DEVELOPMENT OF AN INTEGRATED SYSTEM FOR COASTAL WATERS

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1. ABSTRACT

This paper describes some of the needs and problems associated to assessment of coastal and estuarine problems (sediment transport and eutrophication). The development of an integrated system including EO data, local measurements with special emphasis on modeling tools, is presented as a solution for studying and helping decision making on the subject. Two pilot sites for the implementation and the present development status of the integrated system are depicted. This framework was already presented in a recent AO specific for Portugal, which is still under evaluation.

2. INTRODUCTION

Over the past 20 years, national environmental managers and policy makers have repeatedly complained about the lack of adequate information: information that was often not available in time, and when available was frequently not reliable, or did not meet policy needs, and could be difficult to understand. At the same time the combined advances in modeling, monitoring techniques (in situ and remote sensing) and in information technologies have dramatically increased the ability to deal with environmental problems.

Nowadays there is awareness that low frequency point observations do not solve environmental and ecosystem variability at the appropriate spatio-temporal scales for present needs, and that, remote sensing resources can be extremely useful especially in places where there is a lack of local data. However, accordingly to GMES prerogatives [1] “in-situ and EO data alone can rarely satisfy the user’s purpose. A complete decision support process, including synoptic, analytic and predictive capabilities, is generally needed. It is thus necessary, for most end-uses, to exploit EO and in-situ data conjointly with numerical models, data assimilation, and information presentation methods of varying sophistication”. Still accordingly to GMES, environmental services “must use those data sources that best meet user needs: In most cases this means that EO data, in-situ data and models must be used together to establish an integrated decision-support capability that is of practical use for policy and decision makers”.

The coupling of areas such as, modeling, local measurements and Earth Observation, creates a value added which is for sure greater then the sum of all parts. The classical approach for dealing with the water quality problems in water bodies is based on data collection and analyses. With the development of an integrated system, we aim for the next step in accessing eutrophication processes, which is already recognized in the most recent water management legislation (2002/413/EC and 2000/60/EC), concerning the integration of data with numerical tools, accessing the problems from the ecosystem point of view (evaluation of processes).

3. OVERVIEW OF THE PROBLEM

When assessing nutrient and sediment transport problems in estuaries and coastal areas there are two major areas that interact with each other and together determine all the processes occurring in the system: hydrodynamic flow and ecological processes.

In general, the hydrodynamic flow that determines the ability to transport mass in an estuary is a complicated function of ocean boundary condition, winds, river inflows and estuary geometry and bathymetry. Flow varies over the tide, over days, weeks, and seasons. Flow determines nutrient availability threw transport; light availability threw sediment settling and ressuspension processes and above all determines how long a water mass will stay in a certain place or in other words the water specific residence time. Ecological processes such as primary production only occur if the adequate conditions are found (light, nutrients, temperature) and if there is enough time for the ecological processes to take place.

The physical principles supporting these observations (momentum and mass conservation) apply to all aquatic systems (estuaries, coastal waters, etc). The extraordinary differences observed emerge from the differences in boundary conditions, system geometry and bathymetry. The modeling research work of MARETEC at IST in Lisbon, was developed with these considerations in mind, and translated in to the MOHID modeling system (www.mohid.com).

Considering system complexity associated with highly dynamically spatial (horizontally and vertically) and temporal changes it becomes obvious that any type of monitoring either remote sensing or local data acquisition can only give a brief perspective of the problems in coastal waters and estuaries. (eutrophication, sediment transport). Satelite imagery has an impressive capability of describing spatial distribution but inevitably short term temporal phenomena (in the range of hours) and vertical processes are impossible to track. On the other hand, local data measurements (with high costs) can show these short time trends but usually are unable to give a clear overview of spatial variation. With the proper modelling tools we are able to pick the information given by monitoring work and fill the information gaps thus the combinations of this component gives the perfect managing tool do deal with such complex problems.

With this purpose, the integration of EO data concerning, temperature, light extinction and suspended sediments, will help to define the limiting factors for primary production and to establish the level of confidence of the model concenrning the physical issues. Chlorophyll and DOM maps help to describe and quantify the main processes involved in the eutrophication problem.

4. MODELING TOOL

The modeling tool to support such integrated system should allow the simulation of coastal hydrodynamic processes coupled with biogeochemical processes. It must also provide a way of answering to different scale predictions, complex geometries and to efficiently incorporate different data sources to define boundary and surface conditions. These are some of the features already present in the MOHID modeling system.

The model is being developed by a large team from Instituto Superior Técnico (www.ist.utl.pt) in Lisbon, and includes contributions from the permanent research team and from a large number of Ph.D students on Environmental and Mechanical Engineering and from IST master course on Modelling of the Marine Environment. Contributions from other research groups have also been very important for the development of the model. The whole model is programmed in ANSI FORTRAN 95, using the objected orientated philosophy.

The MOHID system includes a baroclinic hydrodynamic module for the water column and a 3D for the sediments and the correspondent eulerian transport and lagrangian transport modules. Parameters and processes involving non-conservative properties are object of specific modules (e.g. turbulence module, water quality, ecology and oil transformation). The hydrodynamic model solves the three-dimensional incompressible primitive equations [2]. Hydrostatic equilibrium is assumed as well as Boussinesq approximation. The model uses a finite volume approach. This method makes the solution independent of the mesh geometry, allowing the use of a generic vertical mesh. The turbulence module uses the well known GOTM (General Ocean Turbulence Model – http://www.gotm.net/) turbulence model). The model also solves a transport equation for salinity and temperature in order to compute the specific mass. The eulerian transport module used to transport these properties is based in the same finite volume method of the hydrodynamic model and is independent of the property transported. The same transport module is invoked in the sediment transport, water quality and ecological modules to transport different conservative and non-conservative properties.

The MOHID model provides an answer to different scale predictions through its nesting capabilities. With this methodology, it becomes possible to downscale the solution and also to force local models with large-scale processes. The nested modeling methodology can also be used to integrate in only one tool several local models that are forced with the same regional model, or by assimilation of data (local or remote sensing).

The ecological module uses a zero-dimension formulation that enables the application of the same model with both the lagrangian and the eulerian transport models [3]. In this method the model equations are implemented in the form of source and sink terms of the transport models. Those terms are written in a generic form and can be applied both to eulerian cells and to lagrangian particles. The ecological module simulates the nutrient cycle (phosphorus, nitrogen and silica), the oxygen cycle and organic matter cycle. Primary producers include different classes of pelagic phytoplankton, phyto benthos and macro algae. Recently the microbial loop was also included.

The bottom module computes boundary conditions at the bottom of the water column. It computes shear stress as a boundary condition to the hydrodynamic and turbulence modules. It is also responsible for computing fluxes at the water-sediment interface, managing boundary conditions to both the water column properties and the sediment column properties.
Both in the water column and in the sediment column, properties can be either dissolved or particulate. The evolution of dissolved properties depends greatly on the water fluxes, both in the water column and in the sediment interstitial water. Particulate properties evolution in the water column depends also on the water fluxes and on settling velocity. Once deposited in the bottom they can either stay there or be resuspended back to the water column. If they stay there for a determined period of time, they can become part of the sediment compartment by consolidation.

The MOHID model has been applied to several coastal and estuarine areas and it has showed its ability to simulate complex features of the flows. Along the Portuguese coast, different environments have been studied, including the main estuaries (Minho, Lima, Douro, Mondego, Tejo, Sado, Mira, Arade and Guadiana) and coastal lagoons (Ria de Aveiro and Ria Formosa) [4]. The model has been also implemented in most Galician Rías: Ría de Vigo [5], [6], [7] Ría de Pontevedra [8], [9],[10]. Far from the Atlantic coast of the Iberian Peninsula, some European estuaries have been modeled - Western Scheldt , The Netherlands, Gironde, France[11] and Carlingford, Ireland [12] - as well as some estuaries in Brasil (Santos SP and Fortaleza). Regarding to open sea, MOHID has been applied to the North-East Atlantic region where some processes including the Portuguese coastal current, [13], the slope current along the European Atlantic shelf break, [14] and the generation of internal tides, and also to the Mediterranean Sea to simulate the seasonal cycle, [15] or the circulation in the Alboran Sea, [16]. More recently MOHID has been applied to the several Portuguese fresh water reservoirs Monte Novo, Roxo and Alqueva, [17], in order to study flow and water quality.

5. STUDY SITES

Two Portuguese coastal regions with different characteristics were selected to perform the study: Tagus Estuary and Ria Formosa Coastal Lagoon. Both systems belong to the Natura 2000 Network. In addition Ria Formosa is catalogued as a Natural Park and the upper park of the Tagus estuary is a natural reserve area.

Tagus Estuary

The Tagus estuary is the largest Portuguese estuary and one of the largest European estuaries, located near Lisbon and covering an area of about 300 km2 at low tide and 340 km2 at extreme high tide. The estuary is composed of a deep, straight and narrow inlet channel and a broad, shallow inner bay. The inlet channel, allowing the entrance of seawater in the estuary, is about 15 km long and 2 km wide, while the bay is about 25 km long and 15 km wide. Upstream, a single narrow channel marks the entrance of the Tagus river.

The Tagus estuary is strongly influenced by the products of land and riverine runoff and also by the adjacent offshore waters. This two input sources interact to create temporal and spatial complexity, known to be important in the stimulation of primary production supporting all higher trophic levels. The river flow plays an important role during winter and its influence diminish largely during dry months. The estuary is subjected to strong anthropogenic pressure both of urban and industrial nature, although in recent studies we have concluded that the absence of generalized eutrophication symptoms, despite the high concentration of nutrients in the upper Tagus estuary is a consequence of the growth limitation by light due to the high turbidity. From a remote sensing point of view this estuary is classified as class 2.

Ria Formosa

Ria Formosa located at Algarve in south of Portugal is a shallow coastal lagoon protected from the sea by six barrier islands. It has an average depth of 1 meter. Intertidal flats occupy 80% of its area. A complex network of channels drains this system. The system is connected to the open water through four inlets. The lagoon does not receive permanent fresh water streams. During storm events however, important fresh water flows deliver high amounts of suspended matter to the system. Apart from these periods the lagoon is highly dependent of the coastal water conditions. Nutrients coming from the sea are feed to the system due to the high turnover of the lagoon waters. The anthropogenic impact is not high and is mainly from urban discharges.

From a remote sensing point of view Ria Formosa have regions that can be classified mostly as class 2. Some of the Ria Formosa regions alternate between class 1 and class 2 over time. The shallow areas can behave as class 2 during low waters when the depth is reduced and sediment reflection is important. The deep channels can also alternate between class 1 due to strong influence of clean costal waters and class 2 during high precipitation periods due to high inputs of suspended matter discharged from the fresh water streams.

6. PRESENT DEVELOPMENT STATUS

The Integrated System for Coastal Waters is made up of contributions of ongoing research projects (National and European), in which some structuring elements where already developed and implemented concerning modelling, automatic data acquisition, data sampling and organization of the available data.
The MARETEC research group a long experience, with more then 20 years, in application of numerical models to coastal and ocean areas, it also develops strong research work on data acquisition and monitoring. Recently an automatic data acquisition system was deployed; this system build to be adaptive to several sensors, is now fully operational, positioned on a buoy in the Tagus estuary mouth. New buoys will be deployed in the near future. MARETEC is also strongly involved on different monitoring programs for coastal areas concerning water quality and primary production.. The Integrated System for Coastal Waters is being developed regarding the most recent IT issues, concerning GUI development, database management and WebGIS applications.

6.1 Numerical Modeling

The MOHID model, has been applied in both study sites on different occasions. In more recent applications, MOHID has been applied in an extended study on the trophic level of the study areas concerning the implementation of the nitrate directive, in a project funded by the Portuguese Institute of Water. The processes simulated were hydrodynamics, primary production and sediment transport.

6.2 Data Management

Pre- and post-processing modules or programs complement the MOHID model. Output is performed in HDF (Hierarchical Data Format), and a complete graphical user interface was developed which allows establishing all the condition to run the model in a graphical way and afterwards to explore and analyze the results, allowing a quick and easy integration with EO data for calibration or establishing initial and boundary conditions. The necessity of dealing with large amounts of georeferenced data lead us to the development several WebGIG applications acting as front end of databases for management of this information.

6.3 Data Acquisition and Monitoring

MARETEC as done plenty research work on data acquisition and monitoring, especially on the study sites. As a consequence MARETEC has immediate access to the available data on this locations and has its own monitoring logistics ready to use, including different sensors, (2 fluoremeters, turbidimeter, radiometer, current meters), multiple sampling equipment on board a small vessel which is MARETEC's property and experienced human resources including: oceanographers, geologists, biologists and civil and environmental engineers. Until now only SST data has been used in this system, but there is a strong commitment to integrate MERIS data concerning light extinction and suspended sediments, chlorophyll and yellow substance, being the recent AO proposal an evidence of that. The MARETEC team is already familiar with the MERIS/(A)ATSR Toolbox (BEAM), and interface software is being developed to integrate BEAM libraries on MOHID modeling system.

7. CONCLUSION

The development of the integrated system for coastal water is in the right track and reflects the work accomplish by MARETEC on different areas in the last years. The gap concerning the use of EO data is being filled. For that we trust in the commitment of people on the MARETEC team (2 PhD students are now starting their studies in this area), the cooperation with other research teams specialized on the subject. The success of the recent AO proposal will also be important although we do not consider it a limiting factor.

8. REFERENCES

[1] – GMES - http://www.gmes.info/library/files/Reference%20Documents/GMES_Vision_and_progress.pdf.

[2] – Martins, F. (1999) – Modelação Matemática Tridimensional de Escoamentos Costeiros e Estuarinos usando uma Abordagem de Coordenada Vertical Genérica. Ph. D, Thesis, Technical University of Lisbon, Instituto Superior Técnico.

[3] - Pina, P. M. N (2001) – An Integrated Approach to Study the Tagus Estuary Water Quality. Ms. C Thesis, Technical University of Lisbon, Instituto Superior Técnico.

[4] - Martins, F., P. Leitão, A. Silva and R. Neves (2000) - 3D modeling in the Sado estuary using a new generic vertical discretization approach, submitted to *Oceanologica Act*a.

[5] - Taboada J.J., R. Prego, M. Ruiz-Villarreal, P. Montero, M. Gómez-Gesteira, A. Santos and V. Pérez-Villar (1998) - Evaluation of the seasonal variations in the residual patterns in the Ría de Vigo (NWSpain) by means of a 3D baroclinic model, Estuarine Coastal and Shelf Science 47, pp. 661-670

[6] - Montero, P. (1999) - Estudio de la hidrodinámica de la Ría de Vigo mediante un modelo de volúmenes finitos (Study of the hydrodynamics of the Ría de Vigo by means of a finite volume model), Ph.D. Dissertation, Universidad de Santiago de Compostela, in Spanish

[7] - Montero, P., M. Gómez-Gesteira, J. J. Taboada, M. Ruiz-Villarreal., A. P. Santos, R. J. J. Neves, R. Prego and V. Pérez-Villar (1999) - On residual circulation of Vigo Ría using a 3D baroclinic model, Boletín Instituto Español de Oceanografía„n o 15. SUPLEMENTO-1

[8] . Taboada, J.J., M. Ruíz-Villarreal, M. Gómez-Gesteira, P. Montero, A. P.Santos, V. Pérez-Villar and R. Prego (2000) - Estudio del transporte en laRía de Pontevedra (NOEspaña) mediante un modelo 3D: Resultados preliminares, In: Estudos de Biogeoquímica na zona costeira ibérica,Eds. A.Da Costa, C. Vale and R. Prego, Servicio de Publicaciones da Universidade de Aveiro in press.

[9] - Villarreal, M.R., P. Montero, R. Prego, J.J. Taboada, P. Leitao, M. Gómez- Gesteira, M. de Castro and V. Pérez-Villar (2000) - Water Circulation in the Ria de Pontevedra under estuarine conditions using a 3d hydrodynamical model, submitted to Est. Coast. and Shelf Sc.

[10] - V. Pérez-Villar (1998) - Evaluation of the seasonal variations in the residual patterns in the Ría de Vigo (NWSpain) by means of a 3D baroclinic model, Estuarine Coastal and Shelf Science 47, pp. 661-670.

[11] – Cancino, L. and R. Neves (1999) - Hydrodynamic and sediment suspension modelling in estuarine systems. Part II: Application to the Western Scheldt and Gironde estuaries, J*ournal of Marine Systems* 22, 117-131.

[12] – Leitão, P. C. (1996) – Modelo de Dispersão Lagrangeano Tridimensional. Ms. Sc. Thesis, Universidade Técnica de Lisboa, Instituto Superior Técnico

[13] - Coelho, H., A. Santos, T. L. Rosa and R. Neves (1994) - Modelling the wind driven flow off Iberian Peninsula, *GAI*A, 8, 71-78.

[14] - Neves, R., H. Coelho, P. Leitão, H. Martins, and A. Santos (1998) – A numerical investigation of the slope current along the western European margin. In: Burgano V., Karatzas G., Payatakas A., Brebbia C., Gray W. and Pinder G. (Ed.), Computational Methods in Water Resources XII, 2, 369-376, 1998.

[15] - Taboada, J.J. (1999) - Aplicación de modelos numéricos al estudio de la hidrodinámica y del flujo de partículas en el Mar Mediterráneo (Application of numerical models for the study of hydro-dynamics and particle fluxes in the Mediterranean Sea), Ph. D. Dissertation, Universidad de Santiago de Compostela. In Spanish.

[16] - Santos, A. J. (1995) - Modelo Hidrodinâmico Tridimensional de Circulação Oceânica e Estuarina. Ph. D, Thesis, Instituto Superior Técnico, Technical University of Lisbon.

[17] - Braunschweig, F (2001) – Generalização de um modelo de circulação costeira para albufeiras, MSc. Thesis, Instituto Superior Técnico, Technical University of Lisbon.