Ocean Sci., 6, 263–267, 2010
www.ocean-sci.net/6/263/2010/

Ocean Science

Preface

Operational oceanography in the Mediterranean Sea: the second stage of development

N. Pinardi[1] **and G. Coppini**[2]

[1]Corso di Scienze Ambientali, University of Bologna, Ravenna, Italy
[2]Gruppo Nazionale di Oceanografia Operativa, Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy

1 Introduction

The papers of this special issue overview some of the scientific results of the second phase of development of the Mediterranean Forecasting System (MFS) realised during the EU project "Mediterranean ocean Forecasting System: Toward Environmental Predictions-MFSTEP" that started 1 March 2003 and ended in June 2006. The MFS oceanographic service that is now operational in the Mediterranean Sea was developed, implemented and quality assessed during MFSTEP. MFS is composed of: a) a near real time observing system with satellite and in situ elements; b) a numerical ocean forecasting system at basin scale, assimilating all data available in real time, and a set of limited area forecasting models in different sub-regional and shelf areas; c) biochemical models for algal biomass forecasting; d) a product dissemination system. Moreover, the products of MFS are used to develop downstream services, such as oil spill drift and dispersion, sediment transport in the coastal areas and fish stock assessment that demonstrate the value of the operational service for end-users.

MFSTEP contained several phases of development and realised a demonstration exercise, the so-called Targeted Operational Period-TOP that started in September 2004 and ended in March 2005. During TOP all possible observing platforms were active, the numerical models were capable to assimilate the observations and the all models were running in forecast mode, from the basin scale to the shelf areas. The deployed observing and modelling components of MFS are now part of a sustained operational oceanographic service for the Mediterranean Sea, so-called Mediterranean Operational Oceanography Network (MOON, http://www.moon-oceanforecasting.eu).

Correspondence to: N. Pinardi
(n.pinardi@sincem.unibo.it)

2 The challenge of operational oceanography

Operational oceanography is nowadays the branch of ocean science that routinely makes available high quality observational and model data for both fundamental studies and practical applications. The high variability of ocean currents and the need for the assessment of the state of the marine environment require a continuous monitoring of the ocean environment at unprecedented resolution and quality. On the other hand, scientific discoveries require continuous observations of the essential state variables of the system in order to detect new basic mechanisms and processes. Operational oceanography will produce such basic flow of information worldwide, from the collection of ocean observations following international standards to their mapping and forecasting for all users.

The implementation of operational oceanography in the world ocean is still at its infancy for many basins and shelf areas (Pinardi and Woods, 2002; Chassignet and Verron, 2006). In the Mediterranean two European research and development programs have started to implement a basin scale observing and modelling system for the production of oceanographic forecasts. The first project (Pinardi et al., 2003) set up a prototype observing and modelling system while the second, MFSTEP, upgraded the various components of the oceanographic system and demonstrated the quality of the forecasts from the basin to the shelf scales of the Mediterranean Sea. To our knowledge this is the first multi-scale (basin and shelf) forecasting system functioning operationally in the world, making available all basic oceanographic information (several gridded model data sets integrating the observations and the model output via data assimilation) on the state of the marine system and its evolutions on different space and time scales, from hydrodynamics to marine biochemistry.

Published by Copernicus Publications on behalf of the European Geosciences Union.

The concept developed in the Mediterranean implementation of operational oceanography rests upon a "nested approach" where resolution and processes are added gradually, wherever they are needed and where there is competence to use them and control them. This approach requires a comprehensive information system based on a network of centres delivering selected information needed for the value adding chain. Such network was consolidated during MFSTEP and it has never stopped since then, making this volume a very valuable source of information about the system components, their scientific validation and their usage in applications.

3 MFSTEP results in synthesis

The methodology for implementation of operational oceanography in the Mediterranean Sea, developed and demonstrated by MFSTEP, follows a multi-scale, multiplatform observing and modelling system approach schematised in Fig. 1. The project had the goal of developing, implementing and demonstrating some of the components presented in Fig. 1 and the activities can be synthesized in 5 working areas:

1. the real time observing system upgrade and deployment;
2. the numerical ocean forecasting system and its atmospheric forcing development and demonstration;
3. the biochemical numerical modelling development and scientific validation;
4. the data dissemination and information system set up;
5. the end-user applications and services demonstration.

In the following we will overview each working areas results.

4 The real time observing system

The MFSTEP observing system is composed of in situ and satellite elements only at the basin scale (see Fig. 1). For the in situ observing system element the sub-components are:

1. a Ship Of Opportunity Program (SOOP), composed of 9 tracks with 12 nautical miles resolution and full profile transmission (Manzella et al., 2007). The problems connected to the XBT temperature recording system were critically assessed (Reseghetti et al., 2007) and new technology was developed, a multiple launcher for XBT (Zappalà et al., 2007) and a new expandable probe that can collect temperature and fluorescence data (Marcelli et al., 2007).
2. a network of Mediterranean Multidisciplinary Moored Array (M3A) stations with Real Time collection and dissemination of data (Nittis et al., 2007 and Petihakis et al., 2007).
3. a dedicated and customized ARGO float program for the Mediterranean Sea, so-called MEDARGO (Poulain et al., 2007) to sample adequately the thermohaline structure of the basin (Emelianov et al., 2006). The float sampling scheme and the impact of temperature and salinity assimilation on the quality of the model analyses have been analysed with Observing System Simulation Experiments (Raicich et al., 2006 and Griffa et al., 2006);
4. a Fishery Observing System-FOS that allowed the collection of combined fish stock and temperature data (Falco et al., 2007);
5. a glider repetitive track monitoring in the Ionian Sea, collecting for several months temperature and salinity profiles down to 200 m and profiles down to 1000 m for few weeks (P. Testor and U. Send, personal communication).

For the satellite observing element the sub-components are:

1. altimeter near real time products from Topex/Poseidon and Jason-1 missions together with re-processed ERS-1 and ERS-2 altimeter signals;
2. real time daily Sea Surface Temperature (SST) products and re-analyses (Marullo et al., 2007);
3. near real time analysis of scatterometer winds producing daily optimal estimates of surface winds (Bentamy et al., 2007);

5 The numerical ocean forecasting system and its atmospheric forcing

The numerical ocean forecasting system developed by MFSTEP is composed of:

1. a basin scale forecasting model (Tonani et al., 2008) at 6.5 km resolution. The model was set in operational mode during TOP and never stop since then, producing daily ten days forecasts;
2. a daily data assimilation system for the basin scale (Dobricic et al., 2007). In addition, ARGO float position assimilation was developed for the first time (Taillandier and Griffa, 2006) as well as assimilation of local data in nested models (Vandenbulcke et al., 2006);
3. Four limited area ocean forecasting models at 3 km and four shelf scale models at 1.5 km resolution were nested in the basin scale model in operational mode. The regional model areas were: North-Western Mediterranean (Estournel et al., 2009), the Sicily Strait (Gaberšek et al., 2007), the Adriatic Sea (Chiggiato and Oddo, 2008) and the Aegean-Levantine Sea (Sofianos et al., 2006).

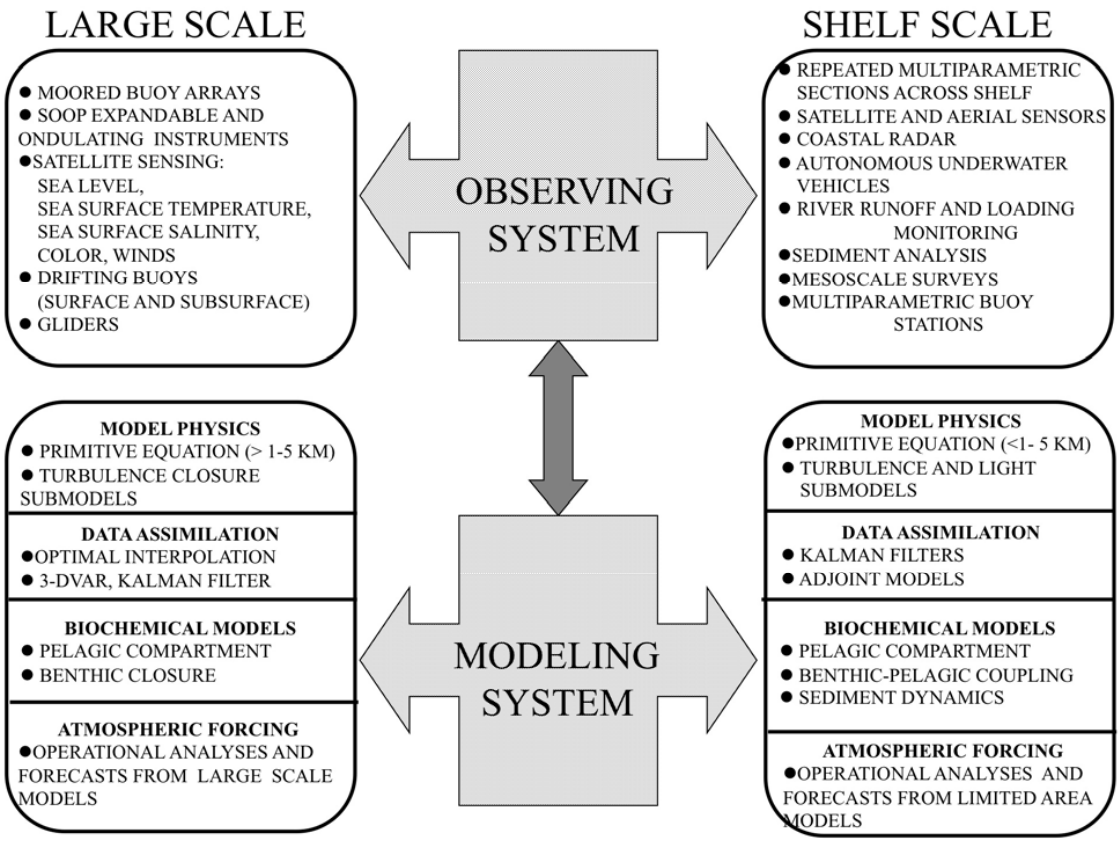

Fig. 1. The operational oceanographic system elements for the observational and modelling components of the Mediterranean Forecasting System.

Two of the shelf scale models are described in this issue: the northern Aegean Sea (Kourafalou et al., 2007) and the South-eastern Levantine Sea (Zodiatis et al., 2008).

The ocean forecasting activities were partially supported by a dedicated limited area atmospheric model run in operational mode (Brožková et al., 2006). This issue contains also some novel scientific interpretations of model results (Jordi et al., 2006; Ahumada and Cruzado, 2007; Olita et al., 2007) and a quantitative assessment of the operational forecast quality during TOP (Tonani et al., 2009).

6 The ecosystem numerical modelling

In MFSTEP a numerical model for the marine food web has been developed (Vichi et al., 2007) to be coupled with the oceanographic forecasting models and one example of such model is reported (Petihakis et al., 2009). Moreover data assimilation of chlorophyll data has been studied (Crispi et al., 2006) and proven to be effective in a large scale biochemical model implementation in the Eastern Mediterranean Sea (Triantafyllou et al., 2007). MFSTEP has put the scientific basis for the future forecasting models of marine biochemistry that are now working in real time.

7 The data dissemination and information system

The observed and model collected data have been organised in a network of Thematic Expert Data Centres (TEDC) mainly composed of Web Portals for the discovery and viewing of the MFS products and activities. The data formats and system architecture was done to be convenient for real time data downloading via ftp protocols both for the system expert teams and the end-users. The basic portal network is still working now and it forms the basis of the MOON Web Portal encompassing the most recent developments in the observing and modelling system after MFSTEP.

8 The end-user applications and services

Several novel applications of the forecasting products were developed during MFSTEP. This is an area of continuous research because the practical implications of a generic, routinely available analysis and forecasting system are still under scrutiny and development. Basically the analyses and forecasts can be used for management of emergencies at sea, for assessment of the state of the environment from pollution to fish stocks and integrated coastal zone management. In this issue we report of operational modelling of sediment transport in a northern Aegean Gulf (Krestenitis et al., 2007) and the hazard mapping for oil spill pollution (Pizzigalli and Rupolo, 2007). New modelling requirements for applications such as wave-current coupling in coastal areas are also explored (Jordà et al., 2007).

9 Conclusions

A short term forecasting system for the Mediterranean basin scale and its coastal areas has been developed that provides continuous monitoring of the flow field evolution in the recent past and daily 10 days forecasts. Generic, all-purpose, high quality oceanographic information is nowadays delivered by the operational integrated system developed during MFSTEP.

The MFSTEP project is a general example of how to deploy an operational oceanographic system in a relatively large area of the world ocean. The Mediterranean Sea is a semi-enclosed concentration basin that is forced by intense air-sea fluxes of momentum, heat and water typical of the open ocean. The shelf area of the basin are complex, a mixture of narrow and extended shelves, both Regions Of Fresh water Influence (ROFI) and areas affected by open ocean transports. Examples of such diverse shelf/coastal conditions are given in details in Pinardi et al. (2006) together with ecosystem and sedimentary differentiations. This diversity is not unique to the Mediterranean but rather common to many ocean basins. An operational oceanographic system that will be of high quality will have to consider different processes, monitor at different space and time scales for each different shelf area. Thus a fast communicating network of monitoring and modelling centres, downscaling from the basin to the shelf areas of interest, is required. The key issue is to be able to use the information from a given spatial and temporal scale to help build the successive scale and processes in a chain that preserves correctly the information and helps the higher resolution, multi-process nesting.

This special issue overviews some of the crucial understandings and technical tools required to demonstrate that forecasting from the basin scales to the shelf areas is practical with present day technology. It is believed that the free, unrestricted access to these products will allow in the near future to improve our basic scientific understanding of the ocean system.

Acknowledgements. This work has been funded by MFSTEP, a project supported by the European Community, V Framework Programme – Energy, Environment and Sustainable Development; Contract no. EVK3-CT-2002-00075. A particular thank is given to the program officers, Alan Edwards and Gilles Ollier, for their support to the project and technical guidance.

References

Ahumada, M. A. and Cruzado, A.: Modeling of the circulation in the Northwestern Mediterranean Sea with the Princeton Ocean Model, Ocean Sci., 3, 77–89, 2007, http://www.ocean-sci.net/3/77/2007/.

Bentamy, A., Ayina, H.-L., Queffeulou, P., Croize-Fillon, D., and Kerbaol, V.: Improved near real time surface wind resolution over the Mediterranean Sea, Ocean Sci., 3, 259–271, 2007, http://www.ocean-sci.net/3/259/2007/.

Brožková, R., Derková, M., Belluš, M., and Farda, A.: Atmospheric forcing by ALADIN/MFSTEP and MFSTEP oriented tunings, Ocean Sci., 2, 113–121, 2006, http://www.ocean-sci.net/2/113/2006/.

Chassignet, E. P. and Verron, J.: Ocean Weather Forecasting. An integrated view of Oceanography, Springer-Verlag, 557 pp., 2006.

Chiggiato, J. and Oddo, P.: Operational ocean models in the Adriatic Sea: a skill assessment, Ocean Sci., 4, 61–71, 2008, http://www.ocean-sci.net/4/61/2008/.

Crispi, G., Pacciaroni, M., and Viezzoli, D.: Simulating biomass assimilation in a Mediterranean ecosystem model using SOFA: setup and identical twin experiments, Ocean Sci., 2, 123–136, 2006, http://www.ocean-sci.net/2/123/2006/.

Dobricic, S., Pinardi, N., Adani, M., Tonani, M., Fratianni, C., Bonazzi, A., and Fernandez, V.: Daily oceanographic analyses by Mediterranean Forecasting System at the basin scale, Ocean Sci., 3, 149–157, 2007, http://www.ocean-sci.net/3/149/2007/.

Emelianov, M., Font, J., Turiel, A., Millot, C., Solé, J., Poulain, P.-M., Julià, A., and Vitrià, M.-R.: Transformation of Levantine Intermediate Water tracked by MEDARGO floats in the Western Mediterranean, Ocean Sci., 2, 281–290, 2006, http://www.ocean-sci.net/2/281/2006/.

Estournel, C., Auclair, F., Lux, M., Nguyen, C., and Marsaleix, P.: "Scale oriented" embedded modeling of the North-Western Mediterranean in the frame of MFSTEP, Ocean Sci., 5, 73–90, 2009, http://www.ocean-sci.net/5/73/2009/.

Falco, P., Belardinelli, A., Santojanni, A., Cingolani, N., Russo, A., and Arneri, E.: An observing system for the collection of fishery and oceanographic data, Ocean Sci., 3, 189–203, 2007, http://www.ocean-sci.net/3/189/2007/.

Gaberšek, S., Sorgente, R., Natale, S., Ribotti, A., Olita, A., Astraldi, M., and Borghini, M.: The Sicily Channel Regional Model forecasting system: initial boundary conditions sensitivity and case study evaluation, Ocean Sci., 3, 31–41, 2007, http://www.ocean-sci.net/3/31/2007/.

Griffa, A., Molcard, A., Raicich, F., and Rupolo, V.: Assessment of the impact of TS assimilation from ARGO floats in the Mediterranean Sea, Ocean Sci., 2, 237–248, 2006, http://www.ocean-sci.net/2/237/2006/.

Jordi, A., Basterretxea, G., Orfila, A., and Tintoré, J.: Analysis of the circulation and shelf-slope exchanges in the continental margin of the northwestern Mediterranean, Ocean Sci., 2, 173–181, 2006, http://www.ocean-sci.net/2/173/2006/.

Jordà, G., Bolaños, R., Espino, M., and Sánchez-Arcilla, A.: Assessment of the importance of the current-wave coupling in the shelf ocean forecasts, Ocean Sci., 3, 345–362, 2007, http://www.ocean-sci.net/3/345/2007/.

Kourafalou, V. and Tsiaras, K.: A nested circulation model for the North Aegean Sea, Ocean Sci., 3, 1–16, 2007, http://www.ocean-sci.net/3/1/2007/.

Krestenitis, Y. N., Kombiadou, K. D., and Savvidis, Y. G.: Modelling the cohesive sediment transport in the marine environment: the case of Thermaikos Gulf, Ocean Sci., 3, 91–104, 2007, http://www.ocean-sci.net/3/91/2007/.

Manzella, G. M. R., Reseghetti, F., Coppini, G., Borghini, M., Cruzado, A., Galli, C., Gertman, I., Gervais, T., Hayes, D., Millot, C., Murashkovsky, A., Özsoy, E., Tziavos, C., Velasquez, Z., and Zodiatis, G.: The improvements of the ships of opportunity program in MFS-TEP, Ocean Sci., 3, 245–258, 2007, http://www.ocean-sci.net/3/245/2007/.

Marcelli, M., Di Maio, A., Donis, D., Mainardi, U., and Manzella, G. M. R.: Development of a new expendable probe for the study of pelagic ecosystems from voluntary observing ships, Ocean Sci., 3, 311–320, 2007, http://www.ocean-sci.net/3/311/2007/.

Marullo, S., Buongiorno Nardelli, B., Guarracino, M., and Santoleri, R.: Observing the Mediterranean Sea from space: 21 years of Pathfinder-AVHRR sea surface temperatures (1985 to 2005): re-analysis and validation, Ocean Sci., 3, 299–310, 2007, http://www.ocean-sci.net/3/299/2007/.

Nittis, K., Tziavos, C., Bozzano, R., Cardin, V., Thanos, Y., Petihakis, G., Schiano, M. E., and Zanon, F.: The M3A multi-sensor buoy network of the Mediterranean Sea, Ocean Sci., 3, 229–243, 2007, http://www.ocean-sci.net/3/229/2007/.

Olita, A., Sorgente, R., Natale, S., Gaberek, S., Ribotti, A., Bonanno, A., and Patti, B.: Effects of the 2003 European heatwave on the Central Mediterranean Sea: surface fluxes and the dynamical response, Ocean Sci., 3, 273–289, 2007, http://www.ocean-sci.net/3/273/2007/.

Petihakis, G., Drakopoulos, P., Nittis, C., Zervakis, V., Christodoulou, C., and Tziavos, C.: M3A system (2000–2005) – operation and maintenance, Ocean Sci., 3, 117–128, 2007, http://www.ocean-sci.net/3/117/2007/.

Petihakis, G., Triantafyllou, G., Tsiaras, K., Korres, G., Pollani, A., and Hoteit, I.: Eastern Mediterranean biogeochemical flux model – Simulations of the pelagic ecosystem, Ocean Sci., 5, 29–46, 2009, http://www.ocean-sci.net/5/29/2009/.

Pinardi, N. and Woods, J. D.: Ocean Forecasting: conceptual basis and applications, Springer-Verlag, 472 pp., 2002.

Pinardi, N., Allen, I., Demirov, E., De Mey, P., Korres, G., Lascaratos, A., Le Traon, P.-Y., Maillard, C., Manzella, G., and Tziavos, C.: The Mediterranean ocean forecasting system: first phase of implementation (1998–2001), Ann. Geophys., 21, 3–20, 2003, http://www.ann-geophys.net/21/3/2003/.

Pinardi, N., Arneri, E., Crise, A., Ravaioli, M., and Zavatarelli, M.: The physical, sedimentary and ecological structure and variability of shelf areas in the Mediterranean Sea, The Sea Vol. 14, edited by: Robinson, A. R. and Brink, K., Harvard University Press, Cambridge, USA, 1243–1330, 2006.

Pizzigalli, C. and Rupolo, V.: Simulations of ARGO profilers and of surface floating objects: applications in MFSTEP, Ocean Sci., 3, 205–222, 2007, http://www.ocean-sci.net/3/205/2007/.

Poulain, P.-M., Barbanti, R., Font, J., Cruzado, A., Millot, C., Gertman, I., Griffa, A., Molcard, A., Rupolo, V., Le Bras, S., and Petit de la Villeon, L.: MedArgo: a drifting profiler program in the Mediterranean Sea, Ocean Sci., 3, 379–395, 2007, http://www.ocean-sci.net/3/379/2007/.

Raicich, F.: The assessment of temperature and salinity sampling strategies in the Mediterranean Sea: idealized and real cases, Ocean Sci., 2, 97–112, 2006, http://www.ocean-sci.net/2/97/2006/.

Reseghetti, F., Borghini, M., and Manzella, G. M. R.: Factors affecting the quality of XBT data results of analyses on profiles from the Western Mediterranean Sea, Ocean Sci., 3, 59–75, 2007, http://www.ocean-sci.net/3/59/2007/.

Sofianos, S. S., Skliris, N., Mantziafou, A., Lascaratos, A., Zodiatis, G., Lardner, R., Hayes, D., and Georgiou, G.: Nesting operational forecasting models in the Eastern Mediterranean: active and slave mode, Ocean Sci. Discuss., 3, 1225–1254, 2006, http://www.ocean-sci-discuss.net/3/1225/2006/.

Taillandier, V. and Griffa, A.: Implementation of position assimilation for ARGO floats in a realistic Mediterranean Sea OPA model and twin experiment testing, Ocean Sci., 2, 223–236, 2006, http://www.ocean-sci.net/2/223/2006/.

Tonani, M., Pinardi, N., Dobricic, S., Pujol, I., and Fratianni, C.: A high-resolution free-surface model of the Mediterranean Sea, Ocean Sci., 4, 1–14, 2008, http://www.ocean-sci.net/4/1/2008/.

Tonani, M., Pinardi, N., Fratianni, C., Pistoia, J., Dobricic, S., Pensieri, S., de Alfonso, M., and Nittis, K.: Mediterranean Forecasting System: forecast and analysis assessment through skill scores, Ocean Sci., 5, 649–660, 2009, http://www.ocean-sci.net/5/649/2009/.

Triantafyllou, G., Korres, G., Hoteit, I., Petihakis, G., and Banks, A. C.: Assimilation of ocean colour data into a Biogeochemical Flux Model of the Eastern Mediterranean Sea, Ocean Sci., 3, 397–410, 2007, http://www.ocean-sci.net/3/397/2007/.

Vandenbulcke, L., Barth, A., Rixen, M., Alvera-Azcarate, A., Ben Bouallegue, Z., and Beckers, J. M.: Study of the combined effects of data assimilation and grid nesting in ocean models – application to the Gulf of Lions, Ocean Sci., 2, 213–222, 2006, http://www.ocean-sci.net/2/213/2006/.

Vichi, M., Pinardi, N., and Masina, S.: An advanced model of pelagic biogeochemistry for the global ocean ecosystem. Part I: theory, J. Mar. Syst., 64, 89–109, 2007.

Zappalà, G., Reseghetti, F., and Manzella, G. M. R.: Development of an automatic multiple launcher for expendable probes, Ocean Sci., 3, 173–178, 2007, http://www.ocean-sci.net/3/173/2007/.

Zodiatis, G., Lardner, R., Hayes, D. R., Georgiou, G., Sofianos, S., Skliris, N., and Lascaratos, A.: Operational ocean forecasting in the Eastern Mediterranean: implementation and evaluation, Ocean Sci., 4, 31–47, 2008, http://www.ocean-sci.net/4/31/2008/.