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An integrated coastal modeling system for analyzing beach processes and beach restoration projects, SMC

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Abstract

A user-friendly system called coastal modeling system (SMC) has been developed by the Spanish Ministry of Environment and the University of Cantabria. The system includes several numerical models specifically developed for the application of the methodology proposed in the Spanish Beach Nourishment and Protection Manual. According to this methodology, the SMC is structured into five-modules: (1) Pre-process module; (2) Short-term module; (3) Long-term module; (4) Coastal terrain module; and (5) Tutorial module. The pre-process module allows the processing of a database of morphodynamic information used as input for the different programs and models of the SMC. Short-, Long-term modules include numerical models to analyze coastal systems on different scales of variability (hours–months–years) and are composed of morphodynamic evolution models in cross-profile 2DV and beach plan 2DH. The coastal terrain module allows the user to modify the working bathymetry and to combine bathymetries from different sources in only one working bathymetry. The tutorial module includes a comprehensive collection of coastal engineering design and analysis software. The SMC has a dynamic design and allows the incorporation of future new databases and morphodynamic models.
The SMC system is freely distributed to coastal practitioners and has already been implemented in several countries.

Keywords: Coastal modeling; Coastal numerical model; Littoral GUI; Beach project design; Beach nourishment

1. Introduction

Spain with more than 6000 km of coastline is a country strongly linked to the sea. The coastal area is one of the basic sources of Spanish economy and is subject to a broad range of land uses. There is also a significant natural diversity in shore types throughout Spain (spits, littoral barriers, long-straight and pocket beaches) and different kinds of beaches (sandy, cohesive, shingle beaches, micro and macro-tidal beaches), with four different marine climates (with different winds, waves and currents) and water levels (spring tidal ranges between 0.1 and 5.0 m).

The *Dirección General de Costas (DGC)* (State Coastal Office) of the Spanish Environmental Ministry has been conducting an integrated program since 1993 to restore existing beaches and build new ones in a so-called "Coastal Plan".

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Presently, the Spanish Government invests around 200 million €/year, only in beach restorations and monitoring, with more than 3 million m^3/yr of sand fills distributed along the coast.

In order to properly respond to this demand, The *DGC* has developed a Beach Nourishment and Protection Manual which includes a design and evaluation methodology and a coastal modeling system (SMC). The aim of this paper is to present the SMC developed by the Ocean and Coastal Research Group (GIOC) of the University of Cantabria, and the *DGC* of the Spanish Ministry of Environment. The paper is organized as follows: first, a general description of the New Spanish Beach Nourishment and Protection Manual is performed. Then, the structure, modules and numerical tools included in the SMC are described. Finally, the dissemination plan for the SMC system is presented.

2. Spanish beach nourishment and protection manual (SBM)

From 1995 to 2003, DGC and GIOC developed a set of documents which are known as "Spanish Beach Nourishment and Protection Manual", SBM. The objective of SBM is: to develop a methodology for the design, execution and monitoring of coastal projects; to establish a strategy in order to prevent coastal erosion and estimate flooding risks of low-lying Spanish littoral zones; and finally, to compile the Spanish experience in the coastal engineering field.

This SBM contains three major parts: (1) science-based documents; (2) engineering-based documents; and (3) numerical tools included in the SMC (see Fig. 1).

The science-based documents are organized to lead the reader from fundamental scientific principles to littoral processes. It includes four subdivisions: Coastal Hydrodynamics (GIOC, 2003a), Coastal Littoral Processes (GIOC, 2003b), Coastal Structures design (GIOC, 2003c) and Environmental Impact Assessment for Coastal Actions (GIOC, 2003d).

The two engineering-based documents, the Littoral Flooding Atlas for the Spanish Coast, and the Beach Nourishment Design and Evaluation Methodology follow a "project-type" approach and include all the information and formulations needed to solve the problem subject to analysis, that is, coastal flooding and beach nourishment. The former focuses on the estimation of the extreme sea-level due to the combined effects of tides, storm surge and wave run-up on beaches (see details in GIOC, 2003e). This long-term analysis was carried out based on data from the Spanish network of wave-buoys and tidal gauges.

The Beach Nourishment Design and Evaluation Methodology (GIOC, 2003g) deals with the analysis of beach restoration projects and suggests a procedure for the different engineering phases involved in this kind of projects (diagnostic, pre-design, design, monitoring and evaluation). Furthermore, a number of formulations and numerical tools are provided for pre-design and design phases. The former with low-cost numerical tools

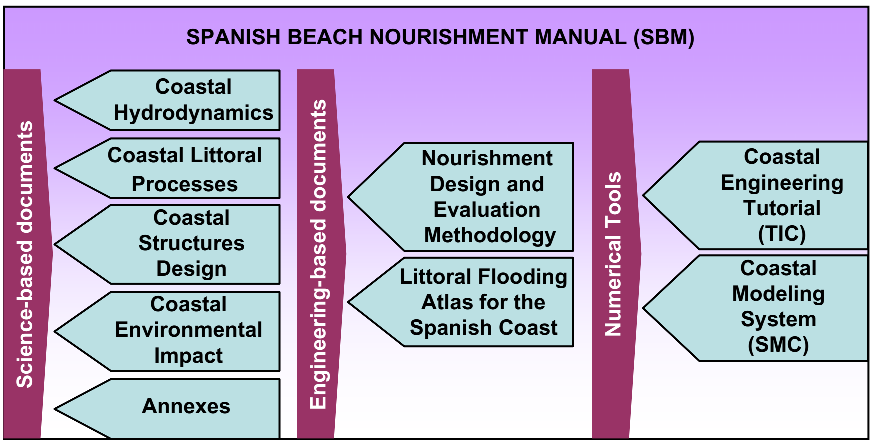

Fig. 1. Structure of Spanish Beach Nourishment Manual (SBM).

and minimum input data in order to allow the generation of a great number of potential project alternatives. Once an alternative is selected by the coastal managers, the solution is then analyzed in a design level using more computational–expensive tools that require more elaborated input data. For each of these levels, the proposed tools allow the user to analyze the functionality and stability of any alternative at long-term time scales (years to decades) and afterwards, to verify the functionality at short-term time scales (e.g. under extreme storm events). All these tools are included in the user-friendly system called Coastal Modeling System (SMC).

3. Coastal modeling system (SMC)

The SMC consists of a series of numerical programs specifically designed to follow the methodology proposed in the Engineering-based Document: ‘‘Beach Nourishment Design and Evaluation Methodology’’. SMC consists of five modules (the global structure is shown in Fig. 2): (1) pre-process module; (2) short-term module; (3) long-term module; (4) bathymetry module; and (5) tutorial module.

In this section a brief description of these modules, along with a description of the programs comprising them is given. A detailed description of model formulations and numerical features of each module can be found in GIOC (2003f).

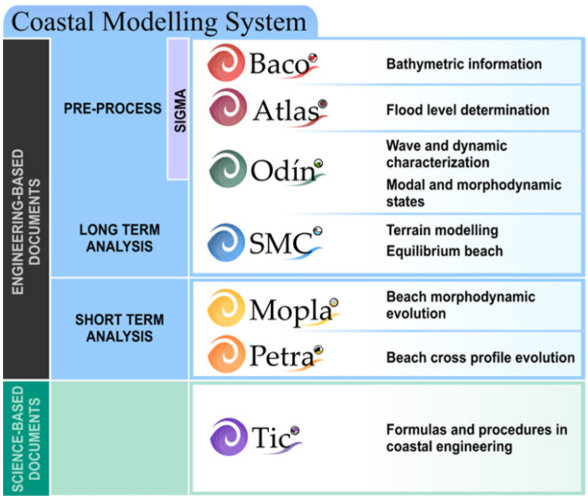

Fig. 2. Schematic representation of modules and numerical models in SMC.

3.1. Pre-process module

This module provides input data for the different programs and models of SMC. The module is composed of three programs: (1) the coastal bathymetry program (*Baco*), which provides bathymetric data; (2) the waves and coastal processes data program (*Odin*), which supplies information regarding waves, littoral drift and beach morphodynamic states; and (3) the littoral flooding level program (*Atlas*), which provides sea-level information along the coast due to the combined effects of tides, storm surge and wave run-up. Although the data initially included in this module covered only the Spanish coast, these pre-process programs have been structured in a generic way, in order to be used elsewhere. Presently, the system also includes data from some other countries (e.g. Colombia, Mexico, Taiwan and Tunisia).

3.1.1. Coastal bathymetry program (Baco)

The main objective of Baco is to provide the user, in a fast and user-friendly way, with the available bathymetric data from any location. Baco also allows coastal practitioners to incorporate their own bathymetric data and merge it with the data provided by Baco. The program takes into account that bathymetric data may be referenced to different ellipsoids and performs the vertical and horizontal coordinate transformations needed to merge the bathymetries.

Baco program allows selecting the digitalized bathymetry for any zone of the Spanish littoral graphically, as it is shown in Fig. 3. The bathymetry has been digitalized from nautical and oceanographic charts provided by different institutions. Furthermore, *Baco* program allows: (1) to combine the bathymetry from the nautical chart with the local surveyed bathymetry and to locate them with the same UTM co-ordinate system for a selected ellipsoid; and (2) to include new bathymetric points (x,y,z) in the combined bathymetry. These points can be digitalized from the nautical charts or other sources.

An example of *Baco* screen appearance is shown in Fig. 3. Red squares represent the nautical and oceanographic charts included in the system.

3.1.2. Waves and coastal processes data program (Odin)

Most of the numerical models included in the SMC require deep-water wave data as boundary

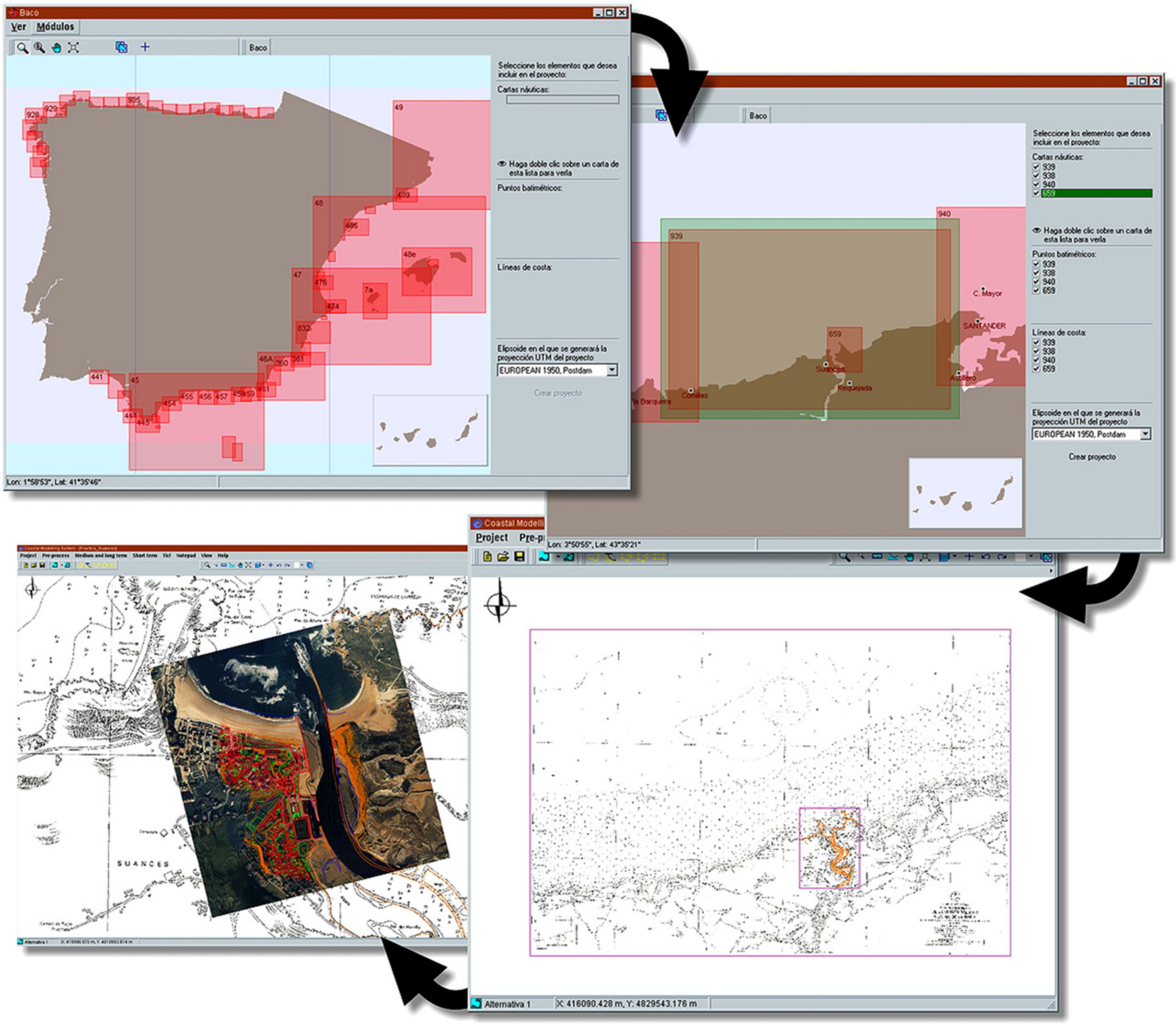

Fig. 3. Coastal bathymetry program (Baco) and SMC interface.

input condition. These input conditions vary depending on the type of model and the time or spatial scales of the processes to be solved. The objective of Odin program is to characterize and to provide the wave data that users need for the utilization of the numerical tools included in SMC. By means of simple coastal formulations, Odin also allows us to estimate several coastal parameters and variables such as: rate of littoral alongshore sediment transport or beach morphodynamic states. *Odin* program includes a database of visual observations of waves reported by ships of the Voluntary Observing Fleet. The wave data was obtained from the comprehensive ocean atmospheric data set (COADS), data supplied through the US National Center for Atmospheric Research (NCAR) and the National Ocean and Atmospheric Administration (NOAA). This offshore wave data set (visual wave height and period) has been calibrated using the measured wave data set (significant wave height and peak period) supplied by the Spanish buoy network.

As stated previously, Odin provides the wave data that users need for the utilization of the numerical tools included in SMC and several coastal parameters and variables. Regarding wave data, the supplied information is summarized as follows: (1) the directional long-term wave climate distributions in deep-water and at a user-defined target location near the coast (see Fig. 4). In order to estimate the wave climate at the target location, *Odin* assumes straight parallel bathymetry to propagate the wave data set from deep-water using Snell approximation. The program is also capable of reading a transfer matrix or function generated by a propagation numerical model to propagate the waves from deep-water to the target location; (2) a list of selected wave cases to be propagated from deep-water (wave height, period, direction and sea-level elevation) in order to better characterize the coastal process at the target location. This list of selected wave conditions are automatically exported to the wave propagation models that will be described in the next sections. The selection of these wave conditions are carried out taking into account the recommendations given in the engineering-based document for a specific case-study (Beach Nourishment Design and Evaluation Methodology, GIOC, 2003g); (3) long-term extreme value wave climate distributions obtained from the Spanish wave network of buoys; (4) time series of waves for evolution models

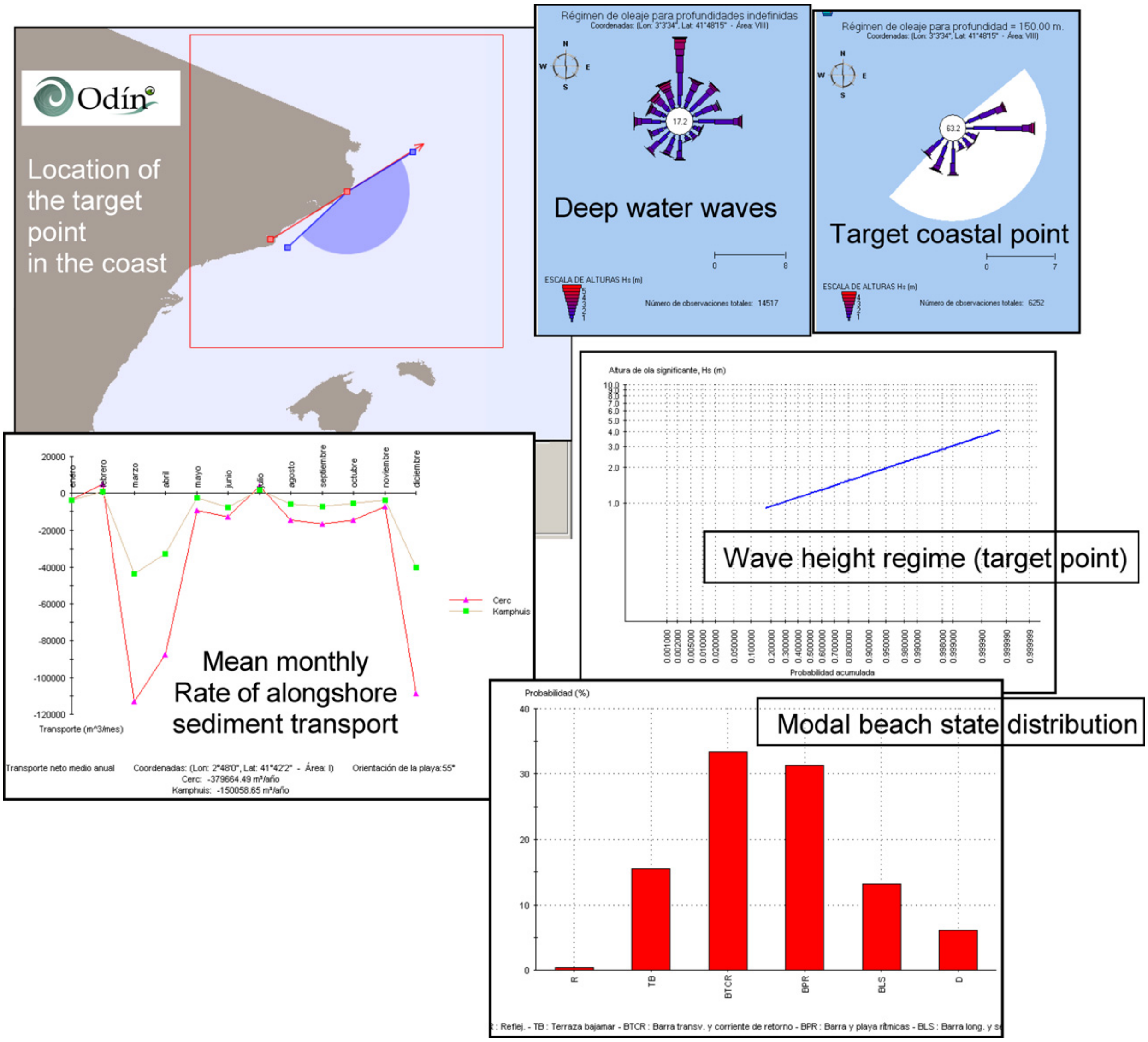

Fig. 4. Waves and coastal processes data program (Odin).

in plan (2DH) and profile (2DV); (5) the direction of the mean energy flux of the waves in deep-water and the target point, the significant wave height exceeded 12 hours per year (H_{s12}) and the closure depth, h_* (Birkemeier, 1985) in the study area. This information is used as input data for long-term scale models (years to decades), models included inside the SMC.

Regarding beach morphodynamic features, Odin provides the following information: (1) the mean monthly rate of alongshore sediment transport (total and net littoral drift), using Kamphuis (1991) and CERC (1984) formulations; (2) the characterization of the modal beach states (annual and monthly beach state distributions). The determination of the morphodynamic state is carried out by employing Wright and Short (1984) in beaches without tides and Masselink and Short (1993) in mesotidal and macrotidal beaches.

3.1.3. Littoral flooding level program (*Atlas*)

Several long-term models included in SMC (e.g. equilibrium beach models, evolution models, coastal structures design) require information regarding the sea-level where the marine dynamics are acting (upper and lower bounds). In a similar way, some short-term models (e.g. wave propagation, wave-induced currents, sediment transport and bottom evolution models) also require information on sea-level.

The criteria for establishing the appropriate ''sea-level'' input for the different time-scale analysis and programs are defined in the Beach Nourishment Design and Evaluation Methodology (GIOC, 2003g). The information about those ''sea-levels'' can be obtained from *Atlas* program. This program provides the information regarding the statistics and particularly the maximum flooding levels reached by joint action of the astronomical tide, meteorological tide, and the run-up of waves on a beach for any given point of the Spanish littoral, (see Fig. 5).

It is remarked that the littoral flooding level is a random variable that must be obtained as a sum of the above-mentioned deterministic and random variables (astronomical tide, meteorological tide, and the run-up of waves on a beach). In the engineering-based document titled ''Flooding Levels'' (GIOC, 2003e), a detailed calculation methodology for the calculation of this flooding level is presented.

The mean and maximum flooding levels are defined in terms of: the exceedance of number of waves in a year (long-term distribution), return period (extreme value distribution), local orientation of the coastline, and average bottom slope (cross-shore). With this information in any given point at the coast, the user is able to define, for example: the level of the berm associated with beach profiles, the elevation associated with the tidal level, the freeboard elevation for coastal structures or the elevation for a side walk.

3.2. Short-term module

This module includes several numerical models to analyze coastal systems on a short-term scale (hours–days). It is composed of morphodynamic evolution models in cross-profile 2DV (*PETRA*) and beach plan 2DH (*MOPLA*). This module allows the practitioner to analyze the beach changes in response to a storm event and to verify that the stability and functionality requirements of a beach restoration project have been met. The module also provides information about coastal processes (current system, potential transport) allowing the practitioner to better understand beach morphodynamic, to carry out a diagnosis and to propose alternative solutions for a specific beach problem.

3.2.1. PETRA model (2DV)

PETRA is a cross-shore process-based beach model, which does not establish any ''a priori'' final profile (open-loop). The model evaluates the sediment transport along the beach profile due to local hydrodynamic and computes the conservation of sand within the beach profile. *PETRA* allows the users to determine the profile shape response to a storm event and, in particular, to estimate coastline recession (see example in Fig. 6).

PETRA model consists of four main modules: the wave transformation module, the wave-induced current module, the sediment transport module, and the morphology module: (1) The wave transformation module is a phase-averaged model which includes refraction, shoaling and energy dissipation. Two coupled stationary differential equations are solved to obtain wave height and wave-induced set-up (wave action equation and the time-averaged momentum balance equation, respectively). In order to solve these equations, a closure relation is required for wave energy dissipation. Battjes and

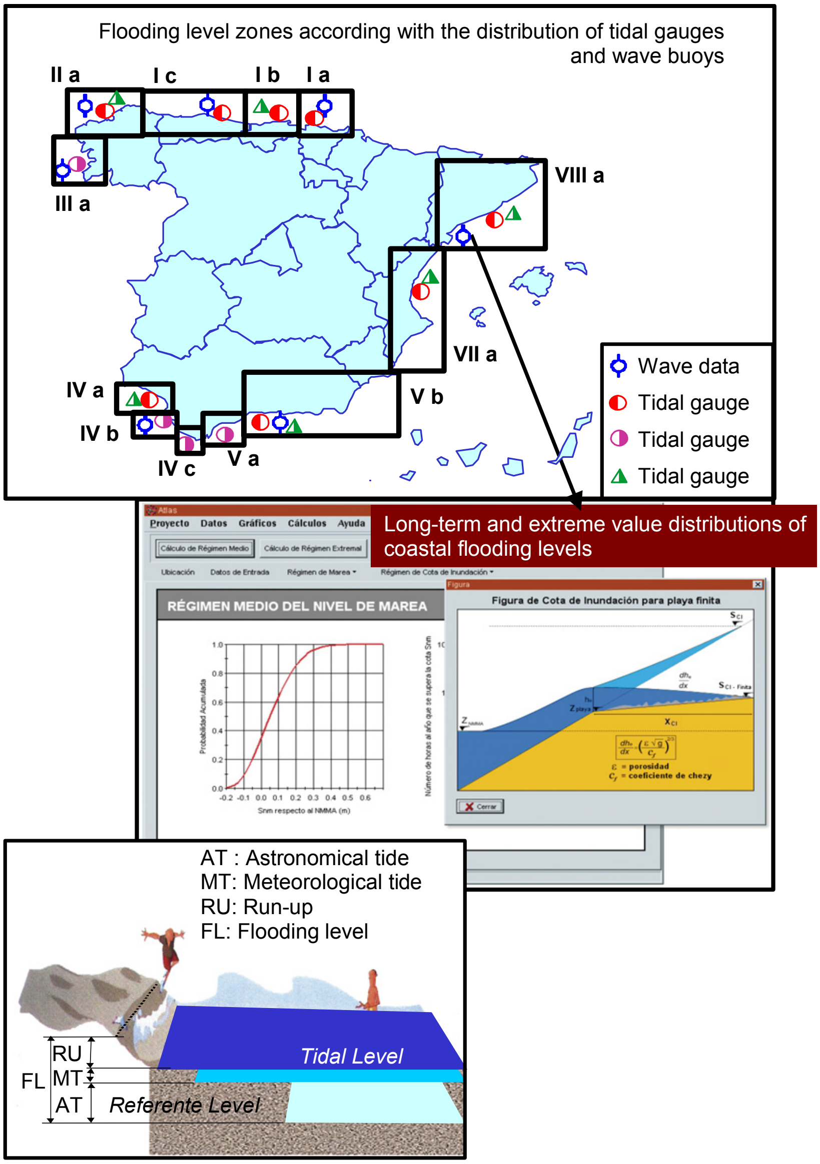

Fig. 5. Littoral flooding level program (Atlas).

Janssen (1978), Thornton and Guza (1983); Larson (1995), and Rattanapitikon and Shibayama (1998) are the formulations included in *PETRA* model. (2) The wave-induced currents are obtained as a vertical distribution of the mean velocity, which is determined locally by the following 1DV formulations proposed by De Vriend and Stive (1987), and Ranasinghe et al. (1999). (3) The sediment transport is calculated as a function of the local conditions, it is obtained by means of the energetic approach formulations: Bailard (1981) and Ranasinghe et al. (1999). The sediment transport in the swash zone is also calculated using Wise et al. (1996) formulation. (4) The morphology module used in *PETRA* update the water depths on a fixed grid by solving the conservation of sediment transport equation for an infinite beach.

The four modules of *PETRA* model have been validated against field measurements and physical model tests in a flume and wave basin. The data set sources to verify the model are summarized as follows: (1) Field data: Data from Egmond Beach

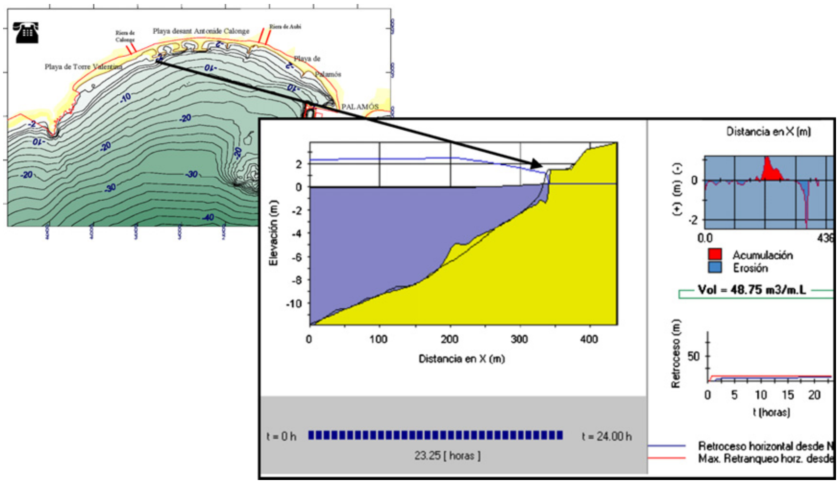

Fig. 6. *PETRA* model (short-term evolution model 2DV). Storm event simulation in Palamós Beach, Spain ($H_s = 3.4$ m, $T_p = 12$ s, Dir = E, Duration = 26 h, Soulsby).

and Haringvliet Estuary, The Netherlands, reported by Battjes and Stive (1985); Data from Torrey Pines Beach reported by Guza and Thornton (1985); Data from Trabucador Beach (Spain) undertow data set collected by Rodríguez et al. (1994); Data from DELILAH CERC Project (Duck Experiment on low-frequency and incident-band alongshore and across-shore hydrodynamics) in Duck Beach (North Carolina), reported by Larson (1995); and finally, data collected at Duck Beach and reported by Ranasinghe et al. (1999). (2) Laboratory data reported by Battjes and Stive (1985), Nairn and Southgate (1993), Mase and Kirby (1992), Okayasu and Katayama (1992), Roelvink and Broker (1993) tests carried out in the Hannover big channel; the SUPERTANK laboratory tests reported by Larson (1995), and Ranasinghe et al. (1999). Details about the formulations used in PETRA, the numerical implementation and model validation can be found in (GIOC, 2003l).

It is worth noting that *PETRA* model is fully integrated in SMC system. Users can obtain input data for PETRA, such as the bathymetry of the initial profile from SMC interface. The input hydrodynamic parameters, waves and tidal range, are supplied by the 2DH propagation model *MOPLA* (which is described in the next section), and by the *Atlas* program, respectively.

3.2.2. MOPLA model (2DH)

MOPLA is a morphological evolution model for coastal areas. It is a short-term process-based numerical model with a similar scope and structure that *PETRA* model, but in a 2DH version instead of a 2DV. *MOPLA* consists of three coupled modules: the wave transformation module (*Oluca*), the depth-averaged currents module (*Copla*), and the sediment transport and morphological evolution module (*Eros*).

(1) The wave transformation module (*Oluca*) is a weakly nonlinear combined refraction and diffraction model, which simulates the behavior of monochromatic waves (*Oluca-mc* version) and a random sea (*Oluca-sp* version), over irregular bottom bathymetry. These models include the effect of shoaling, refraction, energy dissipation (bottom friction and wave breaking), diffraction and wave–current interaction (see Fig. 7a). Both *Oluca* versions are based on the parabolic approximation solution to the mild-slope equation (MSP). The *Oluca-mc* and the *Oluca-sp* were initially based on REF/DIF 1 (Kirby and Dalrymple, 1992) and REF/DIFS (Kirby and Özkan, 1994) models, respectively. *Oluca* versions include several improvements that make the code more robust for coastal engineering applications. These new features include: improvements in the boundary conditions (thin film and structures), improvements in the numerical stability having into account the grid size (Δy), the water depth (h) and the wave length (L) expressed by the dimensionless parameters ($\Delta y/L$, $\Delta y/h$) and improvements in reducing time computational efforts by mean of code numerical optimization. Also, new algorithms are

Fig. 7. *MOPLA* model (short-term evolution model 2DH). Storm event simulation in Pineda Beach, Spain ($H_s = 4$ m, $T_p = 12$ s, Dir = SE, Duration = 72 h).

included for calculation of wave direction, diffraction and wave breaking (in the surf-zone and in front of structures). Finally, some features are included, such as: different dissipation formulations, input spectral waves and models outputs. A detailed description about all of these aspects, formulations, numerical scheme and validation can be found in GIOC, 2003h, j). The wave breaking dissipation model included in the monochromatic version is the one presented by Dally et al. (1985). For the spectral version several dissipation models can be chosen: Battjes and Janssen (1978), Thornton and Guza (1983), and Rattanapitikon and Shibayama (1998). *Oluca-sp* includes the effect of frequency spectrum (TMA or field measurements) and directional spreading. Oluca models are extremely cost-efficient and require very low computational efforts, being approximately 50 times faster than the elliptic mild slope models for the same set up.

(2) The depth-averaged current module (*Copla*) solves the vertically integrated equations of conservation of mass and momentum in two horizontal dimensions (see Fig. 7b). Wave gradient of radiation stresses obtained from *Oluca* model is used as input forcing for Copla. The model is capable of operating with a wave–current space and time-varying hydraulic roughness and turbulent fluctuations (eddy viscosity). A detailed description about the formulations and numerical implementation can be founded in GIOC, (2003i, j).

Finally, (3) the sediment transport and morphological evolution module (*Eros*) includes a deterministic intra-wave period model for non-cohesive sediment (see Fig. 7c). It solves the sediment fluxes equation in the surf-zone, and the bathymetry changes associated to the spatial variations of the sediment transport. The input conditions are supplied by the SMC system as an output of the *Oluca* and *Copla* models. The sediment transport is calculated using (Bailard, 1981; Soulsby, 1997). Some details about *Eros* can be founded in GIOC (2003k). In order to avoid recalculations of the wave and currents fields with *Oluca* and Copla every time step, the perturbed equations proposed by Méndez and Medina (2001) have been implemented in Eros to estimate the wave and current field. This method reduces CPU time when evaluating wave and current fields for sediment transport calculations.

The three modules of *MOPLA* model have been validated against field measurements, physical model tests in flume and wave basin, and compared with other similar numerical models. The data set used to validate the model were: (1) field data: DELILAH Project, measurements carried out by the Coastal Engineering Research Center, in the field research facility in Duck, NC

(Birkemeier, 1991); Trabucador Beach (Spain) undertow data set collected by Rodríguez et al. (1994); The Puntal Beach (Santander, Spain), with a morphodynamic field campaign in 1992 (FLTQ, 1992) and the 2004 field campaign carried out under the frame of the COASTVIEW European project. (2) laboratory data reported by Mase and Kirby (1992), Chawla (1995), Vincent and Briggs (1989), Berkhoff (1982), and Stive (1985). (3) comparison with other numerical models: Nicholson et al. (1997). A detailed description about the MOPLA validation can be founded in GIOC, (2003h,i,j,k).

MOPLA model is an element integrated in the SMC. It receives from SMC interface the necessary input data (e.g. bathymetry, wave data, sea-level). *MOPLA* allows: (1) to characterize the behaviour of local coastal dynamics (wave and current patterns); (2) to analyze the beach's response due to a short-term events (storm, surge); and (3) to estimate design conditions for coastal structures.

3.3. Long-term module

The objective of long-term analysis is to determine the final shape of a beach and/or the temporal evolution of that shape on a scale of years in order to assure that the beach functionality continues throughout its useful life. The existing formulations for this long term analysis do not focus on the processes (for example, wave-to-wave sediment transport), but on magnitudes aggregated to them. The two most widely used models for the analysis of beaches are those based on equilibrium hypothesis (Capobianco et al., 2002; Kraus, 2001) and those based on the diffusion equation (Hanson, 1999). An overview of available numerical model types and different approximations to the long-term analysis is presented by Hanson et al. (2003) and De Vriend et al. (1993).

3.3.1. Equilibrium beach programs

SMC includes a graphical user interface module to test stability or to design new equilibrium beaches taking into account the equilibrium plan form and profile shape (see Fig. 8). This methodology has been applied to various Spanish beaches on the Atlantic and Mediterranean coasts with good results constituting a practical easy-to-use engineering tool in beach regeneration projects (see Gonzalez and Medina, 2001). The system permits the design of equilibrium beaches applying different equilibrium profile and plan form formulations. Related with the equilibrium profile, several formulations have been included in the system, such as Dean (1991), the bi-parabolic profile proposed by Medina et al. (2000), the equilibrium profile in reef-protected beaches Muñoz-Pérez et al. (1999), the equilibrium profile affected by refraction–diffraction Gonzalez and Medina (1997). Concerning with the equilibrium plan form, the SMC includes: the parabolic formulation of Hsu and Evans (1989) and the modification proposed by Gonzalez and Medina (2001). The input data for all of these equilibrium formulations are supplied by *Odin, Atlas* and *Baco* pre-process programs. A detailed description about the long-term module can be found in GIOC (2003f, g).

3.4. Coastal terrain module

This module allows the user to modify the working bathymetry including or excluding rigid structures such as breakwaters, jetties, groins or walls, and bathymetry alterations such as sand fills or pits, see Fig. 9(A) and (B). The module is a very useful tool for the design and evaluation of coastal projects. For nourishment projects, for instance, the equilibrium beach (plan and profile) can be designed using the long-term equilibrium tools described in the previous section; next, the bathymetry module permits updating the original bathymetry with the new equilibrium beach. Required sand fill volume is evaluated by the module and reported to the user. This module also permits combining bathymetries from different sources in one working bathymetry to be used in the different modules of SMC.

3.5. Tutorial module (TIC)

TIC is an interactive module integrated in the SMC that includes a comprehensive collection of coastal engineering design and analysis software (see Fig. 10). Basically, this module has four sections, with the following contents: (1) dynamics: wave prediction, wave theory, wave transformation, wave statistical and spectral analysis, long waves and sea-level; (2) littoral processes: sediment transport, sediment characterization, beach plan and profile, morphodynamic states

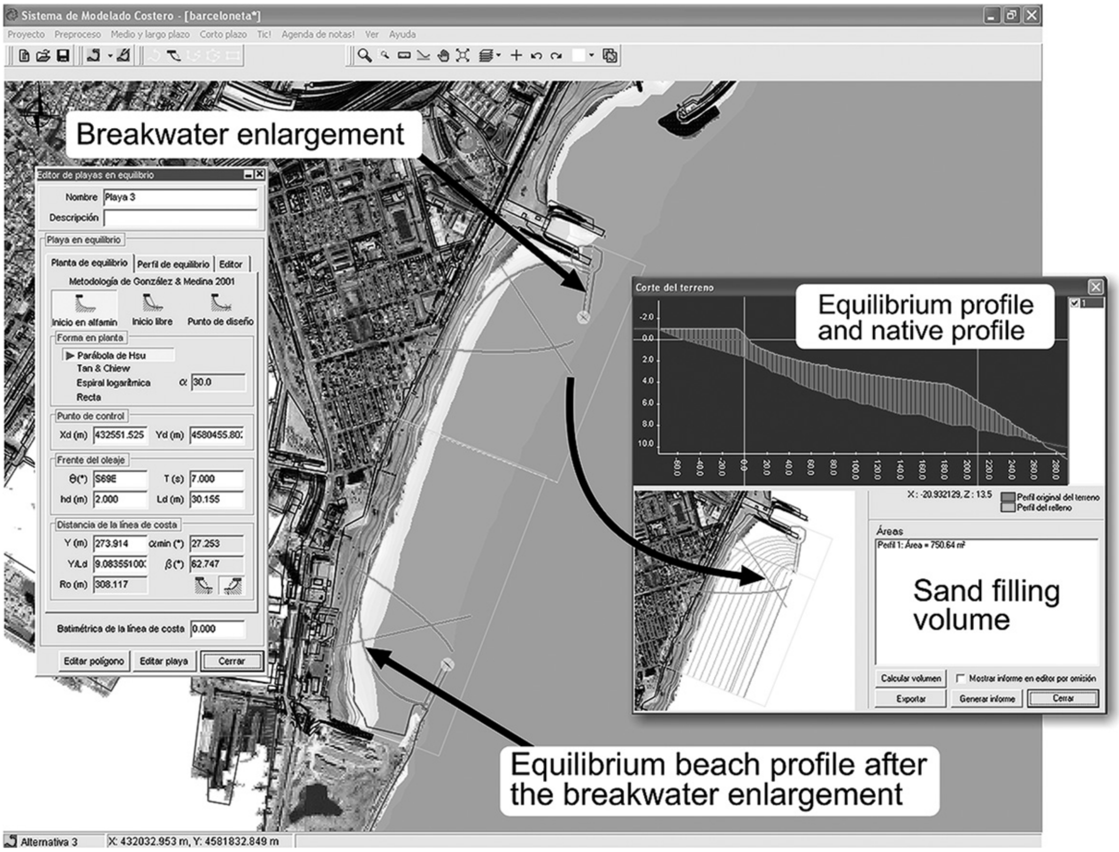

Fig. 8. Equilibrium beach (equilibrium profile + equilibrium plan form). Long-term analysis at Barceloneta Beach, Spain.

and inlet process; (3) structural design: wave–structure interaction (wave runup, transmission, and overtopping), stability analysis (vertical and rubble-mound breakwaters); and (4) coastal environmental impact assessment. Details about formulations included in TIC module can be found in GIOC (2003m).

4. Dissemination plan

In 2002 the Spanish Ministry of the Environment and the University of Cantabria began a dissemination and distribution plan of the new Beach Nourishment and Protection Manual, including the design and evaluation methodology and the coastal modeling system (SMC). The distribution of the system including numerical tools has been carried out for free delivery to National and Regional administration practitioners (coastal office and harbors authorities), coastal consultant firms, and researchers (universities and institutes). The unique requirement is to attend a 40-h training course about the SMC, courses given in the Environmental Ministry in Madrid. Information about the system, updates, courses, etc. can be found in the following web page: http://www.smc.unican.es.

At present, the Spanish Ministry of Environment and the University of Cantabria has signed collaboration agreements for the free delivery of the system to other countries (e.g. Colombia, Costa Rica, Tunisia, Taiwan ...). These agreements establishes four kinds of actors at each country: (1) collaborative institution; which provides the coastal information to be included in the local pre-process modules (*Baco, Odin and Atlas*) of that country; (2) dissemination institution; which is responsible of the dissemination courses of SMC in that country; (3) developer; which improves numerical codes or adapt the codes to the specific country; (4) users.

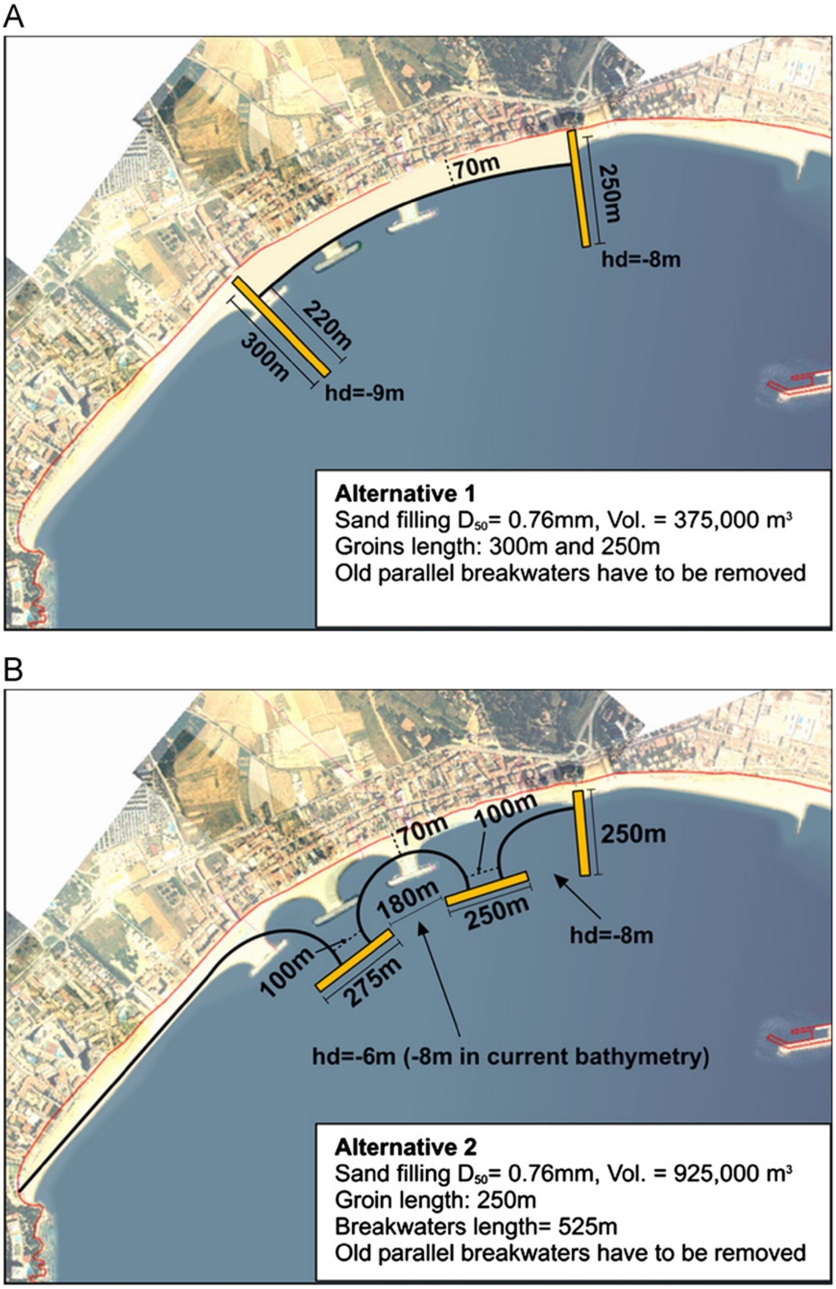

Fig. 9. Bathymetry renovation module permits to modify original digital bathymetry, generating different Project alternatives to be analyzed by the models.

5. Future lines

The SMC is a non-static system. On one hand, it should evolve by completing and incorporating new databases, thus allowing the improvement of the system pre-processing programs. On the other, it must incorporate new scientific knowledge that could be included in the system by means of direct usage applications. As for the pre-processing programs, it is important to include new data sources for offshore waves. Nowadays, there are other more complete sources of data, such as the

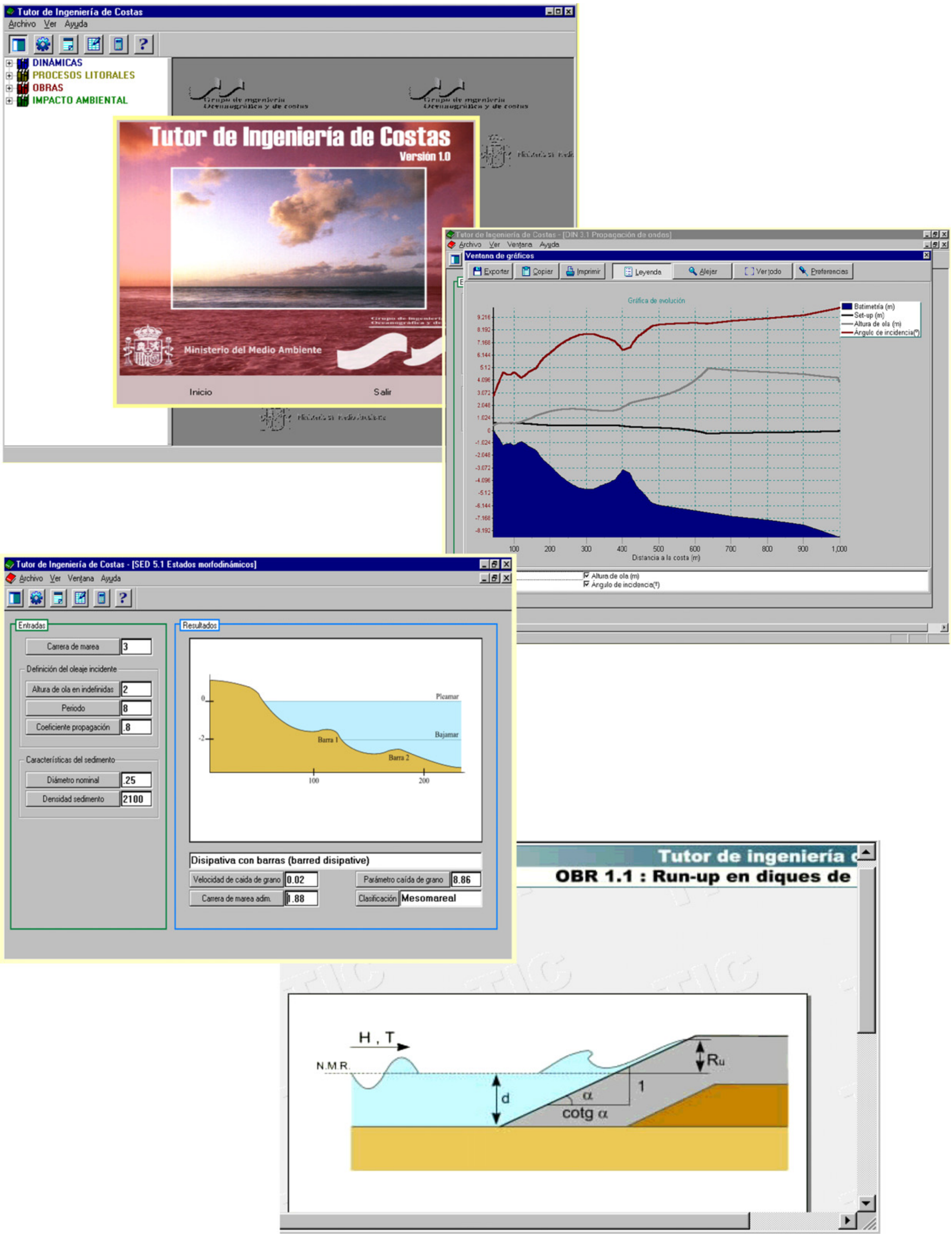

Fig. 10. Tutorial module (TIC).

hindcast wave series, with long-term series (50 years) to a high resolution data (every hour). These databases supply very important information that in the future will allow us to include the wave persistence effect (duration of exceedance of a given wave height, an important aspect in morphodynamic beach evolution models from the middle-term scale (months) to the long-term scale (years–ecades).

6. Conclusions

The coastal modeling system (SMC) consists of a series of numerical programs specifically designed to follow the methodology proposed in the engineering-based document: "Beach Nourishment Design and Evaluation Methodology", SBM. SMC consists of five modules; (1) pre-process module; (2) short-term module; (3) long-term module; (4) bathymetry module; and (5) tutorial module.

The SBM deals with the analysis of beach restoration projects and suggests a procedure for the different engineering phases involved in this kind of projects (diagnostic, pre-design, design, monitoring and evaluation). For each of these levels, the SMC allows the user to analyze the functionality and stability of any alternative at long-term time scales (years–decades) and afterwards, to verify the functionality at short-term time scales (e.g. under extreme storm events).

The SMC is not a static system and it allows the future incorporation of new databases and morphodynamic models. The distribution of the system including numerical tools is being carried out for free delivery to coastal practitioners and scientists worldwide. The SMC system has already been implemented in several countries.

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