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Coastal Vulnerability to Storms in the Catalan Coast

Memoria presentada por

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Chapter 4

Characterizing the response of the beach[b]

4.1 Introduction

The impact of storms in the coastal zone induce a series of processes whose most important and visible morphological effects are produced in sedimentary environments (beaches and dunes), provoking the loss of the emerged beach and inundation. Even though longshore dynamics do exist during high energetic periods, the cross-shore transport is of a greater magnitude and in view of the fact that the goal of this work is to evaluate coastal vulnerability due to storms, we have focused on the cross-shore dynamics.

Although in principle, it seems reasonable to argue that storms with larger energy content will induce larger beach erosion; this is only true to a certain extent, mainly because other parameters modulate the induced morphodynamic response.

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[b] Edited and extended version of MENDOZA, E. T. & JIMÉNEZ, J. A. (2006) Storm Induced Beach Erosion Potential on the Catalonian Coast. *Journal of Coastal Research*, SI 48, 81-88.

Some of these effects are directly related to storm characteristics such as storm duration, wave period, storm intensity, storms sequentially or water level whilst others are related to the coast subjected to the impact for instance: coastal material or morphology (Benumof *et al*., 2000; Hequétte *et al*., 2001), relative shoreline orientation (Cooper *et al*., 2004) and associated nearshore circulation (Stolarzzi *et al*., 2000), among other factors. Additionally, the incidence of high waves with elevated sea levels involve the over washing of the beach by the waves which, in low lying coasts, determines the presence of flooding of marine origin (Sallenger, 2000; Morton, 2002; Hill *et al*., 2004).

When these processes take place in developed or urbanized coasts, the change on the morphology of the beach is usually accompanied by damage in the existing infrastructure (e.g. ports and marine walkways). The problem has become more severe in the last decades, even without considering the possible climatic effects, due to the increasing demand of uses in the coastal fringe and to the more generalized coastal erosion which makes the beach to be progressively narrower (Eurosion, 2005) and, in consequence, to have less dissipation capacity to the storm energy.

Within this context, the aim of this chapter is to characterize the storms that were classified in Chapter 3 as a function of the response of the beach an thus obtaining a category in terms of the induced flood and the induced coastal erosion, which means moving from a classification based on the storm characteristics to one based on the storm consequences along the Catalan coast.

As seen in section 2.2.3 within chapter 2, the beaches along the Catalan coast have been schematized by two representative profiles -reflective and dissipative-. These beaches were used due to difference of types of beaches along the Catalan coast and the difference of the expected processes in the two profiles which present different storm response.

4.2 Flood Potential

The flood potential can be described as the temporary covering of land by water outside its normal confines (FLOODsite, 2005) which may produce harm and damage. Bearing in mind this idea, the flood potential will be characterized through the maximum elevation of water during the storm and was estimated using two parameters: (i) the run up and (ii) the storm surge. Usually in the majority of open coasts subjected to storms, the most important factor is the storm surge (Jorissen *et al*., 2000; Woth *et al*., 2006) but given the magnitude of the storm surge in the Mediterranean the run up presents at least the same magnitude and thus the same importance.

The wave run up, can be defined in general terms as the maximum vertical extent of wave up rush on a beach or structure above the still water level (SWL) (Sorensen, 1997). The runup is important to coastal planers, nearshore oceanographers and coastal engineers because these motions deliver much of the energy responsible for dune and beach erosion (Ruggiero *et al*., 2001; Sallenger, 2000). Therefore characterizing the runup is a key factor to predict the impacts on beaches, dunes and adjacent infrastructure.

Runup values depend largely on the slope, roughness, porosity of the beach, the existence of a berm, its geometry and incoming wave characteristics. So far the methods to assess run up values have been empirical approximations analyzing the data as functions of wave conditions and beach morphology (Shore Protection Manual, 1984; Holman & Sallenger, 1985; Holman, 1986; Mase, 1989; Douglass, 1992) and most recently Stockdon *et al*. (2006).

The storm surge is an increase in the water level that is pushed toward the shore by the force of the winds swirling around the storm. This advancing surge combines with the normal tides to create the storm tide, which can increase the mean water level up to 5 m or more in the case of hurricanes.

Although the NW Mediterranean is characterized by a micro tidal regime, it is important to point out that this phenomenon can cause severe flooding in low lying areas and enhances the ability of storms to affect coastal change throughout their duration which is an important factor for the potential damage of a storm (Zhang *et al*., 2001).

4.2.1 Methodology

The methodology to characterize the storm-induced beach flood potential was developed as a two-step procedure. The first step consists of estimating the potential flood induced by a given storm by simulating its effects on a beach profile using an empirical parameterization for extreme runup approach. The inundation events were characterized considering no inner boundary conditions restricting the runup such as seawalls and waterfronts and, in consequence the estimated response should be the maximum run up induced by the storm. The second step consists on characterizing the maximum storm surge registered during a storm, which was using data recorded by a tide gauge. The addition of both parameters is used to estimate the flood induced by all the storms included in the data set to obtain a 5-category induced flood potential classification.

Runup The first flood parameter was characterized estimating the induced run-up by a given storm using the Stockdon *et al*. (2006) formula. This approach was chosen because it was derived specifically for beaches and uses field data (thus avoiding scale effects) and it can be used on a wide range of beach profiles (which is the case of the Catalan coast).

Equation (4.2.1) shows the runup 2% exceedence (R_2).

$$R_2 = 1.1\left(0.35\beta_f\left(H_o L_o\right)^{1/2} + \frac{\left[H_o L_o(0.563\beta_f{}^2 + 0.004\right]^{1/2}}{2}\right) \tag{4.2.1}$$

However, under extremely dissipative conditions (ξ_0 < 0.3), estimates of runup elevations may be improved using the dissipative specific parameterization given in Equation (4.2.2)

$$R_2 = 0.043\left(H_o L_o\right)^{1/2} \tag{4.2.2}$$

Both Equations (4.2.1) and (4.2.2) were evaluated for all the storms previously identified in Table 3.3.1 and as seen on section 3.3.2. Only the E and S storms were considered given that the other directions (NW) correspond to waves propagating offshore.

Storm surge The second flood parameter was the maximum storm surge registered during a storm, which was obtained from the tide gauge located in the port of Barcelona (see Figure 2.2.1). The sea level data was registered every hour covering a time lapse of 12 years which started in August 1992 until December 2004.

Although the area has a micro tidal regime with an astronomical tide range of 25 cm, the storm surges are frequent and in consequence potentially important when characterizing storms. As seen in previous analysis (see Jiménez *et al*., 1997b) no correlation does exist between storm surge and wave height, in such a way that, severe storms can be present with or without an associated surge. Thus, for instance, E storms can be generated under two different meteorological situations (Cateura *et al*., 2004) that can produce similar wave conditions, although the associated mean water response is different.

Previous observations from a different data set on the area (Jiménez *et al*., 1997b), found no relation between sea level and storm energy content consequently, severe and extreme storms might occur with or without associated storm surge, for this reason the negative meteorological tide (depression of the mean water level) were not taken on account as for the rest of the maximum recorded storm surge levels for each identified storm were classified according to the associated storm scale. It must be emphasized that these water levels were recorded in a sheltered area (harbour) and do not include other effects visible in open coasts beaches such as wind set-up.

4.2.2 Results

A total of 77 storms (38 type I, 22 type II, 12 type III, 4 type IV and 1 type V) were used to evaluate the associated runup for each storm class in both beach types. Table 4.2.1 shows the associated runup for each storm class for the two beach types considered. Overall it can be observed that the runup class increases as the storm class is higher. Runup values associated to reflective beaches presented varied values between 1.47 m and 3.10 m, as for the dissipative beach these values ranged between 0.63 m and 1.34 m. The difference between reflective beaches and dissipative induced run up are quite evident and represent approximately 40% of higher runup values for the reflective beaches. The mean sea level variations recorded during the storms were analyzed in order to identify the existence of a behaviour pattern between the sea level (storm surge) and the energy content of the storms.

Table 4.2.1: Mean calculated R_2 and associated storm surge for each of the five class storm category.

Storm Class	Reflective Run up class		Dissipative Run up class		Storm surge	
	Mean (m)	σ (m)	Mean (m)	σ (m)	Mean ξ (m)	σ (m)
I	1.47	0.27	0.63	0.11	0.18	0.11
II	1.74	0.28	0.75	0.12	0.17	0.11
III	1.88	0.48	0.81	0.21	0.14	0.11
IV	2.35	0.10	1.01	0.04	0.27	0.11
V	3.10	0(*)	1.34	0(*)	0.53	0(*)

(*) Only one event

Figure 4.2.1 shows the relation between the sea level and the maximum Hs during each storm. When interpreting the results it must be kept in mind that these levels were registered in a protected area (inside a port) and do not include the effects that take place in open coasts like the setup associated to wind and waves.

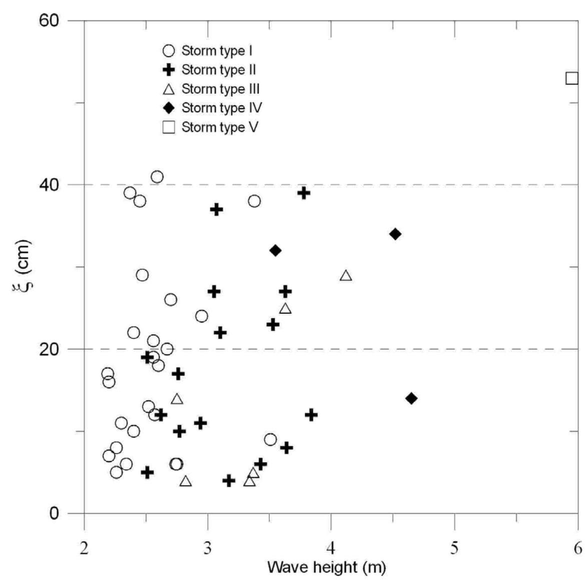

Figure 4.2.1: Registered storm surge during the storms vs. the wave height in the peak of the storm.

A three level division was made, based on the data in terms of the magnitude of the storm surge: type I ($\xi \leq 0.20$m), type II (0.20m $< \xi \leq 0.40$m), type III ($\xi \geq 0.40$m). Only the worst conditions have been considered, which in this case would be produced when the wave storms coexist with a positive storm surge. Thus the maximum registered storm surge was selected for each storm and excluding the data with negative values.

As can be seen and being consistent with previous observations from a different data set on the area (Jiménez *et al*., 1997b), a well defined relation does not exist between sea level and storm energy content consequently, severe and extreme storms might occur with or without associated storm surge. Although there is not a defined correlation, the highest registered storm surge of 0.53 m (Figure 4.2.1) was associated to the most energetic storm classified as class V in section 3.3 and presented severe inundation in low lying coasts (Ebro delta) and flooding in coastal structures along the Catalan coast (Gracia & Jiménez, 2004; Jiménez *et al*., 2002).

Estimated class-averaged run-up values for each storm class and beach type are shown in Figure 4.2.2. As expected, the higher the intensity of the storm is, the larger the run-up, with practically doubling the magnitude of the run-up from type-I storms to type-V ones for reflective beaches. The estimated run-up for reflective beaches is about two times larger than the one associated to dissipative ones.

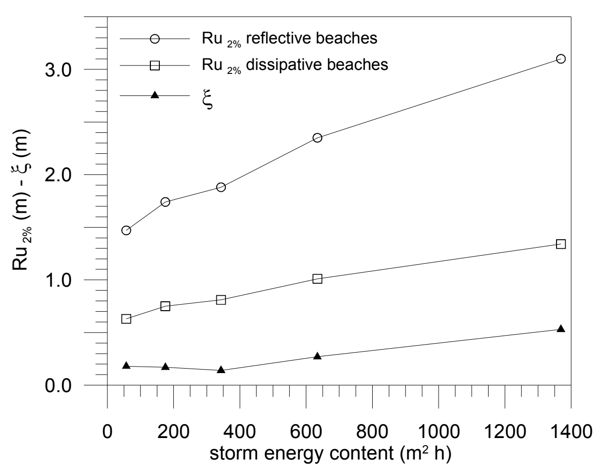

Figure 4.2.2: Class-averaged values of wave run-up in reflective and dissipative beaches and storm surge.

The first parameter to establish the storm induced flood potential can be estimated through the associated runup mean value for each storm class taking into consideration an α factor which means using one or two standard deviations depending on the adopted security range (X + 1σ or 2σ). The second parameter to be taken into consideration is the associated runup for each storm class. Table 4.2.1 shows the 5-class flood potential classification.

4.3 Erosion Potential

Coastal erosion is usually the result of a combination of factors -both natural and human induced- that operate on different scales. On the natural factors we can mention the storms, near shore currents, and relative sea level rise on the human induced erosion we can mention the urbanization of the coast which has turned coastal erosion from a natural phenomenon into a problem of growing intensity. In many coastal areas erosion problems are now increased by human activities and artificially stabilized seafronts are progressively narrowing the sedimentary coastlines. This study defines the coastal erosion term as the loss of material (sand) in the beach system after a storm event. Taking into consideration this idea the erosion potential is regarded as the loss of the beach which may produce damages to the coastal infrastructure.

The Catalan coast has experienced severe impacts from coastal erosion. While estimated spending on coastal erosion management attained an estimated, most of this money goes to dealing with the impacts of erosion in an ad-hoc manner rather than support a pro-active and preventative approach. Failure to correctly deal with erosion implies adverse impacts on biodiversity (squeeze of coastal habitats), weakening of natural -as well as artificial - defences and hence an increase of coastal flooding risk, as well as reduced economic opportunities especially in tourism.

4.3.1 Methodology

The methodology to characterize the storm-induced beach erosion potential was developed as a two-step procedure. The first step consists of estimating the potential erosion induced by a given storm by modelling its effects on a beach profile using a numerical beach profile change model. The erosion occurrence was characterized through two bulk parameters, (i) the maximum shoreline retreat and (ii) the eroded volume from the inner beach. In both cases, no inner boundary conditions restricting the beach erosion are considered such as seawalls and waterfronts and, in consequence the estimated response should be the maximum potential erosion induced by the storm. In the second step, the erosion values obtained were related to a set of dimensionless beach profile change predictors to look for a simple predictor able to properly assess the order of magnitude of the induced response. Once this parameter is selected, it is used to estimate the erosion induced by all the storms included in the data set to obtain a 5-category storm classification based on their erosion potential.

Although beach erosion can be calculated by using any of the existing beach profile models, in this work we have used the SBEACH model, which has been largely used to calculate storm-induced beach profile changes in large-scale experiments and field conditions. Full description of the model can be seen in Larson *et al*. (1989) and Wise *et al*. (1996), although the model shortcomings have been discussed by Thieler *et al*. (2000). In any case, it is recommended to use a specifically calibrated profile model for the area of study if it does exist or, in their absence, to use a robust and verified (in other sites) model as our case is. Since beach characteristics vary along the Catalonian coast and this will affect the beach response to a given storm, this subsection mainly focused on the two representative profiles that have been described in section 4.1.

Only E and S storms were used to simulate the erosion potential in the model, the complete set of storms were used except class I storms where only the most energetic were selected. The number of storms used for each storm category was: 12 weak (category I), 22 moderate (category II), 12 significant (category III), 4 severe (category IV) and the single storm classified as extreme (category V) (see Table 3.3.1).

Beach erosion was characterized using two variables predicted by the SBEACH model: (i) eroded volume and (ii) beach retreat. The eroded volume is taken as the volume of sediment eroded from the inner part of the beach by cross-shore transport during the storm (Figure 4.3.3). The beach retreat is the shoreward displacement of a given control line after the impact of the storm (Figure 4.3.3). This does not necessarily apply to the shoreline but other positions such as the berm or any elevation in the beach face could also be used. This will depend on the kind of beach profile and the type of observed changes.

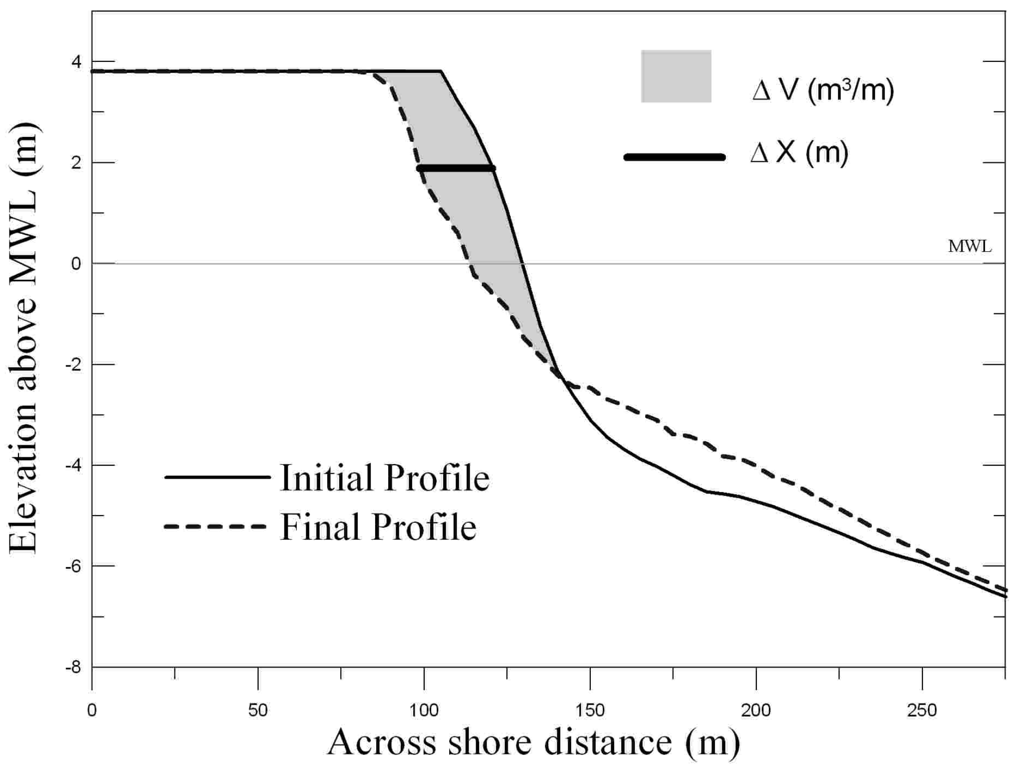

Figure 4.3.3: Main erosion variables used to characterize storm induced profile changes: eroded volume ΔV (m3/m) in the inner part of the beach and beach retreat ΔX.

Beach erosion predictors

Once the erosion potential of each storm was calculated using SBEACH, which is fed by information on storm characteristics (detailed recorded time series of wave height and period during the storm), the next step was to look for a simpler method able to explain the most significant part of the profile response by using simple information. Thus, the final goal was to have a bulk erosion predictor which if fed by representative wave characteristics of a given storm (maximum or mean significant wave height, period and duration) should be able to predict the storm induced eroded volume and beach retreat.

This was done by comparing results obtained with SBEACH with corresponding values of beach profile change predictors. In all the cases, maximum and mean significant wave heights and periods during the storms were tested.

There are numerous studies on the use of beach profile predictors to delineate cross-shore induced beach profile changes, but most of them mainly deal with the qualitative part of the problem, i.e. the type of the induced change (see Larson *et al*., 1989; Kraus *et al*., 1991). In this work we follow the previous work of Jiménez *et al*. (1993) and Jiménez *et al*. (1997a) on the use of such predictors in quantitative terms, i.e. to estimate the volume of sediment eroded from the beach. who found that, in prototype conditions, ***D*** and ***P*** parameters (see description below) were the best predictors of the type of beach profile change, although they fail to quantitatively predict the changes (in terms of sediment volumes). Thus, those authors found that to quantitatively predict beach profile changes, predictors have to include the beach slope ($tan\beta$) as an additional variable. These two observations were used to empirically derive a parameter, the ***JA***-predictor, which makes use of the ability of ***D*** to predict the type of change and that uses the beach slope to improve its quantitative capability. A brief description of the different tested predictors is presented below.

***D* predictor** This parameter was originally developed by Gourlay (1968), although it was proposed as a beach profile change predictor by Dean (1973) who proposed a cross-shore sediment transport model in the surf zone. It assumes that the offshore sediment transport takes place mainly in suspension. It is based on the idea that idea that the breaking waves put the sediment on suspension and, after arriving to its maximum height above the bottom, the net transport is determined by a relation between the time the particle takes to fall and the semi period of the incident waves. It is given by (4.3.3):

$$D_o = \frac{H_o}{w_s T} \tag{4.3.3}$$

where H_o is the offshore wave height, w_s is the fall velocity of the sediment and T is the wave period.

P predictor Although this predictor was formally proposed by Dalrymple (1992), it is equivalent to one originally proposed by Kraus *et al*. (1991) although in a bulk manner (grouping all the terms into a single number) and it is given by (4.3.4):

$$P = D_o = \frac{g{H_o}^2}{{w_s}^3 T} \tag{4.3.4}$$

The original form of the predictor was empirically derived by Kraus *et al*. (1991) by looking the best line for separating accretion and erosion profiles following the works of Dean (1973), but allowing changing the exponent in the used parameters.

JA predictor This predictor which was developed by Jiménez *et al*. (1993) and Jiménez *et al*. (1997a) includes the ***D***-parameter and the beach slope. The ***D***-parameter is included as a function of the excess of the actual ***D*** values (for a given storm) above the equilibrium condition and the result is modulated with the beach slope. It is given by (4.3.5):

$$JA = \left| D_{o,e} - D_o \right|^{0.5} m \tag{4.3.5}$$

where $\boldsymbol{D}_{o,e}$ is the ***D***-parameter at equilibrium (2.7 for deep water), $\boldsymbol{D}_o$ indicates that it is evaluated in deep water. The type of the beach profile change is given by the sign of ($\boldsymbol{D}_{o,e} - \boldsymbol{D}_o$) where positive values indicate accretion and negative ones erosion.

4.3.2 Results

Beach erosion potential values for reflective beaches

Due to the relative high berm of the profile used to characterize reflective beaches, beach retreat (ΔX) was calculated using SBEACH at beach elevation values of Z = +3.8 m (top of the berm), +2 m (middle of the beach face) and 0 m (mean water level) above the mean sea level. Figure 4.3.3 shows a typical simulated storm induced change in a beach profile.

Table 4.3.2 shows the main variables defining the induced erosion on reflective beaches (mean eroded volume and mean beach retreat) for each storm class. As expected, results clearly show that beach erosion increases as the storm class is more energetic, with mean eroded volume values (averaged over the number of storms used for each category) ranging from -17 m^3/m up to -92 m^3/m for classes I and V respectively.

The large difference between classes IV and V storms was due to the properties of the only recorded extreme event in this class. This storm as seen on section 3.3 consisted of a double peak wave event with the wave heights recorded at each peak being the two highest waves in the entire data set and, having a total duration of about 7 days (Figure 3.3.1). This resulted in an extremely high energy content event, which was reflected in significant erosion and flooding along the Spanish Mediterranean coast (Jiménez *et al*., 2002).

Table 4.3.2: Reflective beach storms induced erosion potential and beach retreat.

Storm Class	$\Delta V(m^3/m)$	$\Delta X(Z=+3.8\ m)$	$\Delta X(Z=+2.0\ m)$	$\sigma_{\Delta x}$	$\Delta X(Z=+0\ m)$
I	-17	-05.0	-03.8	2.8	-01.4
II	-22	-06.5	-05.4	2.6	-02.4
III	-36	-10.1	-08.8	1.5	-04.8
IV	-52	-11.0	-11.7	2.6	-09.0
V	-92	-24.2	-22.0	0.0	-15.3

The nature of profile changes for steep profile beaches is such that the lowest retreat values are found at the shoreline level, whereas the largest ones are generally found at the uppermost level (+3.8 m). At this level, the SBEACH model predicts that the beach will start to retreat under the action of class I storms with a mean retreat of -5 m, which progressively increases up to a maximum value of about -24 m for the class V storm. Although reflection is not included in these calculations, some authors contemplate this process to be important in controlling a substantial part of the beach response during storm conditions on reflective profiles (see Baquerizo *et al*., 1998).

Beach erosion potential values for dissipative beaches

The variables that define the induced erosion on dissipative beaches (mean eroded volume and mean beach retreat) for each storm class can be seen in Table 4.3.3. The results show that the induced erosion augments as the storm class is higher. With values that range from 7 m^3/m up to 12 m^3/m for classes I and V respectively, this difference is only of 7 m^3/m between all induced erosion classes. The results show a patent distinction in eroded volumes between the reflective and dissipative beaches. The highest eroded volume (12 m^3/m), represents just about 15% of the eroded volume predicted in the reflective beach (92 m^3/m).

The lowest change in the dissipative profile was found at the shoreline level, which is virtually zero in storms class I and II, and barely 0.5 and 0.7 m for the most energetic storms class (III, IV and V). Despite the fact that the largest retreat value was found on the upper most level (*Z* = +1 m) only for storm class V, the middle level (*Z* = +0.5 m) presented the highest changes for the rest of the storm classes, and a progressive increase, which the model calculated retreat values that range from -1.2 m for class I up to -3.4 m for class V storms. In any case, the overwash transport has to be also considered since it could be important for dissipative and flat beach profiles which for this analysis were not properly considered.

Table 4.3.3: Dissipative beach storms induced erosion potential and beach retreat.

Storm Class	$\Delta V(m^3/m)$	$\Delta X(Z{=}+1.0\ m)$	$\Delta X(Z{=}+0.5\ m)$	$\sigma_{\Delta x}$	$\Delta X(Z{=}+0\ m)$
I	-07	-0.1	-1.2	0.2	0.0
II	-08	-0.1	-1.4	0.1	-0.1
III	-09	-0.5	-1.6	0.3	-0.5
IV	-10	-1.6	-2.6	0.2	-0.5
V	-12	-4.6	-3.4	0.0	-1.0

Beach erosion potential using predictors

Both beach types and all the runs performed for the different storm classes were used in the analysis. For each model run, simulated erosion parameters (eroded volume and beach retreat) were compared to the corresponding value of the selected predictors. As a first approximation, it is assumed that a linear function will describe any relationship between them. The analysis was done by means of a linear regression by least squares in which the determination coefficient, r^2, can be interpreted as indicative of the ability of the linear model to represent the data.

Results for each of the tested predictors (using *Hs* and *Tp* maximum values) are shown in Table 4.3.4. The overall results yield linear fits with r^2 ranging between 0.42 and 0.62 for the reflective beach, while the dissipative beach yielded

Table 4.3.4: Coefficients of determination obtained in the regression analysis between SBEACH and predictors for both beach types.

Predictor	r^2 *Reflective*	r^2 *Dissipative*
D	0.46	0.14
P	0.62	0.20
JA	0.42	0.13

inferior values ranging between 0.13 and 0.20. Moreover, ***D*** and ***JA*** yield approximately the same predictability (which is expected since ***JA*** is based on the use of ***D***, whereas ***P*** showed the best fit. Figure 4.3.4 shows the linear regression concerning the storm data set using the SBEACH volumes versus the ***P*** and ***JA*** predictors involved in the analysis.

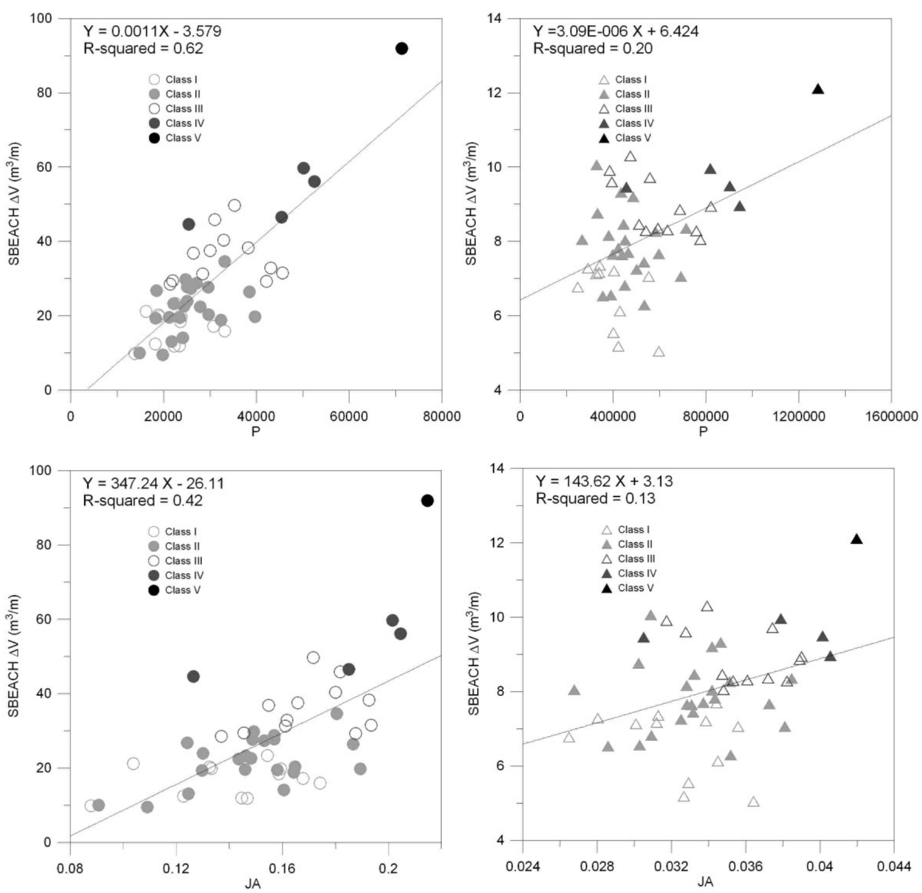

Figure 4.3.4: Linear regression between eroded volumes calculated using the SBEACH versus the ***P*** predictor for reflective (upper right) and dissipative (upper left) and the ***JA*** predictor versus reflective (lower right) and dissipative (lower left).

The observed lack of predictability or the scatter of the results around the linear model could be associated with the fact that no parameter included information on storm duration. This absence of storm duration as a parameter is due to the fact that most beach profile predictors have been derived from laboratory experiments, where wave conditions act on the profile until equilibrium is reached. However, in the field, wave conditions will vary during the storm and, depending on the storm duration, beach profiles will be subjected to a varying impact and in consequence, their response will also vary. Thus, it should be expected that two storms with the same wave height and period but with different durations will induce different erosive responses. This implies that to properly estimate the storm-induced erosion with a simple beach profile predictor, the storm duration has to be included as a key parameter. This need was also considered necessary to derive indicators of beach erosion under storms by Kriebel & Dalrymple (1995), Balsillie (1999) and Zhang *et al*. (2001).

For this reason storm duration was added to all the above-presented predictors. Thus, the final tested parameters were the previously presented ones derived from mean values of *Hs* and *Tp* during the storm multiplied by the storm duration in hours. Table 4.3.5 shows the results obtained in the regression analysis with the new definition of each parameter. As can be seen the overall $\boldsymbol{r^2}$ values increased in all cases and the differences between them significantly reduced.

Table 4.3.5: Coefficients of determination obtained in the regression analysis between SBEACH and function predictors for both beach types.

Function	r^2 *Reflective*	r^2 *Dissipative*
D dt	0.83	0.66
P dt	0.89	0.57
JAdt	0.86	0.69

Figure 4.3.5 shows the relation between the calculated eroded volumes versus the corresponding parameters once storm duration is included. It is clearly seen that, the scatter previously obtained is largely reduced (compare results with Table 4.3.4), especially in the case of the ***JAdt*** function. This improvement is clearly reflected in the r^2 values, which approach those obtained for the ***Pdt*** function.

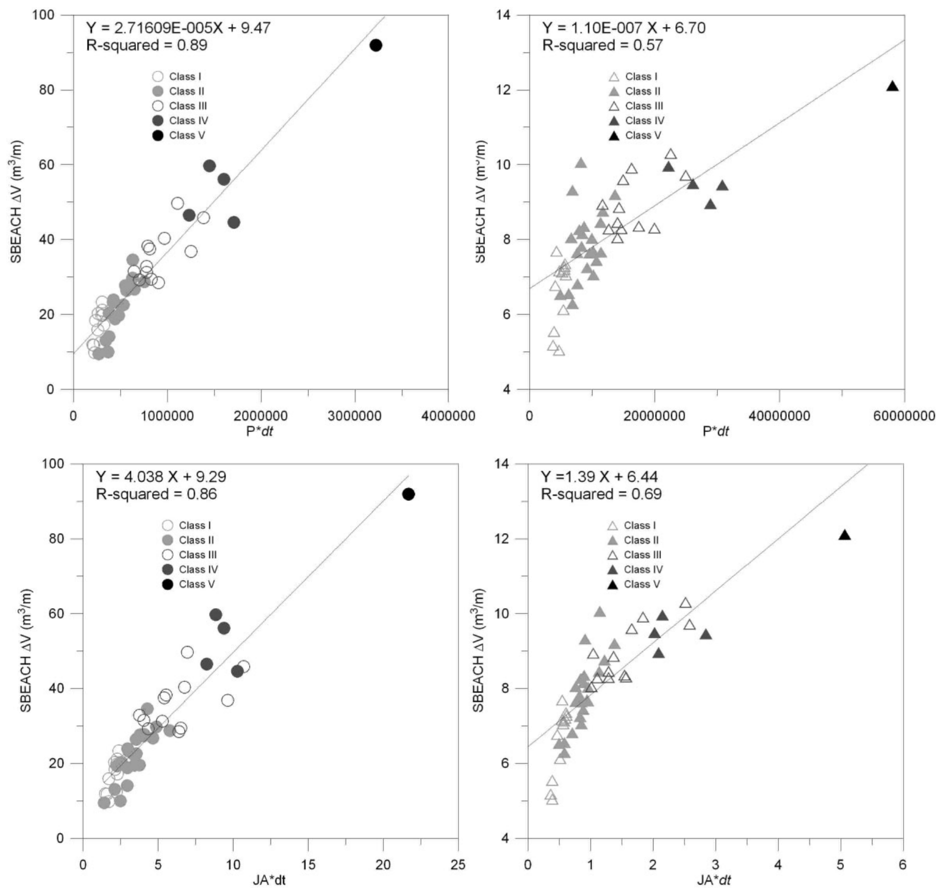

Figure 4.3.5: Linear regression between eroded volumes calculated using the SBEACH versus the ***Pdt*** function for reflective (upper right) and dissipative (upper left) and the ***JAdt*** function versus reflective (lower right) and dissipative (lower left).

Integration of both beach predictors

These results were representative of the two specific beach types along the Catalan coast using them separately, in order to see if the developed method could be used in any kind of beach with in the range of these beaches; the analysis was repeated integrating both profiles.

When the parameter previously identified as best predictor function (in terms of coefficient of determination), ***Pdt***, is applied to both beach erosion volumes calculated (reflective and dissipative profiles), the results appear clustered in two groups, one corresponding to the reflective profiles and the other to the dissipative ones (Figure 4.3.6 left). In both cases, the parameter fits very well both data sets (dashed lines in Figure 4.3.6 left) and in this sense, it can be said that storm-induced beach erosion is equally well simulated using SBEACH and this parameter when different beach profiles are considered separately.

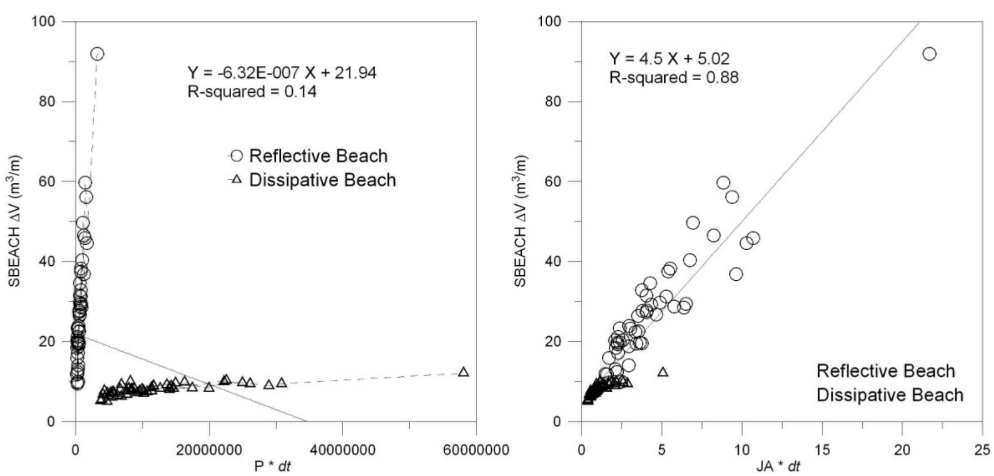

Figure 4.3.6: Joint comparison using reflective (dots) and dissipative (triangles) beaches as the same data set between SBEACH volume change vs. ***Pdt*** function (left) and the ***JAdt*** function (right).

However, when both profile types are jointly considered, the difference between the two approaches is marked (see Figure 4.3.6 left and Table 4.3.6). These results should indicate that a storm with an associated ***Pdt*** impacting on two beaches of different beach slopes would produce an erosive response of different magnitude, with the largest erosion on the steeper profile. As the ***P*** parameter does not include information about the beach slope, it should not be able to properly include this source of variability in the response and, in consequence, its utility to predict overall erosion values along the coast will be limited.

Table 4.3.6: Regression analysis results integrating both beach types for the three functions analyzed (using mean *Hs* and *Tp* values).

Function	r^2
D dt	0.03
P dt	0.14
JAdt	0.88

When this analysis was done with the ***JAdt*** function, a very different behaviour is observed (Figure 4.3.6 right). Thus, when reflective and dissipative beaches are considered as unique data sets, this parameter seems to properly reproduce the overall modelled data set, with a r^2 value of 0.88 (Table 4.3.6). This difference in the predictability with respect to the other parameters is due to the fact that this parameter was the only one including the initial beach slope as a variable.

Final erosion classification

According to the results obtained, ***JAdt*** can be considered to have a similar predictive capacity for storm-induced beach profile changes under offshore sediment transport as SBEACH so and it is proposed the use of Equation 4.3.6 to predict the storm-induced eroded volume. This does not consider events with significant overwash as occurs for extreme storms in relatively low-lying coasts (see Sallenger, 2000).

$$EP = 4.5\left(JAdt\right) + 5.02 \qquad (4.3.5)$$

This function is limited to the same conditions as those tested with the SBEACH model. Moreover Equation 4.3.6 was obtained considering only two profile types (which asides the fact that they cover the range of micro tidal profile variability) and, it would be advisable to check when including profiles with different slopes.

This equation was used for the entire storm data set to reclassify the storms in terms of the induced response. Obtaining a 5-class erosion potential classification (Table 4.3.7). In general terms, erosion potential increases with storm class, defined in terms of their energetic content (Mendoza & Jiménez, 2004) and associated astronomical tide, with eroded volumes ranging from -11 m3/m (class I) up to -103 m3/m (class V) for reflective beaches and from -7 m3/m up to -28 m3/m for dissipative ones. The results obtained for dissipative beaches have to be carefully considered since they are characterized by very low profiles and overwash processes which could play a significant role in beach response under the most energetic storms (classes IV and V) have not been taken into account.

Table 4.3.7: Dissipative beach storms induced erosion potential and beach retreat.

Erosion Class	*Reflective beach*		*Dissipative beach*	
	ΔV (m^3/m)	*σ (m)*	*ΔV (m^3/m)*	*σ (m)*
I	-11	3	-07	1
II	-21	4	-09	1
III	-33	9	-12	2
IV	-46	4	-15	2
V	-103	0	-28	0

4.4 Conclusions

In this chapter, storms along the Catalonian coast have been analyzed to characterize their flood and erosion potential in two representative (reflective and dissipative) profiles found in this coast. The reflective profile is representative of coastal areas such as the Costa Brava (northern) and Maresme (central northern). The reflective profile is usually present in the Costa Dorada (central southern) and the Ebro Delta (southern) region.

The flood potential was developed as a two-step procedure: by estimating the potential flood induced by a given storm, emulating its effects on a beach profile using an empirical parameterization for extreme runup, and characterizing the maximum storm surge registered during a storm, which was using data recorded by a tide gauge.

The addition of both parameters was used to obtain the induced flood potential by the storms and to obtain a 5-class categorization. Results yielded a range of flood potential values from 1.47 m (class I) to 3.10 m (class V) for reflective beaches and 0.63 m (class I) up to 1.34 m (class V) for dissipative ones. The storms surge associated to each storm class was analyzed and yielded values of 0.18 m (class I) up to 0.53 m (class V), although the mean registered values were given, it can be concluded that there is a lack of correlation between the storm surge and the storm intensity given as a function of *Hs*.

It is important to point out that the R_2 in the Catalan coast is more important than the storm surge in terms of flooding, and the results show that estimations of the beach flood potential can be obtained in a simple manner by recognizing the mean characteristics of the runup and storm surge by using Table 4.2.1.

The erosion potential was done through a two stage method. Initially, the erosion induced by a representative data set of storms characteristic of the wave climate of the Catalan coast using a modified storm classification was calculated using the SBEACH model for two representative profiles of the Catalan coast. With this analysis, predicted eroded volumes and beach retreat for each storm were obtained. Secondly, a parametric way to estimate the storm erosion potential measured in the same terms as the SBEACH case was proposed. The idea behind this was to look for a simple erosion parameter in such a way that by simply using synthetic information on storm characteristics, similar bulk erosion values could be obtained as those produced using the SBEACH model.

This was done analyzing the quantitative predictive behaviour of a set of beach profile predictors. Results obtained stress the need to include the storm duration to properly reproduce the calculated storm-induced erosion. The process was repeated for both beaches and results showed that to properly reproduce the behaviour of both types of beaches beach slope must be included in the predictor. From all the analyzed predictors, the ***JA*** parameter multiplied by the storm duration was found to be the best quantitative predictor of the eroded volume for the tested data set. The ***JAdt*** function was used to produce a final five-class erosion potential classification of storms on the Catalan coast. Using the entire data set of storms, results gave a range of erosion potential from -11 m^3/m (class I) to -103 m^3/m (class V) for reflective beaches and from -7 m^3/m (class I) to -28 m^3/m (class V) for dissipative ones. This means that erosion produced by these storms in dissipative beaches would be about a 28% of the eroded volume in reflective ones.

These results show that estimations of the beach erosion potential similar to those predicted by SBEACH can be obtained in a simple manner for the beaches in the Catalan coast by recognizing the mean characteristics of the storm and using Table 4.3.7.