



HAL
open science

THE COPERNICUS MARINE SERVICE OCEAN FORECASTING SYSTEM FOR THE MEDITERRANEAN SEA

Giovanni Coppini, Emanuela Clementi, Gianpiero Cossarini, Gerasimos Korres, Massimiliano Drudi, Carolina Amadio, Ali Aydogdu, Paola Agostini, Giorgio Bolzon, Sergio Cretì, et al.

► **To cite this version:**

Giovanni Coppini, Emanuela Clementi, Gianpiero Cossarini, Gerasimos Korres, Massimiliano Drudi, et al.. THE COPERNICUS MARINE SERVICE OCEAN FORECASTING SYSTEM FOR THE MEDITERRANEAN SEA. 9th EuroGOOS International conference, Shom; Ifremer; EuroGOOS AISBL, May 2021, Brest, France. pp.272-279. hal-03334358v2

HAL Id: hal-03334358

<https://hal.science/hal-03334358v2>

Submitted on 24 Sep 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

THE COPERNICUS MARINE SERVICE OCEAN FORECASTING SYSTEM FOR THE MEDITERRANEAN SEA

Giovanni Coppini⁽¹⁾, Emanuela Clementi⁽²⁾, Gianpiero Cossarini⁽³⁾, Gerasimos Korres⁽⁴⁾, Massimiliano Drudi⁽¹⁾, Carolina Amadio⁽³⁾, Ali Aydogdu⁽²⁾, Paola Agostini⁽¹⁾, Giorgio Bolzon⁽³⁾, Sergio Cretì⁽¹⁾, Dimitra Denaxa⁽⁴⁾, Valeria Di Biagio⁽³⁾, Romain Escudier^(2, 5), Laura Feudale⁽³⁾, Anna Chiara Goglio⁽²⁾, Alessandro Grandi⁽¹⁾, Paolo Lazzari⁽³⁾, Rita Lecci⁽¹⁾, V Vladyslav Lyubartsev⁽¹⁾, Simona Masina⁽²⁾, Francesco Palermo⁽¹⁾, Nadia Pinardi^(1, 6), Jenny Pistoia⁽²⁾, Stefano Salon⁽³⁾, Michael Ravdas⁽⁴⁾, Cosimo Solidoro⁽³⁾, Anna Teruzzi⁽³⁾, Anna Zacharioudaki⁽⁴⁾

⁽¹⁾ Ocean Predictions and Applications Division, Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy

⁽²⁾ Ocean Modeling and Data Assimilation Division, Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy

⁽³⁾ National Institute of Oceanography and Applied Geophysics (OGS), Italy

⁽⁴⁾ Hellenic Centre for Marine Research (HCMR), Greece

⁽⁵⁾ Mercator Ocean International, France

⁽⁶⁾ Department of Physics and Astronomy, University of Bologna, Italy

Abstract

The Mediterranean Monitoring and Forecasting Center (Med-MFC) is part of the Copernicus Marine Environment Monitoring Service (CMEMS) and operationally produces analysis, forecast and reanalysis products for the Mediterranean Sea hydrodynamics, waves and biogeochemistry. The modelling systems are based on state-of-the-art community models, assimilate observational in situ and satellite observations and are forced by high resolution atmospheric fields. Improvements and functioning of the Med-MFC systems are based on the full consistency among the three components which are jointly upgraded and include a continuous amelioration of the accuracy of the products. The focus of this work is to present the Med-MFC modelling systems and the available products, their skill assessment, main recent achievements and future upgrades.

Keywords: Mediterranean Sea, numerical modelling, hydrodynamics, biogeochemistry, waves operationally

1. Introduction

The CMEMS (<https://marine.copernicus.eu/>) Med-MFC is a consortium adopting the state-of-the-art knowledge in scientific modelling developments and implementing since 2015 an operational service to produce Near Real Time (NRT) and Reanalysis (RAN) products for the Mediterranean Sea dynamics, from currents (Med-PHY) to waves (Med-WAV), and biogeochemistry (Med-BIO). These three components are fully consistent in terms of horizontal resolution ($1/24^\circ$ in the horizontal and 141 vertical levels), bathymetry (GEBCO), atmospheric forcing fields (European Centre for Medium-range Weather Forecasts, ECMWF, analysis and forecast fields at $1/10^\circ$ resolution and ERA5 reanalysis fields at $1/4^\circ$ resolution), moreover the wave and biogeochemical systems are forced by the Med-PHY physical fields.

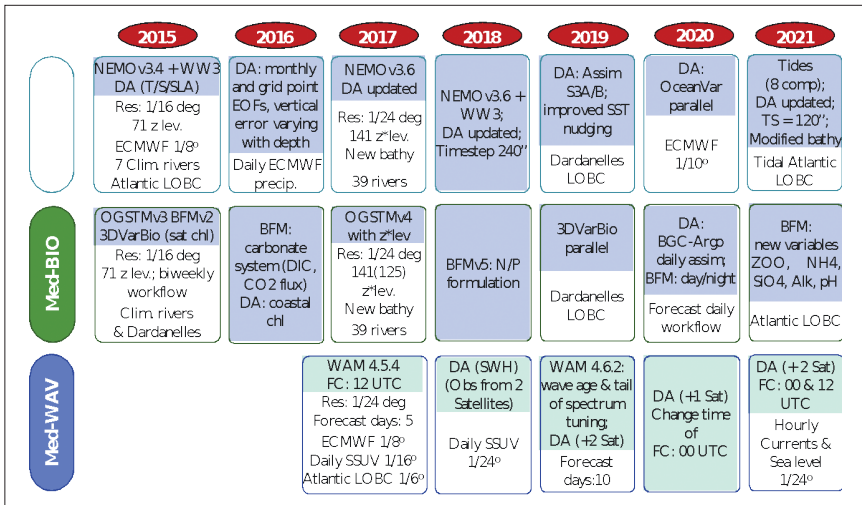


Fig. 1. Med-MFC NRT systems evolutions from 2015 to 2021.

The modelling systems are jointly upgraded and maintain a continuous improvement of the accuracy of the products. The major NRT systems' evolutions are provided in Figure 1 showing the improvements of the numerical models and data assimilation systems since 2015.

2. MED-MFC Physical Systems

The Mediterranean Analysis and Forecasting Physical System, MedFS, is composed by the hydrodynamic model NEMO (Nucleus for European Modelling of the Ocean) 2-way coupled with the wave model WaveWatchIII (Clementi *et al.*, 2017) and forced by ECMWF high resolution atmospheric fields. The system is coupled with a 3D

variational data assimilation system, OceanVar (Dobricic and Pinardi, 2008; Storto *et al.*, 2015), which daily assimilates Sea Level Anomaly (SLA) along track altimetry data and insitu vertical profiles of temperature and salinity. Moreover a heat flux correction is performed using satellite Sea Surface Temperature (SST) data. The system has lateral open boundaries in the Atlantic Sea where it is nested in the CMEMS Global analysis and forecasting daily fields and in the Dardanelles strait; moreover 39 land river inputs are imposed by means of climatological runoff values (Delrosso, 2020). The system has been recently (May 2021) upgraded (Clementi *et al.*, 2021) by including tidal waves, so that the tidal potential is calculated across the domain for the Mediterranean Sea 8 major constituents: M2, S2, N2, K2, K1, O1, P1, Q1.

The skill of the NRT system is continuously monitored by means of comparison with respect to insitu and satellite observations (available on the <https://medfs.cmcc.it/> website and on the CMEMS <https://marine.copernicus.eu/> Product Quality webpage). Figure 2 shows the temperature and salinity Root Mean Square Error (RMSE) in the first 900 m averaged in the whole basin in the period 2018-2021. The temperature error presents a seasonal signal, with larger values during summer around 30 to 60 m depths. The basin is in fact characterized by seasonal variations of the upper-ocean temperature with highly stratified waters in the sub-surface layers during summer and early fall, while during winter the water column is unstratified due to intense vertical mixing processes. The salinity mean error presents larger values (around 0.2 PSU) in the upper layers decreasing below 150 m.

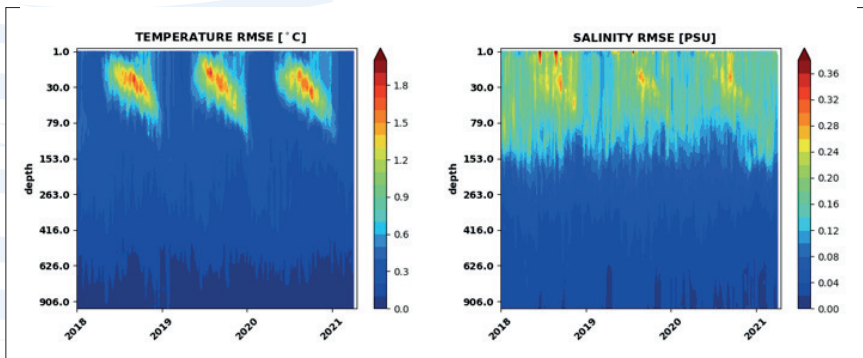


Fig. 2. Hovmöller (Depth-Time) diagrams of weekly mean RMSE of temperature (left) and salinity (right) along the water column averaged in the whole Mediterranean Sea.

A new Mediterranean physical reanalysis timeseries (Escudier *et al.*, 2020) has been recently (December 2020) released with the same NRT system resolution (1/24° horizontal; 141 vertical levels), forced by ECMWF ERA5 (1/4° horizontal, 1-hour temporal resolution) atmospheric fields. The system is nested in the Atlantic within the global reanalysis C-GLORSv5 (Storto and Masina, 2016), is forced by 39 river inputs, also the Dardanelles strait inflow is parameterized as a river. The system assimilates reprocessed SLA satellite tracks and historical temperature and salinity *in situ* profiles. SST nudging is also activated as in the NRT system. The new reanalysis presents an overall increased skill with respect to the previous one (Simoncelli *et al.*, 2019) with a reduced error for all the variables at all the depths when compared to observations (more details in the product QUID: <http://marine.copernicus.eu/documents/QUID/CMEMS-MED-QUID-006-004.pdf>).

3. MED-MFC Biogeochemical Systems

The biogeochemical Analysis and Forecast System (MedBFM, Salon *et al.*, 2019) is composed by the BFM biogeochemical model coupled to the OGSTM transport model and includes the 3DVarBio assimilation scheme. The MedBFM is off-line coupled with the physical component and includes a Z* parameterization, 39 rivers, open boundary conditions at the Gibraltar and Dardanelles straits and atmospheric forcing for nitrogen and phosphorus deposition and CO₂ exchanges (Salon *et al.*, 2019). The BFM model describes the biogeochemical cycles of 5 chemical compounds (carbon, nitrogen, phosphorus, silicon and oxygen) through the dissolved inorganic, living organic (4 phyto- and 4 zoo-plankton groups and one bacteria) and non-living organic compartments (Lazzari *et al.*, 2016), and includes the carbonate system (Cossarini *et al.*, 2015). The 3DVarBio assimilation scheme is based on a variational scheme that decomposes the background error covariance matrix using a sequence of operators that account separately for vertical, horizontal and biogeochemical covariance (Teruzzi *et al.*, 2018) and assimilate the surface chlorophyll retrieved by satellite sensors and chlorophyll and nitrate from BGC-Argo float (Cossarini *et al.*, 2019). The system produces 7-day of analysis every week and 10-day forecast every day for 12 ocean variables that includes nutrients (nitrate, ammonia, phosphate and silicate), oxygen, carbonate system variables (pH, surface pCO₂, DIC and alkalinity), chlorophyll, biomass of zooplankton and phytoplankton and 2 ecosystem processes (surface CO₂ flux and primary production). Depending on the availability of observations (e.g., Emodnet, Socat, WOA, CMEMS OC TAC), the Med-bio products can be validated at three different levels: (1) model capability to reproduce basin wide spatial gradients based on GODAE Class1 metrics; (2) model capability to reproduce the variability due to mesoscale and daily dynamics based on GODAE Class4 metrics and (3) model capability to reproduce key biogeochemical processes based on specific metrics (Salon *et al.*, 2019). As an example of process-based metrics, Figure 3 shows the benefit of using BGC-Argo data to validate modelled chlorophyll dynamics during winter vertical mixed conditions and summer stratified ones.

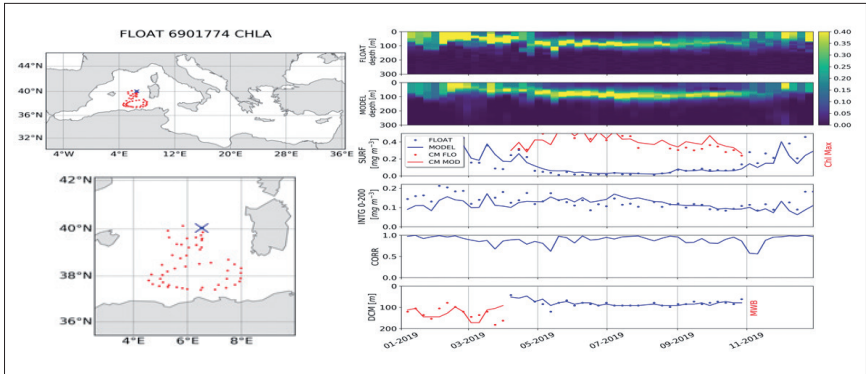


Fig. 3. Hovmöller diagrams of chlorophyll for three selected floats (top-right panels) and the matched-up model output (3rd right panel) for the year 2019, and computation of selected skill indexes for model (lines) and float data (dots). The skill indexes are: chlorophyll at surface and at DCM (SURF and Chl Max, 4th panel), 0-200 m vertically averaged chlorophyll (INTG, 5th panel), correlation (CORR, 6th panel), depth of the deep chlorophyll maximum (DCM, blue) and thickness of the winter layer bloom (WBL, red, 7th panel). Trajectories of the BGC-Argo floats are reported in the left panels, with deployment position (blue cross).

4. MED-MFC Wave Systems

The wave component of the Mediterranean Forecasting Centre (Med-waves), developed and put in operations in 2017 (Ravdas et al., 2018), is providing analyses, short-term wave forecasts (10 days) driven by ECMWF 10m winds and CMEMS surface currents and multiyear (1993 – 2019) re-analysis for the Mediterranean Sea at 1/24° horizontal resolution. The system, based on a state of the art wave model (WAM Cycle 4.6.2), has been continuously upgraded in terms of data assimilation of all available SWH (Significant Wave Height) satellite observations, physics, coupling with currents and sea level and product quality procedures. The wave product available through CMEMS (Korres et al., 2019) consists of 17 hourly wave parameters validated using Class 2 and 4 metrics (SWH and Mean Wave period) using available wave buoy and satellite measurements while full wave spectrum over the whole modelling domain is also freely available to users through a dedicated ftp site to be used in downscaling applications over the basin. The overall quality of the system has been assessed for one year period (July 2019 – July 2020) using all available wave buoys and satellite observations within the Mediterranean Sea. In particular using independent (non-assimilated) *in situ* observations from moored wave buoys obtained from the CMEMS *in situ* Thematic Assemble Centre (INS-TAC) we find that the typical difference (RMSD) of Med-waves SWH varies from 0.17 m in summer to 0.26 m in winter while the Scatter Index (SI) in summer (0.25 m) is slightly higher than the scatter in winter (0.24 m). The SI varies from 0.17 m at the offshore buoys in the western Mediterranean Sea, to

0.41 and 0.53 m at the coastal buoys in the Gulf of Trieste and the North Adriatic Sea respectively. In general, SI values above the mean value for the whole Mediterranean Sea (0.24 m) are obtained at wave buoys located near the coast (e.g. coastal Spanish buoys), particularly if these are sheltered by land masses on their north-northwest (e.g. western French coastline), and/or within enclosed basins characterized by a complex topography.

Until 2020, the multi-year wave product of the Med-MFC has been a 13-year wave hindcast covering the period February 2006 – December 2019 (Korres *et al.*, 2019). Since 2021 the multi-year wave product of Med-MFC is a 27-year wave reanalysis covering the period January 1993 – December 2019. It has been produced using the same setup of the NRT system, ERA5 reanalysis hourly winds, reanalysis surface currents and all available SWH satellite observations for the period that are assimilated into the system. Figure 4 maps the statistics of the comparison of Med-MFC reanalysis SWH with wave buoy observations of SWH at individual wave buoys, for the period 1993-2018. SI values above the mean value for the whole Mediterranean Sea (0.27 m) are obtained at wave buoys that are sheltered by land masses on their west north-west (e.g. western French coastline and eastern coastline of Italy), are near the coast (e.g. coastal Spanish buoys) and/or are surrounded by complex topography (e.g. Adriatic and Aegean Seas). BIAS is mainly negative with positive BIAS found mostly at Greek buoys and at the coastal buoys of the Balearic Islands.

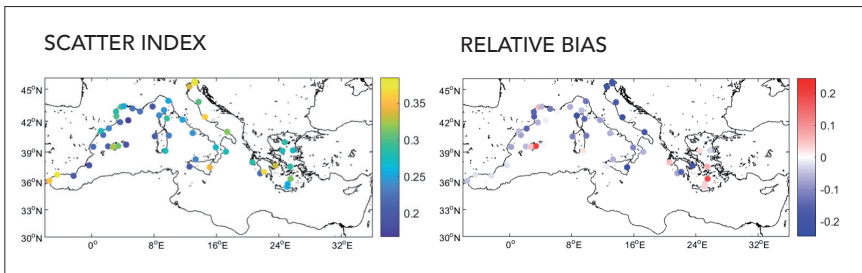


Fig. 4. Med-MFC multi-year reanalysis SWH evaluation against wave buoy observations of SWH at individual wave buoy locations, for the period 1993-2018.

The two multi-year products (hindcast 2006 – 2019 and reanalysis 1993 – 2019), have been intercompared for an overlapping period of 11 years (2007-2017) using independent wave buoy observations merged over the Mediterranean Sea and showed that the skill of the Med-waves multiyear production system in the different seasons is well preserved between the two products (hindcast vs reanalysis). Studies that are underway using the 1993 – 2019 reanalysis data set reveal statistically significant increasing trends of extreme waves in the east and south east Levantine at rates of 2-3 cm/yr.

5. Conclusions

This work presents the CMEMS Mediterranean operational modelling systems, the available products, the recent modelling upgrades and their quality. During the last 6 years, the CMEMS Med-MFC systems have been substantially improved with regard to: increased resolution, improved physical, biogeochemical and wave representations thanks to modelling and data assimilation upgrades. All the systems are now aligned in terms of grid resolution (1/24°), bathymetry and share the same atmospheric and river forcing fields. The quality of the products is continuously monitored by means of comparison with respect to available *in situ* and satellite observations and the validation assessment is published in Quality Information Documents complementing the available products and on dedicated validation websites. The improved validation framework (i.e., novel observing systems and metrics) contributed to the increase of the quality of the model results and their reliability for CMEMS user needs.

Acknowledgements

This work was supported by the European CMEMS Med-MFC (Copernicus Marine Environment Monitoring Service – Mediterranean Marine Forecasting Centre), Mercator Ocean International Service.

References

- Clementi, E., Oddo, P., Drudi, M., Pinardi, N., Korres, G., Grandi A. (2017). Coupling hydrodynamic and wave models: first step and sensitivity experiments in the Mediterranean Sea. *Ocean Dynamics*. <https://doi.org/10.1007/s10236-017-1087-7>.
- Clementi, E., Aydogdu, A., Goglio, A. C., Pistoia, J., Escudier, R., Drudi, M., Grandi, A., Mariani, A., Lyubartsev, V., Lecci, R., Creti, S., Coppini, G., Masina, S., Pinardi, N. (2021). Mediterranean Sea Analysis and Forecast (CMEMS MED-Currents, EAS6 system) (Version 1) [Data set]. Copernicus Monitoring Environment Marine Service. https://doi.org/10.25423/CMCC/MEDSEA_ANALYSISFORECAST_PHY_006_013_EAS6.
- Cossarini, G., Mariotti, L., Feudale, L., Mignot, A., Salon, S., Taillandier, V., Teruzzi, A., D’Ortenzio F. (2019). Towards operational 3D-Var assimilation of chlorophyll Biogeochemical-Argo float data into a biogeochemical model of the Mediterranean Sea. *Ocean Modelling*, 133, pp. 112-128.
- Delrosso, D. (2020). Numerical modelling and analysis of riverine influences in the Mediterranean Sea. *Dissertation thesis*, Alma Mater Studiorum Università di Bologna. Dottorato di ricerca in Geofisica, 32 Ciclo. DOI 10.6092/unibo/amsdottorato/9392.
- Dobricic, S. and Pinardi, N. (2008). An oceanographic three-dimensional variational data assimilation scheme. *Ocean Modelling*, 22 (3-4) 89-105.

Escudier, R., Clementi, E., Omar, M., Cipollone, A., Pistoia, J., Aydogdu, A., Drudi, M., Grandi, A., Lyu-bartsev, V., Lecci, R., Cretí, S., Masina, S., Coppini, G., Pinardi, N. (2020). Mediterranean Sea Physical Reanalysis (CMEMS MED-Currents) (Version 1) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/CMCC/MEDSEA_MULTYEAR_PHY_006_004_E3R1.

Korres, G., Ravdas, M., Zacharioudaki, A. (2019). Mediterranean Sea Waves Analysis and Forecast (CMEMS MED-Waves) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/CMCC/MEDSEA_ANALYSIS_FORECAST_WAV_006_017

Korres, G., Ravdas, M., Zacharioudaki, A. (2019). Mediterranean Sea Waves Hindcast (CMEMS MED-Waves) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/CMCC/MEDSEA_HINDCAST_WAV_006_012

Lazzari, P., Solidoro, C., Salon, S., Bolzon, G. (2016). Spatial variability of phosphate and nitrate in the Mediterranean Sea: a modelling approach. *Deep Sea Research I*, 108, 39-52.

Ravdas, M., Zacharioudaki, A. and Korres, G. (2018). Implementation and validation of a new operational wave forecasting system of the Mediterranean Monitoring and Forecasting Centre in the framework of the Copernicus Marine Environment Monitoring Service. *Nat. Hazards Earth Syst. Sci.*, 18(10), 2675–2695, doi:10.5194/nhess-18-2675-2018.

Simoncelli, S., Fratianni, C., Pinardi, N., Grandi, A., Drudi, M., Oddo, P., Dobricic, S. (2019). Mediterranean Sea Physical Reanalysis (CMEMS MED-Physics) (Version 1) [Data set]. Copernicus Monitoring Environment Marine Service (CMEMS). https://doi.org/10.25423/MEDSEA_REANALYSIS_PHYS_006_004.

Storto, A., Masina, S., Navarra, A. (2015). Evaluation of the CMCC eddy-permitting global ocean physical reanalysis system (C-GLORS, 1982-2012) and its assimilation components. *Quarterly Journal of the Royal Meteorological Society*, 142, 738–758, doi:10.1002/qj.2673.

Storto, A. and Masina, S. (2016). C-GLORSv5: an improved multipurpose global ocean eddy-permitting physical reanalysis. *Earth Syst. Sci. Data*, 8, 679–696, doi:10.5194/essd-8-679-2016

Salon, S., Cossarini, G., Bolzon, G., Feudale, L., Lazzari, P., Teruzzi, A., Solidoro, C., Crise, A. (2019). Marine Ecosystem forecasts: skill performance of the CMEMS Mediterranean Sea model system. *Ocean Science*, 15, 997-1022.

Teruzzi, A., Bolzon, G., Salon, S., Lazzari, P., Solidoro, C., Cossarini, G. (2018). Assimilation of coastal and open sea biogeochemical data to improve phytoplankton simulation in the Mediterranean Sea. *Ocean Modelling*, 132, 46-6.