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Impacts of Human Activities on Dynamic Coastal Processes

(With CD-ROM)

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Keywords: dune erosion; morphodynamics; modeling; coastal process measurements; XBeach; MICORE

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MICORE: DUNE EROSION AND OVERWASH MODEL VALIDATION WITH DATA FROM NINE EUROPEAN FIELD SITES

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Abstract

In this paper we present the first results of beach profile hindcasting with XBeach using recently measured coastal data acquired under storm conditions at eight European sites, including a comparison to model results obtained with off-the-shelf models. The results show consistently that the XBeach has skill in predicting the coastal profile, albeit that in most cases the erosion around the mean water line is overpredicted and the depositions at the lower beach face are overpredicted. The causes for this model effect are under active investigation but not resolved yet. Likely candidates are the modeling of onshore (asymmetry) transports which reduces the offshore transports due to undertow (currents) or the modeling of sediment motion in the swash zone.

Key words: dune erosion, morphodynamics, modeling, coastal process measurements, XBeach, MICORE.

1. Introduction

The European funded project MICORE - Morphological Impacts and COastal Risks induced by Extreme storm events – has as the main objective to develop and demonstrate on-line tools for reliable predictions of the morphological impact of marine storm events in support of civil protection mitigation strategies. Severe storms have historically affected European coastlines and the impact of each storm has been evaluated in different ways in different countries. The project is specifically targeted to contribute to the development of a common probabilistic mapping of the morphological impact of marine storms and to the production of early warning and information systems to support long-term disaster reduction.

The first step in the modeling effort is to compare the results of a newly-developed coastal response model called XBeach (Roelvink et al, submitted 2009) with existing off-the-shelf models, using data gathered at nine different sites in the EU. The second step is to develop a prototype operational system which will be able to predict coastal erosion a few days ahead.

2. Study sites and measured data

The first objective of modeling effort within MICORE is to use, validate and extend a open-source coastal erosion model called X-Beach (Roelvink, et al. 2009) for various European coastal sites and compare its outputs with off-the-shelf packages such as LITPROF, SMC, SBeach, IO-BAS and Durosta which are now

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locally used. The coastal sites where field data was collected are shown in Fig. 1 and include Lido di Dante-Lido di Classe, Ravenna (Italy), Praia de Faro (Portugal), Urban beaches of Cadiz Bay (Spain), Lido of Sete to Marseillan Beach (France), The Dee Estuary (United Kingdom), Egmond Beach (The Netherlands), Mariakerke Beach (Belgium), Dziwnow Spit (Poland) and Kamchia-Shkorpilovtsi Beach (Bulgaria). Each field site has a unique bathymetry/topography and/or wave/tidal climate and will contribute to and test the modeled physics under a wide range of environmental conditions.

Field data collection was initiated in the Fall of 2008. Unfortunately, no major storms have been recorded in Northern Europe but some have occurred in the Mediterranean Sea. For this reason the testing of the model at the Belgian, Dutch and British sites was done using historical storm data. The measured data includes water levels (tide and surge), wave heights (offshore and nearshore) and pre- and post-storm morphology, with which it is possible to evaluate the performance of several cross-shore profile models. This paper will present the first results of the modeling effort for eight out of the nine field sites, since the measurement campaigns have just been concluded. More definitive results will be shown in subsequent publications.

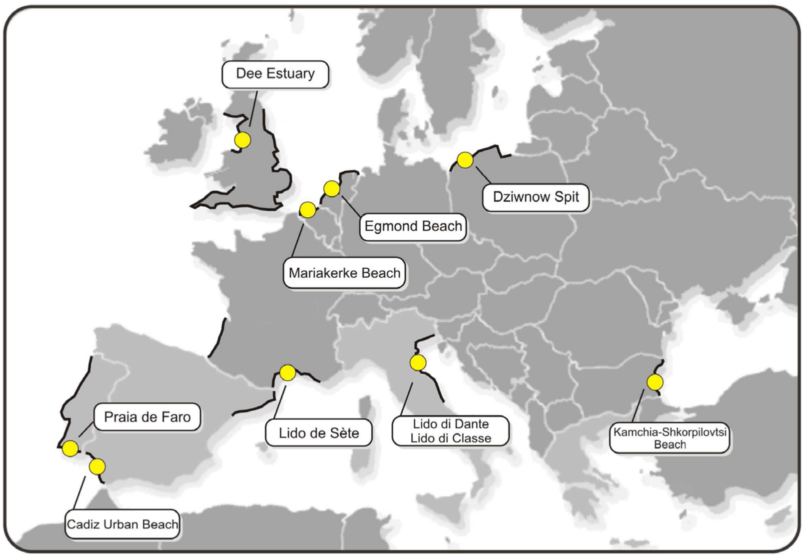

Figure 1. The MICORE study sites in the European Union.

3. Off-the-shelf models

The coastal response is evaluated by a number of existing 1-D coastal profile models. These models include LITPROF (Broker et al, 1991; Elfrink et al., 2000; DHI, 2009), SMC (U. Cantabria, 2009), SBeach (Larson and Kraus, 1989; Larson et al., 1990; Larson et al., 2004), the IO-BAS model (Trifonova, 2007) and Durosta (Steetzel, 1993). These models are limited by the inherent assumption of longshore uniformity in forcing and bed profile. Longshore dynamics caused by changes in dune height, shoreline angle and wave conditions can only be parametrically incorporated in cross shore profile models. Field studies have shown that overwash is highly influenced by spatial variations in forcing and dune strength (Morton and Sallenger, 2003). Also, time-dependency of the wave forcing is only accounted for in a parametric way. It is obvious that this is important since time-varying forcing generates infragravity waves which are important in the swash zone. Therefore it would appear important for any model to incorporate longshore variation and IG wave motion in order to successfully simulate dune erosion and overwash in a broad range of cases. This is the reason why a new two-dimensional and time-dependent model, called XBeach, is an important innovation in this field of coastal research.

4. XBeach model

XBeach concurrently solves the time-dependent short wave action balance, the roller energy equations, the nonlinear shallow water equations of mass and momentum, sediment transport formulations and bed update on the scale of wave groups. We refer to Roelvink et al. (2009) for details on the model description. With respect to the wave action and roller equations, the directional distribution of the wave action density is taken into account in the model. The frequency domain is reduced to a single representative peak frequency, assuming a narrow banded incident spectrum. The wave action and roller energy are used to compute radiation stress (gradients) which are on the right-hand side of the nonlinear shallow water equations. Using these formulations it is possible to generate directionally-spread infragravity waves and time-varying currents. To include short wave-induced mass fluxes and return flows in shallow water, XBeach uses the Generalized Lagrangian Mean formulation (Andrews and McIntyre, 1978).

Sediment transport rates are calculated using an advection-diffusion equation (Galapatti and Vreugdenhil, 1985). The equilibrium concentration source-sink term is calculated using the Soulsby-Van Rijn formulation (Soulsby, 1997).

The XBeach model can be applied to areas extending several kilometers in the longshore and about a kilometer (several surfzone widths) in the cross-shore. This limited extent implies that it needs boundary conditions of tidal- and wind/pressure-driven water levels, deeper-water (outside the surfzone) wave boundary conditions and bathymetry. The wave boundary conditions can be applied as time series of the instantaneous wave height including wave grouping, or alternatively, the time-steady wave forcing can be used (which may still result in unsteady currents and surface elevation).

5. Data-model comparison at selected sites

5.1 ***Ostende, Belgium***

Because the past winter only moderate storms occurred along the Belgian coastline, it was decided to use the available data-set of the Ostende beach (adjacent to Mariakerke Beach) to test the XBeach capacities. The Ostende beach, located almost in the middle of the Belgian coast, is a dissipative beach, characterised by a low beach gradient, a surf zone with the presence of numerous spilling lines of breakers and by fine to medium sandy sediments (D_{50}=0.214 mm). The study area is densely populated with apartment buildings on the dyke and a promenade protected by a seawall without naturally-developed dunes. The coastal defense is designed for to give protection for a T100 storm event (return period of 100 years).

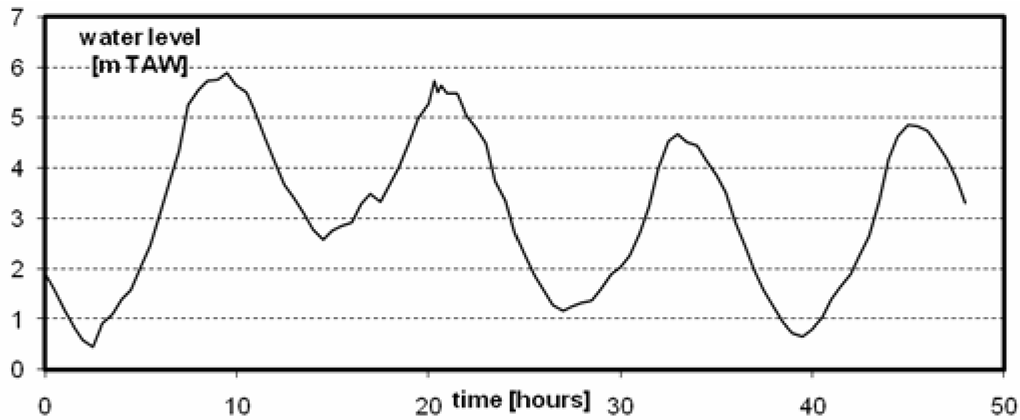

Figure 2. Measured water level at Ostende during the storm of November 2007.

Figure 2 and 3 show the measured hydrodynamic data during the storm event of 8 November 2007. The water level, measured at the tide gauge is Ostend harbour, shows a clear setup (1 – 2 m) in the first 20 hours, reaching a level of about 6 m TAW at high water. TAW is about MSL. At the same time the significant wave height at the “Oostende Noodstrand” buoy (near-shore at -6 m TAW) is 3 to 3.5 m and the peak wave period is around 8 s. The wave direction is almost perpendicular to the coast. In the models, the entire 48 hours have been simulated.

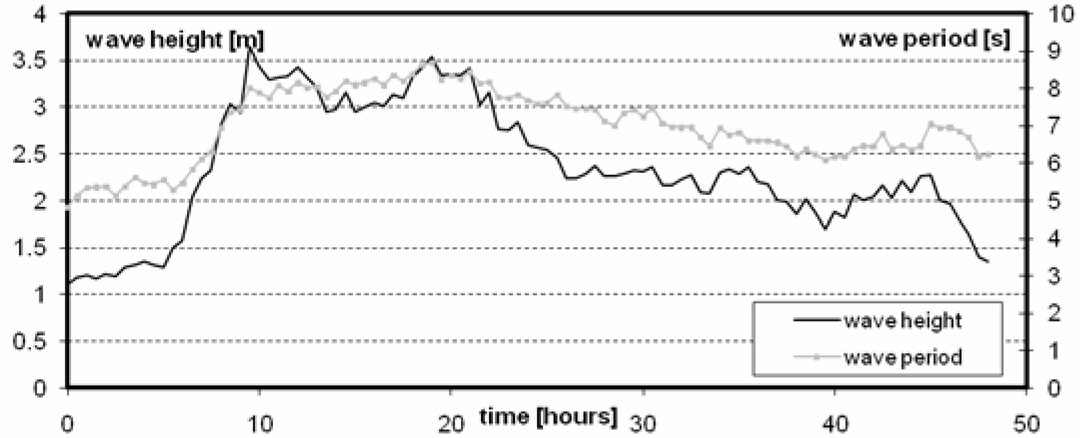

Figure 3. Measured significant wave height and peak wave period at Ostende during the storm of November 2007.

Figure 4 shows the measured beach profile before the storm (October) and after the storm (November), together with the predicted profile from Durosta (default settings) and the result from XBeach. As can be seen, both model results come quite close to the measured beach profile in November, after the storm event. XBeach predicts slightly more erosion above 4m TAW, compared to Durosta. The location of the erosion front, found with XBeach, agrees quite well with the measurements. Both XBeach and Durosta give a more uniform beach profile than the measurements.

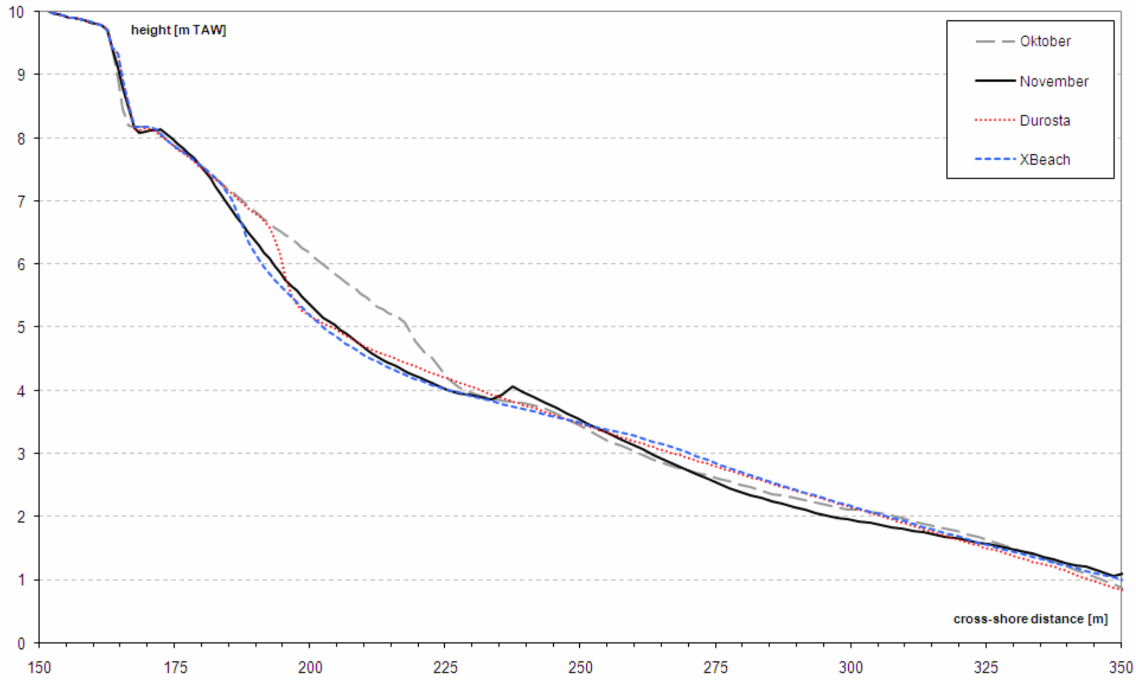

Figure 4. Ostende: Measured and computed profiles at Ostende using XBeach and Durosta.

5.2 *Delfland, The Netherlands*

For lack of a significant storm in the season 2008-2009, model-data comparison for a Dutch case was based on a historic storm. The Dutch coast was hit by a very large storm in February 1953. This infamous storm caused widespread flooding of low-lying polders in the Southwest of the Netherlands, causing nearly 2000 deaths, and was the impetus for a large infrastructural Deltaworks project to safeguard the country from flooding. The storm also caused widespread dune erosion. There are no accurately measured field data but a representative profile for the Delfland coast (South of The Hague) was tested in the Deltaflume and labeled T3 and T4 of the M1263-III (Vellinga, 1986).

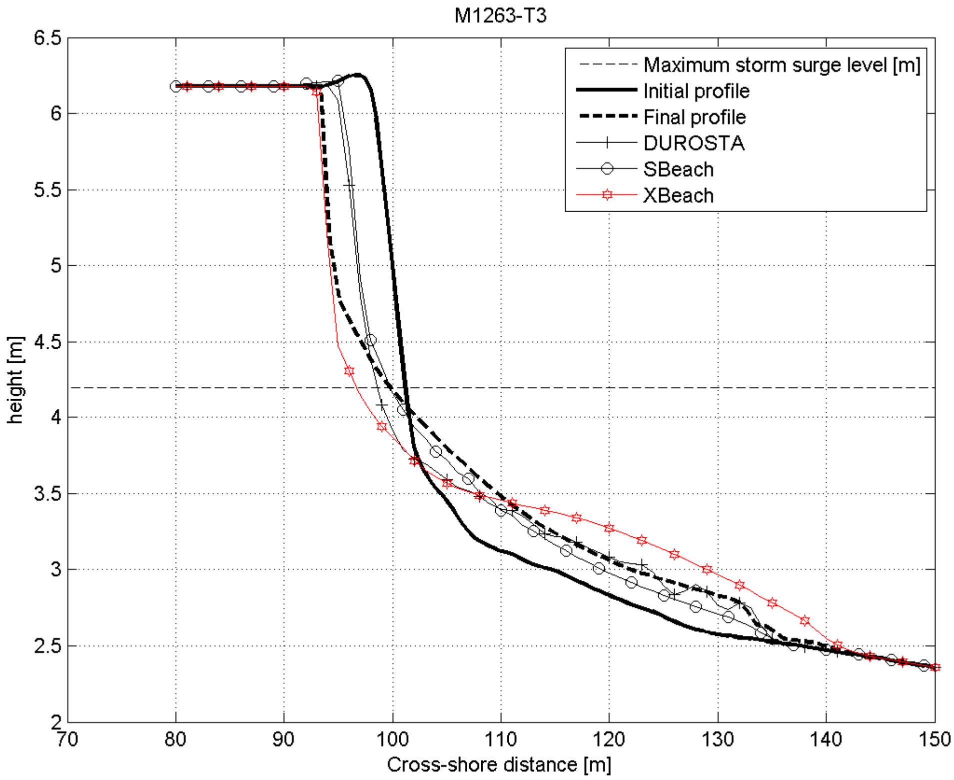

Figure 5. Deltaflume: Measured and computed profiles experiment T3.

The cases concerned a time-varying water level over several tidal cycles, including surge and time-varying wave conditions ranging from H_s = 5 to 7 m (prototype). The results (Figures 5 and 6) show that XBeach predicts the set-back line very well but overestimates the erosion around the mean water line, which consequently (due to mass conservation) translates into too much deposition offshore. The indication is that the overestimated erosion is due to a lack of onshore (asymmetry) transports when the storm abates. This is an active point of research at this moment. The same response can be viewed in other site locations as well.

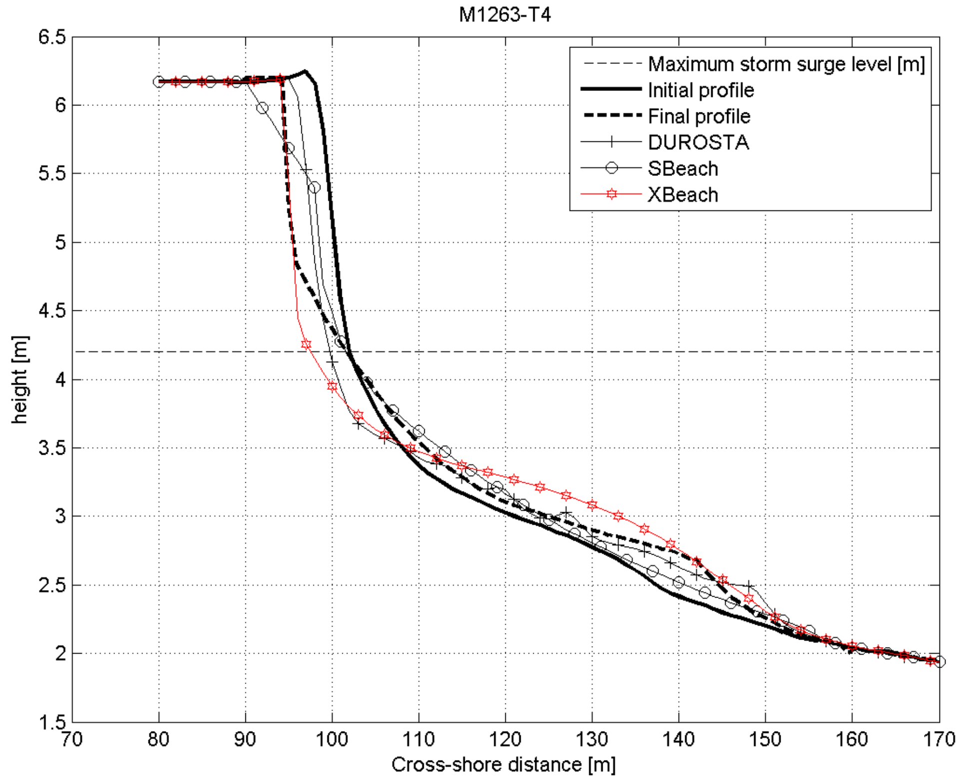

Figure 6. Deltaflume: Measured and computed profiles experiment T4.

5.3 *Praia de Faro, Portugal*

The study area is the Ancão Peninsula which is the westernmost part of the Ria Formosa barrier island system. It is a NW-SE oriented sandy barrier that is attached to the mainland by its western terminus. The Ria Formosa barrier island system is mesotidal, with a mean tidal range of about 2 m that can reach up to 3.5 m during spring tides. Wave energy is moderate with an average annual significant offshore wave height of 1.0 m and average peak period of 8.2 s (Costa et al., 2001).

The model was run for the case of Praia de Faro to simulate the most extreme storm event observed during the winter 2008-2009. For ~24 hours and during spring tide, the beach was exposed to WSW waves, with the significant wave height reaching 5 m and the peak period 8.5 s, while the return period was ~3 years (Pires, 1998). Even though the storm was not exceptional, it had some impact on Praia de Faro, with overtopping occurring along several sections, creating damage to human property and infrastructure. The model was run for five profiles distributed along the whole study site, with circa 500 m spacing between each other.

All studied profiles showed signs of berm erosion and off-shore bar formation, with the impacts of the storm becoming less prominent from the steeper NW profiles to the milder sloped ones, found on the SE boundary. In all cases the model described the general trend of beach profile response relatively well from a qualitative point of view. Because some transects had structures on the backshore, the more natural eastern profile was selected here for comparison. The results show an overestimation (Figure 7) of the offshore sediment transport, mostly by creating an erosive scarp not appearing in the measured data (and much like what has been shown above for the laboratory case). The above discrepancy can be attributed to several factors, such as onshore transport but also the longshore transport, which are often intense on these beaches (e.g. Ciavola et al., 1997), and cannot be described by a beach profile response model in 1D mode (see e.g. Roelvink and Broker, 1993).

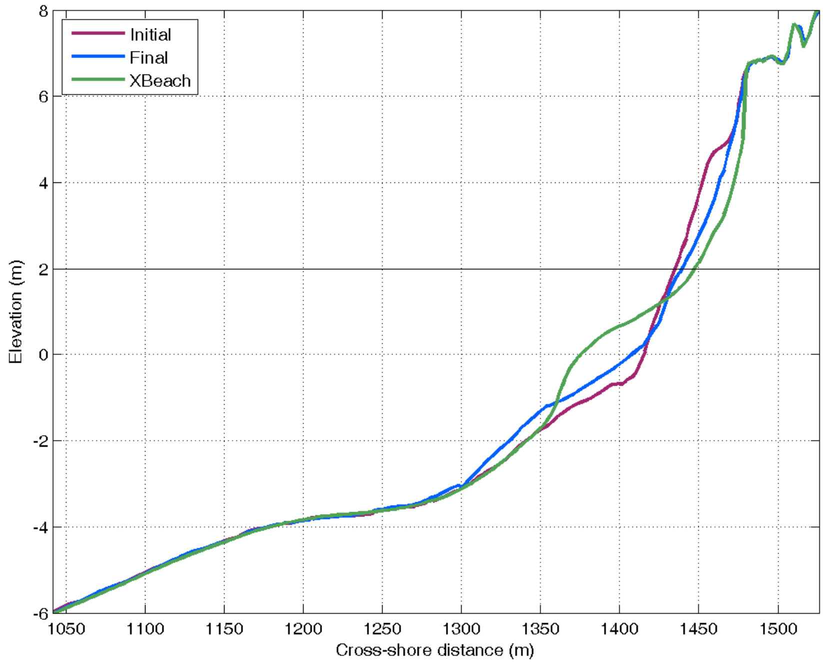

Figure 7. Praia de Faro: Initial (purple), Final (blue) measured vs. the computed profile (green).

5.4 *Cadiz Beach, Spain*

At the end of the summer period the urbanized beach of Cadiz had a typical summer profile characterized by a small berm and a beach slope of 0.026. The sedimentary material of the intertidal zone is composed by fine, well-sorted sand with mean diameter D_{50} = 223 μm and D_{90} = 330 μm. On the 30th October, the first winter storm took place. The duration of the storm was relatively small (~48hours) and had a SW direction which is the predominant storm direction in this region. This event had significant wave height (H_s) reaching 3.7 m and with associated peak periods (T_p) ranging from 7-9.5 sec for the duration of the storm. The tidal phase over the storm was from springs to neaps and with maximum tidal levels reaching 3.5 m. The effect on the beach was moderate erosion over the upper intertidal zone and particularly the berm area and deposition of this sediment on the lower intertidal zone, creating a more dissipative profile with an average slope of 0.020 (Figure 8).

The above event was modeled using the standard parameters values. A topographic-bathymetric survey carried out 2 weeks prior to the storm was used as an initial profile and a post storm profile measured directly after the storm was employed for validation purposes. For modeling purposes, the measured bathymetry to a depth of -5 m (low tide) was extended offshore up to 18m depth using a constant beach slope of 1/10 (the extension of the profile had a constant spatial resolution of 5m). A time series of wave parameters from the coastal buoy of Cadiz was used to represent the storm event. Tidal data from the port of Cadiz were used for water elevation input; these data included both the tidal signal and the atmospheric/surge component. A test run was undertaken with the average calm conditions prevailing between the pre-storm topographic survey and the start of the storm (2 weeks) in order to check the applicability of the initial profile. The changes observed in the profile were within the errors of the topographic survey; therefore, no adjustment in the profile was made.

The model (Figure 8) predicts the evolution of the beach profile during the initial stages of the storm (MODEL 10% of the total modeling time) relatively well, especially over the mid- and low intertidal area. After the peak of the storm (MODEL 50%) the computed profile is in very good agreement with the measured final profile, although it overestimates the erosion (~20 cm on the vertical) over the upper intertidal zone and it consequently deposits the sediment over the lower intertidal area. The final modeled profile follows the same trend but with small increase in the erosion (of the order of 40 cm). Overall the prediction of the high water coastline is underestimated by 4 m.

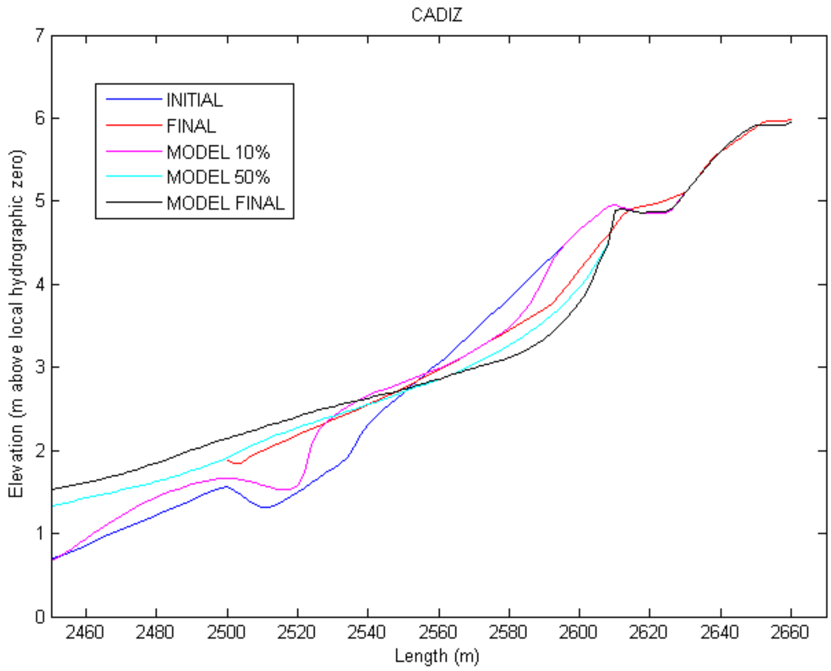

Figure 8. Cadiz: Initial (blue), Final (red) measured vs. computed profiles at 10% (magenta), 50% (cyan) and 100% of the model time. MSL is at about +2 m.

5.5 *Kamchia-Shkorpilovtsi , Bulgaria*

The Bulgarian study site "Kamchia-Shkorpilovtsi" is located in the western Black Sea and is a straight southerly-oriented coast exposed to the East. It includes the longest and largest sandy beach along the Bulgarian Black Sea coastal zone, with well-developed dunes and two river mouths of the Kamchia and Fundakliiska Rivers. The beach is formed as a result of accumulation of beach-eroded and river-eroded sediments. The main morphological feature of the study area is its rectilinear shoreline with almost parallel isobaths. The bottom slope is characterized by vaguely defined long-shore bars. It is covered by different sized sands: on the upper part of the bottom profile, up to 2.5 m depth the bottom sediments are coarse and medium. As the depth increases, the content of coarse and medium fractions decrease and at 8-10 m D_{50} is less than 0.25 mm and further the middle sands turn into fine sands and silts.

During the period 18.02.2009 - 23.02.2009 a moderate storm passed over the western Black Sea area. It is reconstructed in order to provide wave input for morphological modeling. The wave boundary conditions are obtained by means of coupling the WAM wave model, adapted for fetch-limited conditions and run for the whole Black Sea basin, with SWAN, nested to WAM in order to simulate waves in the western shelf zone were used. A point from the SWAN grid, located in front of the Bulgarian study site at 10 m depth, is chosen as the boundary off-shore point of the modeled profile. Further, two measured cross-shore profile were taken into consideration to provide morphological input for modeling. The field campaign covering the storm duration included pre-storm (17.02.2009) and post-storm (27.02.2009) measurements. The measured profile depths range from an elevation of 2 m onshore to – 4.5 m offshore and the profile length is 220 m. The initial profile was extended up to 10 m depth using available bathymetry.

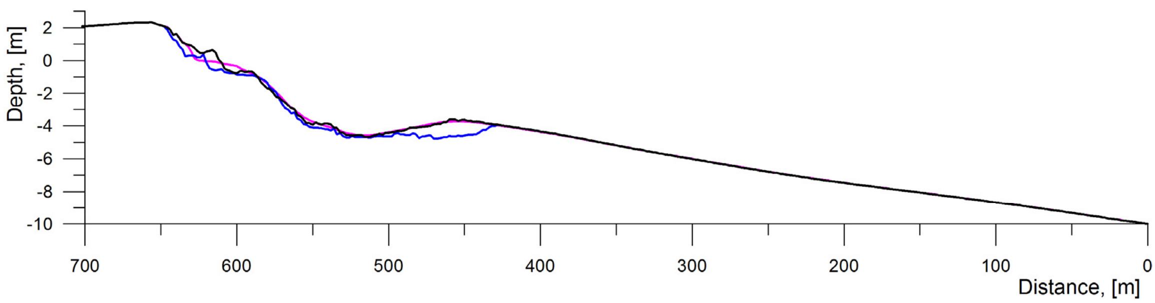

Figure 9. Kamchia-Shkorpilovtsi : Initial (black), Final (blue) measured vs. computed (purple) profiles.

The storm event lasted 136 hours and three phases can be distinguished – growth, stabilisation and decay. During the first phase, which lasted about two days, wind speed increased up to 18.3 m/s, and wave heights up to 2.48 m; periods ranged between 2.5 and 5.5 s. By the end of this phase the wind and wave direction gradually turned from South to East. The second phase with temporal extent of about one day was characterized with a slight decrease of wave height and overall stabilization of the hydrodynamic condition ($H_s \approx 2$ m and $T_p \approx 5$ s). During this phase the wind and wave direction continued turning to North-East. During the storm decay that took place during the last two and half days of the entire storm duration the wind and wave directions remained stable (North-East).

The measured pre-storm profile is characterized by two bottom morphologies, a well shaped terrace at a depth of 0.70 m and an underwater bar at a depth of 3.60 m (located at x=455 m), see Fig. 9. The average bottom slope along the whole profile is about 1.9/100. As a result of the storm action (see the blue line in Fig.9 for post-storm profile) the shoreline retreated was 9 m causing beach face erosion. The average thickness of the eroded layer is 0.40 m, while the maximum erosion of 1.20 m occurred near the shoreline. Part of the eroded material was deposited at depths stretching from depth of 1.30 m to 2.30 m, thus shifting the terrace seaward and extending it mainly shoreward due to the beach face erosion. Thereby, the slope inclination of the newly formed terrace increased up to 2.3/100 and the average thickness of the accumulated layer is 0.25 m. The largest erosion along the measured profile is observed at deeper locations (from -4.80 m to -3.95 m) at x=430 m to 495 m. The average thickness of the eroded layer is 0.60 m, while the maximum is 1.04 m.

According to the modeled results one extensive zone along the profile including both erosion and accumulation can be distinguished. In the upper part of the profile a slanting 27 m wide terrace with inclination 1.3/100 is developed. In this case the modeled shoreline retreats is 14 m, as the beach face is eroded, and the sand is redistributed down the slope forming the terrace. The average thickness of the eroded layer is 0.48 m, whereas the thickness of the deposited layer is 0.18 m.

The comparison of the modeled and measured profiles shows that the thicknesses of the eroded and accumulated layers are of the same order. However, the positions of the erosion and accumulation areas are displaced: the model predicts the newly formed terrace to be placed more shoreward and at higher elevation. The model does not predict the measured strong bar erosion (between x=430 m and 495 m) as well.

5.6 *Formby Point, NW England*

The Xbeach simulation on Formby Point in the Dee Estuary spans a period of 4.5 hours during a large historical storm surge event on 11 February 1997. The hydrodynamic conditions during this time, illustrated in Fig. 10 (a-d), were obtained using a fully-validated hindcasted run of the POLCOMS model (Holt and James, 2001). During this event, the maximum water level reached 5.71 m ODN. This combined with relatively large waves (H_s of 5 m, T_p of 7 s) from the west and resulted is erosion of the dunes. 2D plots of Xbeach output at t+1800 s, t+9000s, t+12600s and t+ 14400s are shown in Fig. 10 (e-h) respectively. These plots show the water level and long waves superimposed on the bathymetry. Inundation of a dune blowout occurs at c. t+12000 s when the waves also begin to undercut and erode the dune scarp. By t+14400s, water levels are high enough to result in some localised flooding (Fig. 10, h) and the beach profile close to the dune changes significantly (Fig. 10, i). By t+16200 s the water level drops and erosion stops. In this simulation Xbeach predicts a dune recession c. 5 m which is approximately what occurs at Formby Point (Pye, 1991).

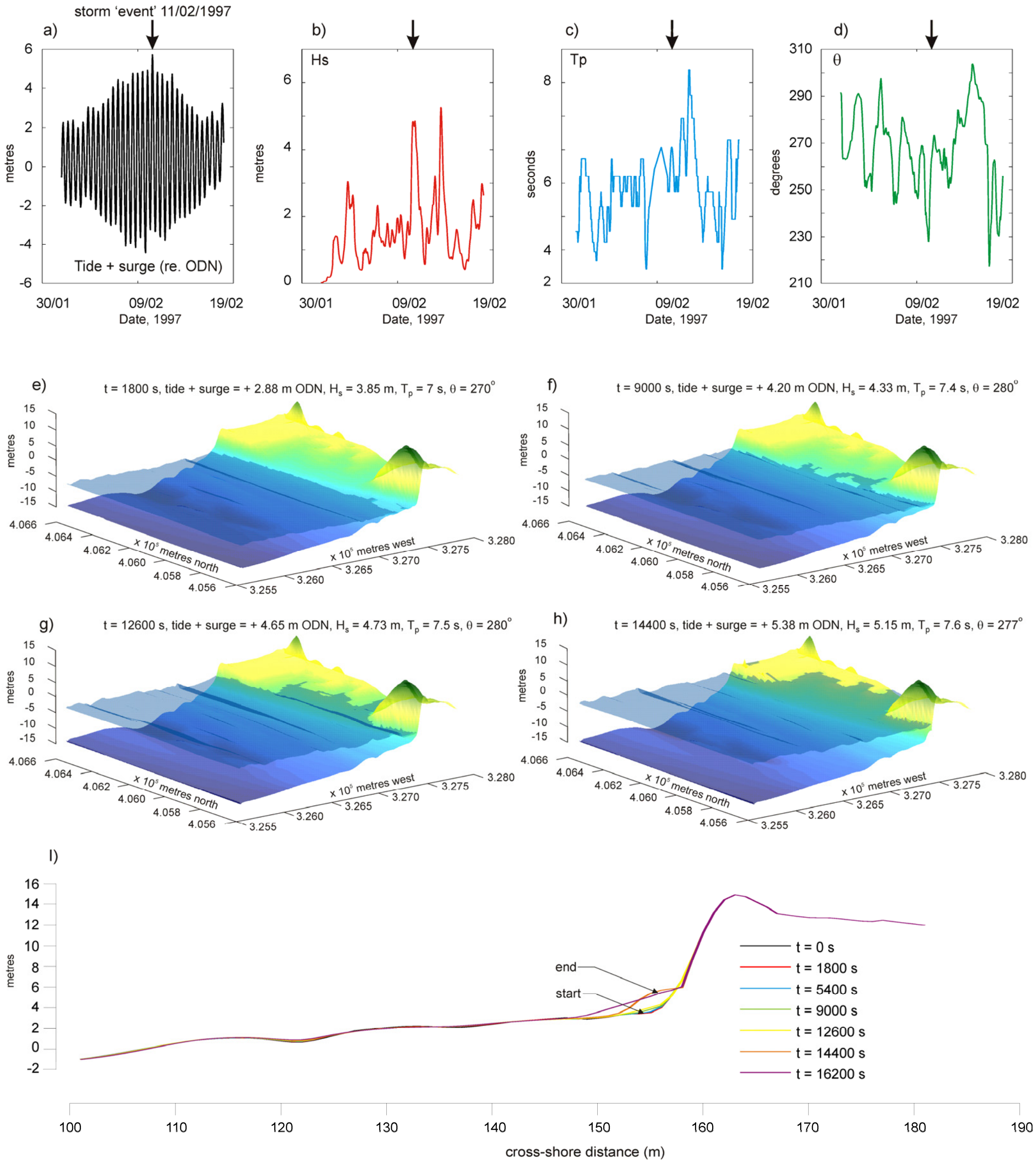

Figure 10. XBeach simulation of storm surge impact at Formby Point, 11 February, 1997

5.7 *Lido di Dante, Italy*

The Lido di Dante beach is a 3 km stretch of coast along the Adriatic coast of Italy, aligned along an almost North-South direction. It is divided in two parts: the one in front of the Lido di Dante village (almost 1 km) is protected by a breakwater and three groins, the other (almost 2 km) is completely natural with dunes and a pine forest behind them. The southern end of the beach is delimited by the mouth of the Bevano, a small stream with an irregular water discharge. The most intense storms are from NE while the most frequent ones are from SE. Although the mean wave height at the site is less than 1 m, during storms considerable offshore waves can occur, as the 1-yr return period significative wave height is 3.3 m. The area is microtidal (mean neap tidal range is 30-40 cm; mean spring tidal range is 80-90 cm) with both diurnal and semidiurnal components. When SE winds blow, significant surge levels are reached, which are able to double the maximum tidal elevation.

The early part of the winter of 2008 (1-3 December) was characterized by the joint occurrence of a small storm with an exceptional tide (one of largest recorded in the 100-yr record of the tide gauge in Venice) which found the dune ridge in a weak state (started many years before, see Balouin et al., 2006) and overtopped it at many locations where elevations of the crest were below 1.5 m above Mean Sea Level. On the other hand, some sections of dunes only showed frontal scarp erosion.

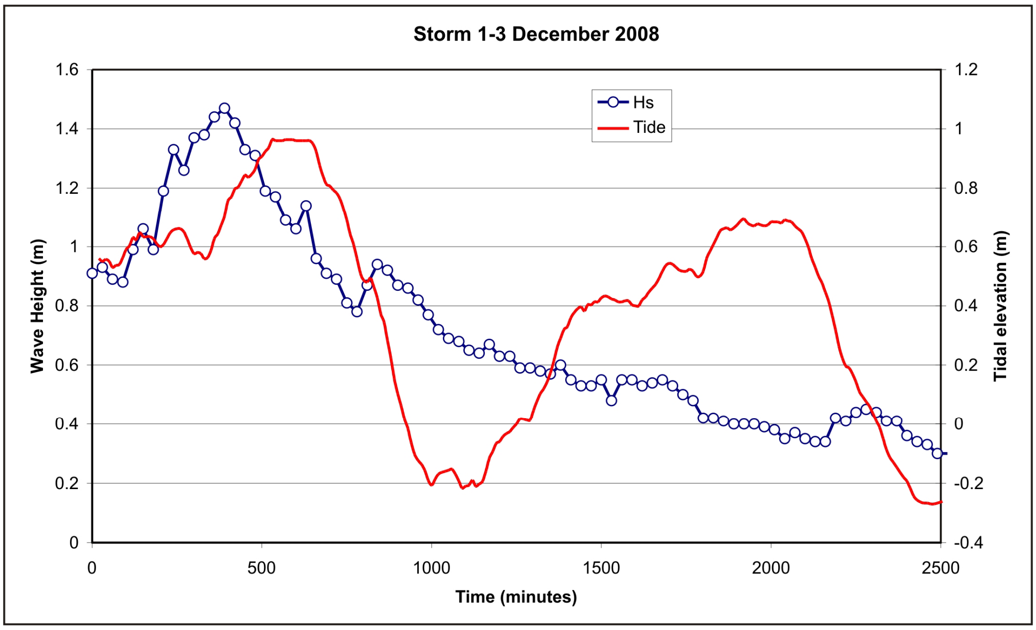

Figure 11. Offshore Significant Wave Height at Cesenatico during the event and tidal curve. Tidal elevations were measured in Ravenna and are referred to local Chart Datum.

For the present purpose we simulated only part of the storm (just over 41 hours) which included the two successive highest tides measured during the event. The time window (Figure 11) started at the rise of the wave height during the storm. Offshore wave height was provided by a nearby offshore buoy located in front of Cesenatico (20 km southwards), managed by ARPA-SIMC and located at a water depth of 10 m. Offshore wave direction during the event was quite constant, around 90°N, while a maximum Peak Wave Period of 8.3 s and a maximum Significant Wave Height of about 1.5 m were measured.

The background morphological dataset used to run the models was a survey carried out by the MICORE project in September 2008. Profiles were measured using DGPS techniques and a single beam echo sounder with a spacing of 100 m. The survey extended from the rear of the dunes to an offshore water depth between 5 and 6 m, thus close to the closure depth of the profiles. In February 2009 the dune survey was repeated to assess the changes in foredune morphology.

While SBeach was run using the surveyed profile on a single basis, XBeach was run building a computational domain with a cross-shore extension of 1050 m and a longshore one of 1345 m. The area chosen is a well-defined coastal cell that is delimited by a groyne at the northern edge and the Bevano river at the southern one. Boundary conditions were provided using the measured wave field and tidal signal. Although XBeach accepts multiple sediment grain sizes, in order to have comparability with SBeach in both models the sediment size was set to 0.295 mm.

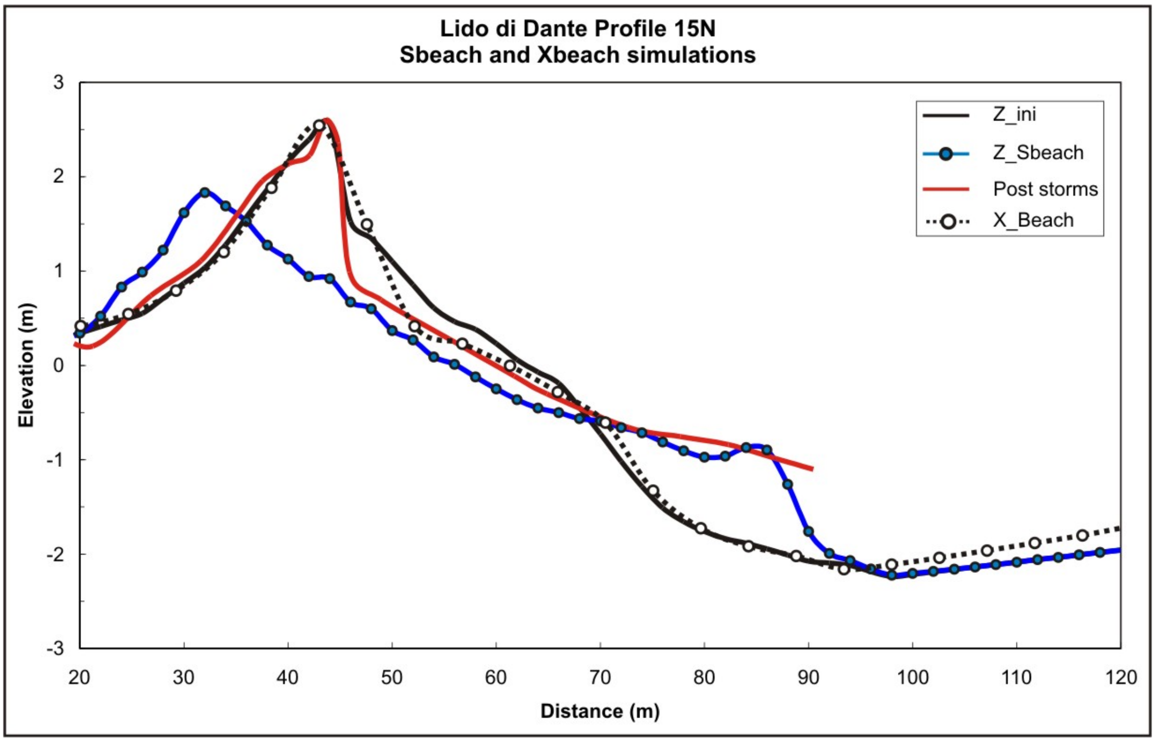

Figure 12. Results of the simulations of the evolution of beach profile using S-Beach and X-Beach. Z_ini is the morphology before the simulation, the post-storm dataset was obtained from a survey of the dunes in February 2009. Elevation is referred to MSL Genoa (Chart Datum).

In Figure 12 the comparison between simulations and surveys is presented for a profile located in the central part of the computational domain. It is evident that SBeach is not reproducing the observed profile as it predicts consistent dune erosion with a retreat of the dune crest of over 10 m. SBeach predicts that most of the eroded sediment is deposited on a shallow bar that forms between – 1 and – 2m. Surveys performed after the storm surge agree well with the presence of the bar but identify a steep dune front, but they do not show evidence of crest overtopping and erosion.

Regarding the simulations with XBeach, the model performs much better than Sbeach, predicting a landward migration of the dune foot of about 5 m, which is quite comparable with the surveys even if most of the erosion is predicted around MSL while in reality it is located between +0.5 and +1m above MSL. The model closes the balance of eroded sediment predicting deposition between -1 and – 2 m, which seems overestimated compared with the survey. However, it should be reminded that the post-storm survey only extended down to a depth of – 1 m. therefore the formation of the inner bar could be related to attachment of one of the rhythmic features that are typical of this area (Armaroli et al., 2007).

5.8 *Lido di Sete, France*

The study area is located on the Lido of Sète (France, Mediterranean coast). The Lido de Sète to Marseillan Beach is trapped between the rocky coast of the Mont Saint Clair at Sète, and the volcanic cliffs of the Cap d'Agde. Exchanges with the adjacent sandy coastlines are very low and this area can be considered as an independent coastal sedimentary cell. Coastal dynamics in this sedimentary cell is induced by two main factors: the wave climate and the wind since the Mediterranean Sea is a micro-tidal system with variation of 10 cm (neap tide) to 46 cm during the highest spring tide. The nearshore bottom in front of the Lido of Sète is characterised by the presence of a set of longshore bars, crescentic or parallel to the shoreline. The progression of the bars is closely related to a sequential dynamics, by a succession of deposits over the bar slopes.

In the winter season of 2008-2009, the largest storm ocurred from December 26th until January 1st, with significant wave heights reaching 4m offshore the Lido of Sète, coinciding with a storm surge of about 25 cm. The measured waves and tides were used as forcing on the model. However, with the present parameter settings and model formulations, the model does not reproduce the beach evolution accurately yet. Indeed, Figure 13 shows that the model damps the external bar and over-estimates the erosion of the upper part of the beach, which is deposited on the bottom part of the beach. This is quite similar to results presented above, and the causes are under investigation.

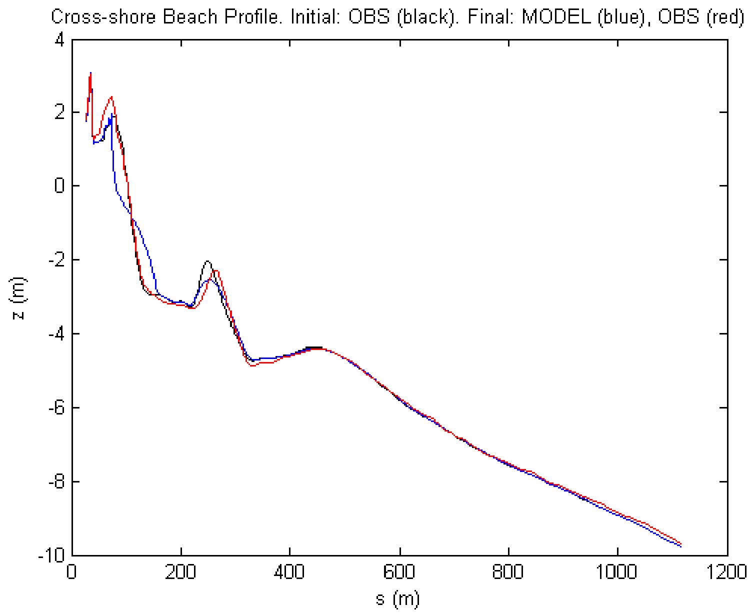

Figure 13. Lido di Sete : Initial (black), Final (red) measured vs. computed (blue) profiles.

6. Conclusions

In this paper we have demonstrated the first results of beach profile hindcasting with XBeach using recently measured coastal data acquired under storm conditions at eight European sites, including a comparison to model results obtained with off-the-shelf models. The results show consistently that the XBeach has skill in predicting the coastal profile, albeit that in most cases the erosion around the mean water line is overpredicted and the depositions at the lower beach face are overpredicted. The causes for this model effect are under active investigation but not resolved yet. Likely candidates are the modeling of onshore (asymmetry) transports which reduces the offshore transports due to undertow (currents) or the modeling of sediment motion in the swash zone.

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