

Ten years to build the GMES Marine Core Service component for the Mediterranean Sea

by Nadia Pinaridi

AROUND THE MEDITERRANEAN SEA, THE LIVES OF MILLIONS OF PEOPLE DEPEND ON A CONTINUOUS MONITORING OF THE STATE OF THE SEA IN ORDER TO PREVENT DAMAGE RESULTING FROM OIL POLLUTION, OVER-EXPLOITATION OF FISH STOCKS, COASTAL EUTROPHICATION¹ AND MARINE ECOSYSTEM HABITAT LOSS. IN THE MEDITERRANEAN SEA, AN OCEAN MONITORING AND FORECASTING SYSTEM, THE SO-CALLED MEDITERRANEAN OCEAN FORECASTING SYSTEM (MFS), IS NOW OPERATIONAL IN SUPPORT OF A VARIETY OF USERS. IT WILL BE A COMPONENT OF THE GMES MARINE CORE SERVICE. FROM OBSERVATIONS TO MODELLING, THE SYSTEM HAS DEMONSTRATED THE QUALITY AND FEASIBILITY OF HIGH QUALITY SHORT-TERM OCEAN FORECASTS IN SUPPORT OF SUSTAINABLE DEVELOPMENT OF ECONOMIC ACTIVITIES AND MARITIME SAFETY.

Why forecast the ocean?

Oceans, like the atmosphere, are a turbulent fluid and evolve over short time scales, even over a few hours. For practical purposes, a knowledge of the state of the ocean using only past data does not ensure a good planning of activities at sea; whether these activities are Search and Rescue, assessment of ecosystem health or support to offshore activities. Just like meteorology, ocean forecasting has to do with the 'ocean weather', i.e. short time-scale variability of currents, sea level, temperature, etc all of them variables that affect most of the important management and preservation activities at sea. In order to advance technology and science in this new field, operational oceanography has developed a sophisticated integrated modelling and observational system that is able to reduce errors in

the estimates of the past state and give reliable initial conditions for the forecasts, thereby reducing the range of uncertainty for the applications.

Observations and models are blended together with data assimilation techniques and long time-series are produced in a standardised way by the forecasting community, which shares common, international rules. These reconstructed time-series provide information about climate change and represent the optimal estimate of the past state of the oceans; a reference data set for many models and communities to use.

In the Mediterranean Sea, the ocean research community started, in the 1990's, to develop a basin-wide system of monitoring and forecasting of marine conditions from the open ocean to the

¹ The growth of marine organisms due to enrichment of coastal waters with nutrients from land sources.



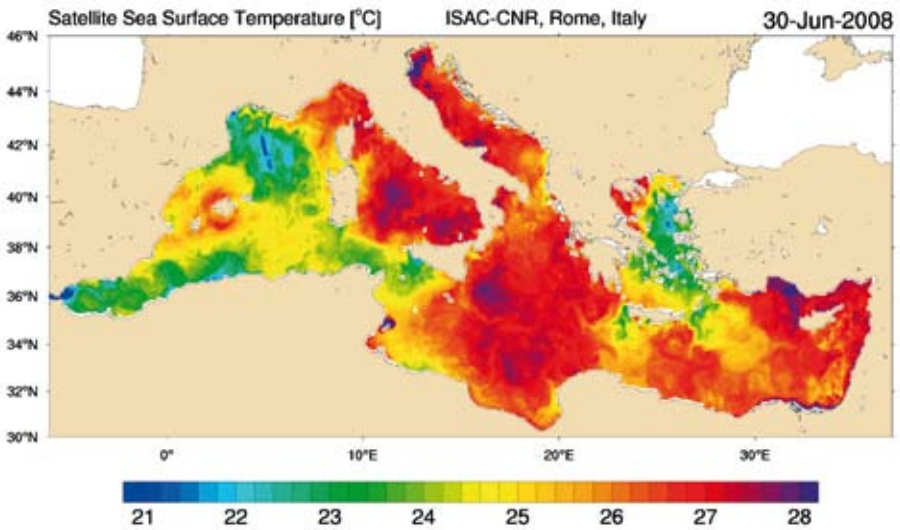
The beautiful beach of Nice, in the south of France, where a 6 km promenade along the seashore has been a tourist attraction for several centuries (Credits: all rights reserved)

coastal zones. The aim was to produce a continuous assessment and prediction of the ocean state, from hydrodynamics to the associated biochemical components, from pollutants to ecosystem health. Before and after the launch of the GMES initiative, applied research projects have developed and provided an assessment of the scientific quality of the MFS products as well as their practical usefulness for applications and downstream services.

Ten years of history

The Mediterranean marine research community started to develop the backbone of the Mediterranean ocean Forecasting System (MFS) in early 1998 and it has been progressing ever since. The Mediterranean Sea was selected as one of the major areas of development of operational oceanography by the EuroGOOS consortium (<http://www.eurogoos.org/>) and, in 1998, an MFS

Science and Strategy Plan was developed for the implementation of the observing and modelling system. More than 70 scientists, from 12 countries around the Mediterranean Sea, have been working, since 1998, to implement the Plan and to sustain its operations. In the past three European Framework Programme projects have contributed to developing the international scientific base for the deployment of an efficient and accurate forecasting system at basin scale, which is nowadays used by 26 institutes/agencies from all the countries bordering the Mediterranean. A new consortium has been established, the Mediterranean Operational Oceanography Network (MOON, <http://www.moon-oceanforecasting.eu/>) coordinating the upgrades of the MFS and its applications. Part of the MOON consortium is now involved in the Marine Core Service of GMES, which will be implemented by the MyOcean GMES project from 2009 to 2011.



The Sea Surface Temperature for the Mediterranean Sea is produced in Real Time (12 hours delay) from the ISAC-CNR (Institute for Atmospheric Sciences and Climate of the National Research Centre) in Rome, Italy. All available sensors are used, in order to compose, every day, an image of the temperature of the sea surface (Credits: CNR-ISAC, <http://gos.ifa.rm.cnr.it/>, Rome, Italy)

The Mediterranean Ocean Forecasting System

MFS is an integrated system of observations and models that estimates the state of the ocean and its possible short-term evolution. It includes three main components:

- a) the real time observing system;
- b) the numerical forecasting models for hydrodynamics and ecosystem assessment;
- c) the service, for intermediate and end-users.

The upstream data collection is an essential component of MFS, as it provides the necessary data for the correction of the initial conditions of the forecasting models. The MFS basin scale model can describe and forecast the 'weather' of the ocean at 5 km scales and 10-day ocean forecasts are produced daily, using both ECMWF (European Centre for Medium-Range Weather Forecasts) atmospheric forecasts and limited area

atmospheric model outputs. Recently, MFS has been expanded by the addition of an ecosystem forecasting capability which is coupled to the hydrodynamics forecasts, providing weekly 10-day forecasts of the state of the ecosystem.

The service to intermediate users is mainly developed through MOON Members receiving the MFS output daily and downscaling the forecast to the coastal areas of interest to them. Other downstream services, which range from support to coastguards to international agencies in charge of protecting the sea from pollution, are being developed.

The Observations

The observing system components of MFS are:

- 1) the satellite data;
- 2) the Ship Of Opportunity Programme (SOOP) vertical profiling system;
- 3) the autonomous drifting and profiling ARGO system;

- 4) the Mediterranean Moored Multidisciplinary Array (M3A) observing platforms.

Real Time remotely sensed data collection and analysis is the backbone of nowcasting/forecasting in the ocean. The most important data sets used are:

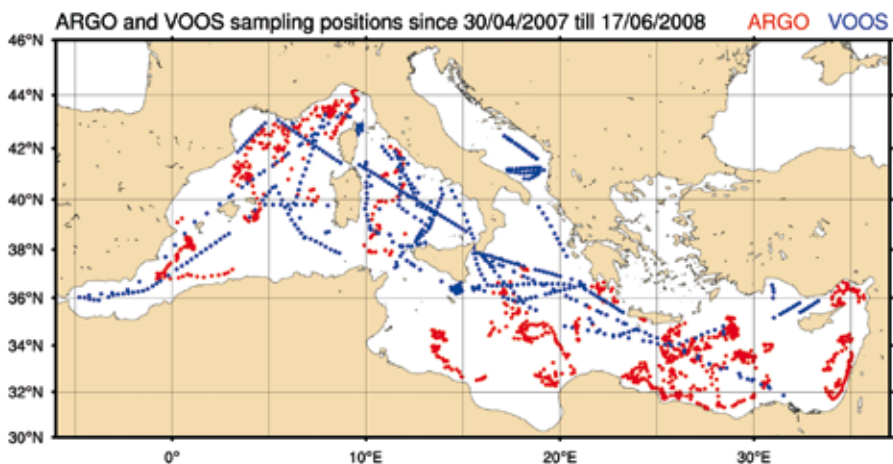
- 1) the Sea Level Anomaly (SLA) from satellite altimeters;
- 2) the Sea Surface Temperature (SST) from satellite infrared radiometers;
- 3) the Ocean Colour Chlorophyll (OCC) from visible radiometers;
- 4) surface winds from scatterometers.

All these observations, except the scatterometer, are currently analysed and made available for MFS in real time, with a well-established quality control protocol.

The real time *in situ* data collection system with SOOP (Ship-Of-Opportunity Programme, that makes use of volunteer merchant ships, which routinely transit strategic shipping routes to deploy expendable probes such as XBT)

and ARGO (a global array of free-drifting profiling floats that measure the temperature and salinity of the upper 700 m of the water column in real-time) was successfully organised with *ad hoc* data collection protocols for the Mediterranean Sea. There are two streams of high quality data, one in real time and the other one in delayed mode. The SOOP tracks are used to deploy the ARGO floats in order to increase the cost-benefit of the monitoring network.

The Mediterranean Moored Multi-sensor Array (M3A) design fulfils the requirements of MFS *in situ* multidisciplinary observations. The system is used to monitor the high temporal variability of the upper thermocline, euphotic zone field variables for the open ocean ecosystem and air-sea interactions. The variables monitored are: air temperature and dew point temperature, surface pressure, surface winds, precipitation, solar radiation for the surface, temperature and conductivity, oxygen, fluorescence, turbidity, and nitrates at



The MFS has developed a SOOP and ARGO profiling data collection system fitting the specific needs of this basin. In the picture, the sampling positions during the period 2004-2006 are indicated with blue dots for the SOOP observations and red dots for the ARGO profiles (Credits: INGV, Bologna, Italy)

selected depths. A group of scientists in the Mediterranean Sea has pioneered the basic idea of a modular system with acoustic links between different mooring lines.

MFS has also constructed a data management system for both real time data dissemination and archiving. This is necessary, since regional data can be at higher resolution than required for the global ocean and will require adapted

quality control procedures. The regional data management structure includes several Thematic Expert Data Centres (TEDC) associated with the different sources of data (see for example, <http://moon.santateresa.enea.it/> and <http://poseidon.ogs.trieste.it/sire/medargo/active/index.html>). The collected data in real time are sent through the Global Teleconnection System- GTS, thus contributing to global ocean real time data exchange.

The MOON forecasting models				
Model Name	Institute	Country	Resolution	Web site
MFS (basin scale)	INGV	Italy	5-6 km	http://gnoo.bo.ingv.it/mfs
OGS-OPATM (basin scale)	OGS	Italy	10-12 km	http://poseidon.ogs.trieste.it/cgi-bin/opaopech/mersea
PAM (basin scale)	Mercator	France	6-7 km	http://www.mercator-ocean.fr/
POSEIDON (basin scale)	HCMR	Greece	8-10 km	http://www.poseidon.ncmr.gr/
Western Mediterranean Sea	IMEDEA-CSIC	Spain	5 km	http://www.eseeo.org/servicios/oceano/eng/ESEOMED.html
NW Mediterranean	Ifremer	France	3 km	http://www.previmer.org/en/previsions/courants
Sicily Strait	CNR-IAMC	Italy	3 km	http://www.imc-it.org/progetti/mfstep/mfs_SCRMresults.htm
ADRICOSM (Adriatic Sea)	INGV	Italy	2 km	http://gnoo.bo.ingv.it/afs
POSEIDON (Aegean Sea)	HCMR	Greece	2 km	http://www.poseidon.ncmr.gr/
ALERMO (Aegean-Levantine)	UAT	Greece	3 km	http://pelagos.oc.phys.uoa.gr/mfstep/bulletin/
Malta Shelf area	IOI-MOC	Malta	1.5 km	http://www.capemalta.net/MFSTEP/results.html
Cyprus Coastal Ocean Model	Oceanogr. Centre Cyprus	Cyprus	1.5 km	http://www.oceanography.ucy.ac.cy/cycofos/forecast.html
Cilician Basin and Northern Levantine basin	IMS	Turkey	1.5 km	http://linux-server.ims.metu.edu.tr/kilikya/ http://linux-server.ims.metu.edu.tr/klevant/
SE Levantine Shelf	IOLR	Israel	1.5 km	http://isramar.ocean.org.il/ShelfModel/default.asp

The models forecasting the weather of the sea

Ocean current forecasts are only possible if initial and boundary conditions are known with sufficient accuracy and if a numerical model is used to predict the future evolution of the flow field. The basin scale MFS model with data assimilation is the backbone of the future GMES Marine Core Service and it produces daily 10-day forecasts. Other basin scale models, from Mercator Océan (France) and the Hellenic Centre for Marine Research (HCMR, Greece) also produce forecasts at basin scale. In the future, they will be used to estimate the uncertainty of the forecast by multi-model ensemble techniques.

The Mediterranean Sea is a unique area of the world ocean where not only the forecasting activities started earlier than for the open ocean areas, but also the downscaling to high horizontal resolution toward the coasts is now routinely implemented. Several MOON Members receive every day the MFS basin scale output, providing initial and lateral boundary conditions for high-resolution models, better resolving the coastal dynamics. Thus regional and shelf models are nested into the MFS products, producing themselves forecasts of up to 1 km resolution in the coastal areas.

The users of MFS

The major environmental issues for the Mediterranean Sea tackled by MFS include:

- changes in the basin hydrological cycle (also due to man-induced changes in the river basins and their runoff), in underground waters and in precipitation events;
- fate and dispersal of oil and contaminants in the open sea;
- fate and dispersal of land derived nutrients and contaminants;

- fishery activities and mariculture/aquaculture;
- algal blooms and adverse effects in coastal areas (anoxia, turbidity, etc.);
- coastal erosion;
- ecosystem changes, invasive species and long-term adverse marine trends.

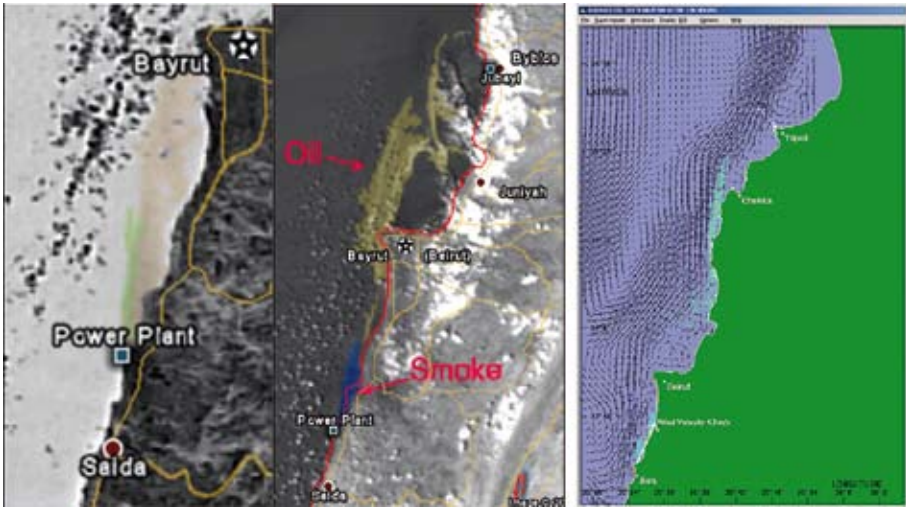
All these issues require a scientific basis for the understanding, monitoring and modelling of the marine environment, from basin scales to the coasts. MFS is the operational system that can support applications in each of these fields.

The forecasts and analyses are available in real time to both an internal and external community of users. The internal community is composed of the national forecasting centres of several countries bordering the Mediterranean Sea. The external community is composed of the EEA (European Environment Agency), UNEP/MAP (United Nations Environment Programme/Mediterranean Action Plan), Member State governmental and military agencies, research institutes and private companies.

End-user applications involve oil spill dispersion monitoring and forecasting, Search and Rescue assistance and Rapid Environmental Assessment modelling.

Oil spill drift predictions

The IMO (International Maritime Organisation) and UNEP/MAP Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC) is now assisted by several MOON forecasting centres and by the GMES Marine Core Service. The support comes from making available wind and current forecasts for “fate and dispersal” predictions of oil spills. The MOON members have developed



<p>(a) July 18 (08:20), 2006: enhanced MODIS image. Land and clouds are dark. Smoke (brown) and oil (green) drifting north from the power plant.</p>	<p>(b) July 19 (10:35), 2006: enhanced MODIS image. Smoke plume (blue) is still rising from the power plant. Oil (yellow) has reached the gulf of Beirut and Byblos.</p>	<p>(c) The predicted oil spill on 18-19 of July, 2006. The green dots in the sea are superimposed to local currents. The simulation started on July 13, 2006.</p>
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Fig. 4 The Lebanon oil spill was monitored both by satellite visible sensors, MODIS in (a) and (b), and by space-based SAR (radar) sensors (not shown). The MFS and CYCOFOS forecasting systems were run in real time with an oil spill forecasting model (MEDSLIK) and the oil dispersal and fate was correctly captured, as shown in (c). (Credits: ISAC-CNR, Rome, Italy Oceanography Centre, Univ. of Cyprus, Cyprus and INGV, Bologna, Italy)

up to five oil spill models coupled to the current forecasts providing, within a few hours, information to REMPEC about the possible direction of oil drift and its transformation or absorption at the coasts.

The Lebanon oil spill accident of July 2006 demonstrated the capacity of such a system to be an effective support to oil spill damage reduction operations. Real time forecasts of the oil spill dispersal along the coasts of Lebanon and Syria were issued as little as a few hours after the information reached the forecasting centres of Cyprus and Italy and predictions were sent to REMPEC and other governmental agencies. The forecast of the oil drift was proven correct and dispersal was monitored for

an entire month after the accident (see figure above).

Search and rescue operations

Several Mediterranean nations' coast-guard organisations and meteorological offices are responsible for the Search and Rescue operations at sea. The prediction of the movement of a drifting object at sea is a very challenging problem, due to the inherent unpredictability of single trajectories in a turbulent fluid and to the difficulty of getting precise information on the object size, floating characteristics, etc. Here again the MOON forecasting models are of great help to give insight in the possible directions of search, making the work at sea easier.

Marine Rapid Environmental Assessment

A relocatable modelling system has been developed in order to provide high-resolution forecasts (horizontal resolution to less than 1 km) within a few tens of hours in arbitrary Mediterranean regions covered by the MFS basin scale model and/or other operational higher resolution models.

First results show that relevant forecast improvements may be obtained by such a relocatable system. This can be useful in case of localised emergencies at sea (like contaminant spills) and for naval operations.

Conclusions

The MFS short-term forecasts and analyses for the Mediterranean, at basin scale have demonstrated to be useful for a new science-based approach to the protection of the sea and its resources. GMES will integrate MFS into a pan-European system with analogous capabilities over the global ocean and other European regional seas. The Mediterranean will continue to be monitored and forecasted, allowing several new applications to develop, building on basic information about the past, future and present state of the ocean and the marine environment. Such a continuous stream of data of standard quality will be made accessible at European and international level through the GMES Marine Core service.



Nadia PINARDI holds a PhD in Physical Oceanography from Harvard University, MA, US, and she is now associate professor of Oceanography at Bologna University, Italy. Her interests range from ocean numerical modelling to data assimilation, numerical modelling of the marine ecosystem and physical-biological interactions. She has written more than eighty papers in peer reviewed journals on a wide range of subjects. The latest topic of her research is the understanding of uncertainties in ocean field estimation and ensemble forecasting with distributed computing networks.

She has coordinated, since the middle of the nineties, the development and implementation of the Mediterranean Operational Oceanography Network, which is now the European service for ocean monitoring and forecasting in the Mediterranean Sea. She is a member of the European Environment Agency Scientific Steering Committee and of the European Research Council for Earth Sciences. Nadia Pinardi was awarded the European Geophysical Union (EGU) Fridtjof Nansen Medal 2007 for Oceanography.

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