PAPER

An Operational European Global Ocean Observing System for the Eastern Mediterranean Levantine Basin: The Cyprus Coastal Ocean Forecasting and Observing System

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ABSTRACT

The countries surrounding the Mediterranean Sea have joined together in several multinational initiatives to conduct long-term, integrated, operational oceanographic observations and modelling of this important region. Some of these initiatives and the country members involved are discussed in this paper. Particular emphasis is given to long-term observing systems and modelling conducted in the Eastern Mediterranean Levantine Basin and the region around the island of Cyprus. A complete operational oceanographic forecasting and observing system has been developed in Cyprus, and has been operational since early 2002. The system is called CYCOFOS—Cyprus Coastal Ocean Forecasting and Observing System—and is a component of the Global Ocean Observing System (GOOS), and its European (EuroGOOS) and Mediterranean (MedGOOS) modules. CYCOFOS is the result of several years of research activities all carried out within the framework of European Union-funded projects including: (1) Mediterranean forecasting system, both pilot project and towards environmental predictions (MFSPP and MFSTEP), (2) Mediterranean network to Access and upgrade Monitoring and forecasts Activities in the region (MAMA), (3) European Sea level Service Research Infrastructure (ESEAS-RI), (4) Mediterranean network of Global sea Level Observing System (MedGLOSS), and (5) Marine Environment and Security in the European Areas (MERSEA strand 1). CYCOFOS at present consists of several operational modules, including flow and offshore waves forecasts, satellite remote sensing, coastal monitoring stations and end user-derived applications. All these operational modules provide regular near-real-time information, both to local and sub-regional end users in the Eastern Mediterranean Levantine Basin. This paper discusses these as well as additional ocean observation stations and features soon to be added to CYCOFOS.

PREFACE

The sustainable development of the coastal and offshore regions of the Mediterranean and the region's marine economic activities depend crucially on the scientific knowledge of the marine system variability, particularly on our capability to monitor and forecast at the relevant space and time scales in near-real-time. These challenges have been addressed in several international fora. In Agenda 21 of the United Nations Conference on Environment and Development (1992), the establishment of a Global Ocean Observing System (GOOS) was addressed. Responsibility for the design, promotion, and implementation of GOOS worldwide was assigned to the Intergovernmental Oceanographic Commission (IOC) of UNESCO. Marine monitoring and forecasting systems on global, regional (e.g., European), and local (e.g., Cyprus) scales will play key roles in balancing the relationship between development and the environment. The development of an operational oceanographic monitoring and forecasting system certainly will support better management of the marine environment, reducing environmental problems that arise from the various economic activities in the marine sector. The research and development of these systems will enable a continued sustainable improvement, potentially helping to mitigate the effects of industrial accidents, thus further benefiting the economy.

GOOS consists of the following main operational modules: a) a network of remote sensing, both *in situ* and satellite oceanographic systems, b) an integrated set of oceanographic models to provide coastal and ocean forecasts, and c) a data network that connects the monitoring systems and the models, and provides updated information to oceanographic databases and to end users (IOC, 1998).

Following the GOOS initiation, the European Global Ocean Observing System (EuroGOOS) and the Mediterranean Global Ocean Observing System (MedGOOS) initiatives were established respectively in 1994 and 1999. EuroGOOS supports the objectives of GOOS at the European level. In EuroGOOS there is a strong emphasis on the development and application of new and existing technology, which will allow more efficient use of forecasting, observing, and other related tools, with minimal cost and human resources (EuroGOOS, 1997).

Similarly, the objectives of MedGOOS are to link existing operational systems in the Mediterranean and to extend the area of operational oceanographic systems to the entire region (MAMA group, 2002). MedGOOS modules will be based upon principles similar to those of EuroGOOS. The development of a regional operational forecasting and observing system for the Mediterranean will benefit local users in all aspects of the marine sector (IOC, 1998). In MedGOOS there are 16 participating

institutions, representing thirteen countries: Bosnia & Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Malta, Morocco, Slovenia, Spain, and Turkey.

TOWARD A SUSTAINED FORECASTING & OBSERVING SYSTEM FOR THE MEDITERRANEAN SEA

The development and promotion of the operational coastal/ocean monitoring and forecasting activities in the Mediterranean and European seas are carried out in the framework of several European Union-funded research projects, which include:

1) The Mediterranean Forecasting System Pilot Project (MFSPP) is a EuroGOOS activity, aiming to model and quantify the potential predictability of the ecosystem fluctuations at the level of primary producers from the overall basin scale to the coastal/shelf areas, through the development and implementation of an operational monitoring and forecasting system in the region. The modules of this project include *in situ* monitoring from volunteer observing ships and multi-variable buoy stations, remote sensing, data assimilation tools, a basin general circulation model, several intermediate and shelf/coastal models, as well as ecosystem models (Pinardi et al., 1999; Pinardi et al., 2003).
2) The Mediterranean network to Assess and upgrade Monitoring and forecasts Activities in the region (MAMA), is a MedGOOS concerted action to promote the coastal monitoring and forecasting in all the Mediterranean countries, following MFSPP and MFSTEP achievements. The general scope of MAMA includes the aim to establish a regional network to identify the gaps in existing capacity for systematic monitoring and forecasting activities, upgrading the competencies of personnel in less developed regions at technical and scientific levels, preparatory design of the initial observing and forecasting network covering the entire Mediterranean basin, and to disseminate knowledge on the importance of oceanographic monitoring and forecasting to policy makers in order to promote national and international action for the Mediterranean (MAMA group, 2002).
3) Mediterranean Forecasting System Towards Environmental Predictions (MFSTEP) is a EuroGOOS activity, aiming, among other objectives, at the further development of an operational forecasting and observing system in the Mediterranean following the MFSPP. Additionally, MFSTEP is intended to demonstrate to end users the usefulness and benefits of the operational oceanographic forecasting products (Pinardi et al., 2002a). MFSTEP benefits from its forty-eight participating institutions, representing 15 countries: Belgium, Cyprus, Czech Republic, France, Germany, Greece, Israel, Italy, Malta, Netherlands, Slovenia, Spain, Turkey, and Ukraine. Since 1999 the Mediterranean Forecasting System (including both phases: MFSPP and MFSTEP) has been providing weekly forecasts of currents, sea temperature, salinity, and sea level throughout the Mediterranean Sea. To produce these near-real-time forecasts, a tremendous amount of data is collected and assimilated from *in situ* observations, buoys, XBTs, remote sensing, etc.
4) Marine Environment and Security for the European Area strand 1 (MERSEA strand 1), is a Global Monitoring for Environment and Security (GMES) activity that ultimately aims to develop a pan-European capacity for operational monitoring and forecasting of ocean physics, biogeochemistry, and ecosystems on global and regional scales. The objective of MERSEA strand 1 is to integrate existing satellite observations with data from *in situ* monitoring networks and perform ocean modelling and data assimilation (Johannessen et al., 2002). MERSEA strand 1 will create the operational framework for the real-time provision of products to European marine environmental agencies from sectors including: 1) marine transportation, naval operations, and tourism; 2) exploitation and management of ocean resources (offshore oil and gas industry, fisheries, and aquaculture); 3) environmental issues from local (pollution crises, impact studies) to global (ocean climate variability and change, contribution to seasonal climate prediction); and 4) research with the goal of better understanding the ocean.
5) European Sea level Service Research Infrastructure (ESEAS-RI) (Plag, 2002) is an ESEAS activity including the Mediterranean network of Global sea Level Observing System (MedGLOSS) activities (Rosen, 2001), whose main objectives are to support the ESEAS research infrastructure, to facilitate pan-European coordination, and to upgrade and standardize the network of sea level

observing sites in the European sea areas.

6) The regional Greek operational *POSEIDON* system provides near-real-time forecasts and *in situ* observations from 11 multi-variable buoys in the Aegean Sea. The development of this multi-module operational system was completed in late 1999 by Greece and Norway and is presently operated by the National Centre for Marine Research of Greece (Soukissian et al., 1999; Nittis et al., 2001).
7) *SKIRON* is a weather and sea state forecasting system in Greece (Kallos et al., 1998) providing near-real-time forecasts in the entire Mediterranean and other European areas. Recently *SKIRON* was expanded to also provide oceanographic forecasts in the Aegean and Eastern Mediterranean seas. Unlike *POSEIDON*, *SKIRON* does not provide *in situ* ocean observations. *SKIRON* is operated by the University of Athens within several European Union projects, such as the MFSTEP, for which it is tasked to provide operationally surface atmospheric boundary layer variables for various operational ocean modelling applications in the Mediterranean Sea.
8) *MERCATOR* is France's contribution to operational oceanography, and is also a EuroGOOS pilot project of the Atlantic task team (Bahurel et al., 2002). While the extent of *MERCATOR's* range is essentially global, the near-real-time operational forecasts it provides of the Mediterranean Sea are particularly germane to this effort. *MERCATOR*, whose mission was defined by various French organizations (IFREMER and Météo-France), became fully operational in January, 2001. *MERCATOR* participates in the European Union MERSEA strand 1 project, as one of the project's four regional forecasting flow models in the European seas and the North Atlantic.
9) The Forecasting Ocean Assimilation Model (FOAM) is a near-real-time forecasting system operated by the United Kingdom's MetOffice (Bell, 2002). While its major focus is the North Atlantic and Arctic oceans, FOAM also provides forecasts in the Mediterranean Sea. FOAM, together with MFSTEP and *MERCATOR*, participates in the European Union MERSEA strand 1 project, in order to provide near-real-time ocean forecasts for all the European seas.
10) The ADRIatic sea Integrated COaStal areas and river basin Management system pilot project (ADRICOSM) is a multinational sub-regional forecasting and observing system involving relevant agencies from Italy, Croatia, Slovenia, and France. The aim of ADRICOSM is to demonstrate the feasibility of near-real-time shelf current forecasts and to develop the integration of the river system modelling with the shelf scale current forecasting in the Adriatic Sea (Pinardi et al., 2002b). The activities of ADRICOSM include modelling and implementation of *in situ* and remote sensing monitoring. The ADRICOSM flow modelling is nested within the operational model of the MFSPP and MFSTEP.
11) *ISRAMAR* is an Israel Oceanographic and Limnological Research Institute forecasting system that provides operational offshore sea state forecasts for the entire Mediterranean and the Eastern Mediterranean (Gertman et al., 2002), using the wind fields from the previously mentioned *SKIRON* weather forecasting system. Moreover, near-real-time coastal sea level monitoring and other related parameters are provided within the frame of the MedGLOSS activities (Rosen, 2001) at selected coastal stations of Israel.

SCIENTIFIC AND OPERATIONAL MODULES FOR THE EASTERN MEDITERRANEAN LEVANTINE BASIN

Promotion of GOOS, EuroGOOS, and MedGOOS requires the establishment of infrastructure for operational oceanography, participation in international and European activities for the development of common methodologies and tools to be used and applied by all the regional partners, and, finally, the development of derived applications to assist decision makers and other end users. In the Eastern Mediterranean Levantine Basin, the institutions developing and applying the scientific modules for operational oceanography in Cyprus are: a) the Oceanography Centre at the Department of Fisheries and Marine Research (DFMR) and, b) the Computational Oceanography Group of the University of Cyprus. The DFMR is a member of IOC, CIESM (International Commission for the Scientific Exploration of the Mediterranean sea), UNEP (United Nations Environmental Program), and ESEAS; is associated with EuroGOOS and is a founding member of MedGOOS.

At present, the oceanographic initiatives related to coastal and open deep sea monitoring and forecasting activities in Cyprus consist of: 1) the Cyprus Basin Oceanography

Figure.1a. CYCOFOS-CYCOM Fine Model Domain

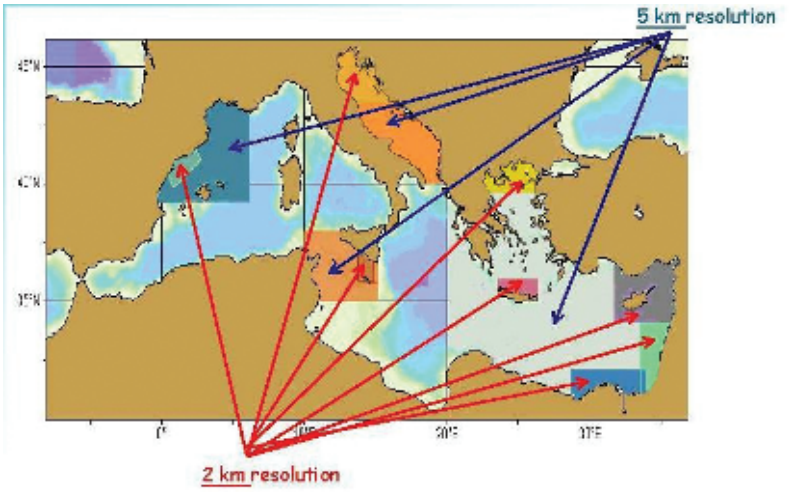
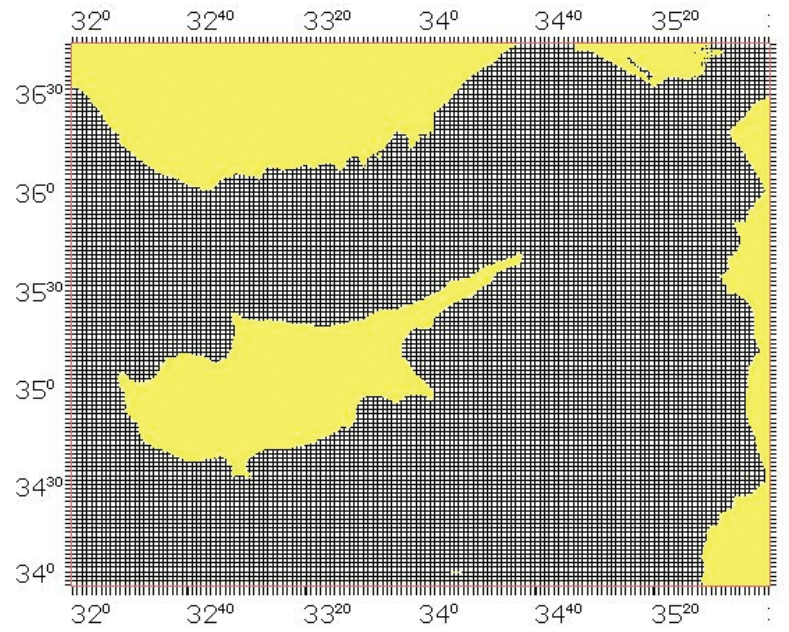


Figure 1b. MFSPP Model Domains



(CYBO), a long-term monitoring project conducted at coastal and deep sea areas of Cyprus and SE Levantine basins. CYBO contributes to updating of the Mediterranean database (MEDAR/MEDATLAS), particularly for the SE Levantine Basin in the framework of the newly released Mediterranean oceanographic database (MEDATLAS, 2002); 2) the Cyprus MedGLOSS coastal station for long-term monitoring of sea level and water temperature, as part of the MedGLOSS and ESEAS networks; 3) the CYCOFOS satellite ground receiving station, capable of providing regular, remote sensing of the sea surface temperature (SST) for any part of the Eastern Mediterranean Sea; 4) the Cyprus costal ocean flow model (CYCOM) and the Cyprus wave model (CYWAM), both high-resolution, nested flow and offshore wave forecasting models in the Levantine; and 5) the *MEDSLIK* and *MEDPOL* oil spill and pollutant-dispersion models for the Levantine Basin.

CYCOFOS—CYPRUS COASTAL OCEAN FORECASTING AND OBSERVING SYSTEM

The Cyprus Coastal Ocean Forecasting and Observing System was developed within the framework of the previously mentioned European Union research projects, to promote operational oceanography in the Eastern Mediterranean Levantine Basin and the sea area around Cyprus (Zodiatis et al., 2002; 2003b; 2003c). At present, CYCOFOS provides near-real-time operational forecasts of sea currents, water temperature, salinity, sea level, significant wave height and direction, as well as operational *in situ* observations of sea water temperature, sea level, and satellite remote sensing of sea surface temperature. CYCOFOS consists of the following forecasting (flow and sea state), observing (*in situ* and remote sensing), and end-users modules :

MFS Cyprus Near Real Time Ocean Forecasts

The CYCOFOS uses the CYCOM flow model (Zodiatis et al., 2001; 2003a), which is a version of the Princeton Ocean Model (POM) (Blumberg and Mellor, 1987) that is being used in the MFSPP and MFSTEP projects for climatological and operational coastal and regional flow simulations. The CYCOM model is a high-resolution flow model that was upgraded to operational status in March of 2002. It has two open boundaries (Fig. 1a) and is nested operationally into the coarse grid of the MFSPP Mediterranean model (Fig. 1b). In CYCOFOS, data for the initial and boundary conditions, both lateral and atmospheric forcing from the European Centre for Medium Weather Forecasts (ECMWF), are downloaded weekly from the MFSPP operational system. CYCOM uses the atmospheric forcing provided by the MFSPP basin model. The latter is based on the 6-hourly ECMWF analyses and forecasts provided by Meteo-France. The air-sea physics used to compute the boundary conditions of the MFSPP basin model are the surface solar radiation, net long wave flux, sensible and latent heat flux, wind stress, and water flux and include relaxation to monthly mean climatology. The MFSPP-provided basin model initial and boundary data used in CYCOM include the assimilation of weekly remote sensing SST and sea surface height (SSH) data. The CYCOFOS flow model provides a weekly forecast for the forthcoming week and daily forecasts of cur-

Figure 2a. CYCOFOS-CYWAM Fine Model Domain

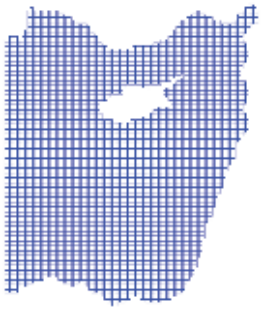


Figure 2b. CYCOFOS-CYWAM Coarse Model Domain

rents, sea temperature, salinity, and sea level. Within the framework of the MFSTEP project, the CYCOFOS flow forecasting module will be upgraded, and its resolution will be increased from 2.5 km to 1.5 km, providing more detailed information that is of particular value to the coastal end users.

Cyprus Offshore Wave Forecasts in the Levantine Basin

CYCOFOS uses the CYWAM wave model, which is a version of the WAM-wave model (WAMDI group, 1988) for offshore wave forecasts in the entire Levantine Basin. The WAM model in CYCOFOS was upgraded to operational status in August, 2002. The fine resolution Levantine WAM model (Fig. 2a) is nested entirely in a coarse Mediterranean WAM model (Fig. 2b). The CYWAM provides operationally high-resolution forecasts of significant wave height and wave direction. The CYWAM model initially used the ECMWF wind forcing, while at present it uses the 3-hourly winds from the 72-hour *SKIRON* weather forecasting system.

The MedGLOSS Paphos Station

Within the framework of Mediterranean network of Global sea Level Observing System, a sea level station was set up in September of 2001 at Paphos Harbor, on the western coast of Cyprus. The station's primary aim is to collect long-term systematic measurements, monitoring the sea level rise, which may be caused by melting of polar ice as a result of global warming. The station's equipment consists of sea level, water temperature, and atmospheric sensors; a GPS antenna; and a PC computer. The data are transmitted every hour to the DFMR facilities for further processing and interpretation. The equipment for the Paphos MedGLOSS station was provided by the International Commission for the Scientific Exploration for the Mediterranean sea (CIESM), and its installation was conducted by Israel's Oceanographic and Limnological Research Institute, which coordinates the MedGLOSS activities. Expansion of the Cyprus MedGLOSS stations in the near future will include similar stations on the south and east coasts of Cyprus.

CYCOFOS Satellite Ocean Remote Sensing

The CYCOFOS satellite ground receiving station has been providing regular (almost daily, depending on the cloud cover) remote sensing SST images of the Levantine Basin since 2001. An HRPT (High Resolution Picture Transmission) SmartTech Professional Researcher model engine is operated by the CYCOFOS team. Depending upon the satellite's orbit, it is capable of covering in one single capture the Eastern Mediterranean and Black Seas 2 to 3 times per day, with a spatial resolution of about 1 km. At present this CYCOFOS module is set up to provide near-real-time daily SST images only for the Levantine Basin. As part of the European Union MAMA/MedGOOS project, CYCOFOS was tasked in addition to provide daily remote sensing SST images for the entire Eastern Mediterranean Sea, while a similar remote sensing system from Spain was tasked to provide SST for the entire Western Mediterranean Sea.

CYCOFOS Ocean Observatory

As part of the European Union MAMA/MedGOOS initiative, and to promote open deep sea operational *in situ* data collection and transmission in the Levantine Basin, the CYCOFOS Ocean Observatory is currently under preparation for deployment in the Eastern Mediterranean, off the southern coast of Cyprus. The CYCOFOS Ocean Observatory is scheduled for deployment jointly with Harris Maritime Communication Services, USA, which developed this buoy-based observing system (Clark 2000, 2001). A similar Ocean Observatory was previously deployed in the Western Mediterranean, off the coast of Sardinia, jointly by the International Marine

Figure 3. MCS Ocean Net Buoy Supporting CYCOFOS Ocean Observatory

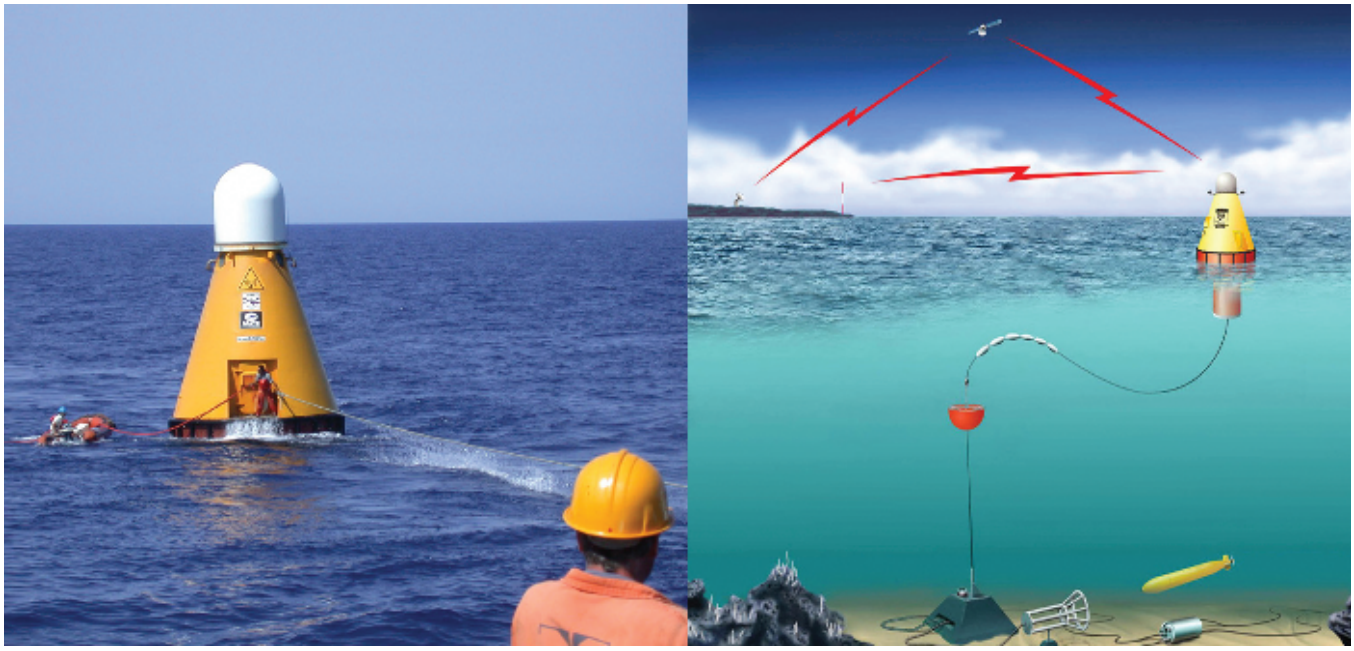
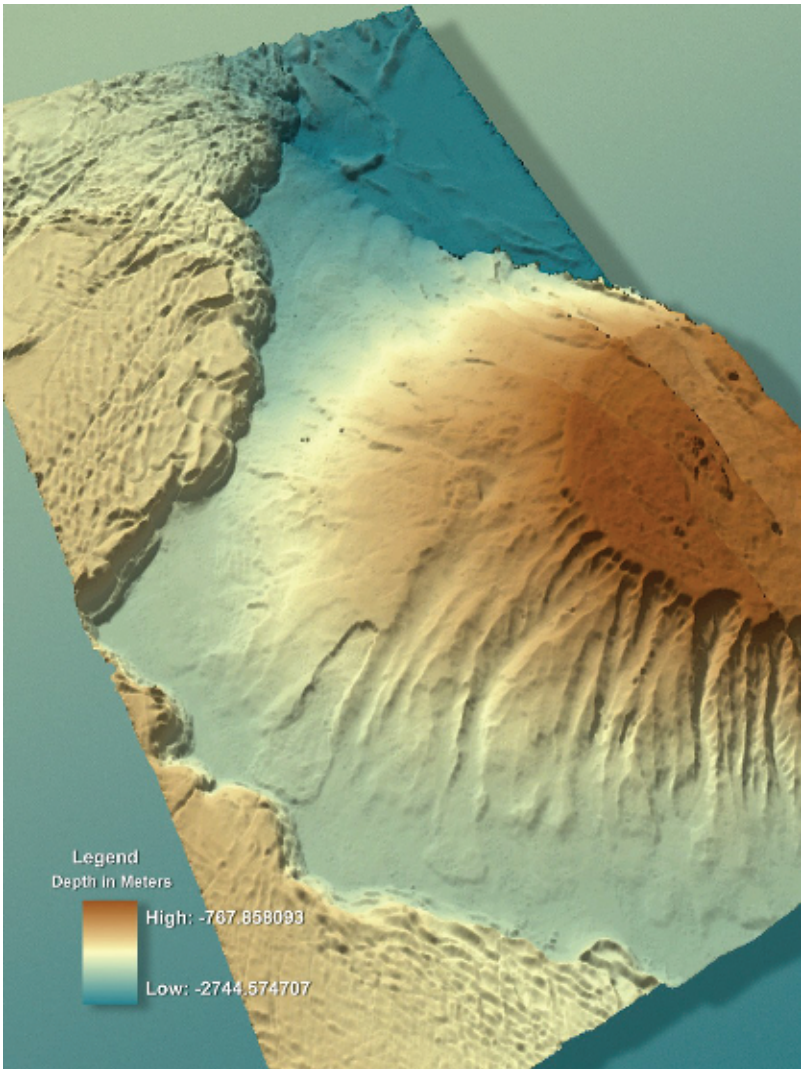


Figure 4. Multibeam Survey CYCOFOS Ocean Observatory Deployment Location



Centre and Harris Maritime Communication Services. The sampling strategy of the CYCOFOS Ocean Observatory includes data on sea water temperatures, salinity, pressure, oxygen, currents from selected depths, as well as air temperature, wind speed, and direction. The system's satellite communication capability and substantial onboard power generation will provide continuous transmission of real-time data at high sampling rates. Figure 3 depicts the seafloor, water column, and sea surface components of the CYCOFOS Ocean Observatory.

The CYCOFOS Ocean Observatory is being deployed at a site of significant multidisciplinary oceanographic interest. Located off the southwestern coast of Cyprus is the Eratosthenes Seamount that extends from the seafloor to within 800 m of the sea surface. This feature is named for the philosopher Eratosthenes (276—194 B.C.) who, armed with only his knowledge of geometry, astronomy, and the sun's reflection in a well, predicted with remarkable accuracy the circumference of the earth. Directly adjacent to the Eratosthenes Seamount is a deep (approximately 2,750 m) depression, part of the Herodotus Basin. Herodotus was born in 484 B.C. and is thought to have lived until sometime around 430 B.C. He is considered the world's first historian. Both these features are clearly evident in the output from a recent multibeam bathymetric survey depicted in Figure 4.

END USER-DERIVED APPLICATIONS

Among the environmental issues affecting the Eastern Mediterranean Levantine Basin are marine pollution, eutrophication, and other algae-growth related phenomena. Commercial activities in the Levantine Basin—growth in oil transfer, exploration and production, pelagic fisheries, shipping and yachting and particularly coastal tourism—are all on the increase.
To provide the scientific basis for any user-derived application that tries to manage either the exploitation or the protection of the marine environment, it is necessary to offer an efficient and quality-controlled estimate of marine state variables. The recommended procedure for responding, for example, to marine pollution incidents, which will assist the local and sub-regional decision-makers to take the appropriate actions, includes the application of operational models in order to provide predictions of the behaviour and movement of the harmful substances. A prerequisite for such an effective operational response is the ability to conduct accurate predictions of the sea's characteristics. Similarly, the same information is useful for other marine activities. Thus the user community interested in ocean forecasting is connected to the exploitation of resources and the protection of the marine environment. Among the potential end users of the CYCOFOS's products are: 1) the National and Sub-regional contingency plans for preparedness and response to major pollution incidents in the Eastern Mediterranean Levantine Basin, between Cyprus, Israel and Egypt, in cases of oil spill emergency in the open sea; 2) Search and Rescue Centres, Port Authorities, and marine police; 3) local and offshore consortiums from the fisheries sector; 4) fish farmers from the marine aquaculture industry; 5) desalination plants, telecommunications cable laying, oil & gas industry, and environmental agencies from the coastal and open sea engineering sector; 6) commercial shipping, recreational boating and the navigation safety sectors; 7) the marine tourism industry; and 8) international policy organizations, research centers, etc.

The exchange of information derived from operational forecasts, both within the scientific community and with end users, plays an important role in the response to certain marine environmental situations. In view of the above, the outputs of operational forecasts, using a visual interface tool for oceanographic data, are regularly exported to the CYCOFOS Web page for direct access by end users. Additional components of CYCOFOS, *MEDSLIK* oil spill model and the *MEDPOL* general dispersion model, were developed specifically for end-user-derived applications, employing the MFSPP, MFSTEP, MERSEA strand 1, SKIRON and CYCOFOS forecasting and observing products.

MEDSLIK Oil Spill Model

The *MEDSLIK* oil spill model, in its pre-operational mode, was developed in 1997 (Lardner et al., 1998) to assist the objectives of the European Union *LIFE* project, "Sub-regional Contingency Plan for Preparedness and Response to Major Pollution Incidents in the Eastern Mediterranean-Levantine."

The MEDSLIK algorithms are based on an earlier version of the *OILPOL* model (Al Rabeh et al., 1995) that was employed during the first Gulf War in 1991 for oil spill predictions. MEDSLIK, developed by the CYCOFOS team, is a 3-D oil spill model designed to predict the transport, fate, and weathering of an oil spill in the Levantine Basin. It has now been coupled operationally to the MFSPP basin model and CYCOFOS operational ocean forecasting products, using either the 6-hour ECMWF or the 3-hour *SKIRON* wind fields. *MEDSLIK* incorporates REMPEC's (Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea) list of over 200 hydrocarbons, together with their physical parameters. Coarse and fine resolution bottom topography and coastlines are used for the Levantine Basin and the NE Levantine, respectively. As part of the European Union MFSTEP and MERSEA strand 1 projects, CYCOFOS was tasked to apply operationally the *MEDSLIK* oil spill model in the Levantine Basin, coupled with the project's forecasting products.

MEDPOL Contaminant Advection-Diffusion

The environmental impact of waste substances greatly depends upon the hydrodynamic state of the area under consideration. The application of advection-diffusion models allows evaluation of the impact of the transfer of a pollutant into the marine environment. Such models should generally apply both to conservative and non-conservative chemical and biological substances. The *MEDPOL* model in its pre-operational mode was first used in 1998 to assist the objectives of an international scientific cooperation on the "Radiological Impact Assessment in the Southeastern Mediterranean Area" (Vosniakos et all., 2000).

MEDPOL is a 3-D general dispersion model, based on algorithms from Lardner and Song (1991), to predict the transport, dispersion, and decay of a pollutant in the Levantine Basin. It has now been coupled operationally to the MFSPP and CYCOFOS. As part of the European Union MFSTEP project, CYCOFOS

was tasked to apply operationally the *MEDPOL* general dispersion model in the Levantine Basin, coupled with the project's forecasting products.

CYCOFOS PRODUCTS ON THE INTERNET

At present the near-real-time operational forecasting and observing products from the CYCOFOS modules, such as daily flow forecasts for the NE Levantine Basin on a weekly basis, 3-hourly sea state forecasts for the Levantine Basin on a 60 hours basis, daily remote sensing sea surface temperature for the Levantine Basin, and hourly *in situ* sea level and water temperature at certain coastal sea stations are available to the end users at the Web page www.ucy.ac.cy/cyocean.

Further development of the CYCOFOS, both in downscaling of the prognostic models and expansion of the ocean/coastal observations, will result in an increase of the available operational oceanographic products, and their utility to the local and sub-regional end users.

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