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Operational Modelling for Coastal Zone Management – Experiences from OPCOM and Application Possibilities for Environmental Impact Assessment

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Abstract

Within the framework of the OPCOM project, operational and pre-operational tools have been developed to help the local players and decision-makers in managing the coastal environment. In this context operational or pre-operational model systems were applied to four very different coastal zones. The results were analysed for coastal zone management purposes according to the specific local demands for coastal management in close co-operation with possible first users. This publication describes the experience and most important conclusions derived in the OPCOM project regarding the importance and application possibilities of local operational models in integrated coastal zone management.

1. Introduction

Coastal zones are very valuable regions in different ways. They are home for a high percentage of citizens, but also the location of most valuable habitats. They are a major source for food and raw materials, a vital link for transport and trade and favoured destinations for tourists. The environment in these areas is extremely sensitive and vulnerable to the many changes affecting them. Coastal zone management is therefore a very complex subject.

The OPCOM project is dedicated to find solutions or at least first approaches to overcome these tense problems.

2. The OPCOM Project

OPCOM (Operational Modelling for Coastal Zone Management) is an EC funded MAST III project conducted by seven partners from Finland, France, Portugal and Germany between 1997 and 2000. The primary objective of the project was to improve methods and techniques for continuous monitoring and operational forecasting in coastal waters by using an existing operational model and monitoring infrastructure to address needs and quality standards of interested first users. Divided into three main fields the following tasks were elaborated:

- site-specific investigations on coastal management aspects to define user requirements;
- sodel investigations on operational aspects and forecast ability;
- elaboration of a dedicated database structure as the basic operational forecast segment of coastal zone management information systems.

To cover the many different hydrographic situations and coastal management problems the following geographical areas and aspects were investigated:

- The Elbe estuary (German North Sea coast) concerned mainly with the analysis of operational forecast data for shipping traffic information, environmental monitoring, and hazard prediction purposes.
- The Bay of Marennes-Oléron (French Atlantic coast) with special emphasis on sustainable management of oyster farming and the impact of natural and anthropogeneous changes in environmental conditions.
- The Tagus estuary (Portuguese Atlantic coast) with prime objective of water quality monitoring in the vicinity of a submarine effluent outfall.
- The Marine Archipelago between Sweden and Finland looking at spill combating and sea rescue activities and the impact of environmentally relevant discharges from rivers and other effluent sources.

3. Minimum User Requirements

Derived from user interviews and information from daily routine work of the project partner, minimum user requirements have been elaborated. Expectations, quality requirements and even the amount of detail vary greatly depending on the specific user objectives pointing to the absolute necessity for a very flexible approach in dissemination of operational model results. The end user requirements may be categorised according to the following rough distinctions:

Availability of information: The information produced by a management tool must be easily and rapidly available. This includes the capability of processing large amounts of information in such a manner as to facilitate easy search and selection operations. For the combination of information with information from other (external) sources a database must be used which must be capable of dealing with, apart from time series, two- and three-dimensional array data. For the distribution of information client–server architecture via Internet is becoming more and more customary.

Handling of the system: A very costly part of the system is the time required to learn it. Therefore pre- and postprocessing of software which is already known by the final user should be adopted. Standard software should be preferred should be adopted. Graphical Information Systems (GIS) are becoming standard tools for visualisation of model results and provision of input data and should be used where possible.

Costs: Modelling tool costs are split into development, maintenance, learning/training and exploitation. Minimisation depends on each case.

Reliability: Quality assurance must be done for the model code and results. To obtain a good results the data provided for the model must also be of high standard.

Actuality: The results must be available in real time, also short- and long-term forecast information must be provided within a short time.

Some of the major experiences drawn from many years of operational modelling show considerable potential for local small-scale operational models if they could be operated in a smooth and fairly inexpensive way. Some conditions have to be met for successful operation:

- A comprehensive data and information basis: One of the most important criteria for the operability of local operational models is the accuracy of bathymetry and boundary conditions. This information has to be easily available for long periods of time and continuously updated.
- State-of-the-art but easy-to-handle and cheap information technology: Nowadays computer capacity is increasing rapidly, whereas the price for computers is falling almost every day. The same goes for field instrumentation technology which enables the implementation of monitoring plans at lower cost and better coverage of the areas of interest (e. g. satellite images, multibeam measuring devices, etc.). The increase of measuring and modelling capacity also leads to an increasing amount of data generated by these processes. Consequently, efficient data management systems are needed, which enables the users to search and analyse the available information easily.
- Sophisticated data assimilation techniques: Data assimilation is necessary to prove the proper functioning of the model and improve the model results. For short-term forecast boundary conditions must also be predicted. By using data assimilation techniques the quality of the boundary conditions can be improved.
- Long-term stability for coastal management and planning purposes: The design and construction of coastal infrastructures must be based on long-term management options. Models can forecast the evolution of an area for different scenarios and can be used to refine previous predictions.

- Ability to describe the hydrographic variability of the area to enable meaningful user investigations: Local operational models have to describe the spatial and temporal variabilities of hydrographic parameters and their governing processes as naturally as possible. The physical conditions alone will point to the minimum resolution necessary to look at coastal variability.

Generally the operation of local models needs a stable background of infrastructure (and respective funding) to ascertain successful long-term support for coastal zone management.

4. Operational Aspects

Local operational models need a certain amount of precise information prescribing state variables and fluxes of mass, energy and momentum at the boundaries of the model domain. The necessary field data information comprises data quality, data sampling period and spatial data coverage. Data quality is essential when hydrographical and meteorological data are used in hydrodynamic models as model boundary conditions. Often large-scale models can be used to define boundary conditions of smaller scale models, but also real-time automatic measurement stations can be used, if available. In this context, some problems may have to be solved, for example, different time and space resolutions between models, inaccuracies in larger scale model predictions and data gaps (e. g. breakdown of measurement devices).

Eventually, the better data at hand, the better are possible boundary conditions and model verification and the more reliable and useful can the results be obtained. The experience of the OPCOM project showed that the necessary data requirements vary from case to case and must be evaluated separately for each model application. The model reliability may be investigated by model verifications, such as comparison of model results and measurement data. Besides direct comparisons indirect methods such as transport computations and plausibility tests can also be used.

For the smooth operation for and flexible adjustments to coastal models, some requirements have to be fulfilled. First of all the whole operational system should have a module-like shape to enable easy adaptation to the state-of-the-art hardware and data links, models, and software solutions. Furthermore, there is a need for actual information from people or organisations outside, e. g. harbour authorities or fish farmers, with their experience of day-to-day routine. Data management is a key element of the operational system, enabling the introduction of more detailed or precise data or improved model algorithms at any time and in this way enhance the quality of long-term monitoring results continuously. Finally, it must be ascertained that the operation of such a system can be performed continuously, without any gaps in funding, data provision or availability of scientific and technical expertise and experience, which comprises the availability of personnel and financial resources.

Local operational models normally produce a vast amount of data and information which has to be managed in such a way that the user can easily retrieve those figures he is interested in without having to worry about data formats and access. Though general rules cannot be defined since every single application has special requirements, some guidelines may be outlined here. One project task was the development of a user-friendly and simple program for assisting the analysis and management of local problems, based on recent information analysis, storage and display technologies (RDBMS – Relational Database Management System, object-oriented DBMS capable of managing binary large objects (BLOBs), web site database, Geographical Information Systems, etc.). Since even powerful databases could not manage the huge amount of data (measurement and model) in a fast and easy way, a solution would be either the use of an object-oriented DBMS capable of managing BLOBs or just storing header or meta information in the database together with a pointer to the location of the affiliated numerical data, or a mixture of both. Different file formats and storing techniques for database-external data (or BLOBs) are available. HDF (Hierarchical Data Format) and net CDF (Common Data Format) are the most widespread and commonly used ones. For the manipulation of data editing and viewing tools must be provided which may range from a simple text editor to graphical map-based parameter editors and 3D visualisation tools. A more sophisticated model management browser requires separate tools for handling model input data, setting of model parameters and displaying of model results. These tools can be handled directly by the user with a graphical user interface (GUI) and affords him access to the data easily and to represent them in an illustrative way. This comprises e. g. the following tasks:

- displaying map information from the model area
- selecting model data to be displayed, e. g. time series 2D fields or animations
- displaying measurement data
- computing statistical information
- exporting data for further processing.

Open application standards such as SQL, SGML, TCP/IP-protocols and Java script were used. Figure 1 depicts an example of an operational model system including a data management tool for handling of model data.

5. Application Possibilities

The examples of the OPCOM project show the wide range of application possibilities for local operational models with user-friendly forecasting and coastal management tools. Some are described in the following.

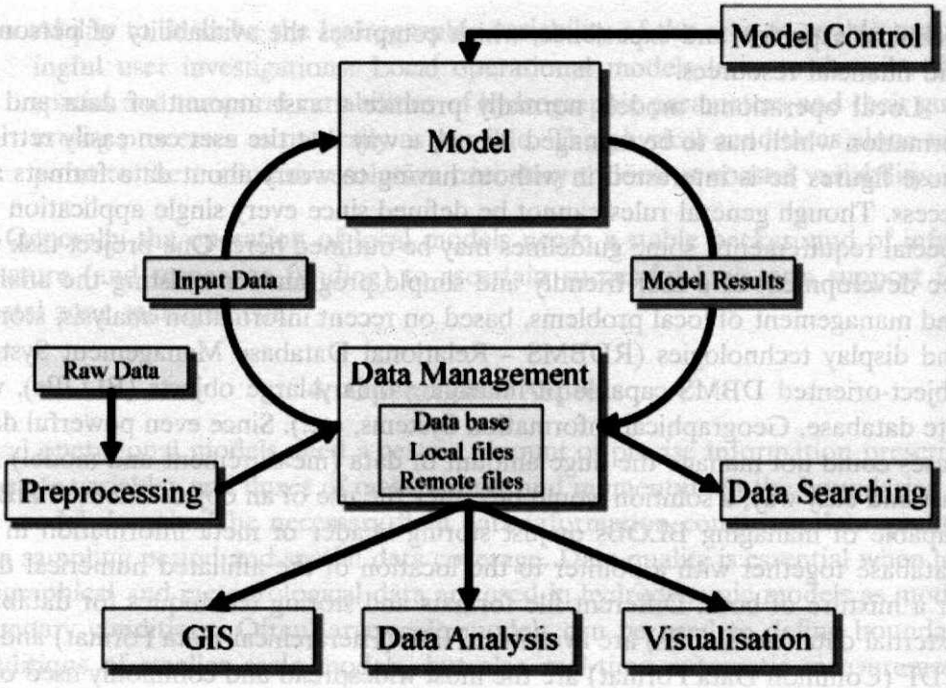


Fig. 1. Management panel of an operational model system

Oyster farmers in the Bay of Marennes-Oléron are very interested in the hydrometeorological conditions under which the plume of fresh water flowing into the bay from the river Charente is pushed to the south-eastern part of the bay, along the coastline, and then enters the Seudre estuary where many oyster farms are located. Freshwater inflow is an important factor for the sustainability of oyster farming (survival, growth and reproduction), therefore there is a strong demand for decision-making tools with integrated model results for overall water quality management of the bay. The system elaborated in OPCOM combines the results from the TELEMAC numerical model with GIS information. An interface based on ARVIEW including the database structure and the AVENUE object-oriented language was developed to select, visualise and superimpose on existing geographical information the output of the hydrodynamic and transport computations. The model output files are converted into direct-access binary files, which support a quick selection and retrieval of data. Furthermore, some tools for statistical analysis were implemented to show the model output on the GIS-like map. With these tools time series of different parameters (e. g. salinity, current velocity, etc.) can be visualised for a selected site, including basic statistics, such as mean, standard deviation, minimum or maximum percentage of values, etc. Statistics of salinity, current velocity or water-level can be computed and mapped for the whole area. Values along a transect can be extracted and displayed as a table or graph. Figure 2 gives an example of graphical model information for a selected part of Marennes-Oléron Bay.

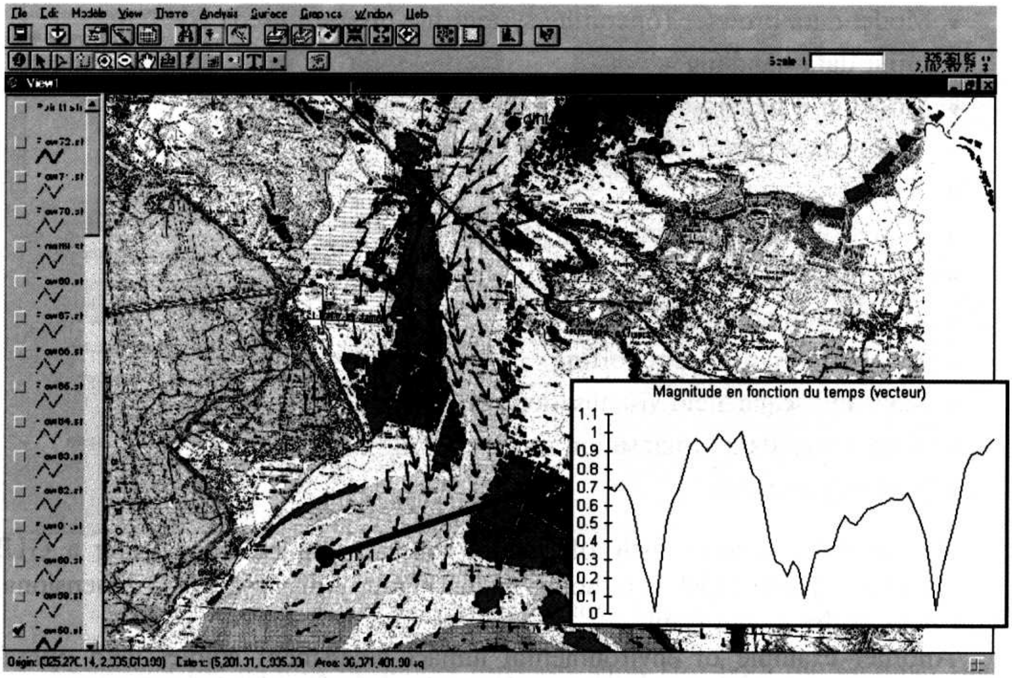


Fig. 2. GIS and model information for a selected part of Marennes-Oléron Bay

Another example is the Archipelago Sea which consists of thousanda of islands and islets. The main problem in the area is eutrophication which causes, a. o., algae blooms including toxic algae and oxygen depletion. Nutrients are transported to the Archipelago Sea from the southern and eastern nutrient-rich waters, but there are also local loadings from watersheds on the Finnish mainland, from fish farming and municipal sources and internal loads from bottom sediment. The objective within OPCOM was to create a verified dynamic flow model for the Archipelago Sea region that can be used as a tool for water flow, water exchange and nutrient dispersion computations. The client for this model system is the South-West Finland Regional Environment Centre which is a participatory and guiding authority. Its task is the assurance of the prerequisites of sustainable development in the Southwest region of Finland. Additionally the centre studies and monitors the state of the environment and reasons for changes.

A model management system integrates a set of existing modelling and data processing software into a modelling system and provides a basis for further development of modelling tools. Different user needs can be supported, ranging from viewing of model results to building of model applications, by providing different tool sets for different modelling tasks. Typical modelling tasks with related tools include:

- Model tool start-up
- Model data browser (operating system file browser used)
- Input data handling
- Model grid generation tool
- Time series import tool
- Data conversion tools
- Model run management
- Model run management tool
- Computational model
- Data visualisation & reporting
- Flow and scalar field visualisation tool
- Time series data visualisation tool
- Report generator

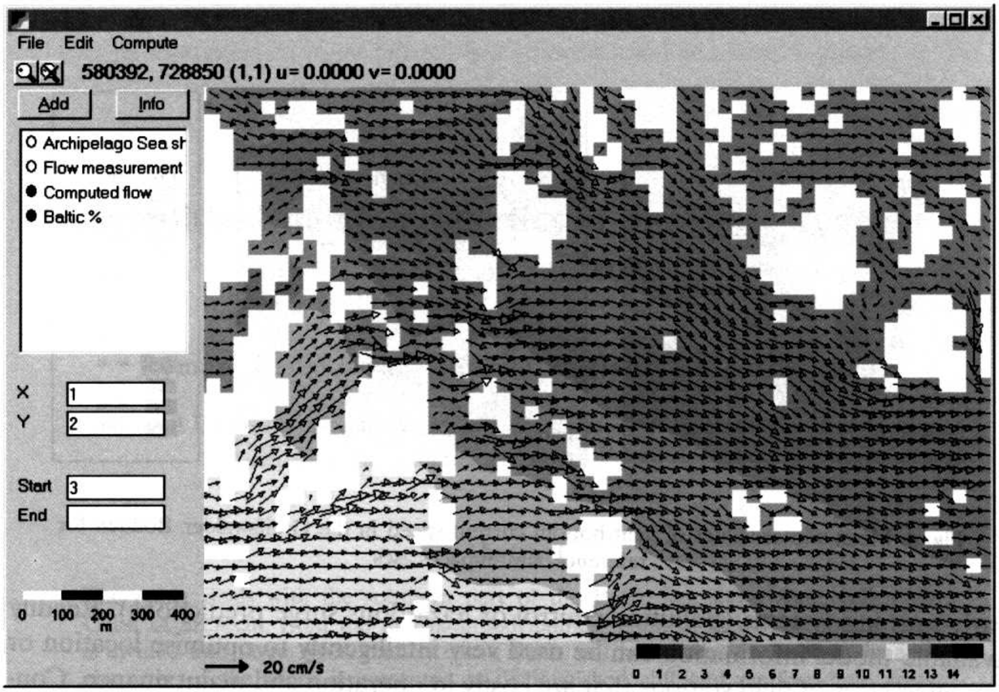
The toolkit consists mostly of custom software implemented using a GUI development system which is in-house made. Figure 3 displays a two-dimensional flow field as the model result.

Another example of environmental impact assessment studies with operational models comes from the German research project KLINO (Climate-Induced Changes in Coastal Zone Dynamics) where the likely impact of climatic changes on the baroclinical dynamics and salinity-temperature variability in two hydrographically different estuaries, the tidal river Elbe and the non-tidal bays of Greifswalder Bodden and Oderhaff, was investigated.

Information of long-term variations of hydrographic and meteorological parameters were obtained from a meso-scale model of the North and Baltic Sea. Special emphasis of the investigations was laid upon the bandwidth of natural variability in both estuaries to compare this with the climate change impact derived from the model investigations.

Base for the model studies were high-resolving three-dimensional baroclinical estuary models which were specially designed to investigate changes in salt water intrusion and associated local transport and circulation processes.

In particular, a climate change scenario in the northern hemisphere was investigated, which implied a strengthening of the westerly wind component between latitudes 52° and 62° North with a seasonal variation with extreme values of approximately +2.4 m/s in winter and +1.4 m/s in summer. The small-scale coastal models received boundary conditions from the meso-scale models which are available for a period of more than a decade (1979 to 1993).



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○ Archipelago Sea sh
○ Flow measurement
● Computed flow
● Baltic %

X 1
Y 2
Start 3
End

Fig. 3. Visualisation tool for a 2D field

Generally the meso-scale model forecasts show (for both the German Bight and the southern Baltic Sea) marked increases in salinity, small variations in surface temperature and a small raise in mean water-levels. The effects for the Greifswalder Bodden application is described in Figure 4. The impact case differs from the reference case only by the wind modification.

The non-tidal waters of Greifswalder Bodden (south of the island of Rügen) and the Oderhaff do show a significant response to the local wind field modifications. This is most prominent in the winter situation. Here the wind-induced currents are enhanced (even in the monthly mean) by up to 30%. Due to higher mean waterlevels and the increased salinity in the Baltic Sea a stronger and more frequent inflow of salt water into the Oderhaff is predicted by this climatic change scenario.

6. Conclusion and Outlook

In general there are quite a number of different objectives of coastal zone management where local operational models could be of considerable help. This includes long-term routine monitoring and assessment activities in coastal waters to complement existing field measurements and observations, assistance in decision support by providing impact assessment information, short-term information, e. g.

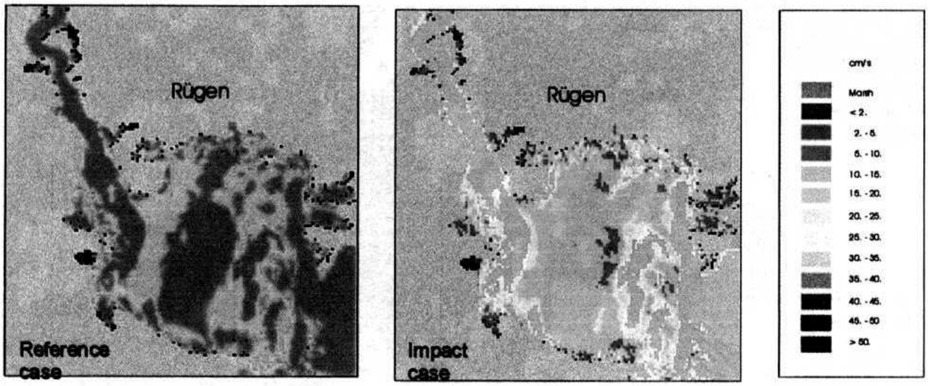

Fig. 4. Mean winter values of near-bottom current speed in the Greifswalder Bodden for reference and impact cases

early-warning systems (pollution control or hazardous surge predictions). Readily available model information can be used very intelligently to optimise location or sampling rates of field stations that are costly in operation and maintainance. Continuous check of field measurement registrations with the corresponding model results could be used very efficiently to look at data quality.

However, improving model strategies for coastal management objectives is still challenging. The possible wealth of background information (including statistics) is not yet fully appreciated by users and not efficiently marketed by model data suppliers. The coupling of coastal models with shelf sea models and river basin models could be pushed more efficiently to arrive at integrated scientific tools. The coupling of hydrological/ecological models with socio-economic planning tools can improve coastal zone management. How to improve model accuracy and efficiency for individual applications? How to improve the model's forecast ability concerning topographic changes within coastal areas of high spatial and temporal variability? These are some open questions and problems which remain to be solved.