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Application of XBeach to model a storm response on a sandy spit at the southern Baltic[a]

by

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Abstract

The process-based XBeach model has been used to simulate changes in beach and dune morphology in terms of influence of the significant storm event on the sandy Dziwnow Spit, located in the western part of the Polish coast. The research was carried out as part of the SatBałtyk project and represents the first stage of XBeach model application to create a system for recording the selected effects and hazards caused by current and expected storm events. The significant storm event, registered in 2009, was used for model calibration. Ten cross-shore profiles were selected and compared against pre- and post-storm morphological data. Model performance was verified on the basis of BSS values for the terrestrial part of the profiles. Verification of the results was performed using two different approaches: on the basis of the highest mean BSS value for all profiles together and for one set of parameters (approach no. 1) and on the basis of the highest BSS value for each profile and most adequate sets of parameters (approach no. 2). Additionally, the observed and modelled beach and dune volume changes were calculated. The research showed that the XBeach model is well capable of simulating the dune and beach erosion caused by the storm event, but the model requires site-specific calibration. High sensitivity of the XBeach model to the facua parameter was determined; the parameter defines the wave shape and affects the sediment transport. The best fit of the profiles was obtained for BSS, ranging between 0.71 and 0.93, with the parameter *hmin* = 0.01 or 0.05, *facua* = 0.2-0.5, *wetslp* = 0.2-0.4 and *dryslp* = 1 or 1.5. The volume estimation error ranged from +0.6 $m^3 m^{-1}$ to -7.7 $m^3 m^{-1}$, which represents 2.7% to 31.6%.

Key words: beach and dune erosion, XBeach, numerical modelling, storm response, volume changes

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Introduction

The increasing number of severe storm events that cause significant changes in the coastal zone and the growing flood hazard have been recently observed. Monitoring of morphological changes is necessary for recording the problem. Morphological measurements of the coast are taken annually by Maritime Offices and changes occurring on the coast as a result of the storm activity are recorded as well. This monitoring consists in estimating the volume of dune erosion caused by storm events (Furmańczyk, Dudzińska-Nowak 2009). Furthermore, the Maritime Institute carried out a morphodynamic monitoring of the Polish coast on the basis of data collected in 2004-2006. The results were used for the evaluation and verification of the effectiveness of the coastal protection program (Dubrawski et al. 2008) and are crucial in terms of the determination of long-term predictions concerning the morphological changes. However, apart from the long-term coastal observations, coastal morphology monitoring performed immediately before and after storm events is necessary for recording the short-term changes, which could be used for modelling and predicting the effects and hazards in the coastal zone caused by storm events. The understanding of the process, its course, parameters and coastal effects induced is crucial for the integrated coastal zone management. Prediction of a coastal response to the hydrodynamic conditions is possible with numerical modelling.

A number of dune erosion numerical models have been developed so far. These include, for example, such models as EDune, (Kriebel, Dean 1985), SBeach (Larson, Kraus 1989), DUROSTA (Steetzel 1993) and XBeach (Roelvink et al. 2009). The cross-shore sediment transport models require knowledge of the offshore wave data and the water level, the nearshore bathymetry and optimization of free parameters.

The aim of this study is to verify the possible implementation of the XBeach model to predict the dune and beach erosion volume in the western coast of Poland. This task will be performed by comparing the results of the XBeach model against field observations obtained after the storm in 2009 in the Dziwnow Spit area. Good results will help to assess the capability of XBeach to estimate accurately the dune and beach erosion in order to create an operational system needed for recording the selected effects and hazards caused by current and expected storm events. This system is created as part of the SatBałtyk project (Woźniak et al. 2011) implemented in 2010-2015. The above-mentioned XBeach model is the main tool applied in the system, on the basis of which hazards occurring in the coastal zone are determined. This model was successfully calibrated in 1D flume tests (Roelvink et al. 2009; van Thiel de Vries 2009) and 1D field tests on sandy tidal coasts of Portugal (Vousdoukas et al. 2011), Italy (Harley et al. 2011), Belgium (Bolle et al. 2011) and Australia (Splinter, Palmsten 2012). The XBeach model was run for the first time on the sandy coast of the non-tidal Baltic Sea conditions under the MICORE project (Bugajny et al. 2013).

Materials and methods

Model calibration was the first stage of the project carried out for Dziwnow Spit at the southern coast of the Baltic Sea. The study area covers a 10 km long section of the dune coast separated by the Dziwna mouth in the middle. The western part of the spit is 2 km wide with a dune system reaching a height of 12 m, whereas the eastern part is much narrower, i.e. 300-500 m in its narrowest point and the dune height only locally reaches 3-4 m. The spit is the accumulation area of marine and aeolian sediments, which consists of fine and medium sand. The coast in the investigated area has an oscillatory nature (accumulative-erosive) with a dominant erosive tendency (Dudzińska-Nowak 2006). In order to protect the endangered sectors of the coast, different kinds of hydro-engineering structures, such as seawalls, various types of revetment, groynes, jetties and activities like beach nourishment and vegetation plantings were implemented (Fig. 1) (Racinowski, Seul 1999; Dudzińska-Nowak 2006; 2015). The coast is accompanied by a 30-50 m wide sandy beach with a gentle profile. The nearshore of the spit is gently sloped, with the north-western exposure. The coastal zone includes also a system of 2-3 underwater longshore bars, which has a relative height of up to 2 m (Dobracki, Zachowicz 2005). The typical cross-shore profile of the coast is shown in Figure 1.

On the basis of wave measurements taken during the period of four months (Paplińska 2001)

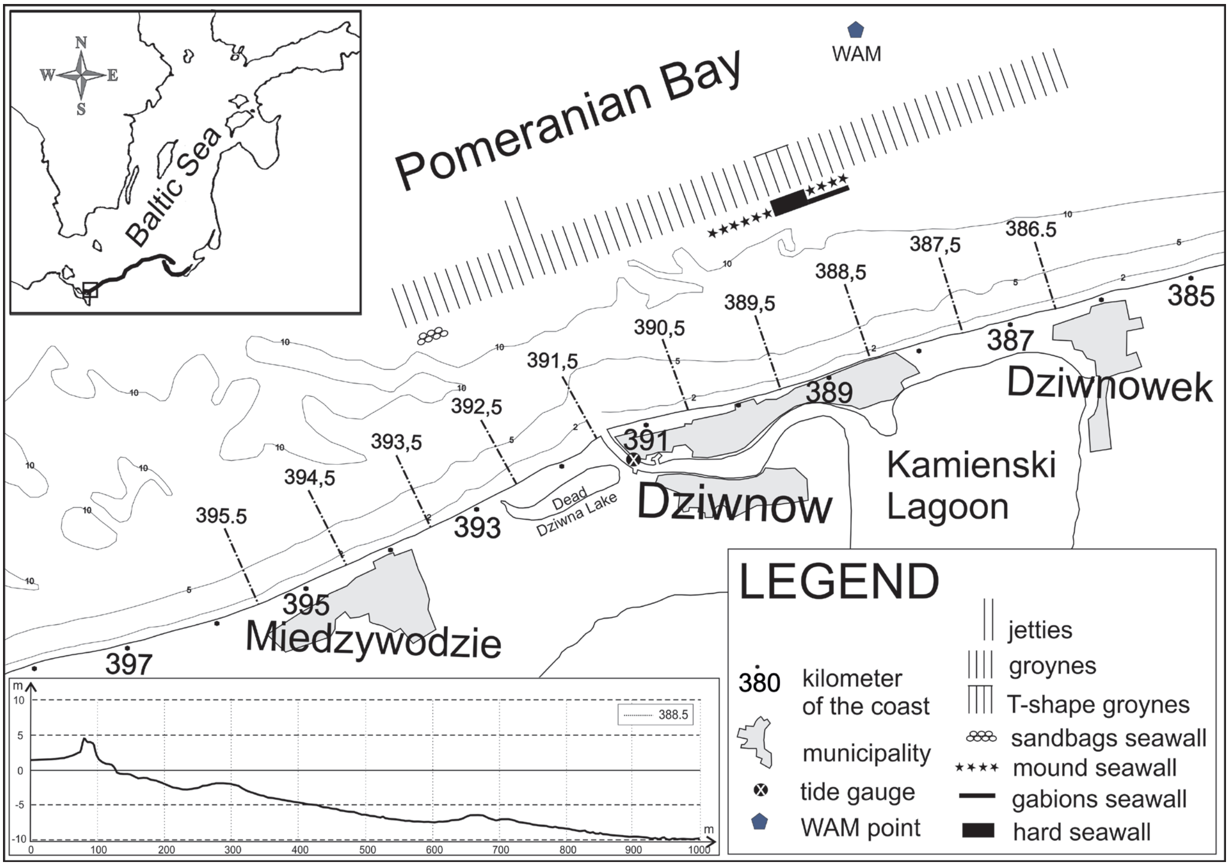

Figure 1

Dziwnow Spit area with the location of the ten cross-shore profiles used for XBeach model calibration

and a 44-year hindcast of the wave field over the Baltic performed within the HIPOCAS project (Cieślikiewicz, Paplińska-Swerpel 2008), the analysis of the regional variability in the wave climate of Pomeranian Bay was performed. Values: 6.5 m and 9.5 s are the highest for an individual wave height and a wave period, respectively, while 3.3 m is the highest significant wave height. Wave modelling analysis proves that wave fields are not uniform in the entire area, which results in large (spatial and temporal) diversification of dune erosion in this area (Furmańczyk, Dudzińska-Nowak 2009; Furmańczyk et al. 2012). Annual mean values of selected parameters gradually increased from the south-western part of Pomeranian Bay towards the north-eastern part. This directional distribution of significant wave height is controlled by the shape of the basin and the predominant western, north-western and south-western wind (Paplińska 2001).

Wave parameters are one of the components of boundary conditions for the XBeach model (eXtreme Beach behavior model), which is a 2D open-source model for waves, sediment transportation, flow and morphological changes in the coastal zone during storm events (Roelvink et al. 2009). XBeach can be run to model processes in various kinds of regimes: swash, collision, overwash and inundation (Sallenger 2000).

In order to run the model, there are other data needed in addition to wave data. These data include coastal morphology and water level oscillations. Morphological data in the form of cross-sections of the coast and hydrological data retrieved from the tide gauge located in the Dziwna mouth (Fig. 1) were received from the Maritime Office in Szczecin. Wave data applied in the XBeach model were obtained from WAM model (Wave Model) Cycle 4 (WAMDI Group 1988), which is provided by the Interdisciplinary Centre for Mathematical and Computational Modelling of Warsaw University (ICM).

For the model calibration, we applied pre-storm morphological data including profiles of topography and bathymetry registered in late August 2009 during annual coastal monitoring. The topographic part was measured using geodetic methods with ±5 cm vertical accuracy and ±10 cm horizontal accuracy, while the bathymetric part of the profile was recorded using a multi-beam echo sounder with ±8 cm vertical accuracy and ±20 cm horizontal accuracy. Post-storm morphological data comprised topographic profiles obtained from TopEye airborne laser scanning (red LiDAR) carried out on 30 November 2009, with the density of 8 pt m^{-2} and ≤0.2 m vertical and horizontal resolution. The data derived from the WAM model refer to a point located approximately 3 km north of Dziwnow at a depth of 11 m (Fig. 1) and include the significant wave height, the peak period and the mean wave direction at one hour intervals. Water-level data were obtained from the tide gauge located in the Dziwna mouth in Dziwnow (Fig. 1), collected at 4-hour intervals, interpolated to every hour.

The first stage of the research, i.e. the model calibration was carried out on the basis of a single, extreme storm event recorded on 12-16.10.2009. The storm caused significant changes in the coastal morphology. The event was characterized by the maximum significant wave height of Hs = 3.75 m and the wave peak period of 11.17 s at the maximum water level of 576 cm, which is 0.76 m above mean sea level, i.e. 500 cm (Normal Null Amsterdam). The characteristics of storm parameter variability in time are shown in Figure 2.

The calibration of 1D XBeach model "revision 1241" was performed for 10 cross-shore profiles located along the investigated area (Fig. 1). Profile labels correspond to their locations according to kilometers along the sea coast used by Maritime Offices in Poland. A variable grid of values from 20 m for the offshore and up to 3 m for the onshore was prepared for each profile in the XBeach model. The calibration focused on adjusting the morphodynamic parameters, like the critical avalanching slope under water (*wetslp*), critical avalanching slope above water (*dryslp*), threshold water for concentration and return flow (*hmin*) and the parameter for the sediment transport related to the wave shape *(facua)* (Roelvink et al. 2010). A few dozen of XBeach simulations were run with different sets of the aforementioned parameters and the model performance was verified upon the Brier Skill Score (BSS), which correlates the modelled post-storm profile with the surveyed pre-storm and post-storm profile. Such an approach is commonly used to evaluate the calibration of morphodynamic

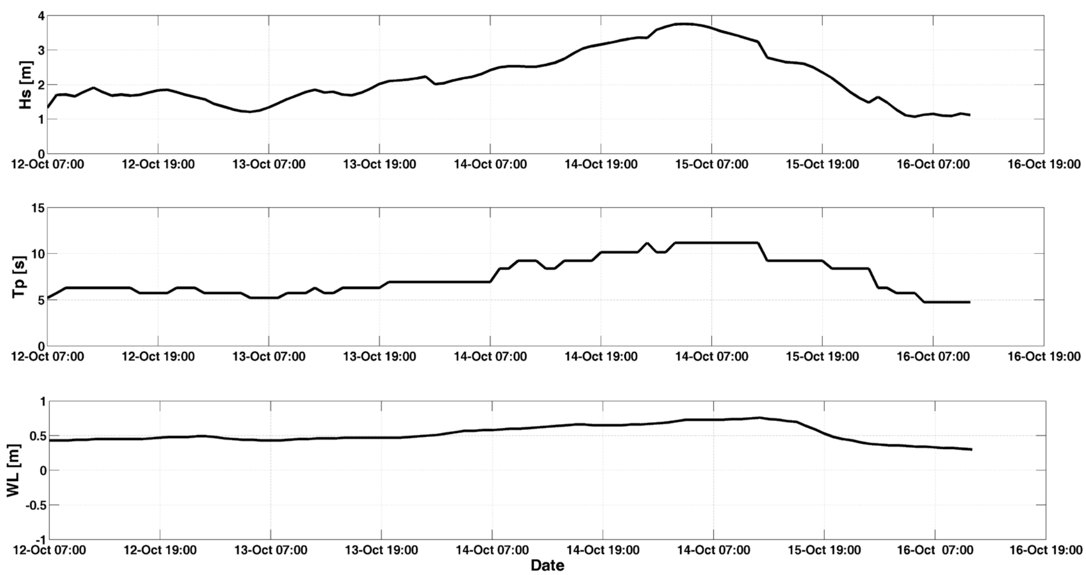

Figure 2

Time-series of storm parameters (significant wave height – Hs, peak period – Tp and water level – WL) variability used in XBeach simulations models. Interpretation of BSS values was described by van Rijn et al. (2003), and identifies the *bad* model performance when BSS < 0, *poor* for BSS = 0-0.3, *reasonable/fair* for BSS = 0.3-0.6, *good* for BSS = 0.6-0.8 and *excellent* when BSS = 0.8-1. BSS values were calculated only for the terrestrial part of the profile: the beach and the dune area. This approach was applied because there were no post-storm data available for the nearshore. The best BSS results obtained for both approaches are listed in Table 1. However, the best BSSs for approach no. 2, which means the best BSSs with different sets of XBeach parameters for each profile, are shown in Table 2 and in Figure 3.

Results and discussion

Verification of the modelling results was performed using two different approaches: on the basis of the highest mean BSS value for all profiles together for one set of parameters (approach no. 1) and on the basis of the highest BSS value for each profile and most adequate sets of parameters (approach no. 2).

On the basis of selected parameters, as the next stage of the research, the analysis of morphological changes of the beach and dune was performed. The volume changes in the modelled dune and beach were obtained as a result of subtraction of the measured and modelled profiles with spatial resolution of 3 m. The results for dune and beach volume changes using the aforementioned sets of parameters are shown in Table 3. Values in parentheses represent the volume change error in percentage (%), which is calculated as a ratio of a difference in volume changes between observed and modelled changes to observed volume changes in the profile.

Brier Skill Score approach no. 1

Testing of the sensitivity of XBeach model free parameters, the same for all the profiles, was performed using the best-fit values and the calculation of BSS. Table 1 includes results obtained for 9 best sets of parameters (simulation 14, 28, 29, 30, 31, 32, 33, 35 and 36). Two simulations, no. 30 and 35, of the following parameter values *wetslp* = 0.3, *dryslp* = 1.5 or 1 (respectively), *hmin* = 0.05 and *facua* = 0.3 yielded the highest mean BSS value for all the profiles at once and amounted to 0.7 (row mean). BSS values for particular profiles of this simulation ranked as *good* (6 profiles – 394.5, 393.5, 390.5, 389.5, 388.5, 387.5). Two profiles had *excellent* (391.5, 386.5) and another two – *reasonable* fit (395.5, 392.5). It can be observed that spatial distribution of BSS values of particular profiles within this simulation shows a diversity in terms of BSS values. The eastern part of the investigated area is characterized by a stable and high BSS value (0.68-0.9), while in the western part, the BSS value is more varied and ranged between 0.35 and 0.93.

Table 1

Brier Skill Scores (BSS) for the best nine simulations for each profile. Also the mean and standard deviation values for each simulation are shown.

Profiles	Simulations								
	14	28	29	30	31	32	33	35	36
395.5	-1.4	-0.9	-0.8	0.35	0.22	0.29	0.78	0.35	**0.82**
394.5	0.4	**0.85**	**0.85**	0.68	0.61	0.61	0.52	0.68	0.33
393.5	-0.02	0.48	0.5	0.69	**0.81**	0.8	0.51	0.69	0.25
392.5	**0.85**	0.83	0.83	0.56	0.3	0.3	0.34	0.56	0.15
391.5	0.26	0.77	0.79	**0.93**	**0.93**	0.92	0.66	**0.93**	0.29
390.5	0.55	0.51	0.56	**0.71**	0.64	0.68	0.59	**0.71**	0.39
389.5	0.83	**0.86**	**0.86**	0.68	0.61	0.6	0.5	0.68	0.31
388.5	-0.75	-0.06	-0.03	0.69	0.71	0.73	**0.79**	0.69	0.53
387.5	-0.49	0.15	0.17	0.77	0.61	0.62	**0.78**	0.77	0.6
386.5	0.65	0.82	0.83	**0.9**	0.88	0.88	0.7	**0.9**	0.42
mean	0.09	0.43	0.46	0.7	0.63	0.64	0.62	0.7	0.41
st.dev	0.75	0.57	0.54	0.16	0.23	0.21	0.15	0.16	0.19

Brier Skill Score approach no. 2

The results of approach no. 2, which examined the highest BSS value obtained with different sets of XBeach parameters for each profile, are also shown in Table 1 in bold font. Three profiles have *good* fit (390.5, 388.5, 387.5) and the remaining seven profiles – *excellent* fit. As it follows from Table 1, the highest BSS values for the profiles can be obtained as a result of XBeach simulations with various sets of parameters, which means that approach no. 2 is more suitable. It is also possible to obtain equally good results (BSS values) for the profiles when applying different sets of XBeach parameters (i.e. for more than one simulation). Five profiles (395.5, 393.5, 392.5, 388.5 and 387.5) have the highest BSS value only in one simulation, while the other five profiles (394.5, 391.5, 390.5, 389.5 and 386.5) yielded

Table 2

Set of parameters of the XBeach model for the best nine simulations

Parameters	Profiles															
	395.5	394.5		393.5	392.5	391.5				390.5		389.5		388.5	387.5	386.5
	Simulations															
	36	28	29	31	14	30	31	32	35	30	35	28	29	33	33	30
hmin	0.05	0.01	0.05	0.01	0.05	0.05	0.01	0.05	0.05	0.05	0.05	0.01	0.05	0.05	0.05	0.05
facua	0.5	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.4	0.4	0.3
wetslp	0.3	0.3	0.3	0.4	0.2	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
dryslp	1	1	1	1	1	1.5	1	1	1	1.5	1	1	1	1	1	1.5

the same value in a few simulations (2-3).

The best simulations (presented in Table 2) were run with the following parameter values *hmin* = 0.01 or 0.05, *facua* = 0.2-0.5, *wetslp* = 0.2-0.4 and *dryslp* = 1 or 1.5. The obtained results are similar to those from the previous research on the XBeach model application to the sandy coast of the Baltic Sea, which was carried out on another cross-shore profiles described by Bugajny et al. (2013). Values of *wetslp* amounted to 0.3 or 0.4 while *dryslp* was 1 or 1.5. Values of the *facua* parameter oscillated between 0.1 and 0.5, and *hmin* was set to 0.05.

Moreover, in the research performed on the sandy coast of the Adriatic Sea in Northern Italy (Harley et al. 2011), related to XBeach model calibration for a storm event, the BSS value calculated for the terrestrial part of a profile was ca. 0.56. The storm was characterized by a significant wave height of Hs = 3.91 m and a storm surge peak of the water level of 0.92 m. The best results were obtained by increasing the *wetslp* parameter to 0.5, which is to some extent consistent with our research.

The influence of wave skewness (*facua*) on the sediment transport seems to be the most sensitive parameter for modelling the dune and beach erosion in XBeach. This parameter also proved to be important in the studies of the storm impact in 2009 at the Australian coast (Splinter, Palmsten 2012). The choice of *facua* values imposed onshore versus offshore wave-driven sediment transport. In storm situations, it is assumed that the offshore sediment transport is predominant (*facua*=0), while in calm conditions – the sediment transport is directed towards the shore (*facua*=1). By calibrating XBeach for *facua* > 0, we try to optimize a balance between the onshore and offshore sediment transport in the nearshore area during storm conditions. Besides *facua*, XBeach does not seem to be so sensitive to others parameters. However, it should be taken into consideration that the application of this model requires site-specific calibration to ensure accurate estimates of volume changes. On the other hand, we are looking for such a set of parameters that will be representative for the longest possible section of the homogeneous coast (of course one should realize that some errors are generated with such an approach).

Volume changes

All cross-shore profiles included in this study were located within a 10 km long section of the dune coast. Despite the similar, homogenous character of the coastal morphology and sediments, coast exposure and homogenous hydrological conditions during the storm, the coast response in the form of beach and dune erosion volumes significantly varied along the study area. This spatial diversification was also observed by Dudzińska-Nowak (2006) in terms of long-term (56 years) coastal changes in this area.

The observations described in this paragraph are summarized in Table 3, which consists of observed and modelled beach and dune volume changes in different profiles. Only erosion-driven changes were observed in all profiles. The general trend of volume changes is growing from west to east, but when we look into individual cross-shore profiles, we observe a high variety of these changes. The largest volume changes, over 30 $m^3 m^{-1}$ were observed at 3 profiles: easternmost profile 386.5, profile 389.5 located on the western side of a hard seawall and profile 392.5 located in the vicinity of Dead Dziwna Lake. The smallest changes in volume (below 20 $m^3 m^{-1}$) were recorded at the westernmost profile (395.5), at the profile located close to the Dziwna mouth (391.5) and at the profile located in the eastern part of the investigated area (388.5). For the remaining profiles, volume changes ranged within 20-25 $m^3 m^{-1}$.

The estimated volume changes for the default

Table 3

Summary of volume changes ($m^3 m^{-1}$) observed and modelled using default values of the investigated parameters, for the simulation with the highest mean BSS for all profiles and for the simulations with the highest BSS for each profile. Mean values are also calculated. Note, that erosion volume is represented by positive values. Parentheses represent the % volume change error. Positive values represent overestimation while negative – underestimation.

Method	Profiles										Mean
	395.5	394.5	393.5	392.5	391.5	390.5	389.5	388.5	387.5	386.5	
observed	13.0	22.5	22.6	30.5	15.4	24.4	35.7	18.4	21.4	32.9	23.7
XBeach default	53.5 (311.5)	46.5 (106.7)	59.8 (164.4)	60.2 (97.4)	48.0 (211.7)	42.2 (73.0)	71.5 (100.3)	63.8 (246.7)	75.5 (252.8)	77.1 (134.3)	59.8 (152.3)
XBeach approach no. 1	21.5 (65.4)	13.8 (-38.7)	19.6 (-13.3)	17.1 (-43.9)	12.1 (-21.4)	16.7 (-31.6)	24.1 (-32.5)	22.8 (23.9)	28.8 (34.6)	28.4 (-13.7)	20.5 (13.5)
XBeach approach no. 2	9.6 (-26.2)	23.1 (2.7)	20.0 (-11.5)	32.1 (5.2)	12.1 (-21.4)	16.7 (-31.6)	39.2 (9.8)	13.8 (-25.0)	19.4 (-9.3)	28.4 (-13.7)	21.4 (-9.7)

model values of the investigated parameters and for both BSS approaches are also presented in Table 3. For such an uncalibrated model simulation, overestimated dune and beach volume changes for all profiles were observed, resulting in volume change errors of 73-311.5%. Hence setting the default parameter values for XBeach resulted in large volume change estimates, which was also confirmed in the studies of Splinter and Palmsten (2012) carried out for the Gold Coast in Australia. This is a consequence of the fact that the default XBeach parameters were set for different hydrodynamic and morphodynamic conditions (Roelvink et al. 2009). Carrying out the calibration of the model to the conditions occurring in the Southern Baltic Sea significantly improved the results. For the simulation with the highest mean BSS value (approach no. 1), the volume change error decreased to about 13.3-65.4% over the modelled storm event with the mean error of volume changes calculated for all profiles of 13.5%. An even better result was obtained for approach no. 2, where simulations with the highest BSS value for each profile were considered. The volume change errors decreased there to about 2.7-31.6% and the mean error was less than half and amounted to 9.7%. XBeach underestimated the erosion volumes and the errors of these changes were in the range of 9.3-31.6% for most of the profiles (395.5, 393.5, 391.5, 390.5, 388.5, 387.5, 386.5). The overestimation of volume changes applies to only three profiles (394.5, 392.5, 389.5), but the errors of changes were small, i.e. in the range of 2.7-9.8%. The mean value of volume changes calculated between the observed and modelled ones (approach no. 2 – the highest BSS value) is 2.2 $m^3 m^{-1}$, with a standard deviation of 3.3 $m^3 m^{-1}$.

The largest volume change error, amounting to 21.4% and 31.6%, and 25.0%, was observed in the breakwater area next to the Dziwna mouth (391.5, 390.5) and in the vicinity of the heavy seawall in Dziwnow (388.5), respectively. A significant underestimation of the eroded material by the XBeach model can result from the impact of hydro-engineering structures (Fig. 1), which cause an increased coastal erosion in their vicinity as evidenced by studies performed in the investigated area (Dudzińska-Nowak 2006; 2015). Large underestimation, amounting to 26.2%, was also recorded for the westernmost profile (395.5). This may be an effect of greater inclination of the profile in comparison with the other ones (Fig. 3), which results from a different nearshore lithology that contains outcrops of glacial tills.

The obtained results of volume change errors are comparable with values obtained for the Gold Coast in Australia (Splinter, Palmsten 2012). In these studies, the volume changes calculated for each of the five profiles were examined, but only for the beach and dune area above z=0 m AHD (Australian Height Datum). Due to a different nature of the investigated coast and the hydrodynamic conditions, the observed changes in the coast volume diverged by an order of magnitude, however, the percentage contribution error in volume changes is comparable. The observed eroded volumes were 66-114 $m^3 m^{-1}$. Results of the uncalibrated XBeach model volume changes varied in the range of 250-386 $m^3 m^{-1}$, which resulted in the volume change errors of 182-

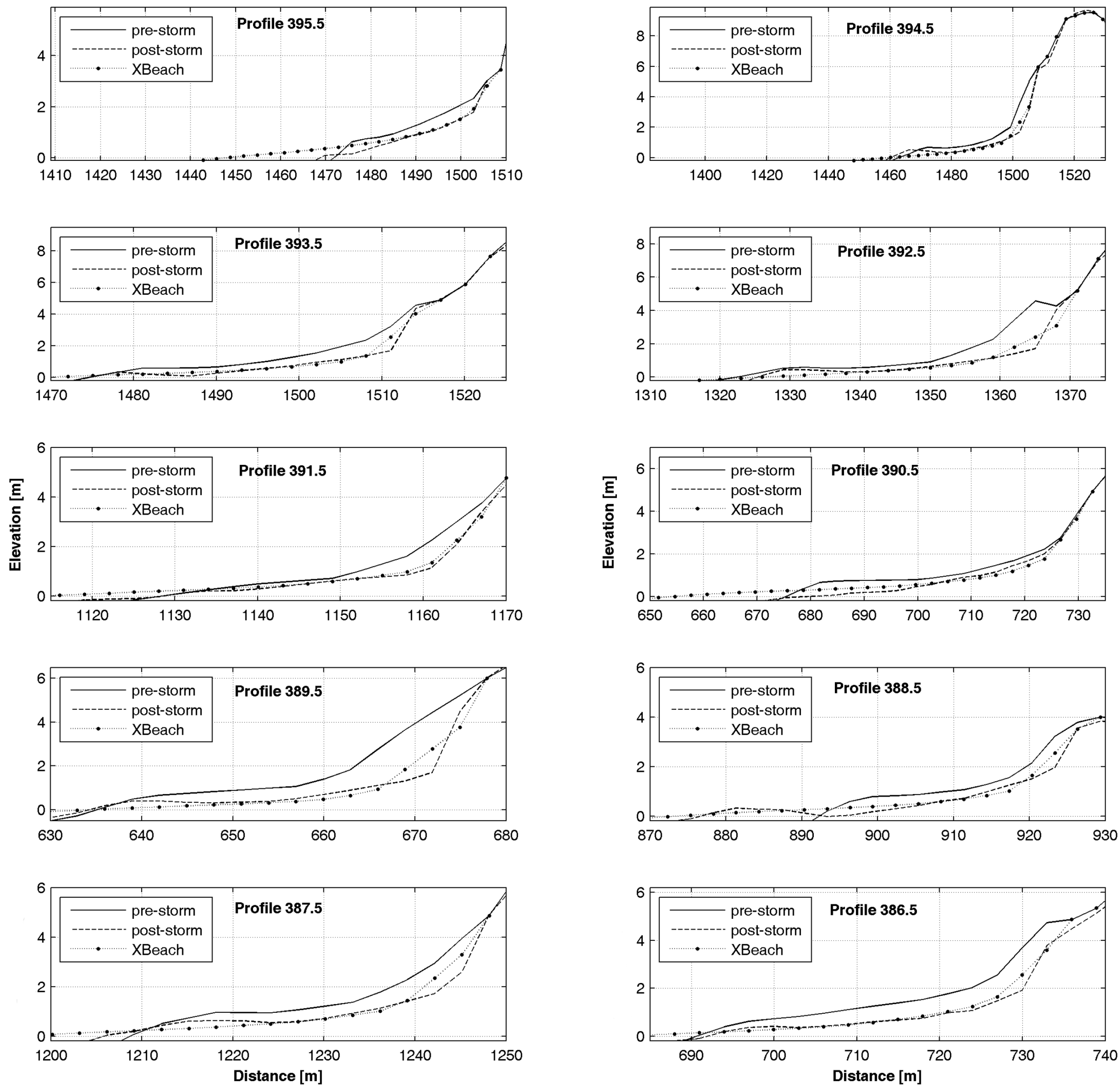

Figure 3

Comparison of 1D XBeach model results (the dashed line with points as markers) and the measured pre-storm and post-storm profiles (solid and dashed lines, respectively)

485%, and 73-311.5% in our research. After the model calibration for the specific conditions of the Australian coast, results of the XBeach model in the form of eroded volumes were more similar to the observed ones and ranged from 77 to 87 $m^3 m^{-1}$, what decreased the volume change errors to 11-30%. For the western Polish coast and for approach no. 2, the calibrated XBeach model produced the volume change errors ranging from 2.7 to 31.6%.

The simulation results for all 10 profiles (approach no. 2 with the highest BSS value for each profile) are demonstrated in Figure 3. It can be noticed that XBeach was modelling well, both dune and beach erosion in each profile, which was proven by high BSS values and estimation of erosion volumes, and was described above.

The observed morphological changes in relation to the storm impact scale, described by Sallenger

2000, belong to the collision regime where total water levels exceed the dune toe and dune erosion occurs. The greatest discrepancies are visible in the upper beach and at the dune base point (Fig. 3). They indicate a slight underestimation of the dune base retreat by the model in relation to the observed data. Moreover, the discrepancies between the modelled and post-storm data are apparent in the lower part of the beach, where an already restored beach berm is evident on most of the recorded post-storm profiles. This is caused by the fact that recording of beach and dune topography took place over a month after the storm event, when the beach restoration had occurred. Moreover, the process of beach berm formation is not included in the model (Roelvink et al. 2010). This was also confirmed in the studies performed on the gravel coast by Ruiz de Alegria-Arzaburu et al. (2011). Therefore, it is highly recommended to measure the coast topography right after the storm when the beach berm is not yet recreated. The other possibility consists in dividing the hydrodynamic conditions into two phases: storm rise (surge) and storm fall, which should be followed by setting different values of the *facua* parameter for both phases. Such an approach was described in Pender et al. (2013). Although it was applied for a medium timescale of morphological changes and the model reproduced well the beach behavior under the storm erosion and post-storm recovery conditions, it may be worth trying to apply this method in modeling of morphological changes of the coast in the shorter time scale.

Summary and conclusion

The objective of the performed studies was to verify the possibility of implementing the XBeach model to predict the dune and beach erosion volume in the western coast of Poland. The obtained good results confirm the possibility of using the XBeach for accurate evaluation of the dune and beach erosion in order to create an operational system under the SatBałtyk project. The XBeach model was calibrated on 10 cross-shore profiles located along the whole Dziwnow Spit area in order to record the selected effects and hazards caused by current and expected storm events.

The fit of the model results and measured post-storm data was set on the basis of BSS, and calculated for the terrestrial part of the profiles. The calibration was carried out for one significant storm event (12-16 October 2009), which caused extreme beach and dune erosion. Two approaches were performed. Approach no. 1 included the selection of the set of parameters, which resulted in the highest mean BSS values for all profiles. The mean BSS value amounted to 0.7 for the best simulation (no. 30 and 35) with the following parameter values *wetslp* = 0.3, *dryslp* = 1.5 or 1 (respectively), *hmin* = 0.05 and *facua* = 0.3. Approach no. 2 consists in the selection of the best set of parameters individually for each profile, in order to obtain the best possible BSS value. The comparison of pre-storm, post-storm and modelled data for particular profiles yielded very high BSS values, i.e. between 0.71 and 0.93, which resulted in a *good* and *excellent* fit. The best model performance was obtained with the following parameters' values: *hmin* = 0.01 or 0.05, *facua* = 0.2-0.5, *wetslp* = 0.2-0.4 and *dryslp* = 1 or 1.5.

As a result of the storm event, all profiles suffered the loss of material in both the beach and the dune. The observed volume changes in the beach and the dune were varied along the investigated area and ranged within 13-35.7 $m^3 m^{-1}$. For the simulation with the highest mean BSS value (approach no. 1), the volume change error was about 13.3-65.4% over the modelled storm event. Better results were obtained for approach no. 2. The analysis of comparison between the observed and modelled volume changes performed for all profiles showed a slight underestimation of the erosion volume in the beach and dune, which resulted in volume change errors of 2.7-31.6%, with a mean erosion error of 9.7%.

The highest volume change error (underestimation of 21.4-31.6%) was observed for profiles located near the hydro-engineering structures, breakwaters (391.5, 390.5) and a heavy seawall (388.5), which cause an increased erosion in their vicinity. Furthermore, the lithology also affects the underestimation of the volume change. The obtained results are similar to those obtained by Splinter and Palmsten (2012).

The research showed that the XBeach model is capable of simulating the dune and beach erosion caused by the storm event, but it requires site-specific calibration. The model calibration for the Southern Baltic conditions significantly improved the results. Once the calibration is done for local conditions, it will be possible to use the XBeach model to predict the volume of changes in the coast within the system for recording the selected effects and hazards caused by current and expected storm events under the SatBałtyk project.

As evidenced by the analysis, it is possible to obtain equally good results (BSS values) for the same profile when various sets of parameters are applied. However, this requires further investigation and continuation of the work.

High sensitivity of the XBeach model to the *facua* parameter was proven on the basis of the obtained results. In order to recreate a better post-storm profile in the future, the storm may be divided into two phases (surge and fall) with proper values selected for the above parameter.

Further calibration of the XBeach model in 1D, which would include analysis of the nearshore area, is still needed to consider the development of the beach berm. Application of the model in 2D, which takes into consideration different types of hydro-engineering structures located along the study area, is also under development.

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