A Coupling Of Heterogeneous And Spatial Multi-Agents Models: Application To A Shoreline System

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EXTENDED ABSTRACT

A contribution to the modelling of coastal erosion, on sandy beaches, is given here. We notice that the last advances in the hydrodynamic systems or in sediments transport still do not enable us to answer, in an efficient and universal way, crucial questions about the evolution of the shoreline. Where and in what state will the shoreline be tomorrow, in a month, in a year, in a decade? What will exactly occur if we use structures like breakwaters, jetties or seawalls?

There are already various models which work on different environments and concepts. Most of them produce good results in their respective fields but always present limits. We met the following models: profile evolution models, one-line models, multi-line models and finally the 3D ones. The profile models tend to study the changes due to cross-shore processes and describe the evolution of the profile only. One-line models consider a contour line and follow its evolution throughout shore. They take into account alongshore processes. The multi-line models can be considered as a synthesis of the profile and one-line models. Finally the 3D models work on a description of the processes in a 3D environment. We chose the one-line models and their environment, located their limits by studying one of them, GENESIS, and proposed here a first model of multi-agent simulation to study the shoreline dynamic which is subject to the actions of erosion and sedimentation. The final goal is to simulate shoreline evolution for finding planning solutions to face erosion phenomenon or for forecasting the effects of such solutions.

In a more simplified way, the principle of the numerical one-line model GENESIS is as follows: suppose that shoreline evolution is due to sediment transport alongshore, use a sediment transport function based on breaking wave energy only, break up the domain into cells and apply the principle of mass conservation on the cells for obtaining an equation that will be resolved by a finite difference method. The evolution (accretion or erosion) of the shoreline is then determined by the amount of sand pulled out or deposited on each cell, at each time step.

Our approach is different and is justified by the nature of the two systems, the ocean and the coast, and the non chronology of their processes. Therefore, it is necessary to make a coupling of heterogeneous systems: the ocean one and the coastal one with its urban and ecological dynamics.

Multi-Agents Simulation shows promise as a tool for studying such a problem and can avoid numerous limits of numerical models. So, our method consists of studying the key elements in the system and their interactions in order to have the organization of the whole system. We won’t describe the erosion system in terms of evolution equation, but will see how the actors (or agents) behave and interact in the environment. The following spatial entities are identified on the coast: shoreline and buildings. The waves and sediments can be considered as the main factors acting on the dynamic of the shoreline. They are represented with bowl-shaped agents (“sand ball agents” and “wave ball agents”) to concentrate the information of a set (for example a group of waves or sediments) in an entity (“a ball agent”). After localizing the elements of the system it remains to implement their interactions. In this phase, we will resort to the studies already undertaken in hydrodynamics and sediments transport. Another basic concept of our model is the segmentation process of the shoreline according to some characteristics (ground types, altitude or level…). So we can keep the regular decomposition used in the one-line models, or find another more adequate, to implement “shoreline segment agents”. This allows us to better define the level of auto-organization in interactions with “sand ball agents” and “waves ball agents”. The model is flexible and can progressively or dynamically integrate other actors (like winds, currents, storms…), which can play a role in the system, without worrying about the evolution equation used by the one-line models.

1. INTRODUCTION

The research on the phenomena of littoral systems is of most interest in the scientific community due to the fact that erosion touches the majority of the coasts and is accentuated by the rise of sea level. The evolution of such littoral systems is mainly due to the effects of winds, waves, currents, sea level and types of sediments. These combined effects cause erosion or sedimentation and strongly modify the shoreline environment. Coastal engineering then becomes necessary for the protection and stabilization of the sensitive areas, particularly sandy beaches. However, human intervention on this system can cause unforeseen or uncontrolled changes, so we need planning policies based on reliable forecasting models. This is not easy because the erosion problem is complex. We are confronted with a wide variety of spatial and temporal scales and the intervening phenomena are variable and not yet well understood at each scale. However, the scales that interest coastal engineers are those which range from years to decades and from ten to a hundred kilometers; the changes that affect the coastal systems are generally conditioned by the large scale processes which occur on long scales of time. We will therefore focus on models that work on large space and time scales.

Before describing a multi-agents simulation of the shoreline system, we provided the state of the art of the existing models, gave their principle concepts and limitations. The one-line models are then studied and are the basis of our study. We propose at the end an example of agents' organization to simulate shoreline changes at Wladyslawowo harbor at Poland.

2. SHORELINE EVOLUTION AND MODELLING

The complexity of erosion is due to the fact that it is hard to follow the movement of the sedimentary particles in a space where the currents are variable and oscillatory. There are others events which are very difficult to foresee; such as complex movements of fluids on irregular bottom, produced energy at the time of the breaking waves or interactions between sediments. To bypass this difficulty, researchers, in several cases, have to assume that there is morphological state of equilibrium which is subject to an external constant forcing (Larson and Kraus, 1989), (Kriebel and Dean, 1985). This is the equilibrium concept and there are several models based on it. The other family of models considers that there is not a state of equilibrium in beaches and tries to study the processes which can lead to shoreline dynamics. Such models are process-based ones.

2.1. Equilibrium and non equilibrium

In the formal definition of static equilibrium, the time-derivative of the bed elevation is identically equal to zero. In the weaker form of quasi-equilibrium, the time-derivative at a certain time scale is globally equal to zero. So, in the equilibrium models, we suppose that the equilibrium orientations and shapes of shoreline and profile are known, what is simulated here is the adjustment of the profile and/or shoreline after a change in the external forces (Swart, 1975). An equation that can describe this concept is:

$$\frac{\partial y(t)}{\partial t} = k\left(y_{ek}(t) - y(t)\right) \qquad (1)$$

Where $y(t)$ is the shoreline position at the time t, $y_{ek}(t)$ the equilibrium position determined by the forcing at time t and k the rate at which shoreline approaches equilibrium. The equation (1) can be solved analytically but we are limited, in this case, in the choice of the function $y_{ek}(t)$. A numerical method can be used to avoid those restrictions (Dean and Miller, 2004). The existence of equilibrium is not proven and is subject of controversies. In fact, it is hard to imagine that all transport processes cancel out and lead to an equilibrium state. So we have to consider that even if there is an equilibrium state, it is dynamic and led by the physical principles. This caused the development of process-based models.

The models which work with the processes (the non equilibrium) simulate the hydrodynamic and sedimentary phenomena occurring in the system and reproduce the process by letting morphology evolve without being concerned with a possible state of equilibrium (Haas and Hanes, 2003), (Szmytkiewicz, al, 2000). These models take into account the non-linearity of the intern dynamics and follow the chronology and morphological changes. From an analytical or numerical resolution of equations based on physical principles, they describe phenomena intervening in the shoreline system. The main difficulties of these models are, first, even if they describe the first order phenomena in a "rigorous" way, the other intrinsic phenomena, which can partly be responsible for changes in the long scales do not result immediately from the basic definition of the first phenomena. And since morphology evolves, inaccuracies can accumulate. Next, they may have problems in calibration and verification, because it is always hard to accurately describe and follow littoral processes.

Many models are developed according to these concepts of equilibrium and non equilibrium. Though equilibrium models are commonly used, the non equilibrium models (or process-based models) are more promising than equilibrium models.

2.2. Models of erosion

Profile evolution models are interested in the evolution of the coast section (Roelvink and Broker, 1993) (Van Rijn, al, 2003). They only consider cross-shore processes and suppose constancy in longshore transport. They succeed in the prediction of phenomena in short time scale like the erosive impact of a storm, but in long scale they have problems because they do not describe the transport in that scale.

One-line models work with the contour line of the shore. The constancy is here supposed on the cross-shore profile evolution. They show good capacities of predictability (Hanson and Kraus, 89], (Szmytkiewicz and al, 2000) and calculate the changes in the position of shoreline on a period going years to decades and on a zone of hundreds of meters to tens of kilometers. The basic assumption: changes in shoreline are due to the differences on the alongshore transport. Cross-shore processes are supposed to cancel out over a long period of simulation. They are also used in coastal engineering, especially for structures management.

Multi-line models try to follow changes in cross-shore and longshore directions (Pearlin and Dean, 1978), (Hanson and Larson, 1999). Suppositions of constancy in longshore and cross-shore transports are then ignored. Then don't work on 3D space but simplify the profile shape or the transport function. They always have problems in accurately predicting hydrodynamic phenomena and need a lot of calculation resources. However, studies on these models must be investigated because they present a good coupling of one-line and profile models.

3D models need equations to describe all processes in a fully 3D space (XinJian, 2004).Such equations are always in study. Waves, currents (caused by tides or waves), sediments transport and changes in the bed level must be calculated point by point; this implies complexity and difficulty of calibration and validation. These models will also have limited utility in the long term because of the large number of parameters taken into account.

One-line models are those which can provide a great applicability in coastal engineering for the moment. They are very useful in the study of the situations met in coastal installations, because they can take into account structures (jetties, groins, seawalls, breakwaters…). In our study, we adopt the one-line principle i.e. we consider a contour line and follow its evolution in a multi-agents simulation.

3. ONE-LINE MODELS

For these models, the shoreline evolution is given by the longshore transport of sand which is due to the breaking wave energy or longshore currents. At first, let's give the governing equation of one-line models.

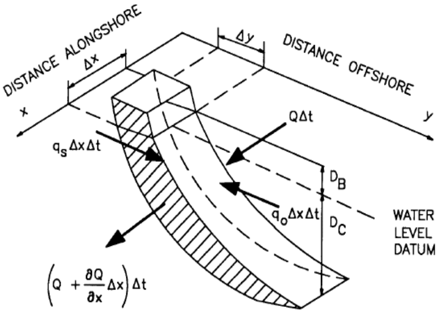

Figure 1. Cross section

The volume Δ_v which can enter or leave the section (Figure 1) is equal to $\Delta_x \Delta_y (D_B + D_C)$. This same volume, by applying mass conservation is also equivalent to the sum of the variation ($\Delta Q \Delta_t = (dQ/dx)\Delta_x \Delta_t$) of longshore transport function Q and the seaward and shoreward variations ($q \Delta_x \Delta_t = (q_s + q_o)\Delta_x \Delta_t$). Equaling the two expressions of the volume, they obtain $\Delta_x \Delta_y (D_B + D_C) = (dQ/dx)\Delta_x \Delta_t + q \Delta_x \Delta_t$. If $\Delta_t \rightarrow 0$, they arrive at the following equation:

$$\frac{\partial y}{\partial t} = \frac{\frac{\partial Q}{\partial x} + q}{(D_B + D_C)} \tag{2}$$

Equation (2) can be rewritten in a simplified way for giving the most used one-line governing equation:

$$\frac{\partial Q}{\partial x} + D\frac{\partial y}{\partial t} = 0 \tag{3}$$

We need the expression of the transport function Q to resolve equation (3). The model GENESIS (GENEralized model for SImulating Shoreline Change) (Hanson and Kraus, 1989, 1991) which is a good model and which can handle combinations of structures, is used. Its transport function is:

$$Q = (H^2C_g)_b\,[a_1 sin2\theta_{bs} - a_2 cos\theta_{bs}(dH/dx)] \qquad (4)$$

H = wave height
C_g =wave group speed given by linear wave theory
b = subscript denoting wave breaking condition
θ_{bs} = angle of breaking waves to the local shoreline
a_1 et a_2 are coefficients (Hanson and Kraus, 1991).

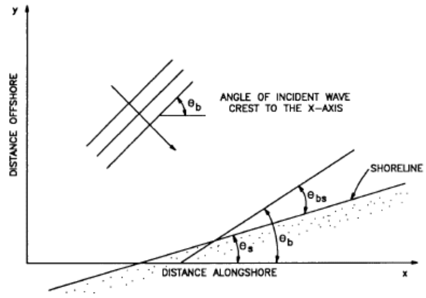

Figure 2. Angle of breaking waves

Equation (3) can be resolved analytically (Larson and al, 1987) but for more flexibility and realism, it must be treated numerically. Before that, simplifications are made. At first, θ_{bs} is supposed to be small and is assimilated to its sinus. Next, with the relation: $\theta_{bs} = \theta_b - \theta_s = \theta_b - \tan^{-1}(dy/dx)$ (Figure 2), the following approximations are taken: $dQ/dx \sim d(2\theta_{bs})/dx \sim 2d(\theta_b - \tan^{-1}(dy/dx))/dx \sim d(dy/dx)/dx = d^2y/dx^2$. Finally, equation (3) is transformed into:

$$\frac{\partial y}{\partial t} = (\varepsilon_1 + \varepsilon_2)\frac{\partial^2 y}{\partial x^2} \qquad (5)$$

$(\epsilon_1 + \epsilon_2)$ gives other terms of equation (4). Equation (5) is well known as a diffusion type equation (Crank, 1975) which has resolution methods, but it is solved numerically in GENESIS by a finite difference method. A grid is used to calculate the various positions of the shoreline. There is one element y_i by cell and its displacement is obtained by the values Q_i and Q_{i+1} of the transport function on the cell's ends (figure 3). An equations system is then obtained for calculating the y_i values for each time step following the Q_i values.

Some discussions must be raised on one-line models. On the one hand, the numerical resolution precision depends on the subdivision of space and on the time steps. Such a discretization is good only if the grid and the time steps used are very small. The inconvenient is the increase of the computing time, especially if we make simulations which relate to several years and several kilometers.

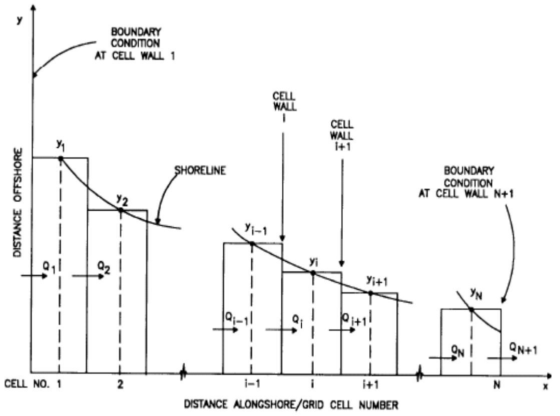

Figure 3. Finite difference grid.

On the other hand, it should be noticed that the improvement of the precision doesn't automatically guarantee the precision of the shoreline evolution. In fact, it is the one-line evolution equation that we try to resolve and not evolution itself; several simplifications were made to obtain equation (5). Two interrogations must then be raised:

- Can we find an equation which can accurately describe the evolution of all processes?
- If such is the case, will we be able to correctly resolve this equation?

Since it seems that the littoral systems are very complex to establish an irreproachable governing equation based on the laws of this system, we propose to find an organization based on interactions of the various system components. So, we can separately study the intervening processes, and integrate them in a multi-agents simulation.

4. MULTI-AGENTS MODELLING AND SIMULATION

4.1. Principles

The multi-agents systems come from distributed artificial intelligence which proposes to define organizations of agents to accomplish collectively tasks which are complex, but "easily" realizable when they are decomposed and distributed. We use this concept to formulate a model in our study. Generally, in modeling process, we can distinguish two ways of proceeding to obtain a model: rules-based modelling and laws-based modelling (Matarasso, 1997). The physical systems use a lot laws-based models which consist in regarding certain characteristics of the elements as variables and studying them by formulating continuous equations (ordinary differential equations, partial derivation equation) based on the evolution laws of the total system. We can take the example of fluids flows where we consider the height of water, speed, etc. Such is also the case for our equations (1) and (5). The rules-based modelling studies the system evolution by following the interactions rules between elements. The evolution is then discrete and emerges from the elements interactions. The description of the interactions is not enough to understand the system; it is rather a first step in the study. The phase of simulation is necessary to follow the system behavior in all its complexity. This is the case of the multi-agents systems. Studies are already taken in this direction, (Servat, 2000) in the modelling of flows dynamics by agents, (Breton, 2002) in the physics of the granular environments and (Tranouez, 2005) the modelling of the aquatic ecosystems. The major qualities of multi-agents models, in comparison with the numerical ones, are the capacity to represent an irregular and dynamic environment but also to be able to group together in this same environment “any” types of agents with different behaviors and various action times or chronologies. The process-based concept meets again here the multi-agents framework which will distinguish phenomena actors in the dynamics of the shoreline. Coastal erosion can thus be studied in a more "simple" way by establishing its description in a Multi-Agent Systems.

4.2. Coupling of the heterogeneous systems

The coupling of the two systems is done by the space delimitation of the environment of interface. It is thus necessary to spatially locate the various elements of the system.

On the coast, we can index the following elements: constructions, roads, vegetation and finally the shoreline. This list is not exhaustive and varies from one zone to another. Among these elements, some are static and others dynamic. The static elements are considered as objects of the system and the dynamic ones are the agents which behaviors depend on the system organization. The multi-agents system objects can be classified by a GIS (Geographic Information System). This one is used only for the recuperation of their geographic coordinates. The use of an intermediate database, to store this information is then desirable for more flexible programming. The principal dynamic element here is the shoreline. For more precision, we use a segmentation technique to divide the shoreline into “segments agents”. This allows us to gather points with same characteristics. These elements are also stored on the database.

On the ocean, the elements which can be taken as agents are numerous. One can list the swell, the winds, the waves and the temperature...Ocean agents can be different from one site to another and depend on available data. In fact, climatic factors are not the same and must be treated especially. In our study, we will only consider the waves which are generated by winds. Like one-line models (particularly GENESIS), we will suppose that longshore transport is due to waves action.

Now that we have located our system with its various components, it remains to define the interactions between these elements to obtain a general model of simulation. Intuitively, we can see the shoreline as points set which moves because of ocean energy. This energy is strongly related to waves’ characteristics. We will here use the CERC formula (CERC, 1984) to calculate longshore transport depending on wave energy. GENESIS transport function is also based on CERC formula. The displacement of a segment is obtained by the calculation of the quantity of sand which it can gain or lose, in a time step, with the detriment or the profit of its neighbors.

4.3. Simulation

One of the problems on shoreline modelling is the availability of data. In fact, we need some information on elements which are taken as agents. This is necessary to first understand the basic behavior of the agent and to implement it in the simulation. We use one study (Szmytkiewicz, al, 2000) which was done at Wladyslawowo harbor (Figure 4), in Poland to develop a multi-agent organization.

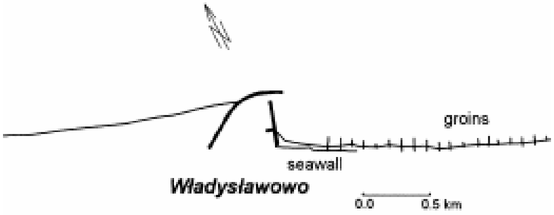

Figure 4. Wladyslawowo harbor.

The construction of the harbor caused sediments to deposit in the western part and erosion in the eastern one. We were interested by the western part only. In (Szmytkiewicz, al, 2000) an inter-comparison of four one-line models: GENESIS (developed by the Department of Army, Corps of Engineers, USA and the Department of Water

Resources Engineering, Sweden), LITPACK (Danish Hydraulic Institute), UNIBEST(Delft Hydraulics) and SAND94(Polish Academy of Sciences, Institute of Hydro-Engineering), was done for the period 1936-1997. 1936 to 1965 for models' calibration and 1976 to 1997 for models' validation. We use this last period to run our model. However, it is important to note that we don't make here a comparison of our model with the other ones. In fact, we don't have all the data and were obliged to use randomly chosen ones. For example for the waves' height period and angle, we randomly chose in given intervals. Some coefficients of CERC formula were also taken to the calibration of GENESIS. For the simulations, we used segments of 50 meters and obtain a total of 83 segment agents in the western part of the harbor. The time step was set to one hour four more precision.

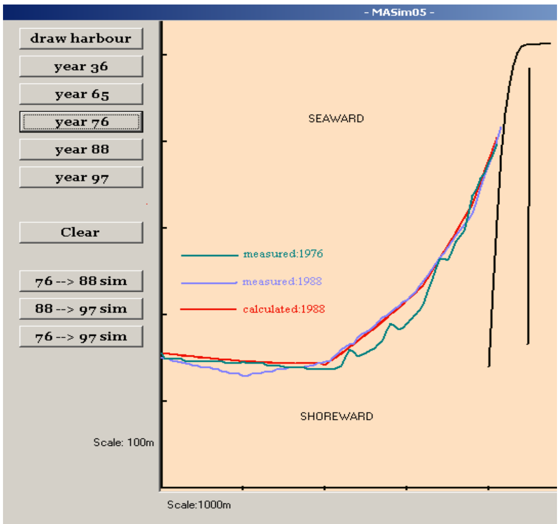

Figure 5. 1976 to 1988 Simulation.

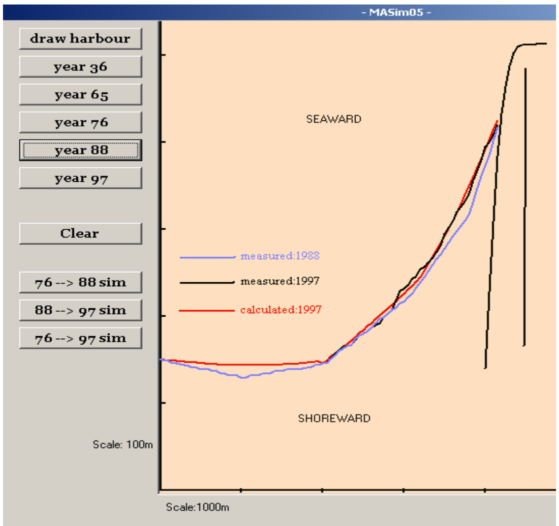

Figure 6. 1988 to 1997 Simulation.

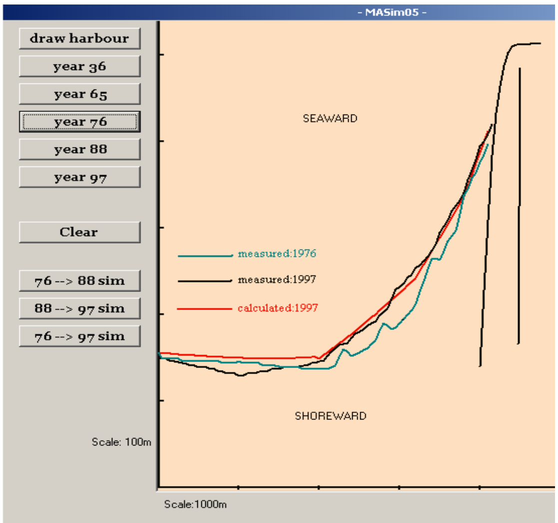

Figure 7. 1976 to 1997 Simulation.

These three simulations (Figure 5, Figure 6 and Figure 7) show that a multi-agent organization can handle the complexity of shoreline erosion and provide good results. However, validation process must be continued with other beaches more general, because this one has a long term trend in longshore transport.

5. CONCLUSIONS

The lack of data is a big problem in shoreline simulation. We were confronted with it when trying to model the shoreline evolution. So, the model must have the capacity to forecast some missing data or to give the user the possibility to choose/ rectify some of them. In our programming, such actions are feasible because the agents' characteristics are variables that can be modified easily. We notice that the computing simulation time is reasonable compared to the time of study and the number of shoreline cells used (segments agents) (83 in this example).

The limits of numerical resolution can be avoided. We can define here a significant number of agents but we must be careful on how we define the interactions between them. They must be elementary if not the organization can be complex and the emergence of properties difficult to understand. Knowledge on the studied system is also indispensable. This study is an exploration and requires further study and refinement. It shows the potential for studying complex dynamic problems using multi-agent systems. However the specification of these systems requires a necessary dialog between the expert and the modeler.

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