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TOWARDS LONG-TERM SIMULATIONS OF TIDAL INLETS: PERFORMANCE ANALYSIS AND APPLICATION OF A PARTIALLY PARALLELIZED MORPHODYNAMIC MODELING SYSTEM.

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Summary: Portuguese coasts exhibit many complex and contrasting tidal inlets of economic and environmental relevance. Due to the strong dynamics of these inlets, associated to a severe wave climate and a meso-tidal range, the prediction of their evolution remains a challenging task, in particular at yearly time scales. This paper presents a partially parallelized morphodynamic modeling system and analyses its performance. Different approaches are proposed to reduce computation time. Finally, the system is applied to the Óbidos lagoon. Results agree with observations of the development of a meander and the formation of sandbars. A comparison between different grid resolutions shows that, at short time scales (a year), a coarse grid can reduce the computation time significantly, without compromising accuracy.

1 INTRODUCTION

The ability to predict the long-term dynamics of wave-dominated tidal inlets/lagoons is fundamental to assess the social, ecological and economical impacts of both human interventions and climate changes in these regions and contribute to their management.

Due to the combination of a meso-tidal range, shallow channels and a severe wave climate, Portuguese tidal inlet and barrier island systems are extremely dynamic and complex environments. The prediction of inlet migration, enlargement (during periods of low-energy waves) and, particularly, infilling (in high-energetic winter conditions) is difficult and requires the combination of an accurate and efficient model with data analysis.

Recently, a few 2DH morphodynamic modeling systems, one of the most promising avenues for the inlet dynamics analysis, were developed to investigate morphological changes of tidal inlets[1,2]. LNEC's morphodynamic modeling system, MORSYS2D[3,4] consists of: (1) a wave propagation model, (2) a circulation model and (3) a sand transport and bottom update model. This system has been able to simulate accurately short-term bottom level evolutions of both wave-dominated beaches and wave-dominated tidal inlets[2]. However, MORSYS2D simulations were restricted to relatively short-term periods (about 6 months) to keep an acceptable computation time (a few weeks). In order to perform long-term morphological predictions, MORSYS2D is evolving towards a highly-efficient, parallelized system.

The present paper describes this improved, partially-parallelized morphodynamic modeling system and presents a performance analysis of the full system and of its different components. We then present other approaches to improve computation performance, such as grid coarsening or the use of morphological factors. Based on the application of MORSYS2D to the Óbidos lagoon, the sensitivity of the predicted morphological evolution on these approaches is investigated. Finally, limitations of these improvements are discussed.

2 MODELING STRATEGY

The 2DH morphodynamic modeling system MORSYS2D has been developed at LNEC[3,4] and has been applied to simulate efficiently bottom level evolution. MORSYS2D consists of the wave model SWAN[5], the circulation model ELCIRC[6] and the sediment transport and bottom update model SAND2D[3], controlled by c-shell scripts (Fig. 1). Hydrodynamic boundary conditions are provided by regional applications of the wave model WW3[7] and the circulation model ADCIRC[8], while winds are taken from the NCEP/UCAR database.

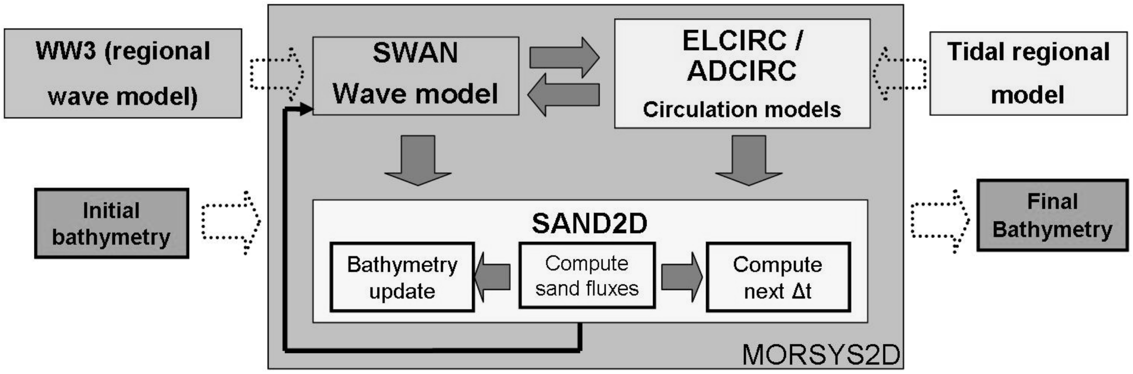

Figure 1: The morphodynamic modeling system MORSYS2D

3 OVERVIEW OF THE ÓBIDOS LAGOON AND SIMULATION SET-UP

3.1 The Óbidos lagoon

The Óbidos lagoon (Fig. 2) is a small and shallow coastal system located on the western coast of Portugal, where the continental shelf is 20 to 30 km wide. Due to the severe wave climate (significant wave height greater than 2.5 m 20% of time), the tidal range between 1 and 4 m, the strong tidal velocities and its marginal stability, this inlet is a stringent testbed for morphodynamic models, in terms of accuracy and numerical stability. Detailed descriptions of the Óbidos lagoon can be found in [2,9,10].

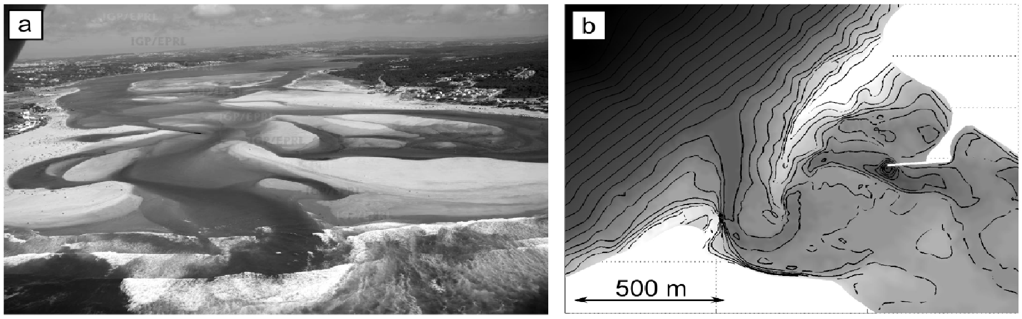

Figure 2: a) Picture of the Óbidos lagoon, viewed from the ocean, showing a complex system of bars and meanders (© IGP/EPRL). b) Bathymetry of the inlet in April 2002.

3.2 Simulations set-up

Two nested grids are used in SWAN to propagate waves from offshore to the tidal inlet. The first one extends from 1000 m water depth on about 21x22 km^2 with a constant spacing of 200 m. The second one is irregular with a maximum resolution in the surf zone and in the inlet (4 km and 1.8 km in the alongshore and cross-shore directions, respectively). Identical unstructured grids are used for the circulation and bottom update models.

To investigate both the sensitivity of the morphological evolution and the computational performance of the modeling system, two different sets of meshes are considered herein:
1) a coarse grid set-up (denoted “coarse grid” hereafter) including an irregular rectangular SWAN grid (4275 nodes with a resolution between 18 m and 60 m) associated with an unstructured hydrodynamic and sediment transport grid (9580 nodes with a resolution ranging from 13 m to 2.5 km),
2) a fine grid set-up (now called “fine grid”) with a SWAN grid of 12700 nodes and a resolution between 9 and 50 m. The unstructured grid has 29400 nodes and a resolution between 7 m and 2 km.

The initial bathymetry corresponds to April 2002, when the inlet mouth was located south (Fig. 2b). As measurements are unavailable in the surf zone, the offshore bathymetry was inferred from satellite images but no subtidal bar is present herein while they can be observed in different images. To compare model results with data, 7 months are simulated. This period was selected because of the availability of a satellite image in July 2002 and another measured bathymetry of the lagoon in October 2002. During this period, observations and measurements indicate the development of a meander and the formation of a new main channel, which are used to validate our modeling approach.

During the modeled period, the significant wave height ranged from 1 m to 5 m (e.g. Fig. 7a, gray band) with a peak period between 6 s and 15 s. Both West South-West and North-West waves were present in the simulated period. Wave fields are updated every 30 min to take into account their variability and the effect of tidal fluctuations.

Finally, to compute bed shear stresses and bed evolution, both the Manning coefficient and the grain size vary in space. Indeed, available data indicate that the grain size varies significantly between the channel and the sandbars and with the distance to the ocean. To allow for the migration of the inlet, homogeneous alongshore distributions were chosen (Fig. 3). The Manning coefficient varied between 0.025 and 0.04 $m^{1/3}/s$ and the d_{50} was ranged from 0.3 to 1.3 mm. Sediment fluxes are computed with the Soulsby / Van Rijn formulation[13] and an adaptive morphological time step is used (between 2 and 30 min).

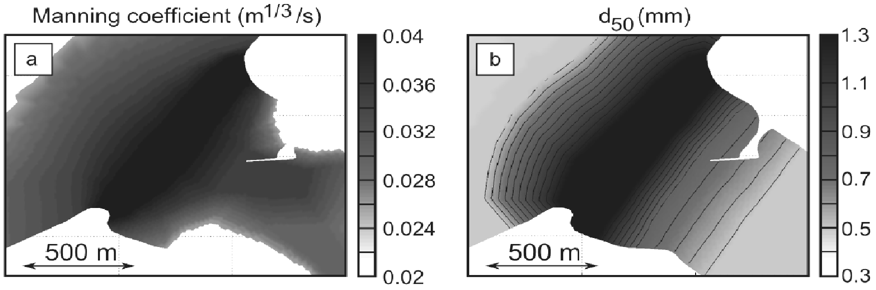

Figure 3: Non-homogeneous distribution of a) the Manning coefficient and b) the sediment grain size (d_{50}).

4 ANALYSIS OF THECOMPUTATIONAL PERFORMANCE

Due to the need to increase the simulation periods, in order to investigate the impacts of engineering interventions and climate changes, MORSYS2D is evolving towards a parallelized and more efficient version. This section describes the new modifications and their impact on efficiency but also the strategy employed for cluster management.

4.1 Partially parallelized system

In the serial version of MORSYS2D, the wave model accounted for over 50% of the computation time. Indeed, ELCIRC is extremely efficient owing to the use of Eulerian-Lagrangian methods. Hence, the first step was to implement the wave model in parallel mode. Figure 4a shows the performance of both WW3 (gray) and SWAN (black) for typical simulations: 1 year simulated with WW3 on a 0.5º resolution grid for the Atlantic Ocean and a stationary state of the fine irregular SWAN grid. Both results show a strong reduction of the computation time by increasing the number of processors. With 20 processors, the computation time is divided by 6-10 depending on the size of the grid. For SWAN, the threshold (around 2.5 s) is associated to the time of pre- and post-processing.

With the parallel version of SWAN, the circulation model becomes the limiting factor (66% of the total time, Fig. 4b). Unfortunately, the parallel version of ELCIRC exhibits computation times higher than the serial version.

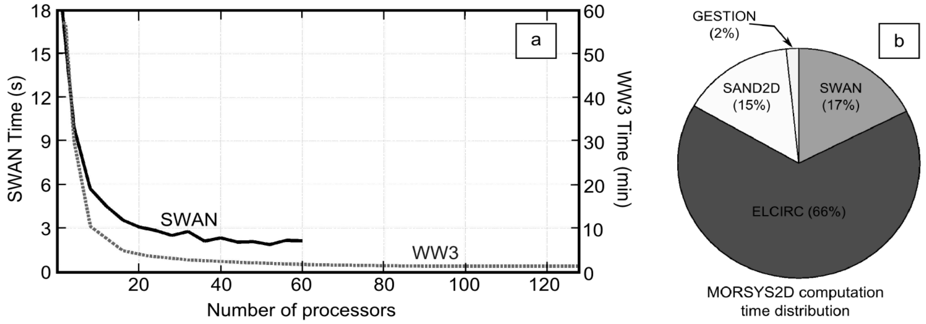

Figure 4: a) Performance of the wave models (SWAN in black and WW3 in gray); b) repartition of the computation time for the whole MORSYS2D system with parallel wave model (fine grids).

Other circulation models, as ADCIRC[11] or SELFE[12] are under consideration. For the same simulation conditions, ADCIRC requires a 1 s time step (against 1 min. for ELCIRC) that increases considerably the number of iterations. However, with the parallel version, encouraging results are obtained (Fig. 5a) with computation time divided by two in this example. The full integration of ADCIRC in MORSYS2D is ongoing.

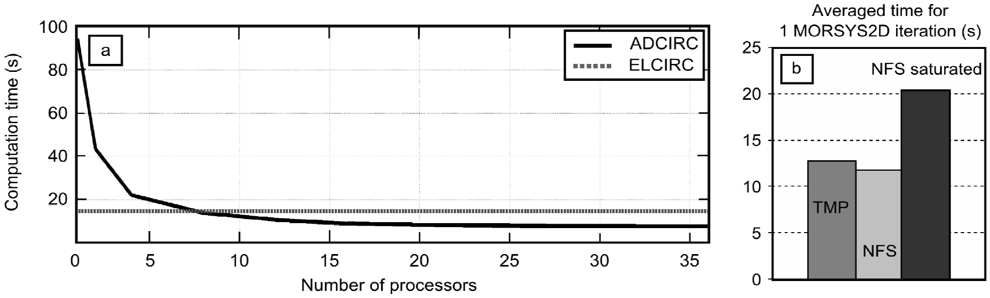

Figure 5: a) Comparison of computation time between the serial version of ELCIRC and the parallel ADCIRC for a 12 min characteristic simulation, b) Comparison of cluster storage performance (MPI with four processors).

4.2 Strategy for cluster management

MORSYS2D is composed of different models that interact through c-shell scripts and input/output files that can cause the saturation of the NFS cluster storage (as queues to access to the storage) when many simulations are running simultaneously. In that case, the cluster performance deteriorates. To overcome this problem, two solutions are investigated: 1) using the local node storage (denoted TMP) and only 4 processors, and 2) improving the script to minimize input/output operations.

The computation times obtained using both the NFS storage and the TMP storage (Fig. 5b) show that the NFS is marginally faster (2.5%) than the TMP when the cluster is not saturated. However, using the local storage is significantly faster (35%, in this experiment) when the cluster is saturated. The limitation of this method is the need to use only the processors of one node (4 in this case) because a processor of one node can only access its own storage.

The second solution was to rewrite the c-shell script in *perl* with the allocation of the variables in memory. This change reduces the total computation time by 4% when the cluster is saturated. The next step will focus on the use of pipes to exchange data between the different models, thus reducing the I/O writing to the disk.

5 MORPHOLOGICAL EVOLUTION OF THE ÓBIDOS LAGOON (PORTUGAL)

Figure 6 illustrates the evolution of the Óbidos lagoon between April 2002 (Fig. 2b) and October 2002 (215 day period). The top figures show the bathymetries during August for both the coarse (Fig. 6b) and the fine (Fig. 6c) grids. Simulations predict the development of a strong meander and the sandbar formation in the northern part of the inlet (noted "Bar" in Fig. 6b,c), which agrees with observations (Fig. 6a). The width of the channel is well represented by the fine grid but over-estimated by the coarse grid. The second comparison (until October 2002) is given by Figures 6d-f with a weak development of a small channel (denoted "Channel") which is more pronounced on the real bathymetry. The development of the two sandbanks (S1 and S2 in Fig. 6d-f) is well represented by both grids.

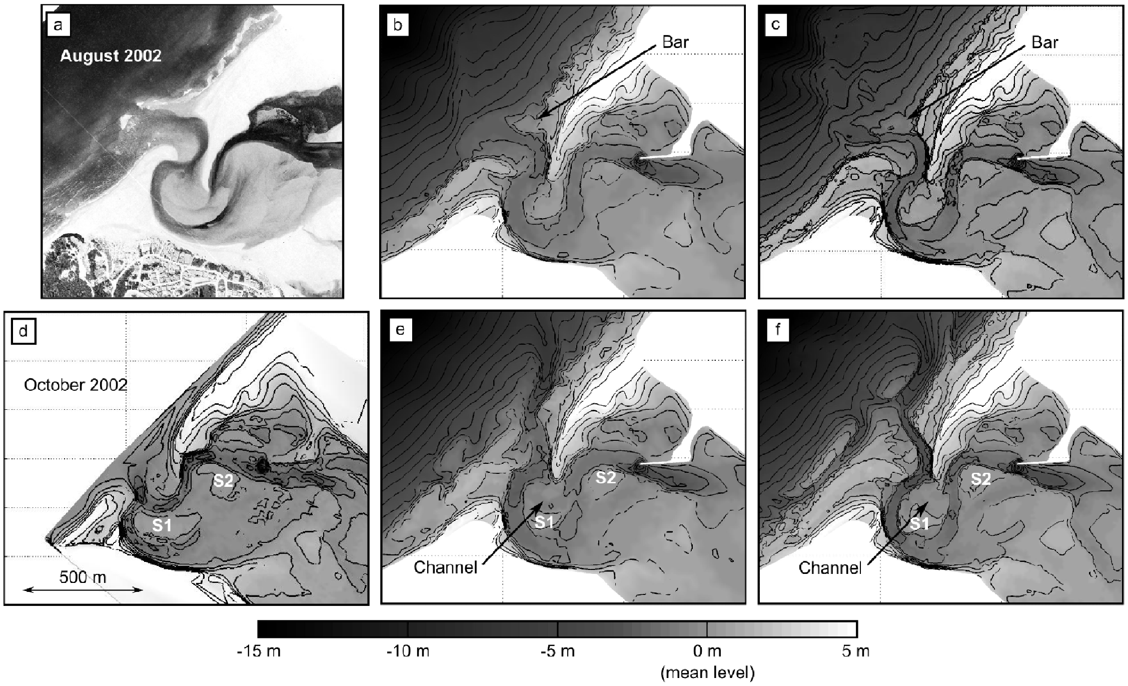

Figure 6: Morphological evolution of the Óbidos lagoon from the bathymetry of April 2002 (Fig. 2b): a) satellite image (August 2002), b) 140 day evolution with the coarse grid, c) 140 day evolution with the fine grid. d) Bathymetry of October 2002, e) 215 day evolution with the coarse grid, c) 215 day evolution with the fine grid.

The modeling system correctly reproduces the development of the meander, the formation of a new channel and the switch of orientation of the inlet channel (east-west in August and south-north in October). The results obtained with the fine grid agree better with data in terms of channel width and sandbar development. In terms of performance, 1 day of simulation requires around 50 min on the fine grid using 16 processors against 9 min for the coarse grid (using 8 processors). In addition, coarse grid results compare fairly well with data. The distribution of the wave heights in front of Óbidos during 6 years is shown in Figure 7.

Using reasonable values of the breaking parameter (0.45-0.75) and of the bottom slope (3-5%), and considering that a minimum of 5 nodes are required to model properly the surf zone, the percentage of waves well represented by each of our grids was evaluated. The fine grid represents over 85% of the waves against only about 35% by the coarse grid. The good results obtained with the coarse grid suggest that the main evolutions are driven by energetic waves.

To further improve the computation efficiency, simulations using a morphological factor (3 or 6) were performed. The results (not shown) show good comparisons between the simulations for short-term periods (<1year). However, for longer periods (>2-3 years), the differences are not negligible. Further investigations will focus on the influence of the morphological factor and on the choice of the representative tide amplitude.

6 CONCLUSION

This study focused on the development of a partially parallelized system to investigate long-term morphodynamics. Analysis of the system performance shows a strong improvement of the computation time due to the use of a parallel wave model. The results also highlights the need to evolve towards a more efficient parallel circulation model (>65% of the global time). Two approaches to improve the interactions between the models and the architecture by reducing the access to the storage (using the local storage and *perl* scripts) were tested and compared.

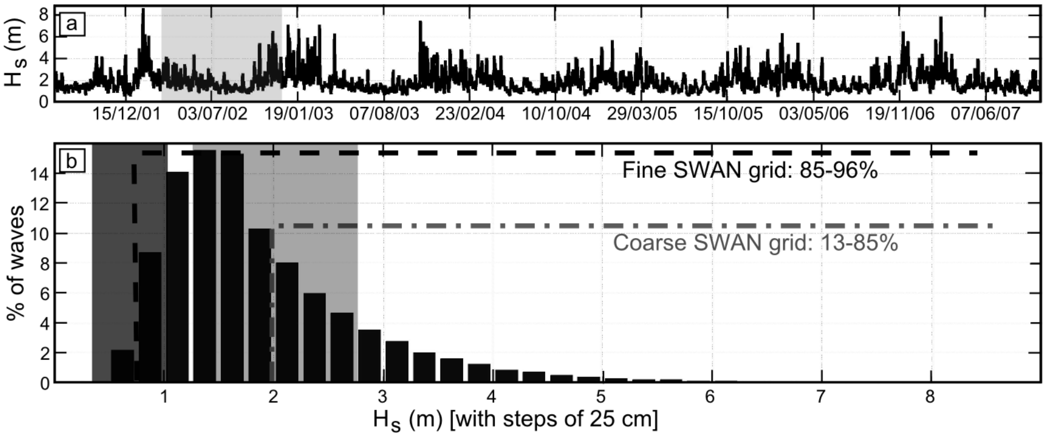

Figure 7: a) Significant wave height between June 2001 and August 2007 (the gray band represents the simulated period). b) Wave height distribution with a step of 25 cm; the dark band shows the variability of the minimum wave height well represented by the fine grid and the gray band by the coarse grid.

The modeling system was able to reproduce well observed morphological behaviors, including the development of meanders and sandbars, with reasonable computation time (around two days to simulate a year on a coarse grid). In addition, the most important morphological changes are induced by strong waves and are thus well represented with a coarse grid. It is now feasible to investigate longer term simulations with realistic results and reasonable computation time in very dynamic and complex environments.

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