The Copernicus Marine Service ocean forecasting system for the Mediterranenean Sea

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(2) OGS- Istituto Nazionale di Oceanografia e di Geofisica Sperimentale)

(3) (HCMR - Hellenic Centre for Marine Research)

(4) (INGV – Istituto Nazionale di Geofisica e Vulcanologia)

Marine Monitoring

COPERNICUS · MARINE ENVIRONMENT MONITORING SERVICE
CMEMS MEDITERRANEAN SEA MFC
Contract MED-MFC Until April 30 2018

European Commission | Copernicus | Implemented by MERCATOR OCEAN | cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici | OGS | hcmr

Marine Monitoring

Outline

- Introduction to the CMEMS science based user oriented service
- Mediterranean Sea Forecasting Service
- System and Service evolution

Marine Monitoring

User-centered Services! Why? For whom?

Safety of navigation

Coastal protection and erosion

Search and Rescue

Pollution emergencies

Climate Change

Protection&management of maring ecosystems

Off-shore activities

Military activities

Renewable energies

Fishery&acquacolture

Tourism

Harbours

European Commission | Copernicus

MERCATOR OCEAN

Marine Monitoring

The Copernicus Marine Service

MULTI-YEAR
10 to 45 years

REAL-TIME
Daily, hourly

FORECAST
2 to 10 days

ESSENTIAL MARINE VARIABLES

- Physics
- Sea-ice
- Waves
- Biogeochemistry

OBSERVATIONS
In-situ & Satellites

NUMERICAL MODELS &
data assimilation

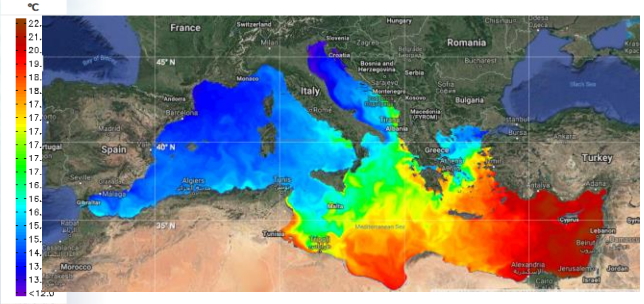
Open and Free access

European Commission | Copernicus

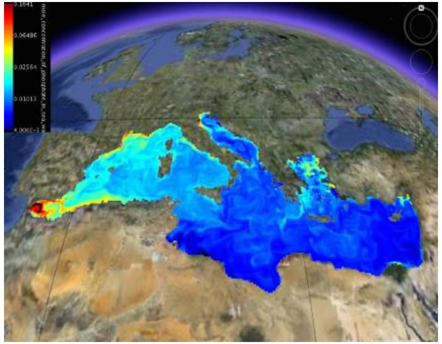
M E D - M F C p r o d u c t s e x a m p l e s

Marine Monitoring

Sea Temperature

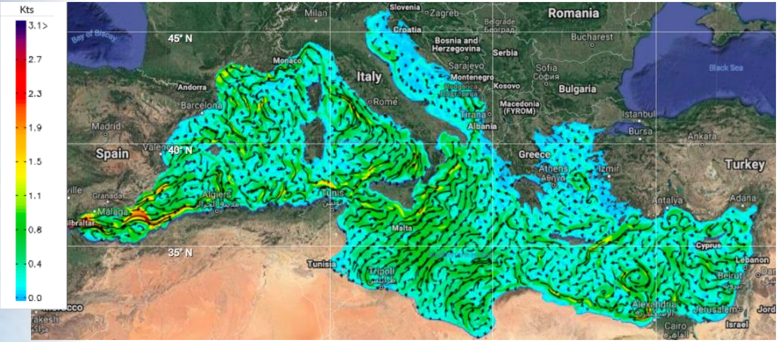


Med Sea Biogeochemistry Chl-a

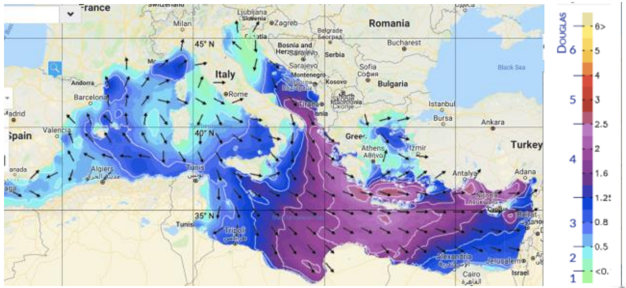


Contribution to
JCOMM
ETOOF

Med SeaOcean currents



Med Sea Waves



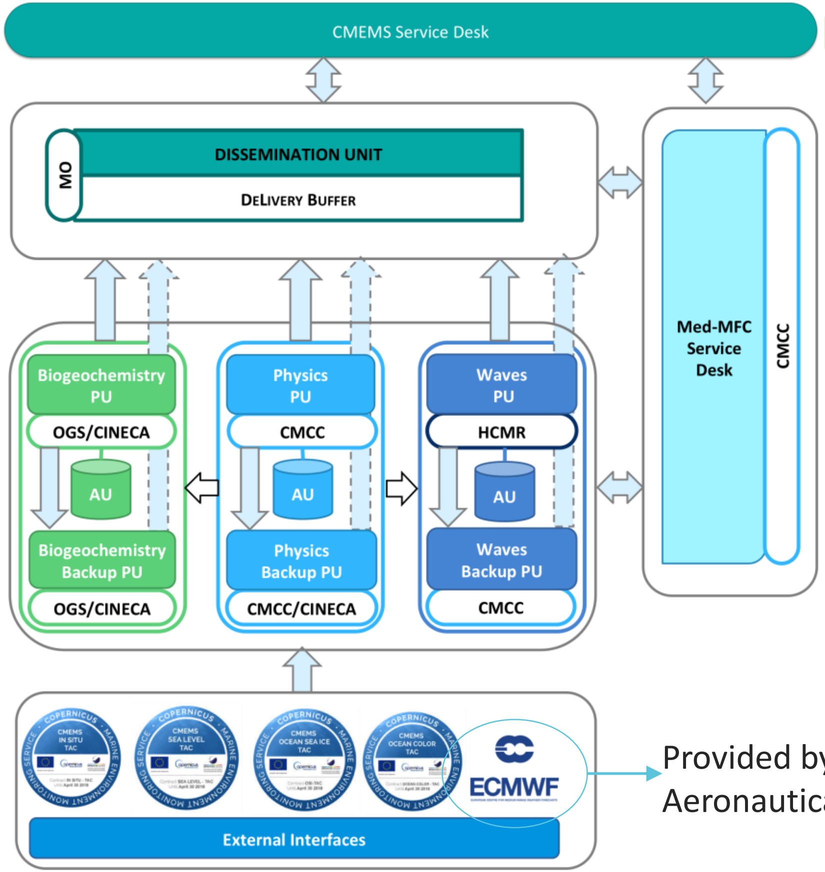
Service Desk

Quality of the products

European Commission | Copernicus | Mercator Ocean

MED – MFC High Level Architecture

Marine Monitoring



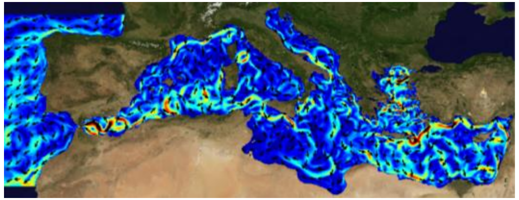
- Current elements (interfaces, PUs, back ups) maintained
- Link with new DU established

Provided by Italian Met Office Aeronautica Militare

Med-Physics Analysis and Forecasting system http://MedFS.cmcc.it

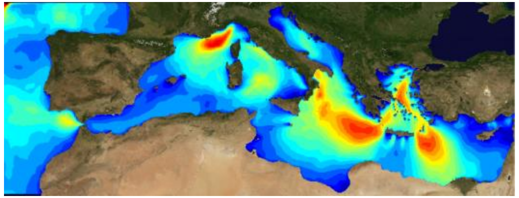
Marine Monitoring

Ocean General Circulation Model
(OGCM) based on NEMO code v3.6



2-way hourly coupling

Wave model
WaweWatch-III (WW3) v3.14



Hor. Res. = 1/24° (~4.5 km)
Vert. Res. = 141 z* vertical levels with partial cells

The two-way coupling consists of inputting **surface currents** to the wave model (for wave refraction) and **air-sea temperature difference** (for wind speed correction) and providing the **neutral surface drag coefficient** from waves used to compute the wind stress

Hor. Res. = 1/24° (~4.5 km)
Spectral discretization:
* 30 freq. bins (0.05-0.79 Hz)
* 24 directional bins

Model solutions are corrected by the data assimilation

Satellites and Insitu observations are jointly assimilated using a **3D variational scheme** adapted to the oceanic assimilation problem with a daily cycle

Non-solar heat flux correction is achieved through satellite SST nudging

Med-Physics Analysis and Forecasting system

Marine

ECMWF 1/8º atmospheric fields:
- MSLP, cloud cover, 2m relative humidity
- 2m T, 10m Wind , Precipitations

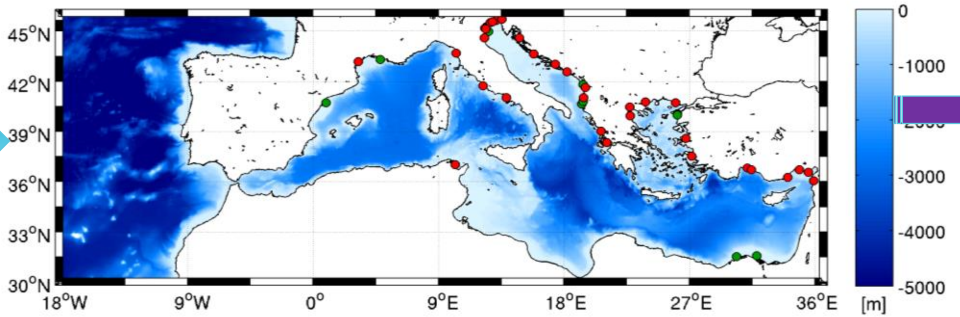
Temporal resolution:
Forecasts: 3hrs for the first 3 days and 6 hrs for the nest 7 days
Analysis: 6 hours time resolution

Land river runoff:
vertical boundary condition for **39** major rivers with annual mean discharge > 50 m^3/s using climatological monthly mean seasonal cycle values

Assimilated Data:
Along track Sea Level Anomaly from CMEMS SL-TAC
- Jason 2/2N,3 - Cryosat2
- Saral/AltiKa - Sentinel3A

Vertical profiles of Temperature and Salinity from CMEMS InSitu TAC: Argo

Lateral Boundary conditions in the Atlantic & Dardanelles Strait:
Daily NRT analyses and forecasts from Global Ocean Forecasting System (GLO-MFC) @ 1/12° horizontal resolution, 50 vertical levels



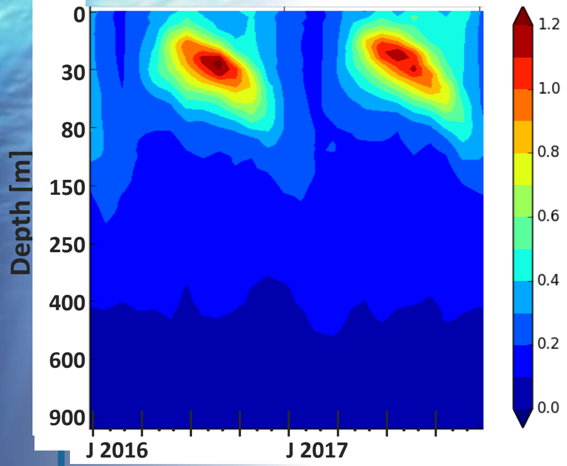
MEDSEA_ANALYSIS_FORECAST_PHY_006_013
Hourly + Daily + Monthly mean:
2016-ogoing
2D Sea Surface Height
3D Salinity
3D Potential Temperature
3D Zonal/Meridional currents
2D MLD
2D Bottom Temperature

ANALYSIS: **Each Tuesday** → simulation for the previous 2 weeks with ECMWF analysis atmo. forcing + assimilation
HINDCAST: **Every day** → the initial condition for the forecast cycle is generated by a model simulation for the previous 24hr hours and forced by ECMWF analysis fields
FORECAST: **Every day** → computed for next 10 days forcing the numerical model with ECMWF forecast fields

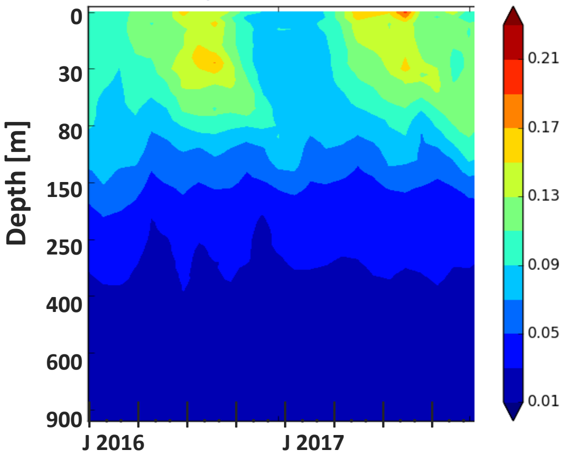
Med-Physics Analysis and Forecasting system: Skill of the syste

Marine Monitoring

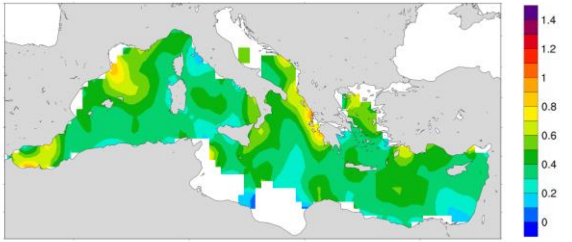
Temperature RMS misfit [^oC]



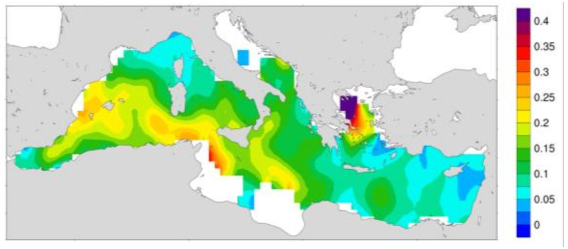
Salinity RMS misfit [*PSU*]



Temperature RMS misfit at 8m [^oC] 2016-2017

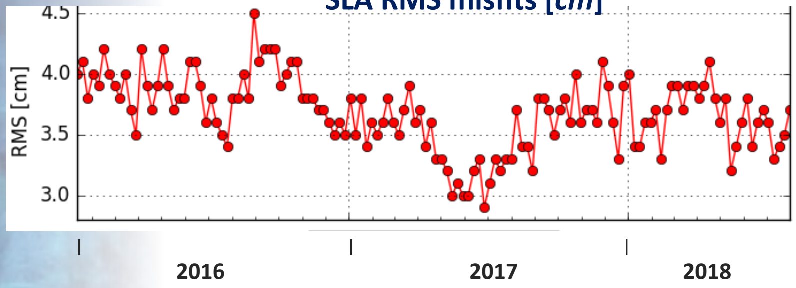


Salinity RMS misfit at 8m [*PSU*] 2016-2017

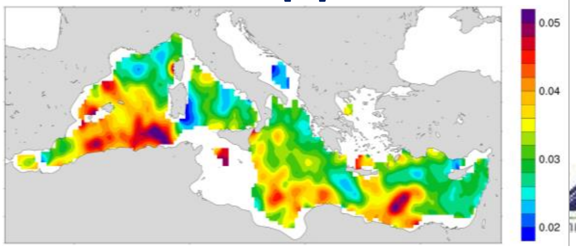


- Larger error during summer
- Larger error at thermocline, that decreases at lower layers

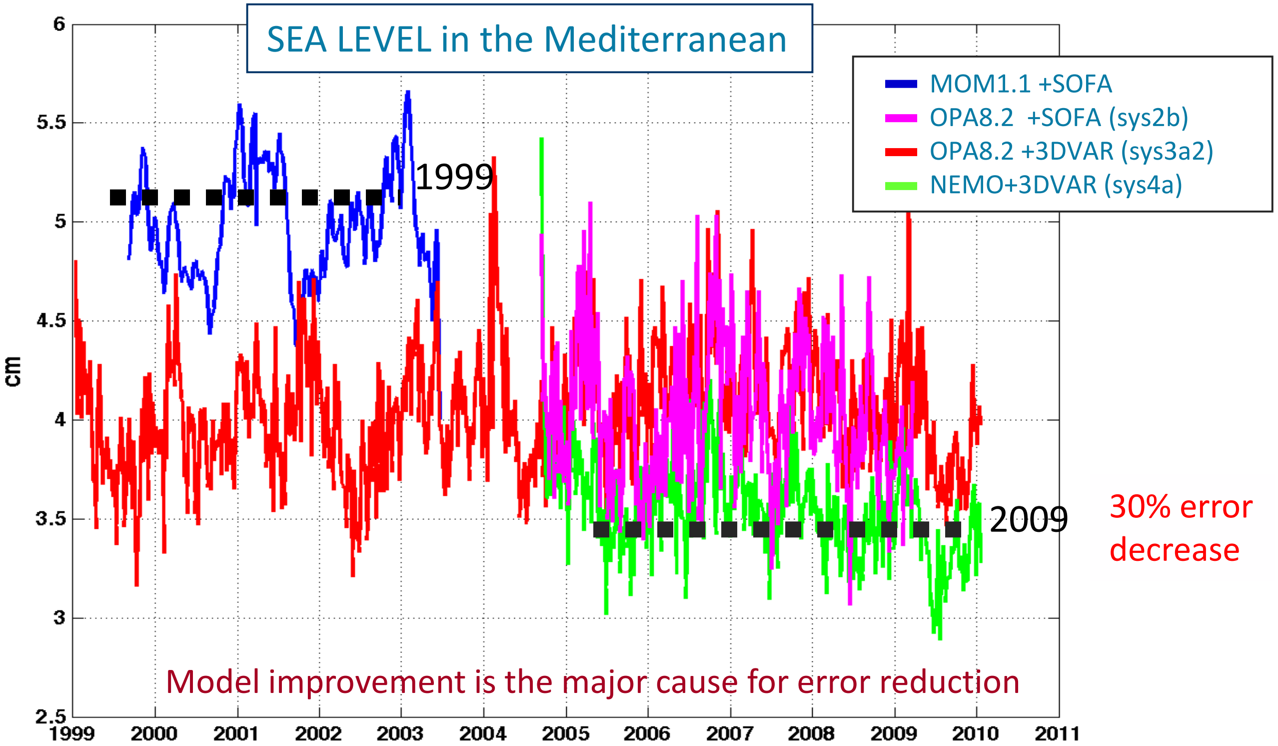
SLA RMS misfits [*cm*]



SLA RMS misfit [*m*] 2016-2017



Some facts: model improvement is key for analysis quality improvement



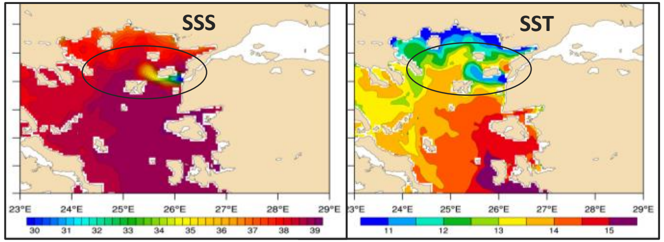
(Pinardi et al., The Sea, 2017)

Med-Physics Analysis and Forecasting system: Future Upgrades

Marine Monitoring

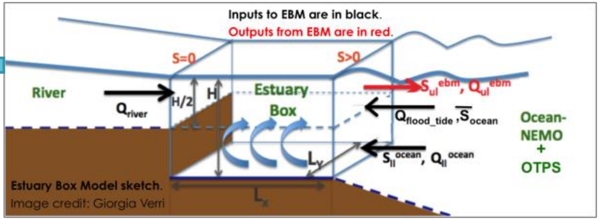
An upgraded analysis and forecasting system will enter in operation in July 2019 with the following improvements:

- **Dardanelles** strait inflow parameterized as an open boundary conditions; nesting through the GLO-MFC analysis and forecasting product
- **Improved SST relaxation**: move from a 24h relaxation to night time relaxation with gaussian coefficient



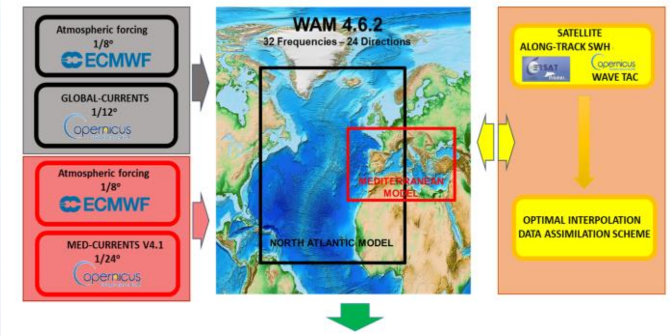
Foreseen major upgrades at end 2019 and 2020:

- Implementation of a 1-way coupled **Estuary Box Model** at river mouth to better represent river inflow and salinity
- Use of high frequency inter-annual **river run off and river forecast**, where available
- **Include tides** in the model
- Use a different **vertical mixing scheme**
- Improve **on-line coupling of NEMO with wave model** (enhanced vertical mixing)
- Data Assimilation: Include **assimilation of SST + Improvements** to account for Tides, new vertical mixing



Med-wave PU: developments and achievements

Mediterranean Sea Waves NRT: MEDSEA_ANALYSIS_FORECAST_WAV_006_017



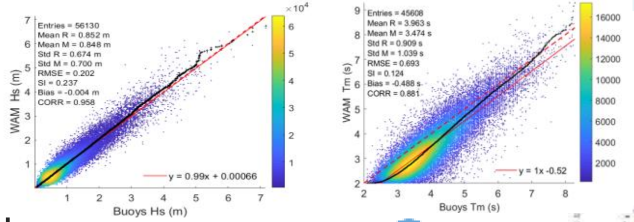
Analysis & 10 days forecast

Data assimilation of along track SWH inter-calibrated satellite observations from JASON2/3, SENTINEL-3A, SARAL/AltiKa, CRYOSAT-2

Quality check using InSitu and Satellite wave products (CMEMS TACs)

System Performance for year 2016

	RMSE	BIAS
SWH	0.202m	-0.004m
Tm	0.693s	-0.488s



Current system (Med-wave NRT)

- **Based on WAM Cycle 4.6.2 with tuning of wave age parameter**
- **1/24 (3-4 km) resolution forced with ECMWF 1/8 analysis and forecast winds**
- **Off-line coupling with 1/24 surface currents from Med-MFC**
- **Imposition of a limitation to the high frequency part of the spectrum based on Phillips spectrum (with tuning of Phillips constant)**
- **OBCs from a North Atlantic model running in parallel**
- **Analysis and forecasts for 10 days.**

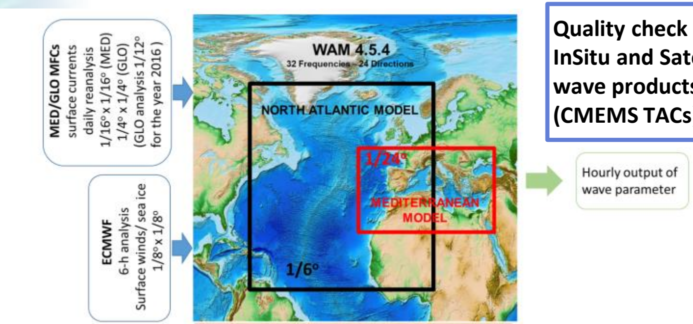
Future developments (Med-wave NRT)

- **One-way coupling with hourly 1/24 currents and sea level from Med-PH.**
- **Nesting with the Global Waves MFC**
- **Two forecast cycles (00:00 & 12:00) per day**

Marine Monitoring

Med-wave PU: developments and achievements

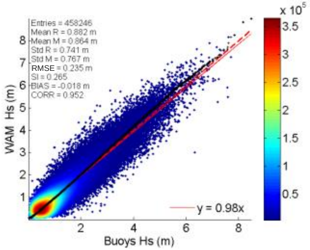
Mediterranean Sea Waves MYP: MEDSEA_HINDCAST_WAV_006_012



A 13 years (2006-2018) time series of Med-waves hindcasts
Current RAN system:

- **Based on WAM Cycle 4.5.4**
- **1/24 (3-4 km) resolution forced with ECMWF 1/8 analysis winds**
- **Off-line coupling with 1/16 surface currents from Med-MFC RAN**
- **OBCs from a North Atlantic model (nesting)**

QQ-Scatter plots of hindcast SWH (Hs) versus wave buoys' observations, for the full Mediterranean Sea, for the hindcast period (2006-2015



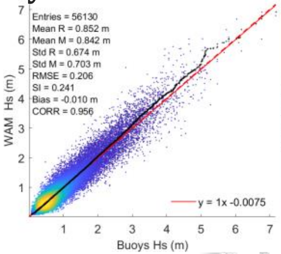
Future developments

A 26 years (1993-2018) time series of Med-waves re-analysis RAN system

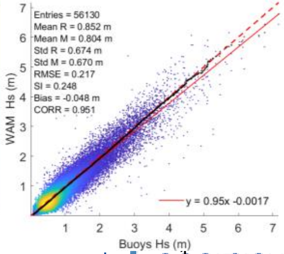
- **Based on current Med-waves NRT system**
- **1/24 (3-4 km) resolution forced with ERA5 ~30km analysis winds**
- **Off-line coupling with 1/24 surface currents from Med-MFC RAN**
- **OBCs from a North Atlantic model (nesting)**
- **Data assimilation of along track SWH inter-calibrated satellite observations**

Comparison with InSitu TAC wave buoys in the Med Sea (one year run 2016)

Current RAN system



ERA5 RAN system



European Commission | Copernicus | Mercator Ocean

The CMEMS Mediterranean biogeochemical component

The **MedBFM** system is composed by **three parts**: **OGSTM** transport model, **BFM model** and **3DVarBio** assimilation scheme. The MedBFM system provides either the **short term forecasts** and the **1999-2018 reanalysis timeseries**

Physical forcing from MED-PHY

NEMO 3.6 daily 3D fileds at 1/24° and 140z levels of **U, V, T, S, ssh and Qsw**

Initial Condition

NODC-OGS datasets climatology and 2-year spinup

Boundary Conditions

1. seasonal profiles of N, P, O, DIC, Alk in the Atlantic buffer zone from MEDAR/MEDATLAS, NODC-OGS and Med-CarbSys;
2. climatological values of N, P, O, DIC, Alk at the OBC of the Dardanelles Strait from literature after tuning

Land and atmospheric forcing

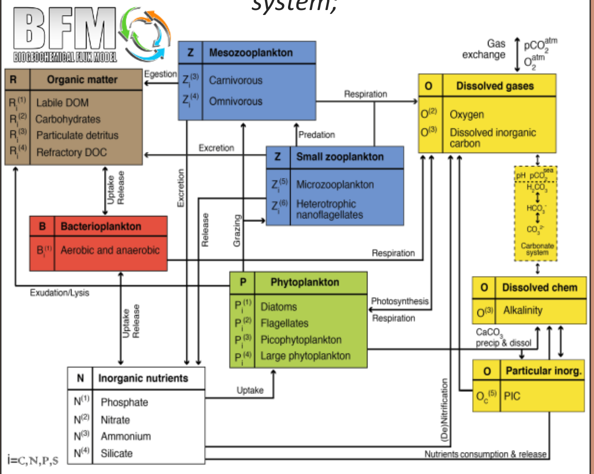
1. yearly and monthly climatological discharges N, P DIC and Alk for 39 rivers (Perseus D4.6 dataset and literature);
2. seasonal estimates for N and P atm. deposition

OGSTM - transport model

1/24° hor res. And 125 vertical Z levels, vvl formulation (non-linear free surface)*

Biogeochemical Flux Model – BFM

51 variables; cycle of C, N, P, Si, O; carbonate system;



Observations:

Chlorophyll Satellite from CMEMS OC TAC

Assimilation

3DVAR-BIO

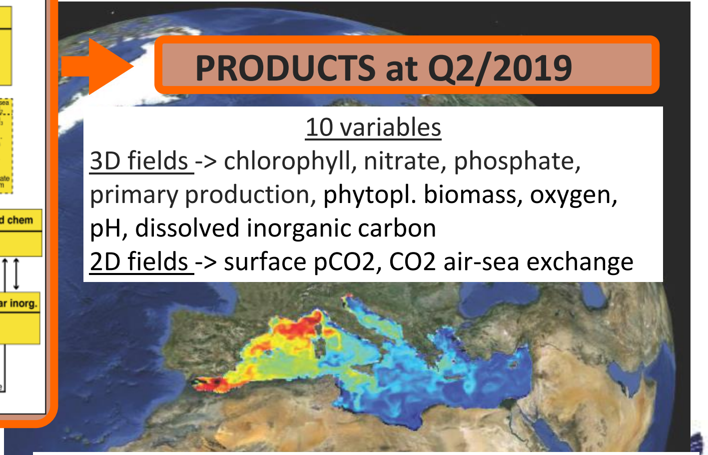
variational scheme; weekly assimilation cycle

PRODUCTS at Q2/2019

10 variables

3D fields -> chlorophyll, nitrate, phosphate, primary production, phytopl. biomass, oxygen, pH, dissolved inorganic carbon

2D fields -> surface pCO2, CO2 air-sea exchange



Analysis&Forecast: updated biweekly with daily data

Reanalysis: monthly from 1/1/1999 to 31/21/2018

MedBFM system is continuously evolving based on scientific achievements and on-going research

Marine Monitoring

Carbonate system, pH and CO2 flux

Estimating the value of carbon sequestration ecosystem services in the Mediterranean Sea: An ecological economics approach
Donata Melaku Canu, Andrea Ghermandi, Paulo A.L.D. Nunes, Paolo Lazzari, Gianpiero Cossarini, Cosimo Solidoro
(Global Environmental Change)

Spatiotemporal variability of alkalinity in the Mediterranean Sea
G. Cossarini, P. Lazzari, and C. Solidoro
(Biogeosciences, 12, 1647–1658, 2015)

DA of satellite chlorophyll data

A 3-D variational assimilation scheme in coupled transport-biogeochemical models: Forecast of Mediterranean biogeochemical properties
Anna Teruzzi, Srdjan Dobricic, Cosimo Solidoro, and Gianpiero Cossarini
(Journal of Geophysical Research: Oceans, 2014)

Assimilation of coastal and open sea biogeochemical data to improve phytoplankton simulation in the Mediterranean Sea
Anna Teruzzi, Giorgio Bolzon, Stefano Salon, Paolo Lazzari, Cosimo Solidoro, Gianpiero Cossarini
(Ocean Modelling)

Optical component

Merging bio-optical data from Biogeochemical-Argo floats and models in marine biogeochemistry,
Terzić, E., Lazzari, P., Organelli, E., Solidoro, C., Salon, S., D'Ortenzio, F., and Conan, P.
Under review in BIOGEOSCIENCES (2018)

WORK IN PROGRESS

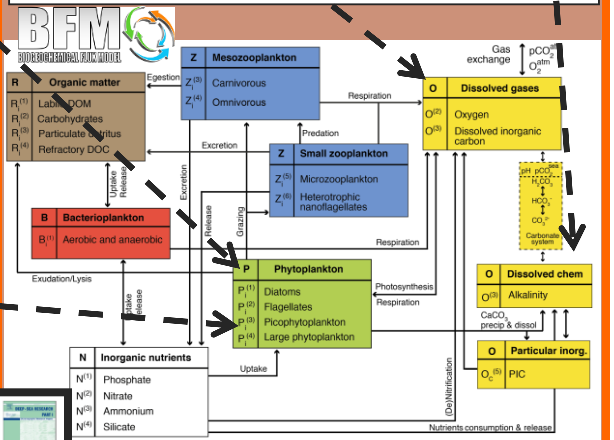
- Dynamics of oxygen
- Dynamics of organic matter and bacteria
- Optical Model and PFTs
- BGC indicators
- Multi-platform DA

Assimilation

3DVAR-BIO

variational scheme; weekly assimilation cycle

OGSTM - transport model



DA of BGC-Argo float data

Towards operational 3D-Var assimilation of chlorophyll Biogeochemical-Argo float data into a biogeochemical model of the Mediterranean Sea
G. Cossarini, L. Mariotti, L. Feudale, A. Mignot, S. Salon, V. Taillandier, A. Teruzzi, F. D'Ortenzio
(Ocean Modelling 133 (2019) 112–128)

Parallel implementation of a data assimilation scheme for operational oceanography: The case of the MedBFM model system
A. Teruzzi, P. Di Cerbo, G. Cossarini, E. Pascolo, S. Salon
(Computers and Geosciences 124 (2019) 103–114)

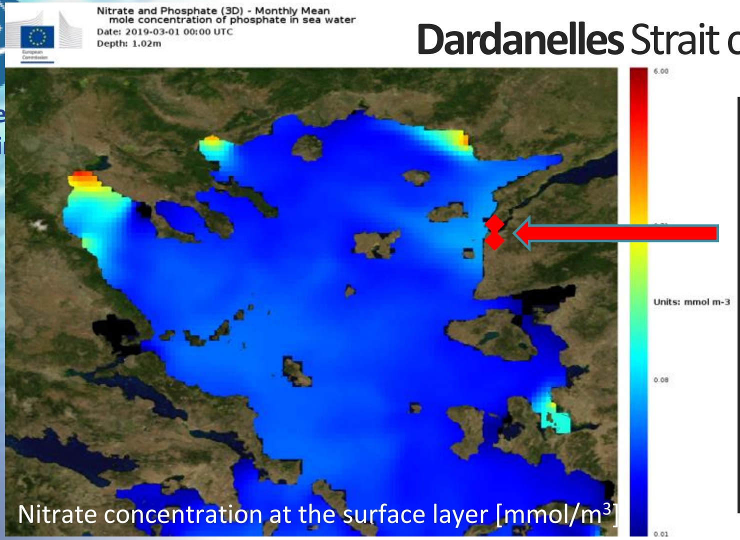
Plankton and nutrient formulations

Seasonal and inter-annual variability of plankton chlorophyll and primary production in the Mediterranean Sea: a modelling approach
P. Lazzari, C. Solidoro, V. Ibello, S. Salon, A. Teruzzi, K. Béranger, S. Colella, and A. Crise
(Biogeosciences, 9, 217–233, 2012)

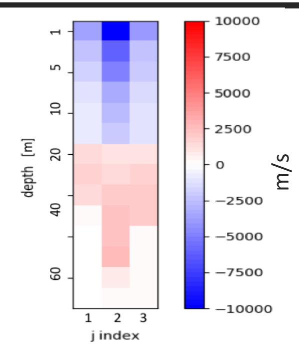
Spatial variability of phosphate and nitrate in the Mediterranean Sea: A modeling approach
P. Lazzari, C. Solidoro, S. Salon, G. Bolzon
(Deep-Sea Research I)

Marine Monitori

RECENT DEVELOPMENTS Q2/2019: New **open boundary condition at the Dardanelles** Strait consistently with MED-PHY system



Nitrate concentration at the surface layer [mmol/m^3]



Zonal velocities at the boundary section (neg -> westward)

New **open boundary condition at the Dardanelles strait**: a 2-layer flux system; global model zonal velocities and typical nutrient concentrations in the Marmara Sea (from literature after tuning) for the two layers

Validation of the nutrient fluxes at the Dardanelles Strait: MedBFM results are in the range of reference estimates

ref. estimates

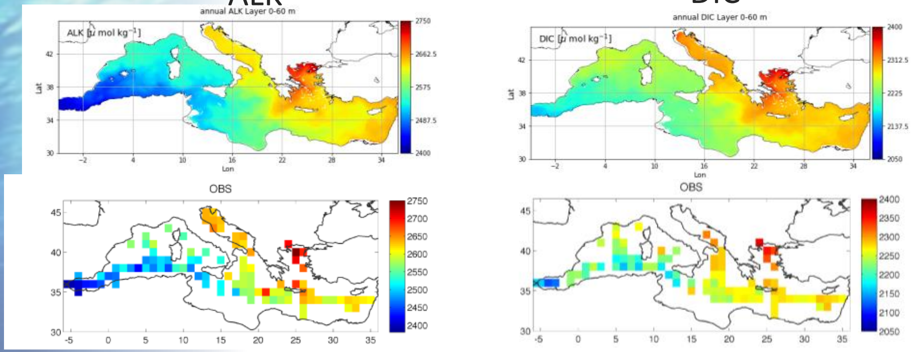
NITRATE		**Flux in mol/s**		**Flux**		
		Winter	**Summer**	**Winter 10^8 mol/m**	**Summer 10^8 mol/m**	**Annual 10^8 mol/y**
Yalcin et al. (2017)	Upper layer	208	168	5.5	4.4	
	Lower layer	-99	-183	-2.6	-4.8	
	Net flux					29.8
Tugrul et al. (2002)		**WIN 10^8 mol/m**	**SPR 10^8 mol/m**	**SUM 10^8 mol/m**	**AUT 10^8 mol/m**	**Annual 10^8 mol/y**
	Upper layer	0.20	0.08	0.14	0.28	2.1
	Lower layer	-0.77	-0.17	-0.25	-0.85	-6.13
	Net flux					-4.0
Perseus D4.6	Net flux 39kT/y					27.85
MODEL RESULT		**WIN 10^8 mol/m**	**SPR 10^8 mol/m**	**SUM 10^8 mol/m**	**AUT 10^8 mol/m**	**Annual 10^8 mol/y**
MedBFM3 simulation	Upper	1.27	1.42	1.35	2.26	18.88
	lower	-0.61	-0.62	-0.42	-0.95	-7.78
	Net flux					11.10

model

PHOSPHATE		**Flux in mol/s**		**Flux**		
		Winter	**Summer**	**Winter 10^8 mol/m**	**Summer 10^8 mol/m**	**Annual 10^8 mol/y**
Yalcin et al. (2017)	Upper layer	113	54.6	2.97	1.43	
	Lower layer	-48	-52	-1.26	-1.37	
	Net flux					+19.7
Tugrul et al. (2002)		**WIN 10^8 mol/m**	**SPR 10^8 mol/m**	**SUM 10^8 mol/m**	**AUT 10^8 mol/m**	**Annual 10^8 mol/y**
	Upper layer	0.061	0.019	0.024	0.070	0.526
	Lower layer	-0.034	-0.011	-0.014	-0.026	-0.279
	Net flux					+0.266
Perseus D4.6	Net flux 0.6kT/y					0.48
MODEL RESULT		**WIN 10^8 mol/m**	**SPR 10^8 mol/m**	**SUM 10^8 mol/m**	**AUT 10^8 mol/m**	**Annual 10^8 mol/y**
MedBFM3 simulation	Upper	0.05	0.05	0.05	0.08	0.70
	lower	-0.03	-0.03	-0.02	-0.05	-0.39
	Net flux					0.31

RECENT DEVELOPMENTS Q2/2018: **carbonate system of BFM model** and production of OMI of CO2 flux at the air sea interface

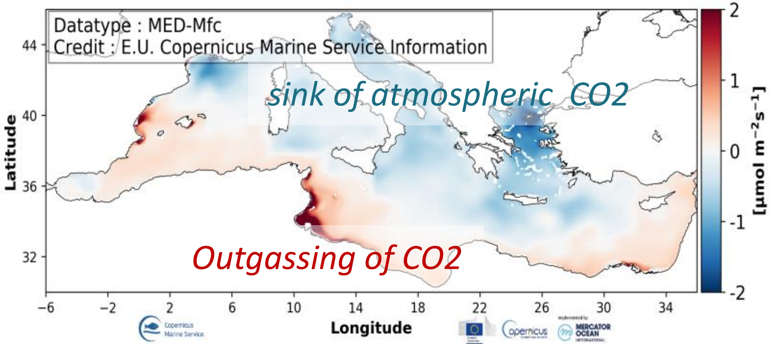
(1) Validation of the carbonate system variables: ALKALINITY and DISSOLVED INORGANIC CARBON

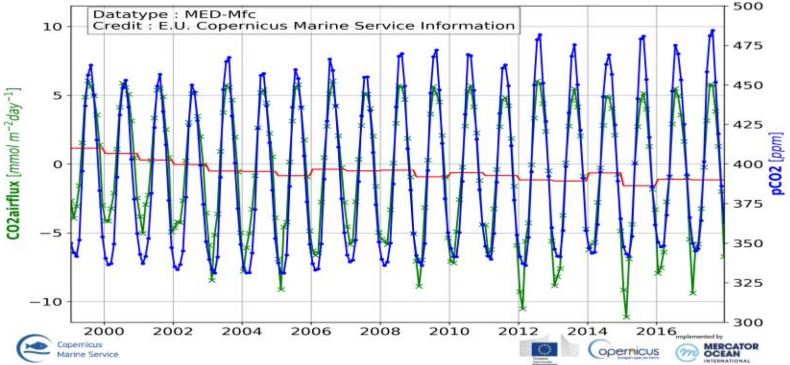


	ALK			DIC		
Layer depth	BIAS	RMSD	CORR	BIAS	RMSD	CORR
0-60	-2.4	25.4	0.9	7.7	19.7	0.9
60-100	-9.4	31.2	0.9	0.7	22.1	0.6
100-150	-9.6	19.4	0.9	-2.9	21.3	0.6
150-300	-2.5	26.3	0.8	-3.4	16.5	0.4
300-600	1.3	15.2	0.8	-3.5	9.5	0.6
600-1000	2.7	16.2	0.7	-5.3	6.7	0.6
1000-2000	1.5	11.2	0.7	-3.7	6.1	0.7
average	-2.6	20.7	0.8	-1.5	14.6	0.6

Skill metrics of comparison between a reconstructed 1°x1° climatology. **Uncertainties are of the order of 0.3-1%**

(2) Use of the MedBFM reanalysis to estimate climatological map and trend of **Air-sea CO2 exchanges:**



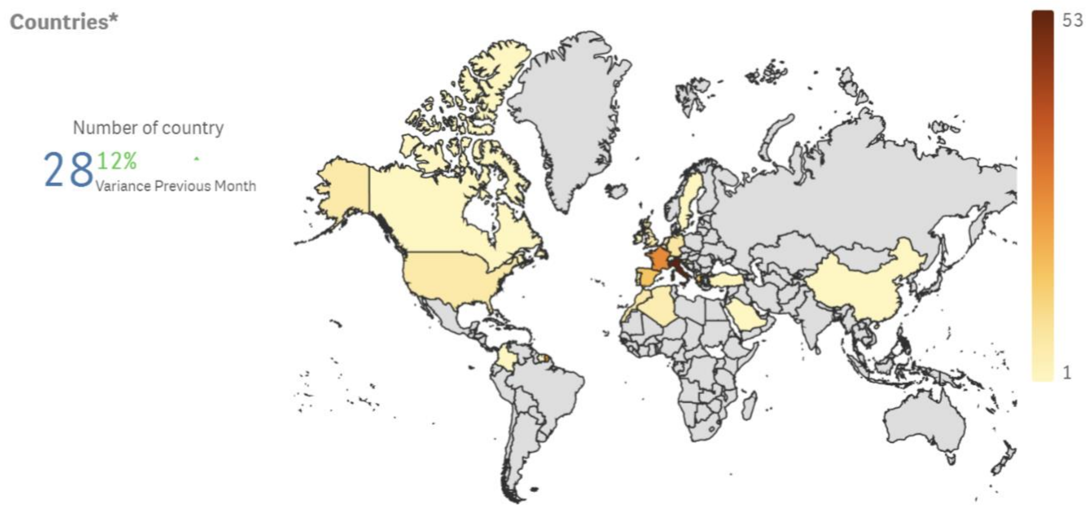


Positive trend of the sink of atmospheric CO2 due to the increase of pCO2atm from 365 (1999) to 408 ppm (2018) *[in OSR2 von Schuckmann et al.,*

User uptake

Marine Monitoring

174 active users in the last month



Oil Spill emergency service

JCOMM ETMEER

Marine Monitoring

Daily scenario forecasts of the oil spill drift and spreading during emergencies / operational service

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Contract MED-MFC Until April 30 2018

+ ECMWF

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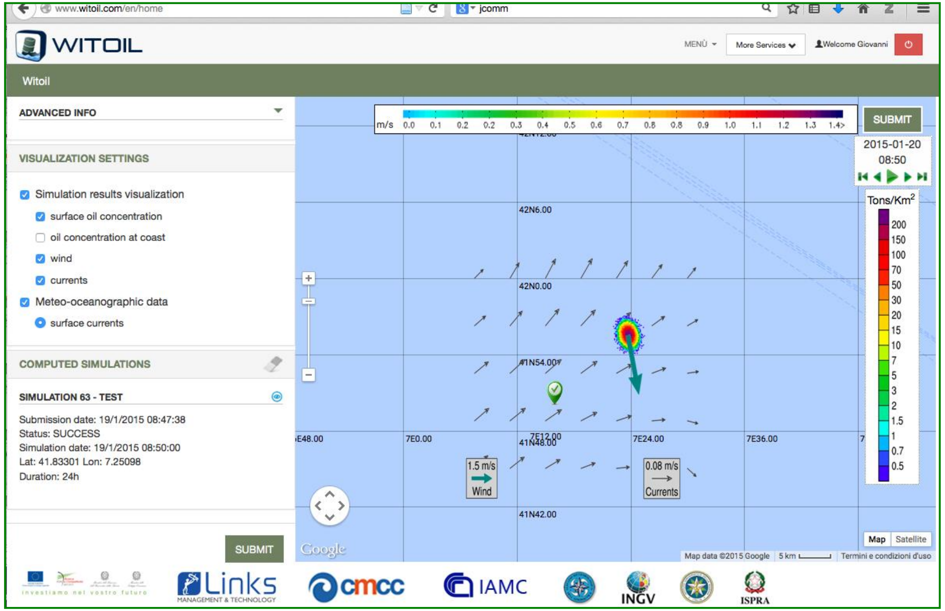
Currents and winds forecasted in the area

Oil spill scenario derived locally Using Medslik-II



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Conclusions

- Copernicus Marine Service is a fully operational service providing ocean in situ, remote sensing, and modelling products from the Global to the regional scale (e.g Mediterranean Sea)
- Quality control of products, open and free data policy, robustness and reliability of the operational Copernicus Marine Service service provide a long-term, high quality , trustful service ready for supporting downstream applications by private sectors
- Copernicus Med-MFC delivers state of the art ocean products for ocean hydrodynamics, waves and biogeochemistry which are in constant evolution and freely available for the development of added value services by intermediate users

New UNIBO PhD "Future Earth, climate change and societal challenges"

https://phd.unibo.it/future-earth-climate-change-societal-challenges/en

Marine
Monitoring

Thanks for your attention

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