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MODELING IN THE MEDITERRANEAN SEA: THE MONGOOS CONTRIBUTION

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Abstract

In the past years, the MonGOOS modeling community has developed an important expertise in the application and development of numerical models to the Mediterranean Basin. The applications cover both operational systems and process modeling, in the whole or in part of the Mediterranean. The present contribution pretends highlight the main successes and challenges derived from this MonGOOS activity.

Keywords: MonGOOS, Mediterranean, Operational Oceanography, process modeling

1. Introduction

Operational forecasting models show a wide spectrum of application areas and parameters predicted. Specific areas where the models are applied range from Spain, via the Italian peninsula, Cyprus to the Israeli coast. Basin wide scales as well as regional and sub-regional scales are resolved. Most of the forecast models use Copernicus Marine Environment Monitoring Services (CMEMS) products that are then downscaled to the desired resolution and the chosen area. Quantities modeled are currents, levels and waves, as well as biogeochemical ones. An active field of research is the simulation of meteorological tsunamis that can lead to high flooding in otherwise less vulnerable parts of the Mediterranean Sea.

The improvement of resolution from open sea models is a common need of operational systems and process oriented implementations. Some of the models apply nesting techniques to zoom to the desired resolution; others use unstructured meshes such as finite elements that allow a flexible increase in resolution. Whereas the finite elements describe by default two-way interactions, with nesting the two-way interaction is more difficult to obtain. In both cases some of the sub-grid parameterizations have been or need to be reviewed.

Even if the Mediterranean is a micro-tidal basin, the effects of tides can be important. This is especially true in areas of relative high tides (North-Adriatic Sea) and of important tidal currents, such as in the Messina and Gibraltar Straits. Here the focus is on the description of the interaction of the open sea with the coastal zone. This interaction is bi-directional, where the small-scale features can also influence the open sea.

One of the major MonGOOS community project in recent years was the "Mediterranean Decision Support System for Marine Safety" (www.medess4ms.eu), dedicated to the maritime risks prevention and strengthening of maritime safety related to oil spill pollution in the Mediterranean. MEDESS-4MS main objective was the implementation of an integrated multi-model oil spill prediction system for the entire Mediterranean connected to existing monitoring platforms (EMSA-CSN and REMPEC), using well-established oil spill modeling systems and met-ocean data from the Copernicus services and the member states ocean forecasting systems. The majority of the MonGOOS forecasting systems, a total of 28 from 9 Mediterranean EU countries (14 hydrodynamic, 7 wave and 7 atmospheric forecasting models), were homogenized in terms of their input/output data format, common data exchange protocols, file naming specifications, archiving, etc., in order to suit the well-established oil spill models of MEDSLIK, MOTHY, POSEIDON, MEDSLIK-II in any part of the Mediterranean (Zodiatis *et al.*, 2016). The MonGOOS community of the MEDESS4MS project has set, for the first time ever in cooperation with REMPEC the guidelines for the integration of the multi parametric forecasting systems with operational oil spill models, following the EMSA-CSN relevant requirements.

This presentation of the ongoing studies and operational activities is far from being comprehensive, and is based on a MonGOOS workshop held on the 15th November 2016 in Split. There will certainly be other operational systems present in the Mediterranean and the fact that they are not mentioned here does by no way imply any preference nor does it give any value to the systems.

The reader will find an extensive information of numerical forecasts available in the framework of MonGOOS on the website : http://www.mongoos.eu/*in situ*-and-forecasts.

2. Operational oceanography in the Mediterranean under MonGOOS

Most of the forecast systems presented in the MonGOOS community either are CMEMS products or use CMEMS products that are then downscaled to the various desired solutions. The CMEMS Mediterranean Sea Monitoring and Forecasting Centre (Med-MFC) is operationally providing physical, biogeochemical and wave numerical parameters for the whole Mediterranean Sea that are freely available through the CMEMS Catalogue (http://marine.copernicus.eu). Specifically, the CMEMS Med-Currents operational system is concentrating on the description of the main physical parameters as currents, tracers and sea level inside the whole Mediterranean basin (Clementi *et al.*, 2017). It uses NEMO with a resolution of 1/16° with 72 z-levels, it is coupled with a wave model (WaveWatch3) providing the neutral drag coefficient and assimilates satellite Sea Level Anomaly and vertical temperature and salinity profiles from Argo, XBT and gliders.

Coupled offline with the abovementioned one at the same resolution and domain, the CMEMS-Med-Biogeochemistry operational system features the BFM biogeochemical model (Lazzari *et al.*, 2012) and the 3DVAR variational assimilation of surface chlorophyll (Teruzzi *et al.*, 2014). CMEMS-Med-Biogeochemistry provides daily fields of water quality parameters (i.e., nutrients, dissolved oxygen, primary production and phytoplankton biomass) and essential climate variables (i.e., pH and pCO2; Bolzon *et al.*, 2017).

Finally, the wave-forecasting component of the Med-MFC is applying a wave model on the whole Mediterranean with a resolution of 1/24 of a degree, based on the WAM model (Cycle 4.5.4) (Günther and Behrens, 2012). This model receives its boundary condition from a similar model applied to the Atlantic (1/6 resolution). It uses off-line current information for the current-wave interaction and in its final version the model will assimilate observations to produce a wave analysis product.

Downscaling of CMEMS products are successfully carried out at sub-regional scale for the Western Mediterranean sub-basins, throughout the implementation of POM based operational systems namely TSCRM (Sorgente *et al.*, 2016) and WMED (Olita *et al.*, 2013). Both models provide daily forecast of the main ocean variables that are also used as boundary conditions for implementation of coastal ocean models applications (Cucco *et al.*, 2012), as input data for MEDSLIK simulations (Sorgente *et al.*, 2016) and for trajectories prediction of floating objects (Di Maio *et al.*, 2016).

What concerns models that focus on smaller areas, such as in the Spanish SAMOA project of Puertos del Estado, the downscaled CMEMS products (in this case, using also its regional Atlantic CMEMS IBI products) are used for assessing parameters (waves, currents, sea level) in the Spanish harbors. The ROMS model is used to reach high resolution and new processes in harbor areas.

Downscaling of CMEMS Med-MFC have been performed in the coastal waters of Southern-eastern of Italy, with a special focus on the Apulia region, through SANIFS (Federico *et al.*, 2017) forecasting system, based on three-dimensional hydrodynamic SHYFEM model and implemented at sub-regional (3km res.), coastal (100m res.) and harbor scale (20m res.).

SANIFS (Southern Adriatic Northern Ionian coastal Forecasting System) is a coastal-ocean operational system based on the unstructured grid finite-element three-dimensional hydrodynamic SHYFEM model, providing short-term forecasts. The operational chain is based on a downscaling approach starting from the large-scale system for the entire Mediterranean Basin (MFS, Mediterranean Forecasting System), which provides initial and boundary condition fields to the nested system.

In Cyprus, the CYCOFOS forecasting system at regional and sub-regional scales provides a) high resolution flow forecasts in the entire Eastern Mediterranean at 2km resolution, as well as in the EEZ of Cyprus at 1km resolution, b) wave forecasts in the Mediterranean and the Black Sea at 5km resolution and c) forecast of the surface forcing using the WRF model at the same domain and resolution as the SKIRON, for back up purposes (Zodiatis *et al.*, 2015; 2016). Modeled parameters are hydrodynamic, atmospheric and waves. A complex nesting procedure allows CYCOFOS the downscaling of CMEMS products to a resolution of ½km in the Levantine basin. The CYCOFOS products used by the MEDSLIK model for operational oil spill predictions.

In front of the Israel coast the forecasting system SELIPS has been implemented. It is nested into ALERMO, and atmospheric forcing is taken from SKIRON. The model is a modified POM model and the resolution is about 1km with 27 sigma levels. Outputs produced are hydrodynamic parameters that can also be used for MEDSLIK simulations. The Balearic Rissaga Forecasting System is a highly specialized system that tries to predict resonant meteo-tsunami that might form in the Ciutadella harbor. This system can then be used for early warning systems against predicted flooding.

Finally, the Kassandra system is simulating the storm surge impact in the whole Mediterranean Sea, with a focus on the Italian coast, where a resolution of less than 1km can be achieved due to the flexible finite element grid. Forecasted parameters are total water level and wave parameters, with a wave-current interaction implemented (Ferrarin *et al.*, 2013).

3. Process studies in the Mediterranean under MonGOOS

Some of the MonGOOS process studies are dealing with tides. Even if tides are normally not very relevant in the Mediterranean Sea, locally they might be important such as in the Messina Strait and in the Northern Adriatic Sea. Two applications are shown, where in both cases the unstructured model SHYFEM (Umgiesser *et al.*, 2004) has been used for downscaling to the desired resolution. In the Messina Strait the tidal currents and the complex vertical advection has been successfully modeled (Cucco *et al.*, 2016). The sensitivity of the solution depending on tides, thermohaline and atmospheric forcing has been investigated. In the other application, the influence of lagoons on the far field circulation has been studied. It is shown that neglecting and considering the feedback of the lagoons, the tidal amplitude in the center of the Adriatic Sea can change by some centimeters, a fact that should be considered when applying tidal models to marginal seas (Ferrarin *et al.*, 2017).

Circulation modeling with a focus on the water exchange in inlets and estuaries is explored in other applications. One is the case of the riverine freshwater release, which is found to strongly affect both the coastal and basin wide overturning circulation and dynamics (Verri *et al.*, 2017). Thus the regional ocean modeling needs a reliable representation of the non-zero salinity outflows at river outlets; the coupling with a diagnostic estuarine box model has been proposed and applied to the Ofanto river outlet as first case study. Another one is the circulation in harbor domains which shows similar estuarine patterns with important horizontal and vertical segregation.

Regional atmospheric models outperform the other applications where climatological data was used. In the Algeciras Bay (Strait of Gibraltar), the high-resolution surface dynamics has been modeled using a Lagrangian particle tracking system. The SAMPAv2 model is used with a double regional-to-local nested model to achieve an increase of solution from 6400 meters to down to 30 meters inside the harbor. Lagrangian modeling is then used to assess water quality renewal efficiency. In the same area, the SAMPA model is also used to model the Atlantic water intrusion in the Mediterranean Sea, both through Lagrangian and Eulerian methods. A validation of these local PdE SAMPA products, together with the regional CMEMS IBI ones was also achieved through the release of buoys and ad hoc measurement campaigns (for instance in the context of the previously cited MEDESS-4MS Project; Sotillo *et al.*, 2016).

In the North-Western Mediterranean Sea, along the French coast, a two-way zoom model has been applied, resolving the regional circulation close to the coast with a resolution from kilometer until 100 meters (Garnier *et al.*, 2014; Herbert *et al.*, 2014). This configuration has been also used for different research, process studies or numerical improvement (e.g., anchovy recruitment, biochemistry, impact of heat waves on red gorgonian, contourites along the continental slopes, impact on sub-mesocales processes on convection, spectral nudging etc.).

In the CMEMS Med-MFC-Biogeochemistry forecast model a new assimilation scheme is currently being developed to integrate BGC-Argo floats data with ocean color satellite data into the operational model. A 3D variational assimilation scheme (3DVARBIO) uses chlorophyll concentrations available from the two platforms, background error covariance decomposition and relative observation errors to correct the dynamics of the phytoplankton and biogeochemical components on a daily basis.

Finally, an active area of research is the field of meteo-tsunamis. Applications to areas in Mallorca and the Croatian islands are shown and the importance of these local processes is highlighted. It is especially important to consider a very high resolution of the models and the quality of meteorological forecasts. One application is the COAWST model, where WRF, ROMS and SWAN are combined to predict the effects of these meteo-tsunamis. The bathymetry is identified as one of the bottlenecks for reliable forecasts. In the case of the Ciutadella harbor in the Baleares, synthetic forcing of atmospheric parameters is used to get a better insight in the physical processes governing the phenomenon.

4. Conclusions

In this article, we present the activities of the MonGOOS community dealing with operational modelling and process based studies. These activities are on the core of the MonGOOS group and the article show the extreme bandwidth of applications that are being developed and maintained. The meeting in Split was a way to maintain the necessary bridge between operational constrains and a more academic research. This community has already shared some common projects (MEDESS-4MS, Zodiatis *et al.*, 2016). In the future, it would be important to attract even more contributions from the Mediterranean modelling community in order to establish a firm working group that could then take the lead in model development and project participations.

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