The ADRICOSM Pilot Project: a coastal and river basin prediction system for the Adriatic Sea

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The ADRICOSM project was launched in October 2001, and ended in March 2005, with the main objective of demonstrating the feasibility of a near real time operational marine monitoring and forecasting system at the shelf and coastal scales, with connections to river basin runoff and coastal town sewer systems. The basic system consisted of an efficient network for the collection of marine data such as in situ *temperature and salinity profiles and satellite sea surface temperature, a regional (AREG) and shelf scale modeling system, a data assimilation system and finally a coastal scale modeling system. Every week AREG releases 7 day marine forecasts at 5 km horizontal scales, which are used to nest other hydrodynamic models toward the coastal scale. Two shelf models (ASHELF-1 and ASHELF-2) at a 1.5 km horizontal scale were nested in AREG in order to simulate (and in the future to forecast) shelf scale oceanographic features. Another important aspect of ADRICOSM was the integration of the Cetina river (Croatia) and urban sewage monitoring/ modeling (Split, Croatia) systems with the shelf marine model. This integrated model system was used to simulate the dispersion of sewer discharges from the urban area in the coastal waters for water management performance studies. ADRICOSM is one of the first integrated land and marine waters operational oceanographic systems able to meet the urgent needs for reliable integrated coastal forecasts for the effective management of marine areas.*

Key words: ADRICOSM, prediction, Adriatic Sea

INTRODUCTION

The Adriatic Sea is an important shelf area where the occurrence of critical environmental issues such as extensive algae blooms, seawater anoxia and coastal erosion may affect the economic activities of the area. An effective management of the Adriatic marine environment in order to control its evolving state and its trends is essential. An "operational coastal management system (OPCOMS)" is needed, and should include systematic and long-term routine oceanographic/wave/atmospheric and biochemical measurements and modeling, along with their rapid interpretation/dissemination to a large number of end-users. OPCOMS therefore has great potential as the basic support for environmental coastal assessment and

the development of marine warning systems. Examples of possible data products include warnings (of coastal floods, storm damage, harmful algal blooms, oil spills and other contaminant dispersal, etc.), optimal ship routing, predictions of primary productivity, ocean currents, ocean climate variability, etc.

The ADRICOSM Pilot Project (ADRIatic sea integrated COastal areaS and river basin Management system pilot project) is a scientific pilot "pre-operational" project aimed at the implementation of a NRT (Near Real Time) OPCOMS at the shelf area scale. ADRICOSM is based on experience drawn from the MFSPP project (Mediterranean Forecasting System Pilot Project, PINARDI et al., 2003), which was aimed at building a NRT Mediterranean scale monitoring and nowcasting/forecasting system (Fig. 1) to become the backbone of an operational and sustained Mediterranean operational oceanography system for the open ocean and its coastal areas.

The main objectives of the ADRICOSM Pilot Project were:

• to demonstrate the feasibility of NRT nested coastal current forecasts,

• to develop the integration of a river monitoring and modeling system with coastal marine forecasting at a test site near Split (Croatia).

The ADRICOSM Pilot Project was launched in October 2001 within the Adriatic Ionian Initiative, which has demonstrated the political will to construct a multinational force for the environmental protection of the Adriatic Sea. Moreover, ADRICOSM was built upon the Italian-Slovenian-Croatian agreement for scientific and technological collaboration in the Adriatic Sea. ADRICOSM was also designed to be consistent with the international directives defined in the UNESCO-IOC Coastal Global Ocean Observing System (C-GOOS) and the UNEP-Mediterranean Action Plan Integrated Coastal Areas and River Management Program. ADRICOSM involved sixteen Scientific Institutions from three Adriatic riparian countries (Italy, Slovenia and Croatia) and from France. Furthermore, the ADRICOSM Project was also designed as the backbone of the ADRICOSM Partnership, which was launched as a Type II
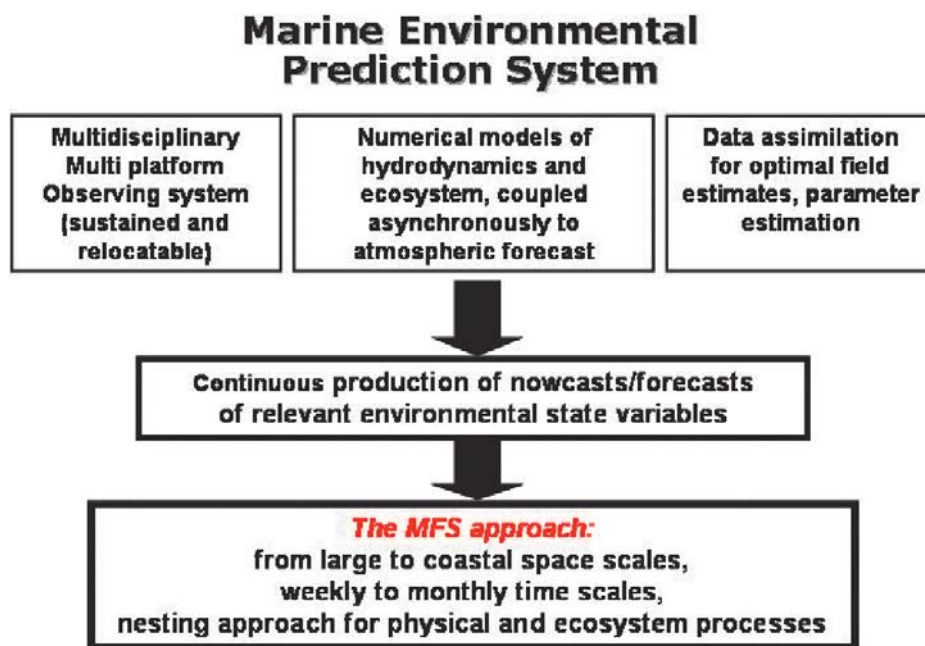

Fig. 1. The Mediterranean Forecasting System approach as a basis for constructing a marine environmental prediction system

Initiative at the World Summit on Sustainable Development (WSSD) in Johannesburg in September 2002 by the Italian Ministry of Environment and Territory. On April 2004, the ADRICOSM Partnership was inserted as one of the Mediterranean Components of the EU Water Initiative. Finally ADRICOSM was also part of the Mediterranean Forecasting System Toward Environmental Predictions (MFSTEP) project as one of the regional Mediterranean components. The ADRICOSM Pilot Project ended in March 2005, although some other projects such as ADRICOSM – PULA BAY and NERES (NEretva River delta Environmental requalification and Sustainable development) started within this context.

In the following paper we shall describe the ADRICOSM system components such as the observing and marine forecasting systems and the river basin integrated modeling, concluding with a discussion on the societal usage of the marine forecasting system. The detailed scientific results from each component are illustrated in other papers of this volume.

THE ADRICOSM OBSERVING SYSTEM COMPONENTS

The ADRICOSM project co-ordinated a highly complex network of platforms for oceanographic NRT data collection. The components were:
  • Voluntary Observing Ship (VOS) temperature profiles by XBTs,
  • satellite sea surface temperature and chlorophyll data,
  • CTD (Conductivity-Temperature-Depth) coastal networks for temperature and salinity profiles, and *in situ* buoy stations for ocean surface variables and meteo-marine parameters.

The Voluntary Observing Ship (VOS) temperature profiles

Two XBT tracks (so-called ADRIA-VOS-1, ADRIA-VOS-2) for collecting temperature profiles, with 10 nautical mile resolution along track, were organized and implemented with monthly and bi-weekly sampling frequency during ADRICOSM. This horizontal resolution was selected in order to resolve the mesoscale
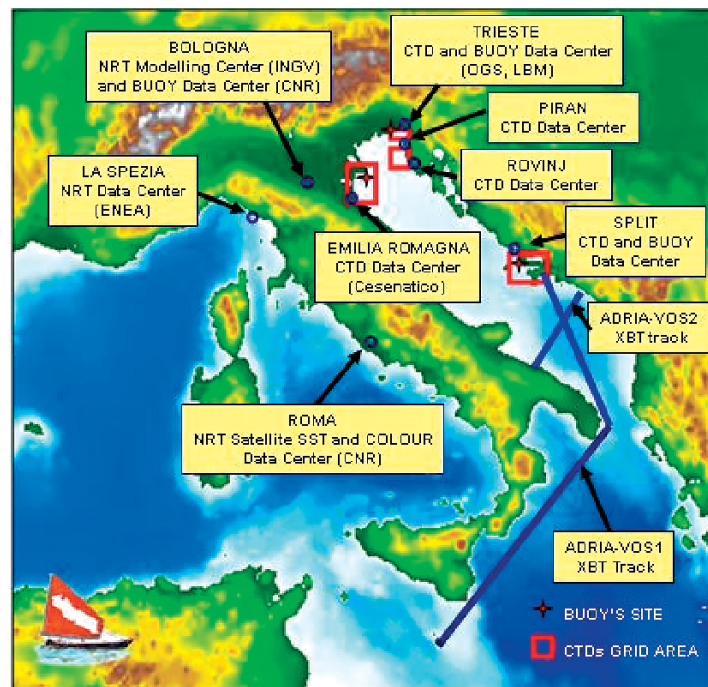

Fig. 2. The ADRICOSM marine monitoring system (CTD, XBT and buoys) with the different data collecting centres

in the southern Adriatic basin, where the first baroclinic radius of deformation is about 10 km. The ADRIA-VOS-1 runs from Ploče (Croatia) to Malta, while the ADRIA-VOS-2 extends between Dubrovnik and Bari (Fig. 2). The Ploče-Malta track, managed by OGS (Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Trieste, Italy), was established during the MFSPP project and continued during the ADRICOSM project (GAČIĆ *et al*., 2006). The Dubrovnik-Bari track was managed by IOF (Institute of Oceanography and Fisheries, Split, Croatia) (MOROVIĆ *et al*., 2006) and ENEA (Agency for New Technology, Energy and the Environment, La Spezia, Italy). Both tracks started on October 1, 2001 and were completed in October 2004. Inter-comparison of the profiles between the two different tracks at a cross-check station in the central Southern Adriatic basin showed the consistency of the data collected by the two VOS ships. The XBT measurements were collected according to common protocols for data acquisition, transmission and control (MANZELLA *et al*., 2003; MANZELLA *et al*., 2006). The full-resolution VOS-XBT profiles were transmitted in NRT via cellular phone to the ENEA collecting centre (La Spezia, Italy) where quality checks on the data were performed.

The satellite data

The Satellite Oceanography Group of ISAC-CNR (Institute of Atmospheric and Climate Sciences – National Research Council, Rome, Italy) developed, during the ADRICOSM project, the first NRT distribution system of satellite data products consisting of remotely-sensed ocean colour and sea surface temperature (SST) data (SCIARRA *et al*., 2006). The service comprised of data acquisition, data processing and data distribution and it provided satellite data products for the period October 2002 – March 2005. This long-term time series of satellite data products was used to validate the regional model seasonal temperature cycle and contributed to the monitoring of water type properties in the Adriatic Sea. The following data products were available during the ADRICOSM project:

- Adriatic Sea Real-Time satellite-derived SST, Chlorophyll *a* concentration, case I and case II waters along with cloud mask images at a 1-km resolution,
- Daily Optimally Interpolated-OI SST at a 5-km resolution (model grid),
- Daily Optimally Interpolated-OI Chlorophyll *a* at a 5-km resolution (model grid).

The CTD data

During ADRICOSM a network of coastal monitoring stations measuring depth, temperature, conductivity (salinity) and oxygen profiles was upgraded or established in order to capture the low frequency signals that have periodicity greater than the tidal and inertial oscillations. In the case of ADRICOSM the sampling interval was chosen to be two weeks during the pre-operational period and one week during the operational period and data were collected within two days for each area (synoptic sampling). The areas where the CTD stations were implemented (Fig. 2) were:

- the Emilia-Romagna coastal area (EM), which was managed by ARPA (Regional Agency for Environmental Protection of Emilia Romagna, Cesenatico, Italy) (MANZELLA *et al*., 2006);
- the Gulf of Trieste (GT), which was managed by LBM (Laboratory of Marine Biology, Trieste, Italy) (CELIO *et al*., 2006) and by MBS (Marine Biological Station, Piran, Slovenia) (MALAČIČ & PETELIN 2006; MALAČIČ *et al.*, 2006);
- the Rovinj coastal area (RO), which was managed by CMR (Centre for Marine Research - Institute "Ruđer Bošković", Rovinj, Croatia) (LYONS *et al*., 2006);
- the Pelješac-Vis-Drvenik coastal area (PVD), which was managed by IOF (Institute of Oceanography and Fisheries, Split, Croatia) (GRBEC *et al*., 2006).

Some of these areas were defined *ad hoc* for the project while others were derived from existing monitoring systems such as the Emilia-Romagna and the Trieste areas. During ADRICOSM an intercalibration experiment for the marine probes (CTD) used for this network

was conducted and showed consistency among the measurements. A CTD data collection protocol was developed for all the CTD coastal networks. All network CTD data were collected in about one, or maximum two, days and were transmitted after a few hours to the ENEA Data-Center (La Spezia, Italy) through an ftp data transmission system. The bi-weekly and weekly data collections were conducted from September 2002 to December 2003, except for the Emilia-Romagna area where monitoring continues for institutional purposes, the network being part of the traditional ARPA monitoring network.

The *in situ* buoys

Two *in situ* multi-parametric permanent stations were used in addition to one completely developed during ADRICOSM with the main purpose of evaluating the marine forecast quality (Fig. 2):

- the Po river "S1" buoy station (BORTOLUZZI *et al*., 2006);
- the Tagliamento river "MAMBO" buoy station;
- the Marjan Cape (Split) station (DADIĆ *et al*., 2006).

The S1 buoy was started during ADRICOSM (BORTOLUZZI *et al*., 2006) while the others were already functioning and the data, if requested, were made available to the ADRICOSM partners. The S1 station data were compared each day to the products derived from the forecasting model of the Adriatic Sea, thus contributing to a real time validation system.

Marine data transmission and management

During the ADRICOSM project a number of centres were networked (Fig. 2). Each of these had a different responsibility yet all of them worked with ftp and Web pages to make available in NRT the different ADRICOSM products. In particular, for CTD and XBT a robust transmission strategy was applied. The XBT data, after collection, were sent by GSM phone to the ENEA Data-Centre, where they were quality-controlled and archived. The NRT procedures for the XBTs quality control were developed in the MFSPP project (MANZELLA *et al*., 2003; MANZELLA *et al*., 2006), and usually took about 20 minutes to quality-control the data. Finally, through a Web service it was possible to access the raw XBT data (the original temperature profiles) and the CTD quality controlled data in MedAtlas format, which is the European data standard developed in the context of different European projects over the past ten years.

THE MARINE MODELING COMPONENT AT BASIN AND SHELF SCALE

The ADRICOSM modeling system consisted of the following components (Fig.3):

- the Adriatic Regional Model (AREG),
- the north Adriatic Shelf Model (ASHELF-1),
- the Adriatic Shelf Model for the Split coastal area (ASHELF-2),
- the Gulf of Trieste models (ACOAST-1 and ACOAST-2).

The AREG and ASHELF models

In ADRICOSM the most widely used circulation model was the free-surface, three-dimensional finite-difference numerical model based on the Princeton Ocean Model (POM) (BLUMBERG & MELLOR, 1987). During this project POM was implemented in two main versions: the Adriatic Regional Model (AREG) covering the entire Adriatic basin (ZAVATARELLI & PINARDI, 2003; ODDO, 2005; ODDO *et al*., 2005; ODDO *et al.,* 2006) while the Adriatic Shelf Model covered the north Adriatic Sea (ASHELF-1) (ZAVATARELLI & PINARDI, 2003; ODDO, 2005) and the coastal area of Split (ASHELF-2) (ORLIĆ *et al*., 2006).

The AREG, ASHELF-1 and ASHELF-2 models all use grids with constant horizontal resolution. The AREG grid has a resolution of 5 km (approximately 1/20°), and its model domain encompasses the entire Adriatic basin and extends south of the Otranto channel into the Northern Ionian Sea, where the only open boundary is located. The ASHELF-1 grid has a horizontal resolution of 1.5 km (approximately
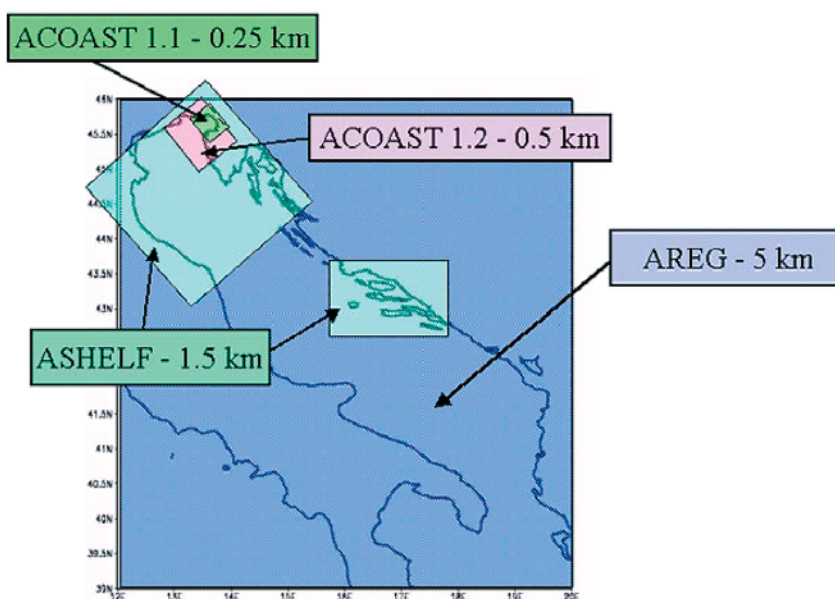
Fig. 3. The ADRICOSM nested modeling network

1/37°), and the only open boundary cuts the basin across an ideal line running from the southern tip of the Istrian peninsula to the Italian coast at approximately 43.6° lat. N (ODDO, 2005). Finally, the ASHELF-2 grid has a horizontal resolution of 1 km and its domain covered the Split coastal area including the islands of Brač and Šolta, the channel between the Pelješac peninsula and the island of Korčula, and the channel between the mainland and the island of Hvar (ORLIĆ *et al.*, 2006).

The atmospheric forcing for AREG, ASHELF-1 and ASHELF-2 was provided by ECMWF (European Center for Medium range Weather Forecasting) surface variables with interactive air-sea physics (ODDO *et al.*, 2005). In the AREG model the monthly river runoff data were obtained from the monthly climatology, and the major Adriatic rivers were considered as point sources while minor contributions have been defined as distributed source functions. The ASHELF-2 model included four rivers: Jadro, Žrnovnica, Cetina and Neretva (ORLIĆ *et al.*, 2006). The models were hierarchically connected to one another by simple one-way nesting techniques. In addition, the AREG model was connected to the Mediterranean Forecasting System general circulation model covering the entire Mediterranean basin (Fig. 3).

The ACOAST 1.1 and ACOAST-1.2 models

Very high horizontal resolution marine models were also developed for the Gulf of Trieste in two different versions: ACOAST-1.1 and ACOAST-1.2. The ACOAST-1.1 domain is a grid with a horizontal resolution of 250 m. The ocean model used was the MIT circulation model (Massachusetts Institute of Technology, Boston), which is a three-dimensional, finite volume (with partial cells capability), free surface numerical model (CRISE *et al.*, 2006). It can be run in non-hydrostatic mode and allows the use of alternative numerical schemes for the advective and diffusive terms. The ACOAST-1.2 was a POM model installed with a resolution of 0.5 km x 0.5 km, which was one-way nested in the ASHELF-1 model of the Northern Adriatic. Its domain covers an area surrounding the Gulf of Trieste in the Northern Adriatic (MALAČIČ & PETELIN, 2006).

The AREG forecasting system

ADRICOSM demonstrated the feasibility of an NRT marine forecasting system working
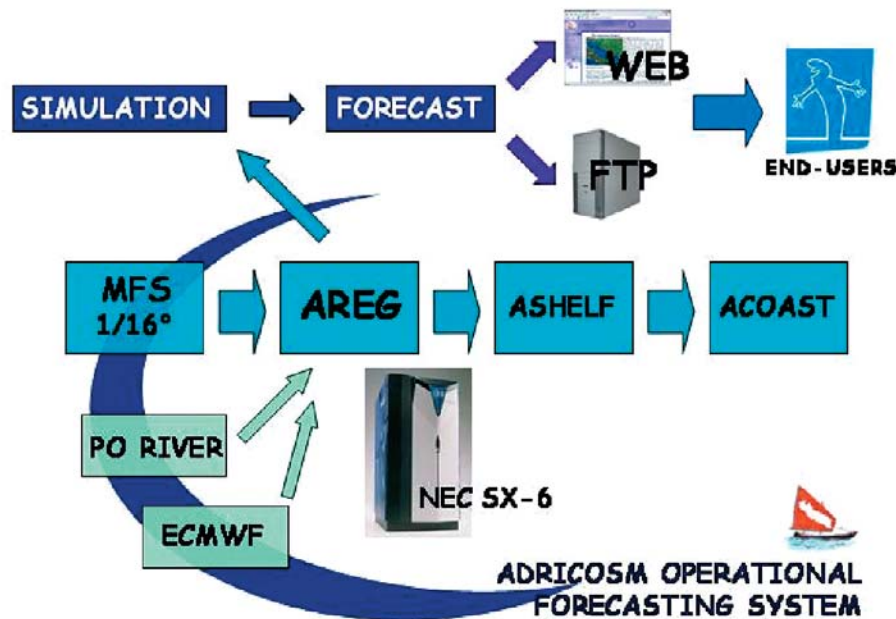
Fig. 4. The ADRICOSM operational forecasting system is composed of the AREG model at a 5-km horizontal resolution which gets the boundary conditions from the Mediterranean model. The downscaling is performed along the nested model chain, ASHELF at a 1.5-km horizontal resolution and ACOAST at 0.5 km. Input data are the atmospheric forcing from ECMWF and the daily Po River discharge from ARPA Emilia Romagna. AREG runs on an NEC-SX6 supercomputer, situated at the NRT-Modeling-Centre (INGV, Bologna, Italy). Model simulations and forecasts are released once a week and disseminated via FTP. The forecast bulletin is published on the ADRICOSM Web site and data are available to the end-users on request

at shelf scales. This result is the outcome of a complex technological and scientific chain (Fig. 4). In the Adriatic Sea, the forecast time span is determined by the capability to predict the river run-off, such as the Po River (ODDO *et al.*, 2006). The forecast lead time was then established to be seven days even if ECMWF forecast was available for ten days.

The dissemination of the AREG simulations and forecasts was conducted through the Web network on a regular weekly basis. Forecasts and simulations were produced once a week and published (http://www.bo.ingv.it/adricosm) on Wednesday at noon, 24 hours after the actual start of the forecast. Three types of graphic outputs were produced:

1) horizontal fields in the entire model domain (Fig. 5), with the exception of the velocity fields which were divided in sub-regions to show the circulation in finer detail,

2) zooms over selected regions,

3) sections along transects (Fig. 6) where CTD data were collected.

The available fields over the entire basin were:

- Surface fields: Total Heat Flux (Wm^{-2}), Sea Surface Elevation (m), Sea Surface Anomaly (m), Wind Stress (dyn cm^{-2}),

- 3-D fields: Temperature (°C), Salinity (psu), Temperature Anomaly (°C), Salinity Anomaly (psu), Total Velocity (m s^{-1} and knots).

Another important step was the development of a data assimilation scheme for the CTD and XBT data collected during ADRICOSM. However, data assimilation was not implemented in Real Time and the project produced only a delayed mode assimilated data set that was available on request. The data assimilation system used in ADRICOSM was SOFA (System for Ocean Analysis and Forecast, DE MEY & BENKIRAN, 2002), and it was applied for the first time in coastal areas (GREZIO & PINARDI, 2006).
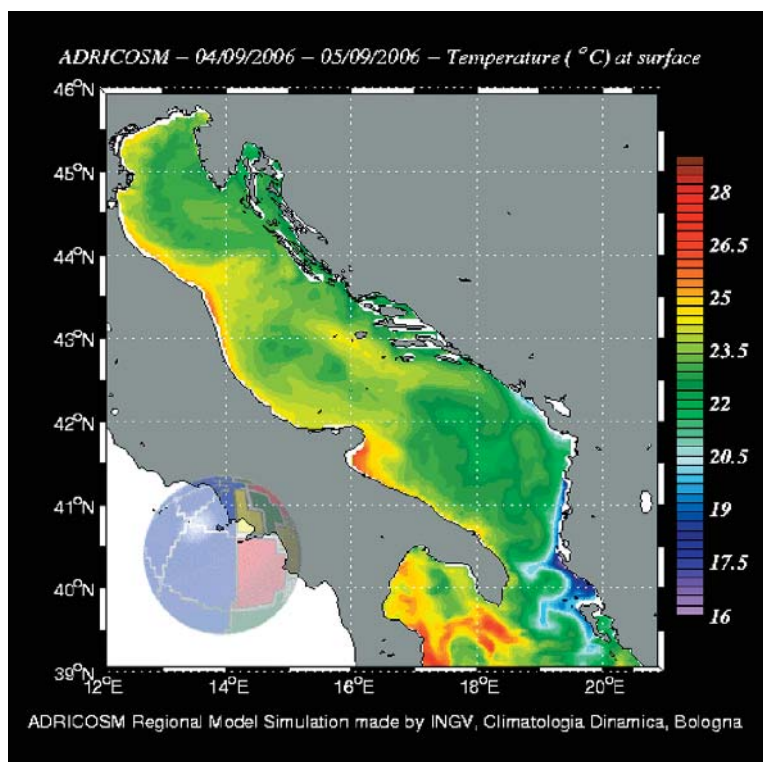
*Fig. 5. Graphic output for the entire basin: sea surface temperature simulation
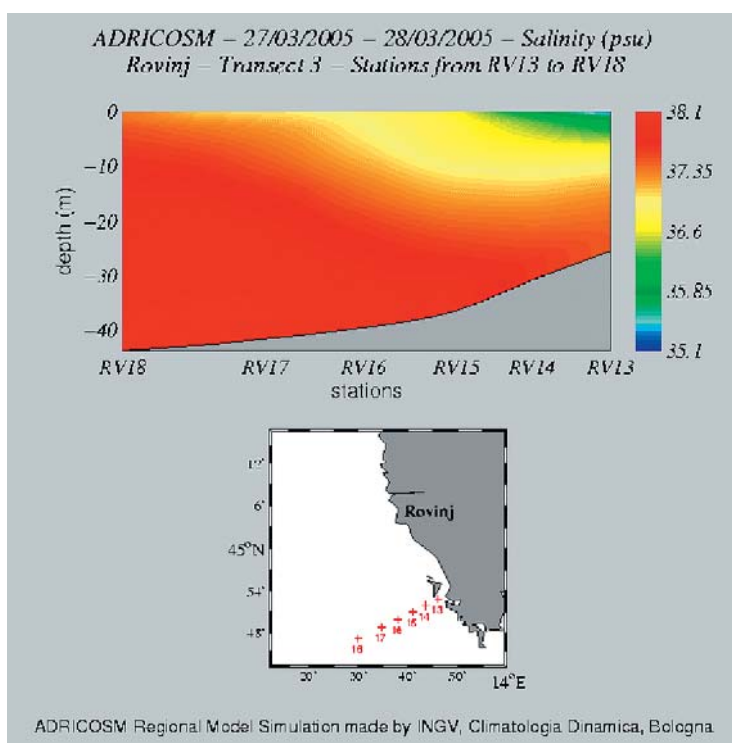as an average for 4-5 September 2006*

*Fig. 6. Sections along transects disseminated through the Web: an example
of the salinity field along the southern transect of Rovinj*

THE INTEGRATED RIVER BASIN AND COASTAL AREA COMPONENT

The third important development in ADRICOSM was based on the Split-Brač-Hvar coastal area with connections to the Cetina river basin and Split sewer system. The Cetina is an important river in the middle karstic coastal area of Croatia and, due to its large water flow, is used as a water supply for agricultural activities, for hydro-electric purposes and for recreational activities. This river is now completely regulated although it still provides the coastal area with organic and inorganic suspended materials making these areas among the most critical on the Croatian coastline.

Existing hydrographic data for the river basin, along with data of the Split sewer system, the river watershed and the coastal area, were acquired and organised in a data-base (BETTIN *et* *al.*, 2006). Water quality data were then obtained through automatic samplers placed at suitable locations within the sewer network and in the Cetina river. Finally, measurements of quality parameters (Total Nitrogen – COD, Suspended Solids – SS) were provided through laboratory analyses. The water quality measurements were essential for analyses of urban drainage impact on the receiving water body and for the planning of measures to reduce the pollution. In order to simulate all components of the watershed of the Cetina river basin and the urban sewage system the following models were used (Fig. 7):

• the MOUSE model (Danish Hydraulic Institute - DHI) for the Split Sewer System,

• the MIKE11 (DHI) for the Cetina river,

• the RMA2-SMS (Surface water Modeling System) from Environmental Modeling System, Inc., Utah, for the Split coastal area (Fig. 8).
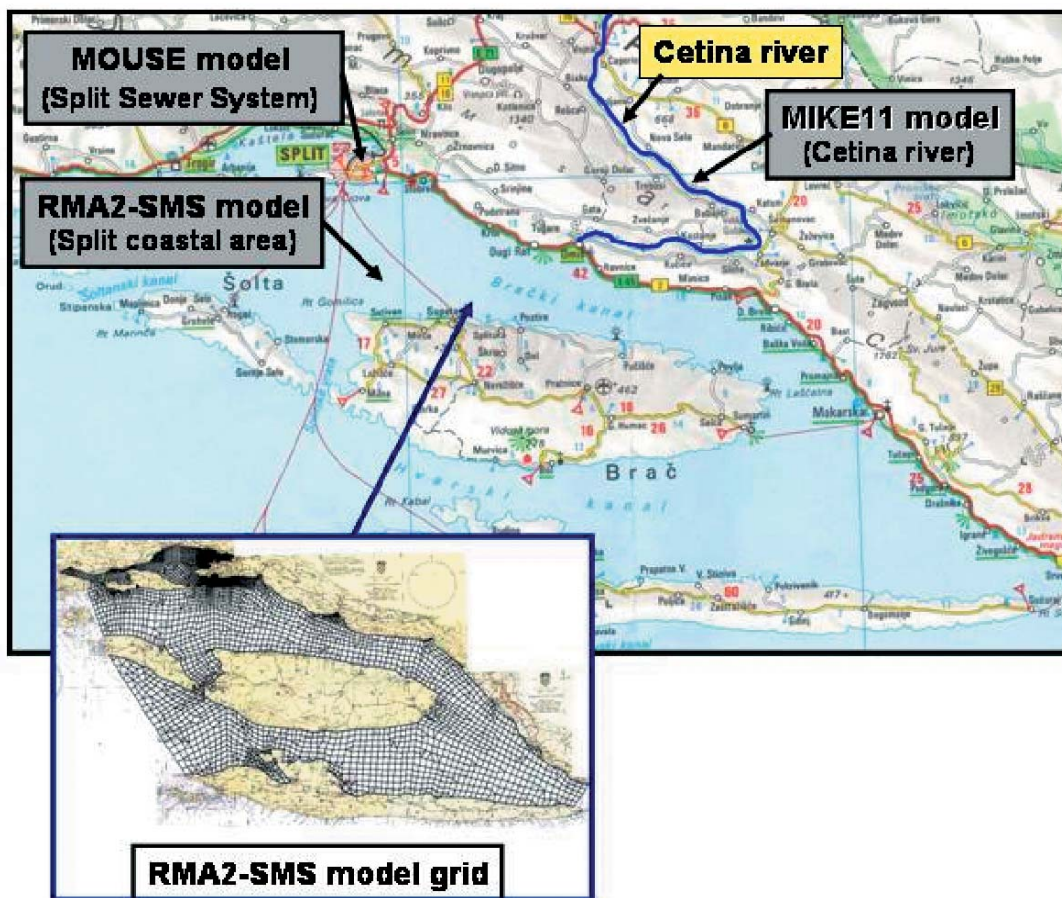

Fig. 7. The three different models used for the Cetina catchment analysis: the MIKE11 model, the MOUSE model and the RMA2-SMS model
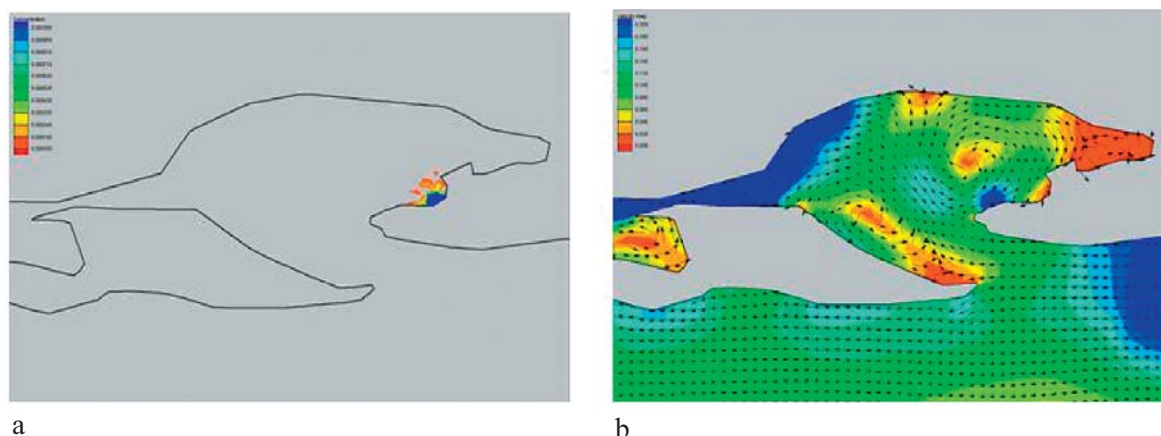
Fig. 8 A zoom of the RMA2-SMS model domain in Kaštela Bay (horizontal resolution 20 m – 200 m):.(a) - the simulation of dispersal of pollutants from the Split sewer outflow in Kaštela Bay; (b) - simulated hydrodynamics with very complex two eddy system within the Bay. The arrows indicate the current direction with amplitude given by colour

All these models were integrated and connected (BETTIN *et al*., 2006). In addition, an interface between the RMA2-SMS two-dimensional model and the ASHELF-2 three-dimensional model was developed in the coastal area of Split in order simulate the urban outflow of pollutants in Kaštela Bay. Coupling two models with different horizontal resolutions from 1.5 km to 20 m was a challenge and the project only demonstrated the feasibility of building such a system.

This model system, calibrated with the collected data, was used to evaluate the status of the coastal area by considering all the pollution inputs coming from urban discharges, industries, rivers and diffusive loads from agriculture. These hydrodynamic simulation results showed that critical areas are located especially on the south-western side of the Split network, along the coastal pipe collecting waters all the way to the main outlet in the deep sea. This integrated system can be used as an effective DSS (Decision Support System) for management and planning of the wastewater facilities and receiving marine waters, and can also be used as a collaborative tool among the various bodies in charge of the operation and quality control of the Split area.

USE OF THE FORECAST PRODUCTS

One of the aims of ADRICOSM was the provision of suitable information, derived from the operational forecasts, to end-users. A target end-user group for the marine forecasts is the coastguard corps. They are interested in oil spill forecasting to help in the management and remediation action against accidental and operational release of oil in marine areas. The project produced an interface between the oil spill prediction MEDSLIK model (ZODIATIS *et al*., 2003; LARDNER *et al*., 1998) and the forecast products that are suitable for rapid deployment of oil spill forecasts in areas of interest. This end-user tool was presented during a training course on "Operational Oceanography of the Adriatic Sea" at the IMA (International Marine Academy) in Trieste (Italy) at the end of the year 2004.

Detailed knowledge of the current velocity field and wind forcing are essential elements for prediction of the fate of pollutants and oil spills in the sea and the relevant products from the ADRICOSM forecasting system were included as a basic input data set to MEDSLIK.

One of the main features of the MEDSLIK application is a user-friendly graphical interface, which makes it easy to insert the input data describing the oil spill accident source, and to choose between different data sets of current and wind data. The results are visualized in Fig. 9 for a study case where an accidental oil release occurs near the Croatian coast. For the reasons explained above, ADRICOSM-MEDSLIK
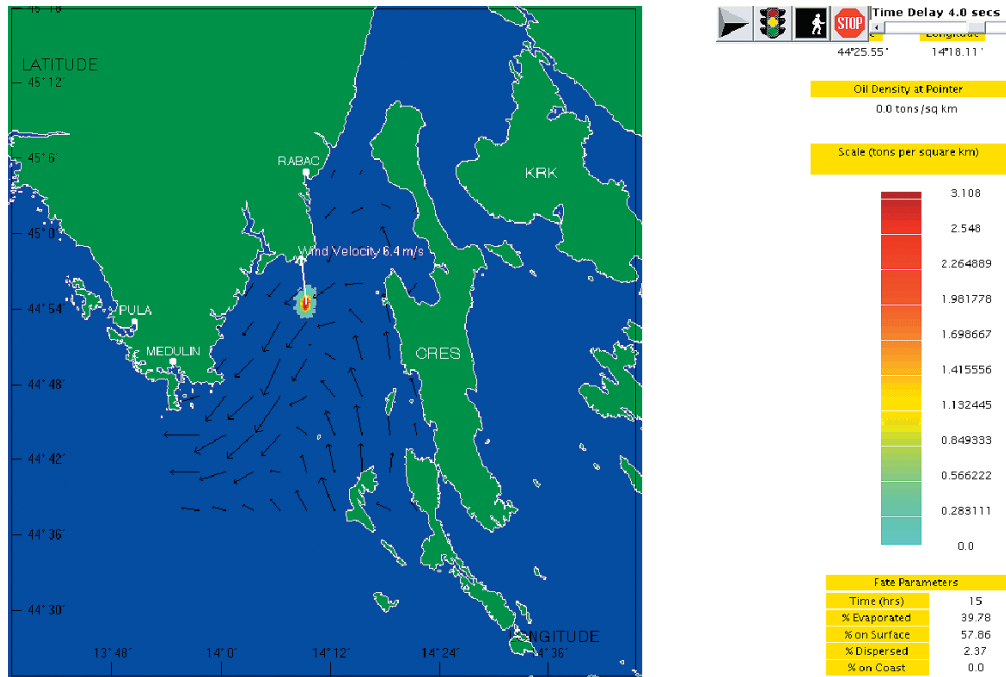
Fig. 9. The oil spill simulation in the Adriatic Sea near the Istrian coast using the Medslick model coupled with the AREG forecasting model. The arrows indicate the modeled flow field, the colours the concentration of the contaminant a few days after its release and the white arrow the direction of the wind at the sea surface

represents a seminal example of the possible end-user applications of the information derived from an operational forecasting system.

CONCLUSIONS

The ADRICOSM project demonstrated the feasibility of a NRT operational monitoring and forecasting system of marine physical parameters (temperature, salinity and velocity) at the shelf scale of the Adriatic Sea. The innovative aspect of the project is, above all, the downscaling to coastal area resolution from basin scale circulation hydrodynamics and the integration of land-derived water and material inputs with appropriate resolution to study pollution impacts. The integrated system approach that ADRICOSM has started will probably be a useful example for future developments that will require a much closer interaction with end-users.

At present, applications such as oil spill models and fishery assessment models (ARNERI, personal communication) can be interconnected with the output of the ADRICOSM operational system. Further development of this system both in downscaling of the marine models (by increasing the complexity of the nested model network and the horizontal resolution of each model) and expansion of the marine coastal observations (by also collecting the marine biochemical parameters) will result in an increase in the value of such systems and the usage of their products by the local and regional end-users.

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ADRICOSM pilot projekt: Sustav predviđanja u obalnim područjima i riječnim bazenima Jadranskog mora

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SAŽETAK

Projekt ADRICOSM započeo je u listopadu 2001. i završio u ožujku 2005. godine. Glavni je cilj projekta bio pokazati mogućnosti operacionalizacije monitoringa i prognoze u skoro realnom vremenu na šelfu te u obalnim područjima koja su povezana s riječnim bazenima i gradskim otpadnim vodama. Sustav je bio opremljen efikasnom mrežom sakupljanja podataka izmjerenih u moru kao što su profili temperature i saliniteta te satelitske površinske temperature mora, regionalnim jadranskim modelom (AREG) i modelom na skali šelfa, sustavom asimilacije podataka te konačno, obalnim modelom. Svaki tjedan AREG je izrađivao 7-dnevnu oceanografsku prognozu na horizontalnoj skali od 5 km koja je upotrebljavana za gniježđenje drugih hidrodinamičkih modela duž obale. Dva modela na šelfu (ASHELF-1 i ASHELF-2) horizontalne rezolucije od 1.5 km ugniježđeni su u jadranski AREG model s ciljem simuliranja (te u budućnosti i prognoziranja) oceanografskih osobina šelfa. Drugi važan aspekt ADRICOSM projekta bio je integracija monitoringa i modeliranja dotoka rijekom Cetinom i sustavom otpadnih voda s oceanografskim modelom šelfa. Ovaj je integracijski sustav upotrebljen za simuliranje disperzije urbanih otpadnih voda u obalnom području. Projekt ADRICOSM je jedan od prvih integracijskih sustava kojim se za potrebe operativne oceanografije i prognoze ujedinjuju obalne vode s dotocima s kopna s ciljem efikasnog upravljanja obalnim područjima.

Ključne riječi: ADRICOSM, predviđanje, Jadransko more