

REASSESSMENT OF THE COASTAL PROTECTION DUNES AS NATURE BASED SOLUTIONS IN THE BALTIC SEA FOR CLIMATE ADAPTION

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INTRODUCTION

The German Baltic coast is highly vulnerable. Past storm surges have often led to severe erosion along the coastline, which then had to be compensated for by costly sand nourishments. For instance, in October 2023 an exceptional storm surge hit the German Baltic Sea coast and restoring the eroded beaches will cost up to ~6 million €. Past research in the state of Mecklenburg-Vorpommern (MVP, Germany) highlighted that severe storm surges can affect an area of up to 1,018 km² (STALU MM 2013). The research project “ResCAD - RESistance and Climate Adaptation of Dune systems” aims to evaluate the resilience and climate change preparedness of coastal protection dunes in MVP, which are found ~106 km along the coastline. By developing two stand-alone tools intended to be used by coastal stakeholders and authorities, the design process of dune and beach nourishment will be supported by (i) a stochastic storm surge generator (SSG), enabling to model consistent storm surge scenarios described by both seastate and extreme sea levels and (ii) a dune erosion model (DEM), which is based on combining hydro-morphologic-numerical and statistical modelling. The analyses are supported by site specific field measurements before, during and right after storm surges like UAV, stationary LiDAR, photogrammetry of damaged coastal structures and a comprehensive access of hydraulic research data.

OBJECTIVES

For more than a hundred years, coastal authorities responsible for protecting the shallow and sandy German Baltic Sea coast, rely on a nature-based protection concept, consisting of dunes covered by vegetation and locally combined with groynes. Regular dune profiles (cross-sectional) usually contain a fixed safety part of 10 m, a reserve part (volume decrease in a 200 year’s event according to an idealized cross section) and a wearing part (local volume loss per year x10 years). Because it is highly dependent on local exposition, the total cross section can differ from 14 m to 56 m (Newe 2019). They are renewed by nourishment of marine sands at latest when the wearing part is eroded (Figure 1) on the average scale of 500.000 m³ sediment for 4 million € per year.



Figure 1 - Dune and beach nourishment near Prerow 2023

In general, the verifiable reshaping is carried out from the dune to the water surface. In the absence of effective bathymetry measurement in the course of the ongoing nourishment process, the cross section under water can differ from the idealized profiles. Therefore, ResCAD aims to evaluate the influence of different cross sections under the current design concept within the dune erosion model, including the variation of the under-water profile.

The DEM is also considering the longshore transport, small scale beach evolution due to long lasting moderate hydraulic conditions and a better representation of storm surge events due to the combined hydraulic modelling of water level and sea state by the SSG. In the long term, the accelerated mean sea level rise will set the current coastal protection concept under permanent pressure and demands flexible solutions as long as the coastal areas of the german baltic sea remaining important for economic, ecological and recreational needs. By expanding the functionality of the tools in ResCAD to analyse future hydro-morphological scenarios, these flexible solutions can be evaluated.

METHODOLOGY

The ResCAD approach is divided into two parts (A&B), where subproject A focusses the hydrodynamic and statistical analyses modelling of the research area on a larger scale and B is using the hydrodynamics for hydro-morphological modelling. Figure 2 illustrates the schematic relations between working packages and models in development. Local observation data is provided by stakeholders like BSH, IMK, WSV and StALU MM, supported by own measurement campaigns. The SSG Modul I is intended to model water levels while Modul II can also simulate the sea state.

To represent events that are physically possible but have not been observed (so far), the analyzed scenarios of the numerical modelling of dune erosion in subproject B are complemented by stochastically simulated, artificial hydrographs derived from a multivariate (copula) model. The numerically generated system response in the form of volumetric dune evolution is used to build the dune erosion model using multiple regression relationships. Comparable natural data with sufficient temporal and spatial resolution are essential for the successful calibration and validation of the models. For this purpose, the study area is regularly documented by UAV flight in the form of geo-referenced 3D terrain models. The greatest uncertainty is to be expected in the coastal bathymetry, but advanced satellite technology provided by EOMAP is applied to minimize it.

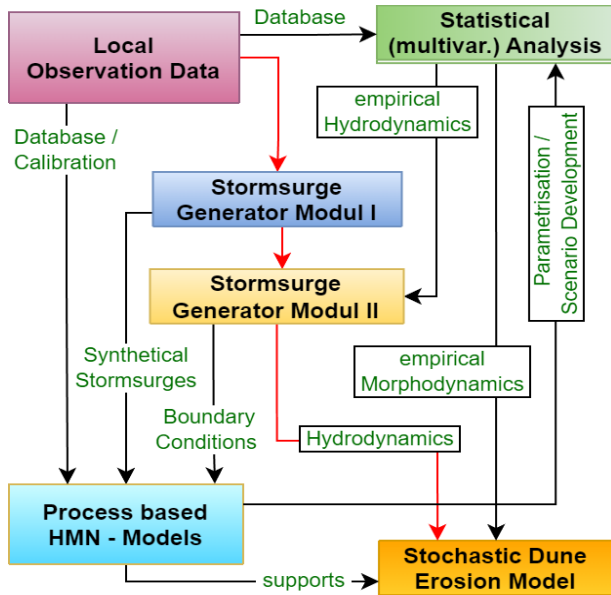


Figure 2 - Modelling approach and data flow in ResCAD

Building up the most representative model bathymetry for the hydro-morphodynamic-numerical (HMN) modelling in ResCAD part B is challenging, because surface elevation models and sea bed data of different resolutions, from different times and different quality need to be combined. Necessary for the calibration are at least two measured states of the research area with a representative event in between, a time difference not too small but also not as big as the simulation can be done with affordable computational cost. They are compared with the resulting dune profiles from the HMN-simulation. Once the best state of calibration is reached, the results are subjected to a Bias-Correction including ANN-algorithms (Artificial Neural Network).

Wind and wave impact is the reason for grain size sorting and mixing, that is why the erosion parameters could be changed. To consider these effects, regular soil-mechanical sampling is done at the foot of the dune and at the transition from the shore to the beach.

FIRST RESULTS AND NEXT STEPS

In its first year, some important milestones for fulfilling the goals of the project could be reached. The observation network is included into the modelling work flow. The Baltic Sea was set up using the modelling software MIKE 21 by DHI to provide hydraulic boundary conditions, where no observation data was available.

A publicly accessible research database for the Baltic Sea is still not available. Until then, data acquisition for research projects or infrastructural ventures will remain time consuming, what is a big challenge in the rising need for climate adaptation actions, especially for the coast. However, several institutions are working on it, each within their special subject and resources (e. g. ERA 5 weather and climate data set from Copernicus EU, Global Extreme Sea Level Analysis GESLA3 and HELCOM Bathymetric data). The results of the simulation are

processed by using a Bias correction method and then they can be provided as the first input data for the SSG and DEM. First simulations of selected events (Allerheiligenflut 2006, storm surges 2009 & 2023) could already achieve promising accuracies of modeled water levels of +/- 20 cm.

An own measuring program has started successfully in March 2023 using UAV-LiDAR & photogrammetry, GNSS-monitoring (especially for near-shore bathymetry) and simple soil sampling methods to verify second-hand data and getting aware of site-specific characteristics. Figure 3 is documenting the resulting beach profile after a storm surge in 25. February 2023. The dune shape is still untouched by the last storm surges, but a cliff of 0,5 m - 0,8 m has formed in the first third of the beach. On October 20th 2023 several sites were documented directly after the severe storm surge, including 3D-photogrammetry of coastal damages.

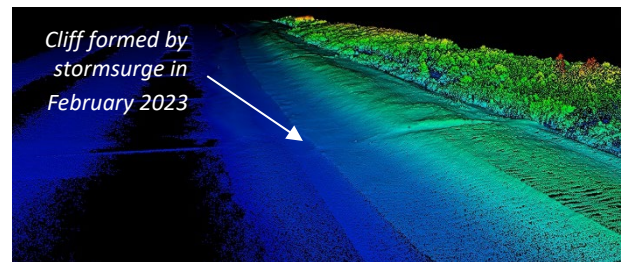


Figure 3 - Colored point cloud measured on a dune close to Ahrenshoop by UAV-LiDAR-Scanning (Fleischer 2023)

CONCLUSIONS

The ResCAD project intend to provide robust, user-friendly and practice-oriented tools, to adress the ongoing and future structural adaptation and maintenance of coastal protection dunes due to mean sea level rise. They consider non-linear processes of erosion (and perspectivevely regeneration) caused by hydrodynamic extreme events under changing bounding conditions better than previous models, based on empirical-numerical forecast of erosion and volume loss like NewDune (Newe 2019) and Sbeach (Larson & Kraus 1989). Compared to the current design concepts relying on strongly simplified and deterministic approaches, the combined implementation of sea state and stochastically simulated, time-varying hydrographs by multivariate (copula) models represents a clear step forward.

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