditions (average significant wave heights and directions) are assed. Finally, possible changes of the local long-shore sediment transport capacities (both directional and net-sediment transport capacities) are estimated from changes of the local wave climate.

2. Data and Methods

The determination of the climate change signal of the sediment transport capacities bases on dynamical downscaled wind data from the regional circulation model

Table 1. Cosmo-CLM model runs (remark: 'x' denotes no experiment).

20th century observed anthropogenic forcing	21st century forced by emission scenario A1B	21st century forced by emission scenario B1	transient time series of wind parameter
C20_1	A1B_1	X	C20_1+A1B_1
C20_1	x	B1_1	C20_1+B1_1
C20_2	A1B_2	X	C20_2+A1B_2
C20_2	x	B1_2	C20_2+B1_2
C20_3	x	X	x

Figure 1. Locations of the study area at the German Baltic Sea Coast.

Cosmo-CLM (Rockel *et al.*, 2008) which has been forced by the global atmosphere-/ocean-ice-model ECHAM5/ MPI-OM.
Climate data from different Cosmo-CLM model runs are available from the CERA climate data archive (Lautenschlager *et al.*, 2009).
The climate variability of the 20^{th} century (1960-2000) is represented through 3 independent realisations (C20_1, C20_2 and C20_3) as compiled in Table 1.
For the modelling of the future climate, only the first two of the climate model runs for the 20^{th} century were continued and forced by the SRES (Nakićenović *et al.*, 2000) scenarios A1B (global economic) and B1 (global environmental), resulting in 4 independent realisations.
The realisations for the past and the future have been combined to 4 transient time series (cp. Table 1) of near surface wind conditions (10 m above surface) covering a period from 1960-2100.

For the calculation of the wave climate we are using wind-wave-correlations that have been derived from measured wind and waves for three locations at the German Baltic Sea Coast (Fröhle and Fittschen, 1999). Figure 1 shows the locations which have been used in this study: Warnemünde (cp. Figure 1 right), Travemünde (Bay of Lübeck, cp. Figure 1 bottom) and Westermarkelsdorf (Island of Fehmarn/Bay of Kiel, cp. Figure 1 top).

3. Changes of average wind conditions

For the assessment of future changes in wind, wind data for different time periods, each with durations of 30 years, from the Cosmo-CLM model were extracted at grid points close to the locations of the study area. The changes of the wind conditions were analysed by calculating the frequency of occurrence and average values for the wind velocities and directions using the future scenarios 2050 (2021-2050) and 2100 (2071-2100) and comparing them to values for the control period 1971-2000.

At all 3 locations it became clear that due to shifts of the frequency distributions the average wind velocity is going to increase in the future and that the average wind direction is changing to more westerly directions. Maximum changes of up to +4% for the average wind velocity and up to +11° for the average wind direction have been found (location Westermarkelsdorf) to the end of the 21st century compared with actual conditions (1971-2000).

4. Changes of average wave conditions

From the 4 transient time series of wind conditions (cp. Table 1) long-term time series of wave parameters (significant wave height, mean wave period and direction) are calculated. This has been done, using a hybrid approach that combines wind-wave-correlations and numerical wave simulations at each location. The time series of wave parameters where finally analysed over time periods of 30 years, comparing the average values for the scenario 2050 (2021-2050) resp. 2100 (2071-2100) to the control period 1971-2000.

The changes of the average wind conditions can be linked to changes of the average wave conditions depending on the alignment of the coast towards westerly wind directions. Regarding the wave heights it can be concluded that for locations exposed to westerly winds (e.g. locations Warnemünde and Westermarkelsdorf) the average significant wave height can increase up to +7% to the end of the 21st century compared with actual conditions. At the same time the average wave direction is changing to more westerly directions (up to 8°).

A contrary development, with a small decrease of the average wave height (-1%), was found for the location of Travemünde in the middle of the second half of the 21st century (2041-2070). In contrast to the other locations of this study, the location of Travemünde is exposed to north-easterly winds and the average wave direction changes towards more easterly directions (up to 6°).

5. Changes of Longshore sediment transport

On the basis of the long-term time series of wave parameters we used the shoreline change model GENESIS (Hansen & Kraus, 1989) to calculate long-term time series of the local longshore sediment transport capacities (both directional and net-transport). The model was set up, using the actual form of the coastline and measured sediment parameters (mean grain diameter) at the different locations.

The changes of the transport capacities where analysed within time periods of 30 years, comparing the values for the scenario 2050 (2021-2050) resp. 2100 (2071-2100) to the control period 1971-2000.

The spatial pattern of the changes of the average wave conditions can also be linked to the spatial pattern of change of the long-shore sediment transport. At locations exposed to westerly winds (e.g. locations Warnemünde and Westermarkelsdorf) both the directional sediment transport capacity in the direction where the wind is blowing to and the net-sediment transport capacity are increasing. Maximum increases of the net-sediment transport capacity up to +57% (e.g. location Westermarkelsdorf; cp. Figure 2) were found in the second half of the 21st century. At the same time, the directional sediment transport capacity where the wind is blowing from is decreasing at these locations.

Due to different changes of the average wave conditions at locations exposed to easterly winds, both the local directional and the net-sediment transport capacities are going to decrease down to 22% in the second half of the 21st century (e.g. location Travemünde; not shown here).

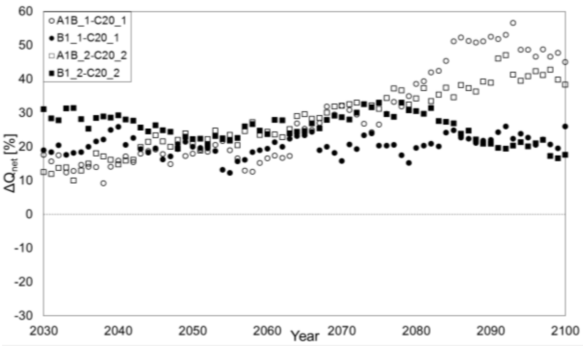

Figure 2. Change of net-transport capacity over time periods of 30 years for different transient runs of the climate change scenarios A1B and B1 compared to the control period (1971-2000); Westermarkelsdorf

6. Summary

Significant changes of regional wind conditions induced from global climate change can have significant effects for the functional and the constructional design of coastal and flood protection structures at the German Baltic Sea Coast. Comparatively small changes of the average wind conditions towards higher wind velocities (+2% to +4%) and more westerly directions can be directly connected to the changes of the average wave heights (-1% to +7%) and waves from westerly directions becoming more dominant.

Due to the changing wave climate the local longshore sediment transport characteristics are affected significantly (-22% to +57% change of net-transport capacity) what has to take into consideration for the functional design of future coastal protection measures like e.g. beach-nourishments, nearshore breakwaters or jetties.

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