Ocean climate variability in the Mediterranean Sea: climate events and marine forecasting activities

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Abstract

The long-term ocean variability of the Mediterranean Sea has been studied intensively in the past twenty years. Results illustrate the correlation between atmospheric forcing variability and ocean response at seasonal, interannual and interdecadal time scales. Major climate variability events have occurred in the 1980s and 1990s driven by long-term interannual variability of atmospheric forcing over the basin. The changes involve inversion of current direction in deep regions of the basin, strengthening and weakening of sub-basin scale circulation structures. Moreover, shorter-term ocean variability, connected with the time scales from the seasonal to the mesoscale, has been thoroughly investigated. This has produced the implementation of a Mediterranean ocean Forecasting System (MFS) to predict ocean variability in the Mediterranean Sea from the global scale to the shelf areas. The MFS started operational activities in January 2000. Presently it produces daily analyses and weekly 10-day forecasts of currents and temperature and salinity fields for the entire Mediterranean at approximately 10 km resolution.

The main elements of the MFS -simultaneously operating in a near real time observational data network, general circulation model and data assimilation scheme- were implemented and upgraded as part of two EU funded projects The main goal of the most recent research has been to advance monitoring technology to achieve maximum reliability of the Near Real Time observing system, to demonstrate regional forecasting in several Mediterranean subregions (3 km resolution). One of these regions is the Adriatic Sea where forecast activities started in 2003 within a project called ADRIatic sea integrated COastal areaS and river basin Management system pilot project (ADRICOSM). The latter demonstrates that, given proper downscaling in the Adriatic Sea, realistic currents can be predicted down to the scale of 5 km and less. Products of MFS and ADRICOSM are available at www.bo.ingv.it/mfstep and www.ingv.it/adricosm.

1. Ocean climate variability in the Mediterranean Sea

The Mediterranean Sea is a semi-enclosed basin (Fig.1) with deep ocean areas and narrow continental shelves. Exceptions to this rule are given by the extended shelf areas of the Adriatic Sea and the Tunisian plateau. The Gibraltar Strait balances the water and heat losses at the air-sea interface of the basin, maintaining a long term steady state equilibrium. The complex morphological structure of the basin and its exchanges with the Atlantic Ocean make the Mediterranean Sea circulation particularly unsteady and variable, from the deep ocean areas to the shelves. A recent overview of the shelf scale circulation of the Mediterranean Sea has been given in Pinardi et al. (2004).

The ocean climate variability of the Mediterranean Sea has been observed by several recent interdisciplinary international Projects such as POEM (Physical Oceanography of the Eastern Mediterranean, Robinson et al., 1991, Malanotte-Rizzoli et al., 1999, Roether et al., 1996) and MATER (MAss Transfer and Ecosystem Response, Monaco et al., 2002). The main findings show that the basin circulation is formed by subbasin scale gyres, free and boundary current jets and that mesoscale processes are pervasive. Numerical modelling of the circulation has shown that the variability of all these structures is controlled by atmospheric forcing variability to a degree unknown up to few years ago (Pinardi et al., 1997, Korres et al., 2000, , Molcard et al., 2002, Demirov et al., 2002).

It is worth mentioning two of the largest climate variability events documented in the literature. The first (Brankart and Pinardi, 2001) is concerned with an intermediate water cooling event that affected the entire extent of the Ionian and Levantine basins between 1981 and 1983. This event was due to a large anomaly in wind stress curl and heat fluxes over the Eastern Mediterranean that can be seen in Fig. 2 and 3. The wind tress curl anomaly is outstanding in winter of 1981 while the heat flux anomalies in 1981-1982 are only the third lowest minima. This forcing anomaly combination produces intermediate waters (at 200 meters) which were 0.45 ^{o}C cooler than in the previous decade water masses at the same depth in the Eastern Mediterranean. Brankart and Pinardi (2001) show with different simulation experiments that this temperature anomaly was due to the atmospheric forcing anomaly of 1981-1983.

The second event is the so-called Eastern Mediterranean Transient (Roether et al., 1996). This produced deep waters in the Cretan Sea that outflowes through the Straits and replaced the abyssal waters of the Eastern Mediterranean. The EMT started around 1988-1989, reached maximum amplitude in 1992 and then relaxed down. Its remote effects are still continuing to appear in distant regions of the basin, such as the Adriatic Sea and the Western basin. The Cretan Deep Waters are saltier and warmer than the previous deep waters of the Eastern Mediterranean originating in the past fifty years from the Southern Adriatic Sea. The Cretan Deep Waters lifted the layer corresponding to Levantine Intermediate Waters (LIW) by several tens of meters so that saltier waters were entering into regions connected by sills and Straits, such as the Otranto channel and the Sicily Strait. Research is still underway to understand the effects of such transient on the ecosystem dynamics of the basin.

The slowly varying atmospheric forcing variability of atmospheric surface fields is related to remote forcings that teleconnect the Mediterranean region with the tropical and mid-latitude global atmospheric variability. For example, the winter wind stress variability between the 1979-1987 period and the following is connected to the North Atlantic Oscillation (NAO) index (Demirov and Pinardi, 2002). The heat flux variability is instead correlated positively with NAO in the western and negatively in the Eastern Mediterranean (Marzocchi, personal communication). Moreover, teleconnections of summer Mediterranean climate variability with Indian Monsoon and Sahel atmospheric variability have been studied (Raicich et al., 2003). The large anomaly events, such as the great heat losses in the winter of 1992-1993, are found to be best correlated with other regional

climate regimes, such as Etesian wind variability (Josey, 2003).
In response to these changes in atmospheric forcing, the large scale circulation in certain areas can also invert the direction of flow. Pinardi et al. (1997) documented the change of the cyclonic circulation of the Northern Ionian Sea into an anticyclonic circulation after 1987. In Fig. 4 we show the other change that occurred at the end of the 90s, that brought the Northern Ionian Sea back to a generally cyclonically circulating flow field. In Fig. 4 it is evident that the flow field between the smaller negative values (yellow and red) and the larger negative values (blue) in 1997 is southward, producing an overall anticyclonic circulation in the western Ionian Sea. In 2000 the situation is totally changed and the overall circulation in the western Ionian is cyclonic. Satellite data confirm such changes (Lermusieaux and Robinson, 2001) together with *in situ* data (Manca et al., 2003).
This complex picture of the large scale basin circulation and water mass structure makes it impossible to assess the state of the system only from episodic surveys of the basin, collecting scattered data in different subregions. A large scale monitoring system should be set up that is capable of detecting changes in the circulation when they occur and follow them, from the large scales to the coastal areas.
The shelf area circulation is in fact extremely sensitive to changes in large scale current strength. An example is given by Echevin et al. (2003) in the Gulf of Lyon, where the along-slope, westward flowing Liguro-Provencal current can intrude on the continental shelf, changing the local circulation structure. The Liguro-Provencal current is part of the large scale Gulf of Lyon gyre that is a large scale, wind and thermohaline forced gyre. The changes in position and strength of this current are due to the large scale vorticity balance of the North-western basin and the impacts on the shelf areas can be as large as changes induced by local atmospheric forcing over the specific continental shelf area. Another example of shelf area 'forced' by the large scale flow field, is the Adriatic Sea where the Otranto Strait provides the heat restoring mechanism for the large heat losses occurring in the shallow northern areas during winter (Artegiani et al., 1997, Maggiore et al., 1998). This restoring mechanism is like the one working in the Gibraltar Strait and regulates the long term buoyancy balance of the basin (Zavatarelli et al., 2002).
The Northern Adriatic Sea heat budget is then partially controlled by the lateral exchange of waters occurring during the year. Such lateral exchange is maintained by the balance between the Eastern Adriatic Current (EAC), flowing northward along the Adriatic Sea eastern side and the Western Adriatic Coastal Current-WACC, flowing southward. The EAC is partially determined by exchanges in the Otranto Strait and the WACC in connected to the Po river runoff and the wind forcing (Zavatarelli and Pinardi, 2003). Thus the circulation at the mouths of the Venice lagoon is connected to the local atmospheric forcings (heat losses) and the circulation related to the Otranto Strait transport. This poses the conceptual basis for a possible predictive system of the circulation at the mouths of the Venice lagoon: the monitoring should consider both large and shelf scale monitoring and downscaling from the open ocean to the shelf scale (Pinardi et al., 2002).

2. The Mediterranean Forecasting system

The large amplitude natural variability discussed above couples with man-induced changes in the Mediterranean regions. Anthropogenic effects are evident, especially on the hydrological cycle of the basin and particularly on runoff. The largest man-induced changes are occurring in the Nile Delta and generally in the Northern shore rivers where agricultural activities have induces changes in the timing of runoff peaks and total runoff (Sanchez-Arcilla et al.,2002, Hamza, 2003).
Thus the coastal areas cannot be managed without a nowcasting/forecasting system that will allow the continuous assessment of system evolution. Such a system is at the base of the most urgent societal concerns for the further exploitation and preservation of world's natural resources in the coastal regions of the Mediterranean Sea and the world's ocean.

Since September 1998, the Mediterranean Forecasting System (MFS) programme (Pinardi and Flemming, 1998) has begun to implement the backbone of a future fully integrated system for the protection of the Mediterranean Sea marine environment and the sustainable exploitation of its resources. The first Project to implement elements of the MFS programme was the Mediterranean Forecasting System Pilot Project (MFSPP) that lasted from September 1998 until June 2001. The second Project is the Mediterranean Forecasting System Toward Environmental Predictions (MFSTEP) which begun in March 2003 and will end in 2005.

In parallel with these large scale monitoring and nowcasting/forecasting efforts, a regional and shelf scale forecasting system for the Adriatic Sea has been started that will provide the necessary downscaling to the shelf areas with appropriate horizontal and vertical resolution. The ADRIatic sea integrated COastal areaS and river basin Management system pilot project (ADRICOSM) started its activities in October 2001 and will end its first phase in October 2003: this system has established the first real time coastal monitoring and nowcasting/forecasting system for the Adriatic Sea as a three-dimensional hydrodynamic state, nested within the large scale MFS forecasts.

In the following discussion we start first with the description of the MFS components and then consider the ADRICOSM implementation and results.

2.1 The large scale observing and data management system

The four observing system components of MFS are: 1) the satellite data, near real time data analysis and dissemination network; 2) the Voluntary Observing Ship (VOS), vertical profiling system; 3) the Mediterranean Moored Multidisciplinary Array (M3A) observing platforms and 4) the autonomous drifting and profiling system.

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) Sea Surface Height (SSH) or Sea Level Anomaly (SLA) from satellite altimeters; 2) Sea Surface Temperature (SST) from satellite radiometers; 3) Sea Surface Chlorophyll (SSC) from radiometers and 4) surface winds from scatterometers. SST, SLA and surface winds are currently produced in real time by several centres and Institutions. Retrieval algorithms have become very reliable and allow the accurate computation of derived quantities.

For the Mediterranean Sea, real time SST and SLA are assimilated in the forecasting ocean model. The algorithms developed for real time analysis of along track SLA seem to give reasonable data for the assimilation scheme. SST is produced as a weekly mean of daily nighttime images, taken from different passes over the Mediterranean, collected by two different data collection centres, in France and Italy. The SST data set is used in the assimilation scheme as a heat flux correction term at the model surface. The scientific analysis of the satellite MFSPP data set was done by intercomparing SST and SLA and SLA and XBT (eXpendable Bathy-Thermograph) data (Buongiorno Nardelli et al., 2003).

SSC and surface winds are not analysed yet in real time. However, SSC is analysed in real time for the Adriatic Sea (see below) and surface wind analyses are evaluated with respect to operational analyses before starting the real time production.

The Voluntary Observing Ships (VOS) for temperature data collection has been and will continue to be performed along several tracks (Fig. 5) across the Mediterranean deep ocean areas. The along track nominal resolution tracks is 12 nm and XBT are used down to 400 and 700 meters. The Real Time (RT) data collection system was successfully organized and harmonization of the data collection exercise was achieved. The results are presented in Fusco et al. (2003) and the structure of the data management system is analyzed in Manzella et al. (2003). There are two streams of data, one real time and without high level quality control and may be decimation, the other highly quality controlled and fully resolved in the vertical. The data collection is now done with full resolution profiles sent by portable phone teletransmission at the end of each track, i.e. with a maximum time delay of 24 hours after data collection. The VOS tracks will be used to deploy subsurface drifting buoys and to develop a new expandable instrument that will collect temperature and fluorescence data in order to reduce the cost-benefit ratio for such a monitoring system.

The Mediterranean Moored Multisensor 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 monitored state variables 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 selected depths. The basic idea of a modular system with acoustic links between different mooring lines is a promising one. The 2-3 months maintenance interval guarantees the high quality of data with the exception of turbidity and PAR (Photosinthetically Available Radiation) measurements. One year's physical, optical and biochemical data were successfully collected at a location in the Cretan Sea, 1050 m deep (Nittis et al., 2003). The data were used for calibrating ecosystem models in the area and the buoy system proved to be a valuable data collection platform for that purpose (Triantafyllou et al., 2003). The developments being carried out now are the adaptation of two more existing mooring lines to the M3A 'philosophy', one in the southern Adriatic and the other in the Ligurian Sea (north-western Mediterranean).

The present day observing system developments are concerned with the definition of a autonomous drfting and profiling network for the Mediterranean Sea. This will consists of:

1. a high space-time resolution network of autonomous subsurface profiling floats (Array for Real-Time Geostrophic Oceanography (ARGO). Initial drifting depth will be fixed at 400 metres with descent down to 700 m and surfacing every three-five days. Two different floats are already deployed in the Western Mediterranean to check the functioning of the system, a total of 20-25 floats will be deployed.
2. a basin scale glider autonomous on completition vehicle experiment (Fig. 6). The target for the glider experiment is to carry out continuous unattended glider profiles along a 300 km section of the Northern Ionian, approximately along the 23 E longitude meridian. The repeat period should be approximately 30 days. Launching and recovery will be executed by small boats from a support base in Messina.

The main objective of the MFS data management system is to build a *regional data management* structure that will consider 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 philosophy behind data management in regional/shelf areas is that quality control and data collection procedures should be validated and intercompared between the basin scale and the shelf scale systems and have substantially the same protocol of data exchange.

The basin scale data management system considers the development of two streams of data in real time: one 'raw' and the other quality controlled and filtered. Such data management structure is illustrated in Manzella et al. (2003) for the VOS subsystem.

The regional data management structure will include a centralised Archiving and Dissemination Data Centre (ADDC) and several Thematic Expert Data Centres (TEDC) associated with the different sources of data (Fig. 7). The communication between the data centres will be undertaken by WWW, ftp and email, with both automatic and manual retrieval modes. The ADDC system will provide the subsampling procedures necessary to send the collected data in real time to the World Meteorological Organisation-WMO Global Teleconnection System-GTS, thus contributing to global ocean real time data exchange.

2.2 The basin scale assimilation and forecasting activities

Ocean current forecasts are possible only if accurate initial and boundary conditions are known with sufficient accuracy and a numerical model is used to predict the future evolution of the flow field. In order to fulfill these requirements, an assimilation system and a numerical model have to be developed and coupled to the observing system data collection in real time.

The Ocean Data Assimilation algorithm and the impact of data strategy and accuracy is an important issue of MFSPP. Results has been achieved through the development of a new data assimilation scheme (Scheme for Ocean Forecast and Analysis, SOFA, De Mey and Benkiran, 2002). SOFA is an Optimal Interpolation reduced order scheme that uses multivariate vertical Empirical Orthogonal Functions as components of the reducing order projection operator. Vertical multivariate EOF have been computed for the basin, both from historical hydrological data and model results and intercomparison has been carried out successfully (Sparnocchia et al., 2003). SOFA has been implemented for combined SLA and XBT assimilation and tested in several different combinations of EOF and input data (Demirov et al., 2003).

Numerical forecasting was, and it still is, performed using an Ocean General Circulation Model (OGCM) that was implemented in the Mediterranean basin at 1/8 x 1/8 degrees resolution and 31 vertical levels. The pre-operational system started in January 2000 and is continuing now with a second version of the assimilation system, implemented on Jan 1^{th}, 2003. Real time atmospheric data collection is realised for surface atmospheric field analyses and forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF). Forecasts for ten days are produced once a week using an asynchronous coupling with atmospheric surface parameter forecasts. The forecasting system for MFSTEP is presented in Fig. 8. It includes NRT collection of ocean observations and meteorological forcing, production of analysis/nowcast on Tuesday of each week and the release of weekly 10-day forecasts. In addition, every week the forecast will be published on the Web site of MFSTEP (www.bo.ingv.it/mfstep).

Analysis of forecast skill scores indicate that the rms (root mean square) surface temperature error is always less that 0.5 ^{o}C and that at all levels, rms persistence error is always greater than the forecast error after the first to the tenth day (Fig. 9).

2.3 The regional and shelf predictive system: a nested approach

Towards a better description of the dynamics and processes of the different areas within the Mediterranean basin, regional and shelf models will approximately double and quadruple respectively the spatial resolution of the OGCM in critical areas.

Regional models will run on a weekly basis initialised from the MFSTEP OGCM fields (see Fig. 8), carrying out forecasting simulations for five days with high resolution atmospheric fields. Lateral open boundary conditions for the regional and shelf models will be also provided by the MFSTEP-OGCM forecast fields.

During MFSTEP the meteorological community will actively be involved in producing the best estimates of atmospheric forcing fields at the best available temporal and horizontal resolutions. The Arpege (Deque and Piedelievre, 1995) Aladin (Radnoti et al. 1995, Horanyi et al. 1996) and Skiron/ETA (Kallos G., 1997) limited area models will be run explicitly to produce 10 km hourly fields to force the basin scale and regional models. Together with the ECMWF fields, this will produce the best atmospheric data set for future studies of ocean forcing and air-sea interaction coupling.

High resolution simulations in the coastal and shelf areas with nested model implementation have already been performed during MFSPP. Four 5 km intermediate models nested within the forecasting OGCM and nine shelf models (2-3 km resolution) nested into the intermediate, have been implemented and calibrated. Novel model implementation in areas previously lacking modelling experience has been successfully carried out (Korres et al., 2003). Understanding local shelf dynamics for forecasting needs has been accomplished in preparation for the next phase. All models were able to capture known features of the seasonal circulation in the basin and different resolution models are consistent, even if the high resolution models are more realistic.

3. The shelf scale forecasting system for the Adriatic Sea

ADRICOSM represents the downscaling of the MFSTEP forecasting to the required scale for the shelf areas. This is the scale capable of resolving the physical flow field transport processes and the optimal scale to couple the physical flow field with land derived sources of pollutants and nutrients that normally determine the state of health of the coastal system.
Thus the major aims of this project are:

- to demonstrate the feasibility of Near Real Time (NRT) nested coastal current forecasts;
- to develop the integration of the river monitoring and modelling system with the coastal current forecasting.

On the basis of the MFS experience, the forecasting activities at weekly time scales have been demonstrated to be applicable also in this critical shelf area. An important aim of the project is also to develop a data assimilation scheme for both the large scale and the coastal data sets.

3.1 The shelf scale Observing System

The ADRICOSM observing system is composed of two parts: one for the open ocean, encompassing the Southern Adriatic deep areas, and the second one focusing on the shelf/coastal processes. The space and time resolution of the two components is quite different. The shelf scale is centered at weekly time scales and the deep ocean areas at monthly time scales. The effort here is to unify data collection protocols and data transmission procedures so that shelf scale data are also disseminated in real time.
The ADRICOSM shelf scale observing System is localised in 4 different coastal regions: Emilia Romagna, Gulf of Trieste and two areas along the Croatian coast. In these regions, traditional transects of temperature and salinity (from CTD) are realised and data transmitted in real time. In Fig. 10, the exact locations of the CTD network and the buoy stations are shown. Here the buoy network is dedicated to air-sea interaction monitoring and to the upper water column but the measurements are still not as interdisciplinary as in the M3A open ocean case.
This shelf scale observing system is coupled with the two VOS-XBT tracks that are part of the deep ocean monitoring system and which run in the Southern Adriatic (see Fig.6).

3.2 The Adriatic and shelf numerical modelling and forecasting

The numerical modeling system for the Adriatic Sea is shown in Fig. 11. The Adriatic Sea regional model is at 5 km resolution and 21 sigma layers in the vertical. It is based on the POM (Princeton Ocean Model, Blumberg and Mellor, 1987) which was initially implemented for the Adriatic Sea by Zavatarelli and Pinardi (2003). The lateral open boundary conditions in the Northern Ionian Sea (see Fig 11) are nested within the MFSTEP OGCM. The high frequency forcing is provided by ECMWF surface variables with interactive air-sea physics (Oddo et al., 2004).
In the shelf area of the Croatian Islands that considers the major town of Split and the Cetina river outflow, a shelf model (POM at 1.5 km horizontal resolution, see Fig. 11) has been implemented and nested within the Adriatic regional model. In addition, the very near

coastal waters of the same area have been modelled by a 2D hydro-dynamical model of variable resolution (with a finite elements grid), down to 20 m horizontal resolution. This very high resolution model receives lateral boundary conditions from the shelf model but in addition it is coupled with a river basin modelling and forecasting system developed for the Cetina river and for the sewage system of Split.

In May 2003, a pre-operational system was set up with forecasts done in real time once a week, coupled with the MFSTEP forecasting cycle, as depicted in Fig.8. The Po runoff is included with daily flow data while all the other rivers are represented by monthly mean runoff values. The Croatian shelf scale forecasting is also undertaken in real time. This on going real time experiment (www.ingv.it/adricosm) shows that nested forecasts are possible and under several circumstances are accurate.

In the Adriatic Sea, the forecast accuracy is limited by the capability to predict the run off of the major rivers and by the unavailability of resolved atmospheric forcing fields (of the order of 5-7 km in horizontal). It is in fact already well known that atmospheric forcing variability is high in this region and can generate jets and gyres due to wind stress curl structures of the order of several tens of kilometers.

Conclusions

A short term forecasting system for the Mediterranean basin scale and the Adriatic coastal areas has been developed that provides continuous monitoring of the flow field evolution and its changes. Such a system is the backbone for more environmentally oriented systems that it should provide forecasts in the near future of coastal algal biomass variability, pollutant dispersion and indicators of ecosystem health and change.

The concept is that dynamical downscaling is required in order to reach the necessary resolution for the appropriate simulation of transport and coastal processes and for coupling with biochemical tracers. This paper demonstrates that forecasting from the basin scales to the shelf areas is practical with present day technology.

This system also provides the meaning to improve our understanding, and our capability to accurately model, the physical processes with an incremental approach and the optimal usage of all information. In the future it will be necessary to couple such a system with monitoring and modeling of biochemical fluxes. This will give rise to a complete, predictive system of ecosystem variability and change.

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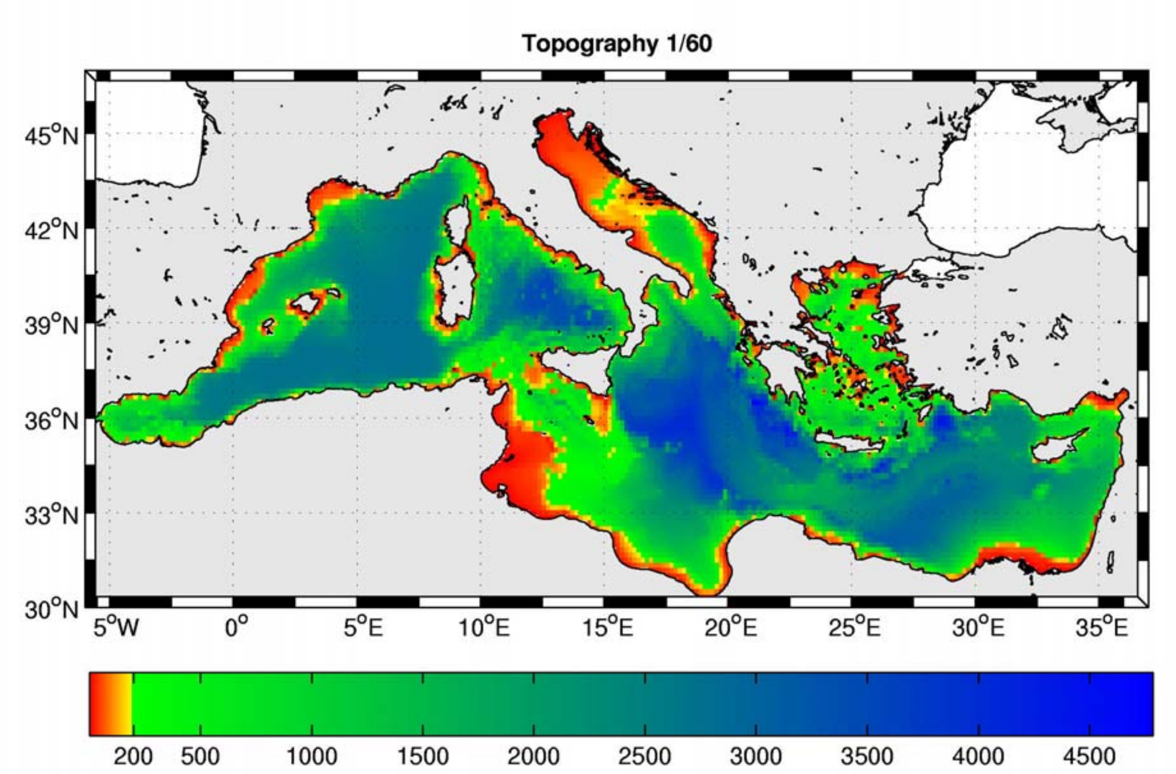

Fig. 1 The basin coastlines and geometry. The bathymetry is shown with contrasting coulours for the continental shelves and the deep ocean basin. The Western Mediterranean is the subregion west of the Sicily Strait while the Eastern Mediterranean normally indicates the region east of Sicily, comprehensive of the Adriatic and Aegean Seas. Horizonatl resolution is at 1/12 ^{o}C (=1/60).

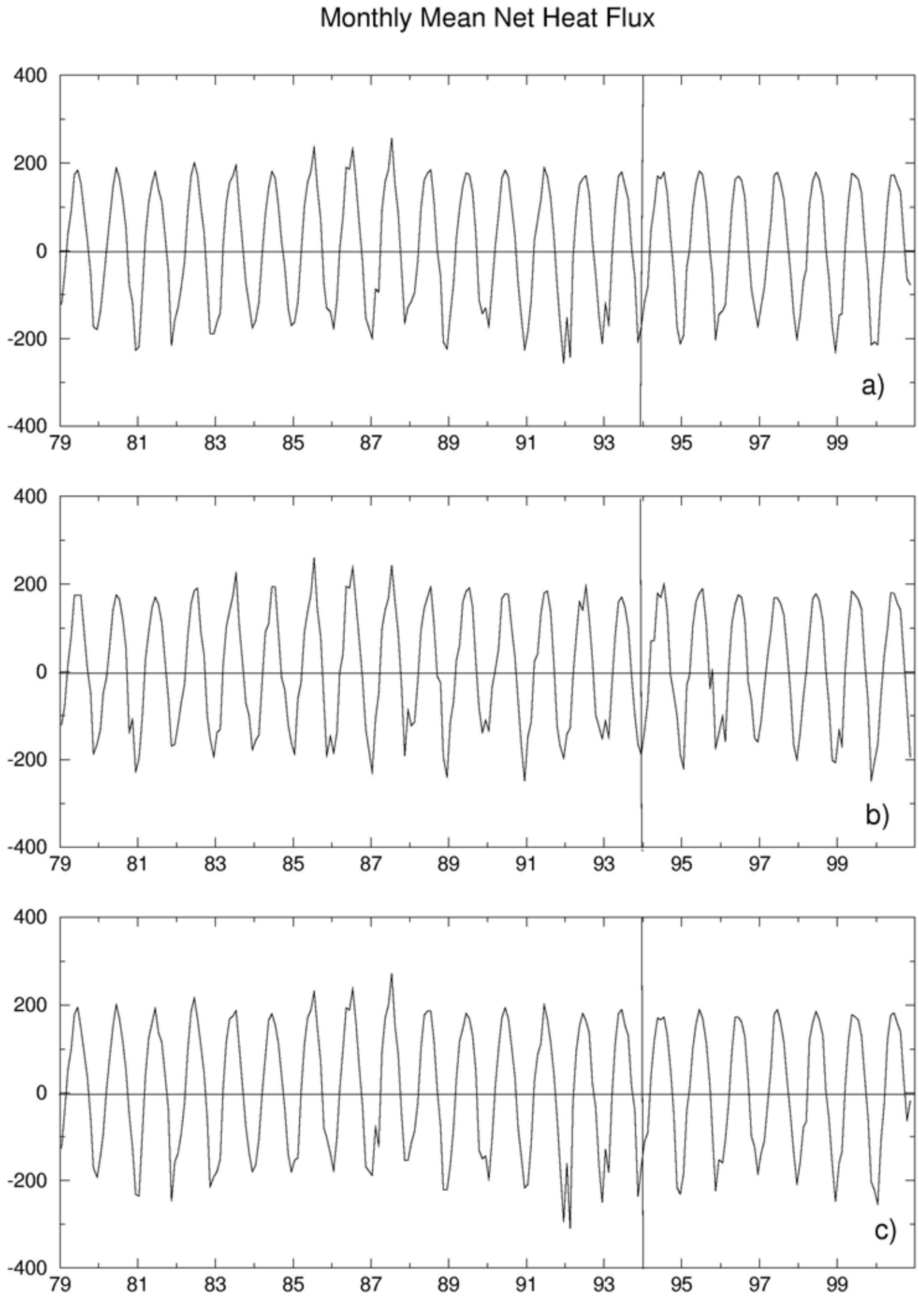

Fig. 2. Surface average heat fluxes (W/m^2) computed from a 1979-2001 model simulation forced by six hours ECMWF atmospheric forcing variables, as described in Castellari et al. (2000). a) whole basin, b) Western Mediterranean; c) Eastern Mediterranean averages . The simulation was restarted at the end of 1993 to reduce the climated drift of the model.

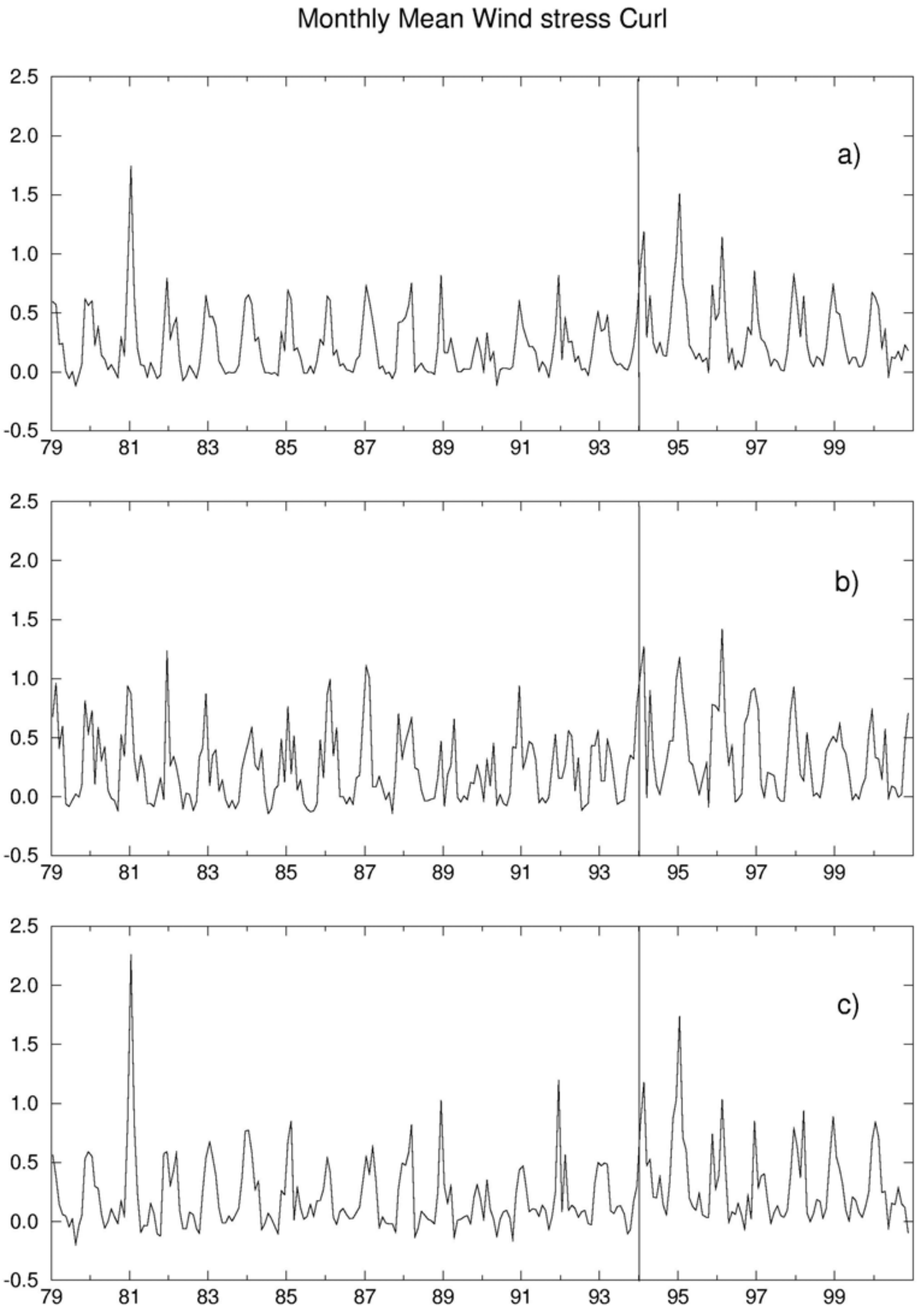

Fig. 3 Wind stress curl surface average time series (dyn/cm^2) from a 1979-2001 model simulation forced by six hours winds from ECMWF analyses. a) whole basin; b) Western Mediterranean and c) Eastern Mediterranean averages. The simulation was restarted at the end of 1993 to reduce the climated drift of the model.

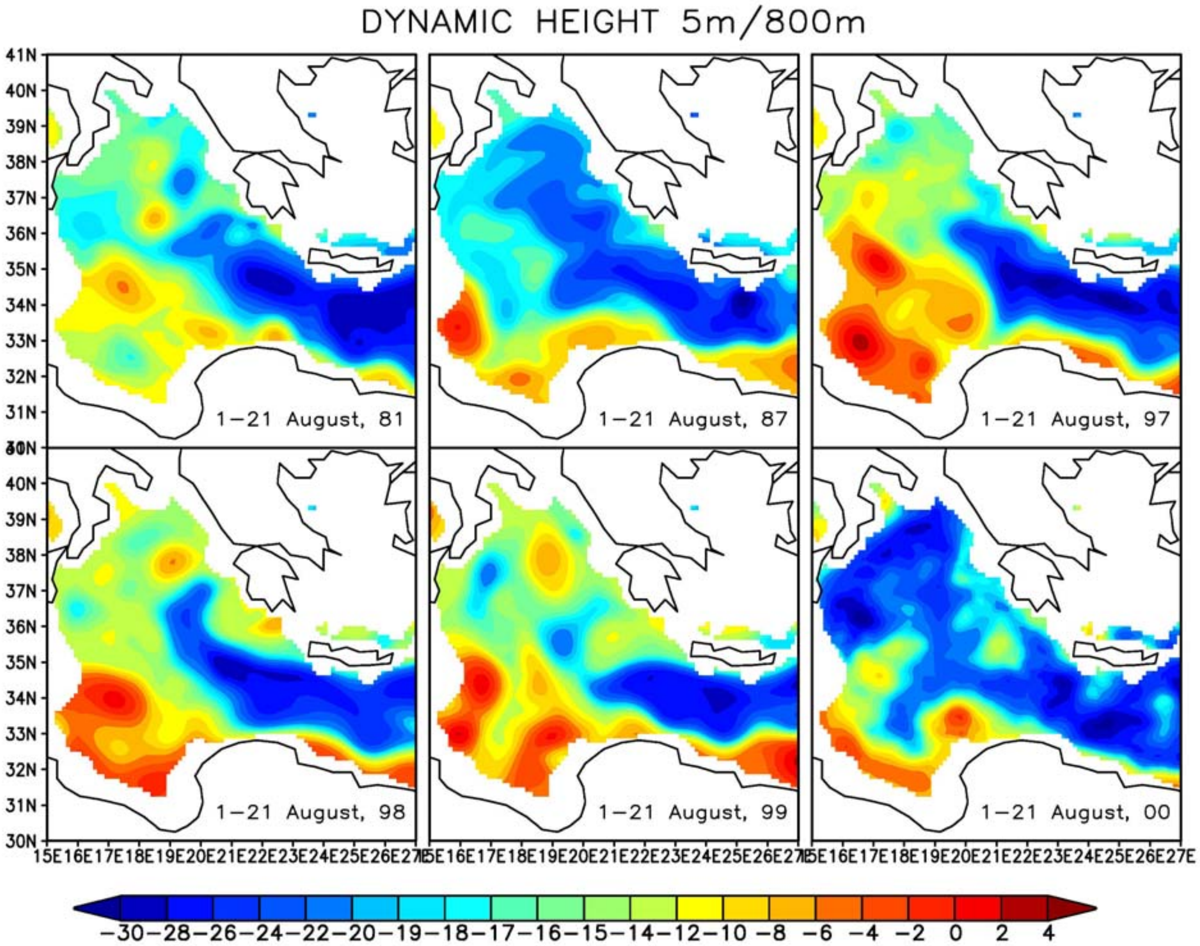

Fig. 4 Dynamic height anomaly at 5 meters with respect to 800 meters reference level calculated in the Eastern Mediterranean for different august years, indicated in the lower right corner of each image. The units are cm.

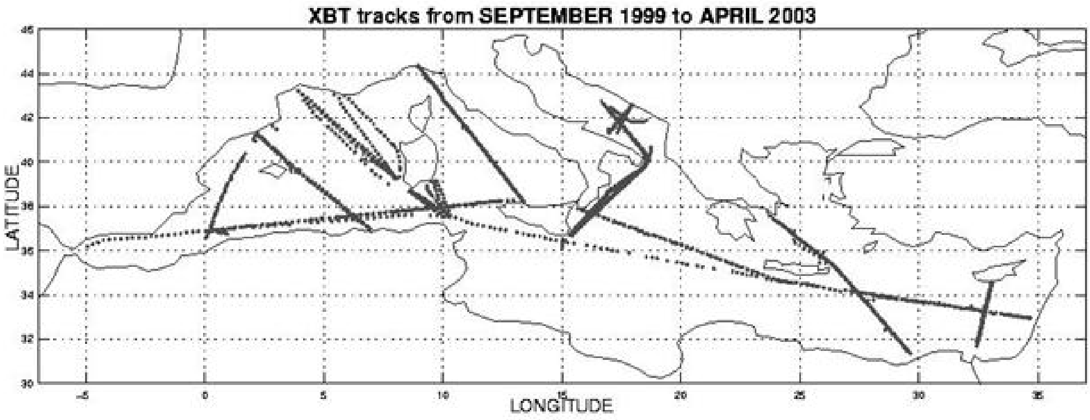

Fig. 5 The VOS tracks for the period September 1999-March 2003. Only the southern Adriatic tracks were continued from September 2000 untill march 2003. The others will be re-started in September 2004.

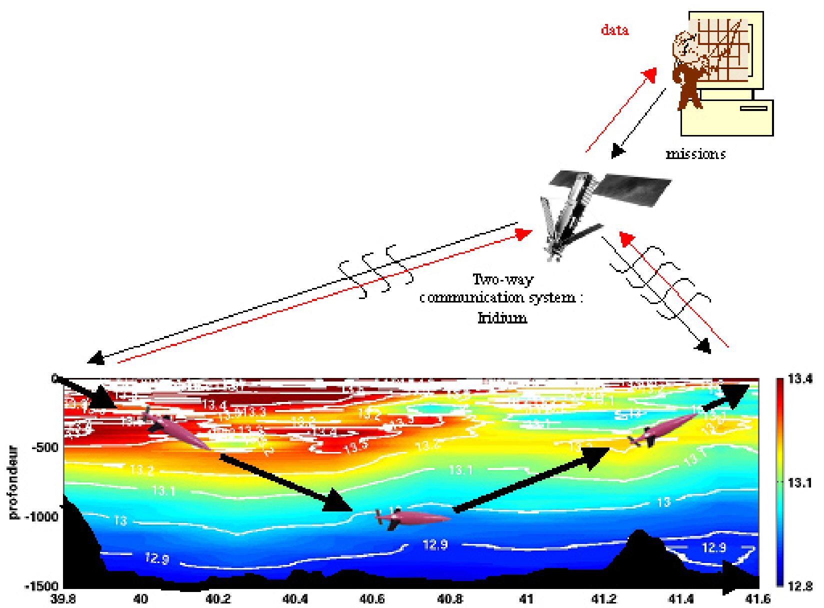

Figure 6: A possible configuration for the glider experiment in the Mediterranean Sea. The glider should sample to a depth of 1000 meters and will survey a section of about 300 km length.

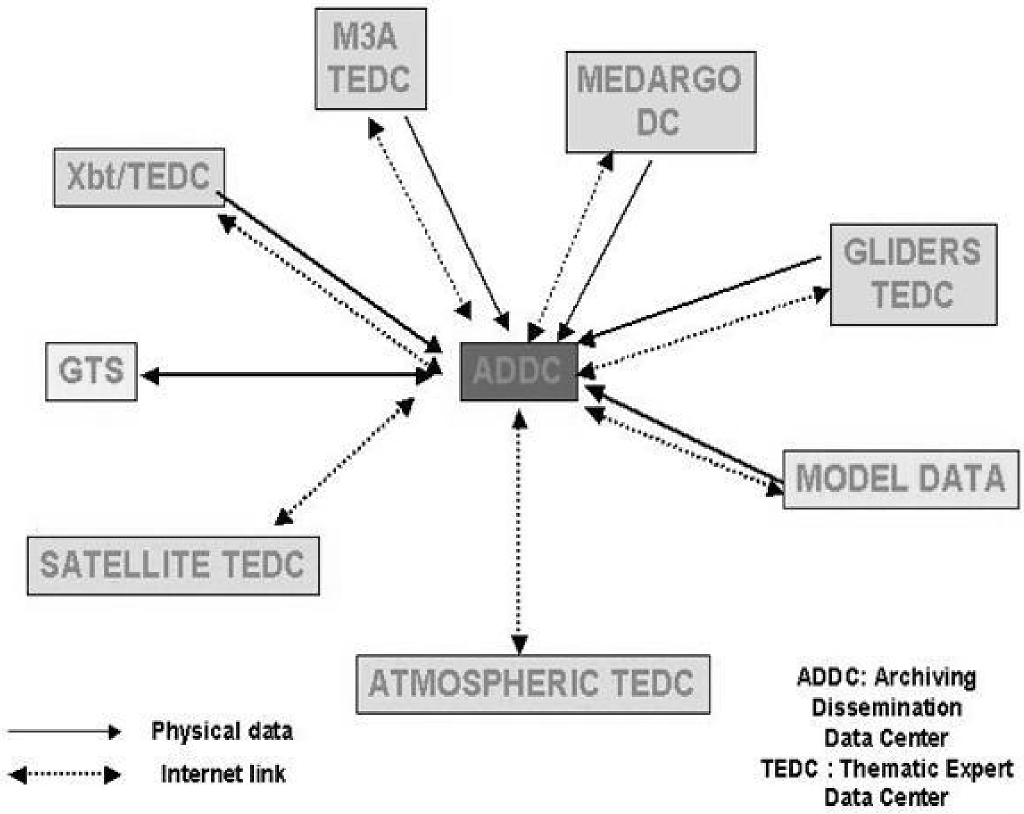

Figure 7. MFS data management scheme. The centers are: 1) ENEA (IT) (http://www.santateresa.enea.it) for the VOS/XBT data (centre called XBT/TEDC); 2) NCMR (GR) (http://www.ncmr.gr) for the M3A data (centre called M3A/TEDC); 3) CLS (FR) (http://www.cls.fr) for the satellite data (centre called SATELLITE/TEDC); 4) OGS (IT) (http://www.ogs.trieste.it) for the MEDARGO data (centre called MEDARGO/TEDC); 4) IFM-KIEL (GE) (http://www.ifm.uni-kiel.de) for the gliders data (centre called GLIDERS/TEDC); 5) IFREMER (FR) (http://www.ifremer.fr) for the ADDC. 6) IASA (GR) (http://www.iasa.gr) for the atmospheric data (ATMOSPHERIC TEDC); 7) INGV (IT) (http://www.bo.ingv.it) and UAT (GR) (http://www.oc.phys.uoa.gr) for the model data, analyses and forecasts

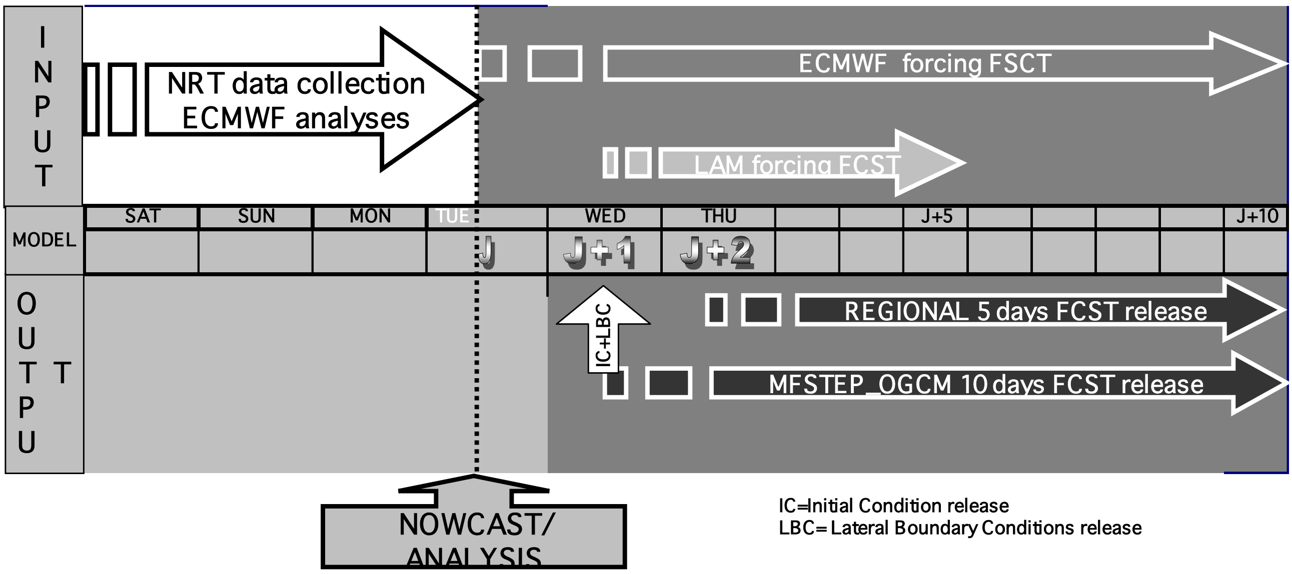

Figure 8: The MFS weekly information flow for forecasting. The forecast starts every week at 12:00 fo Tuesday from an analysis/nowcast produced from data collected in the previous week. The basin scale forecast is done with ECMWF forcing and on Wednesday the initial and lateral boundary conditions are given to limited areas models, nested within the MFS OGCM.

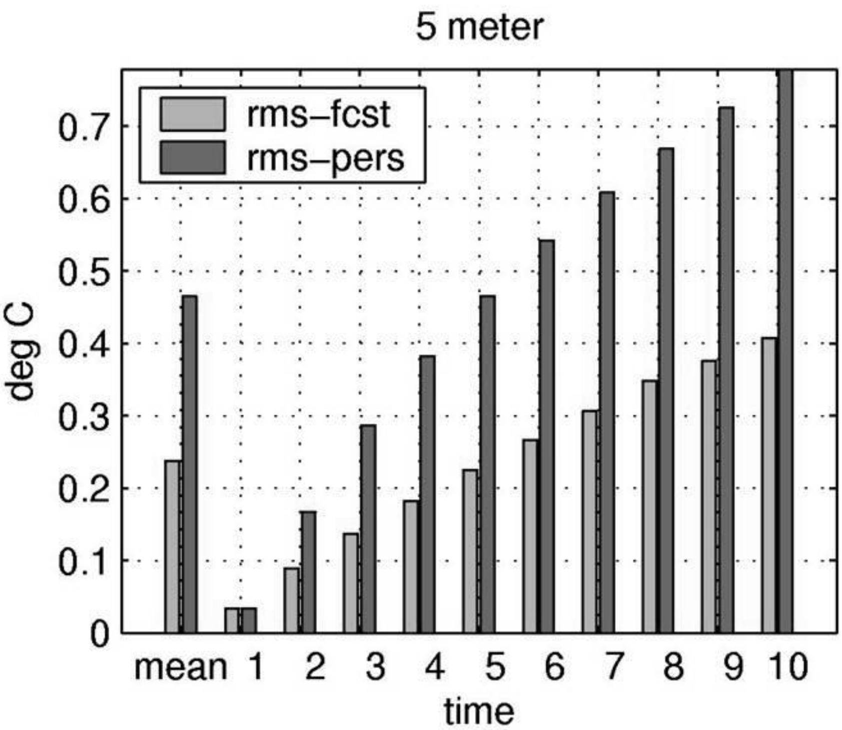

Figure 9: The root mean square forecast error for the mean of the ten days and for each of the ten days of the forecast for sea surface temperature and for the enire basin and the whole 2002 year. The blue bars indicate the forecast error computed as a difference between forecast and analyses, the purple bars indicate the persistence forecast error computed as a difference between the initial condition (nowcast or persistence) and the analyses for following ten days.

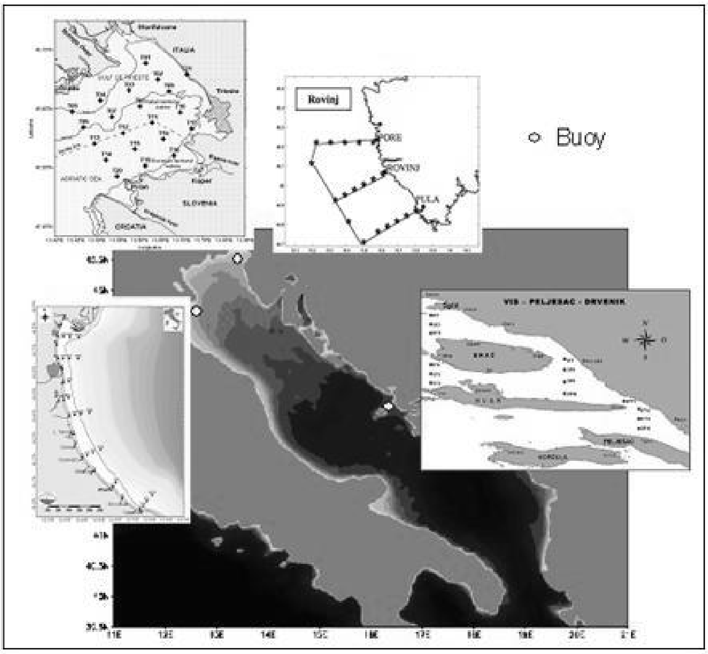

Figure 10: Shelf monitoring system in the Adriatic Sea (CTD and Buoys stations)

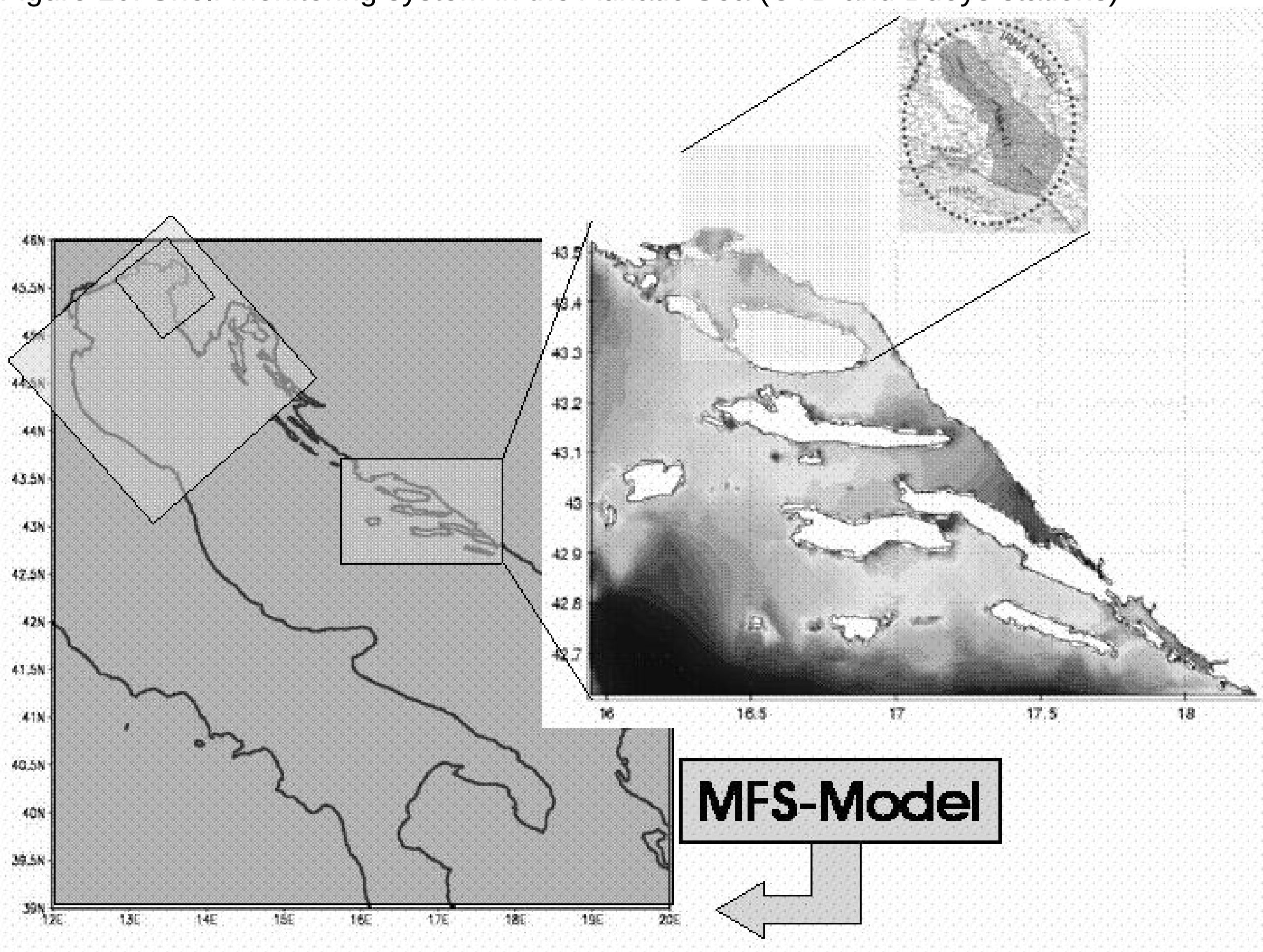

Figure 11: The ADRICOSM modeling system