First DBCP Mediterranean Training Workshop on Ocean Observations and Data Applications-Part 2

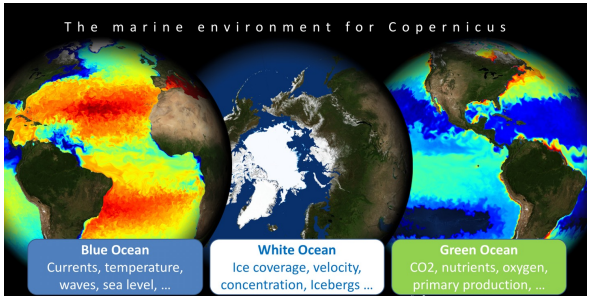
The Copernicus Mediterranean Physical system: latest model upgrades and accuracy

Emanuela Clementi (1), Ali Aydogdu (1), Anna Chiara Goglio (1), Jenny Pistoia (1), Massimiliano Drudi (2), Alessandro Grandi (2), Antonio Mariani (2), Vladislav Lyubartsev (2), Rita Lecci (2), Sergio Cretí (2), Simona Masina (1), Giovanni Coppini(2), Nadia Pinardi (1,3)

(1) Ocean Modeling and Data Assimilation Division, Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy
(2) Ocean Predictions and Applications Division, Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy
(3) Department of Physics and Astronomy, University of Bologna, Italy

Copernicus Marine Service

The Copernicus Marine Service provides free, regular and systematic authoritative information on the state of the **Blue** (physical), **White** (sea ice) and **Green** (biogeochemical) ocean, on **global** and **regional** scales.
It is funded by the European Commission (EC) and implemented by Mercator Ocean International



REANALYSES 10 to 45 years → **REAL-TIME** Daily, hourly → **FORECAST** 2 to 10 days

Mediterranean MFC

Copernicus Marine Mediterranean Monitoring & Forecasting Center

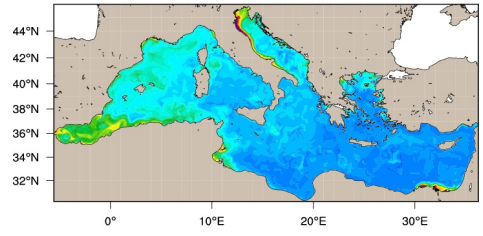
The Med-MFC is one of the 7 MFCs
A consortium of 4 institutes

MED-MFC ~40 experts

CMCC (Leader of the consortium and responsible for the Physical product) → **Med-PHY**
OGS (Responsible for the Biogeochemical product) → **Med-BIO**
HCMR (Responsible for the Wave product) → **Med-WAV**
CINECA Support to operational production (new from 2022)

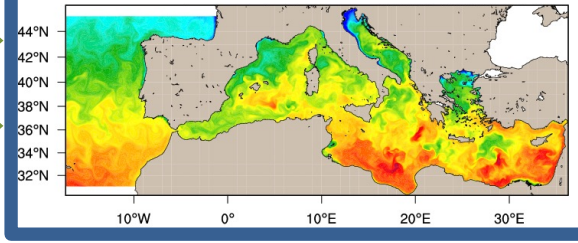
Med-Biogeochemistry PU

OGS



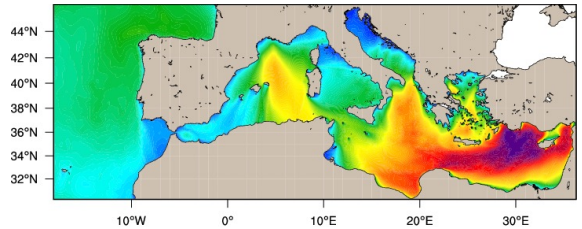
Med-Physics PU

cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici



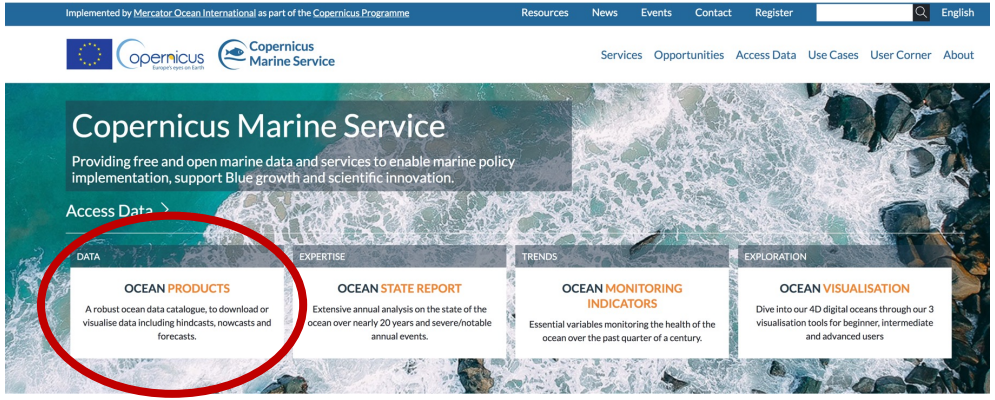
Med-Waves PU

hcmr ΕΛΚΕΘΕ

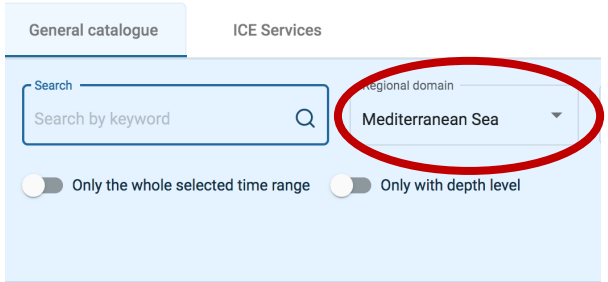


The modelling systems are based on **state-of-the-art community models**, **assimilate *insitu* and satellite observations** and are forced by **high resolution atmospheric fields**.
Improvements and functioning of the Med-MFC systems are based on the **full consistency among the three components** which **are jointly upgraded** and include a **continuous amelioration** of the accuracy of the products.

Copernicus Marine Med-PHY Products



Med-MFC products are operationally produced, constantly updated and freely available through the Copernicus Marine Service website catalogue



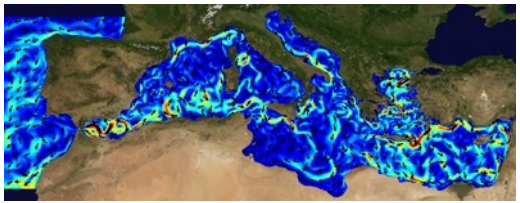
2 Numerical Modeling Products

Near Real Time Products
Analysis and Forecast

Multi-Year Products:
Reanalysis

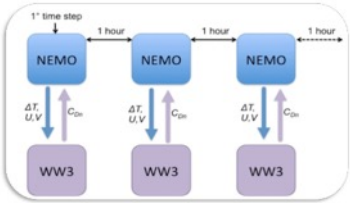
Copernicus Marine Med-PHY NRT System

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

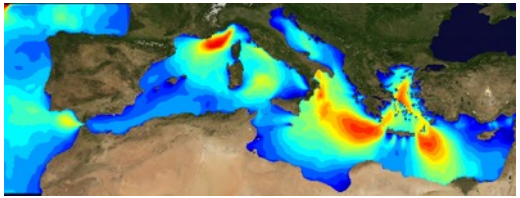


Hor. Res. = 1/24° (~4.5 km)
Vert. Res. = 141 z* vertical levels with partial cells

2-way
hourly
coupling



Wave model
WaweWatch-III (WW3) v3.14



Hor. Res. = 1/24° (~4 km)
Spectral discretization:
* 30 freq. bins (0.05-0.79 Hz)
* 24 directional bins

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

Copernicus Marine Med-PHY NRT System

ECMWF 1/10° atmospheric fields:

- MSLP, cloud cover, 2m relative humidity
- 2m T, 10m Wind , Precipitations

Temporal resolution:

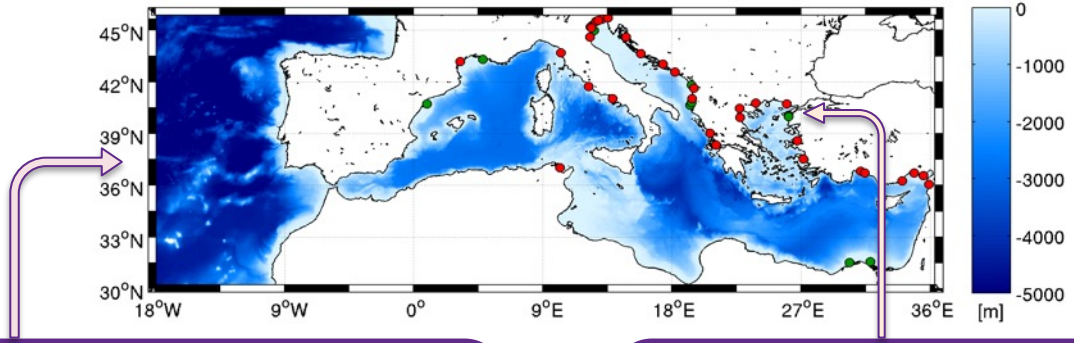
Forecasts: 1hr – 3hrs – 6 hrs

Analysis: 6 hours time resolution

Land river runoff:

Surface boundary condition for **39** major rivers with annual mean discharge > 50 m^3/s using climatological monthly mean values

Po river daily observations



Lateral Boundary conditions in the Atlantic:

Daily NRT analyses and forecasts from Copernicus Global Ocean Forecasting System (GLO-MFC) @ 1/12° horizontal resolution, 50 vertical levels

Lateral Boundary conditions in the Dardanelles Strait:

Turkish Straits System (TSS) box model (Maderich et al. 2015) daily climatologies

+

Temperature from GLO-MFC

Copernicus Marine Med-PHY NRT System – Data Assimilation

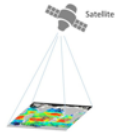
Model solutions are corrected by using observations

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

The assimilated data are:

Along track Sea Level Anomaly from CMEMS SL-TAC

- Jason 2/2N, 3
- Cryosat2
- Saral/AltiKa
- Sentinel3A/B

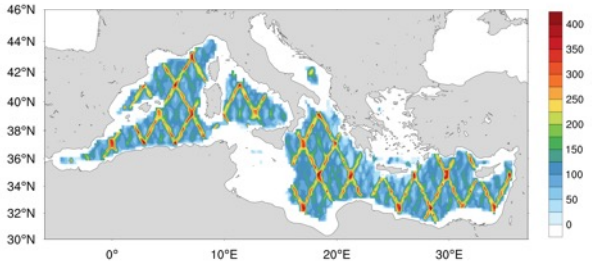


Vertical profiles of Temperature and Salinity from CMEMS InSitu TAC:

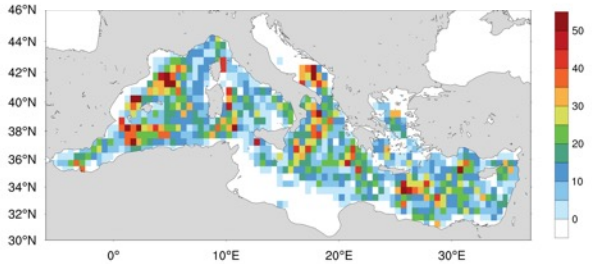
Argo XBT

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

SLA data assimilated in 2016-2017

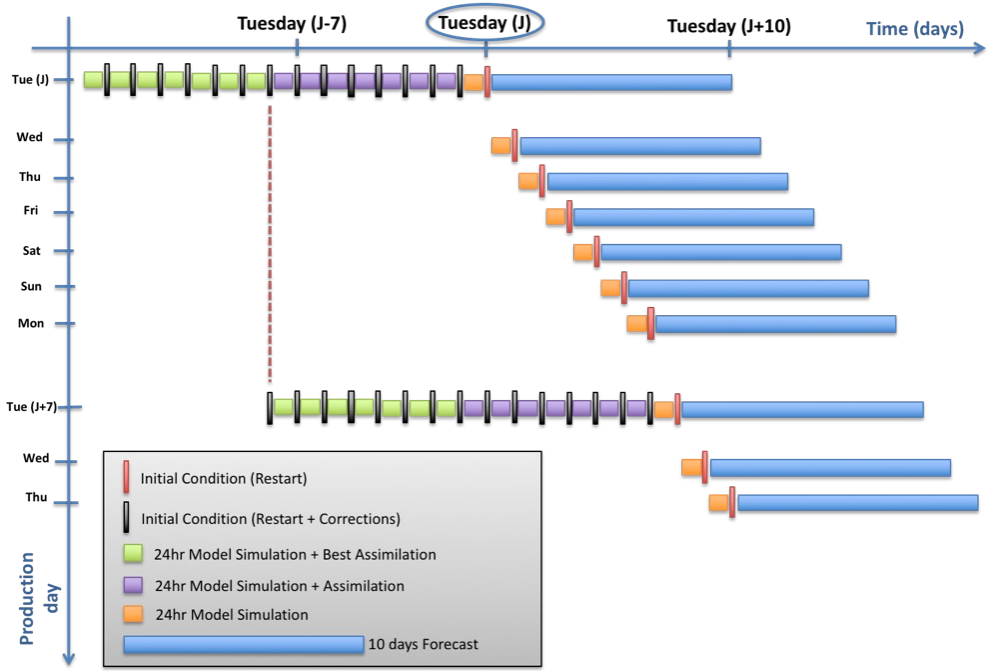


ARGO data assimilated in 2016-2017



Copernicus Marine Med-PHY Operational Chain & Products

Med-PHY Operational Chain



Med-PHY NRT Product

From years-2 → 10 day future

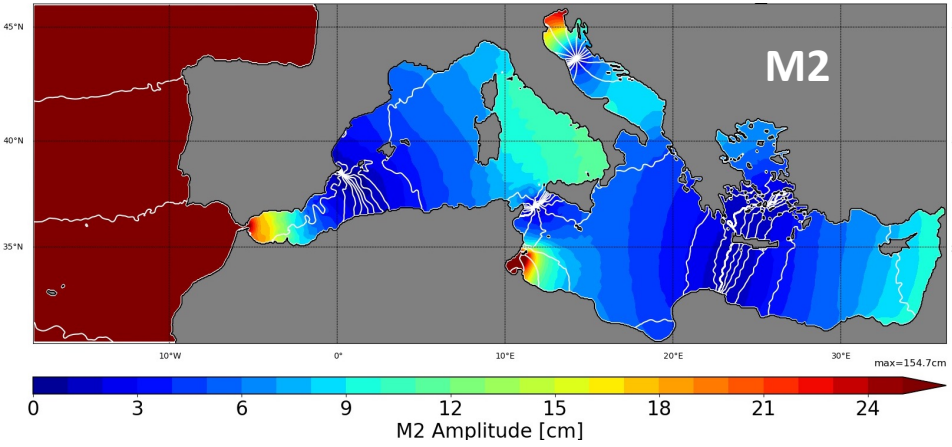
- **3D**
  - Temperature
  - Salinity
  - U,V Currents
- **2D**
  - Sea Level
  - Mixed Layer Depth
  - Bottom Temperature

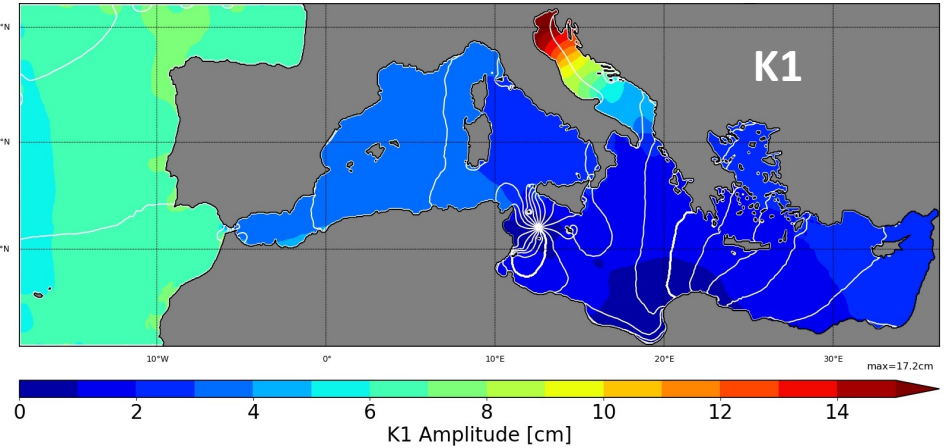
Copernicus Marine Med-PHY NRT System with tides

Tides and their interactions with the complex dynamics of the Mediterranean Sea represent a crucial and important challenge

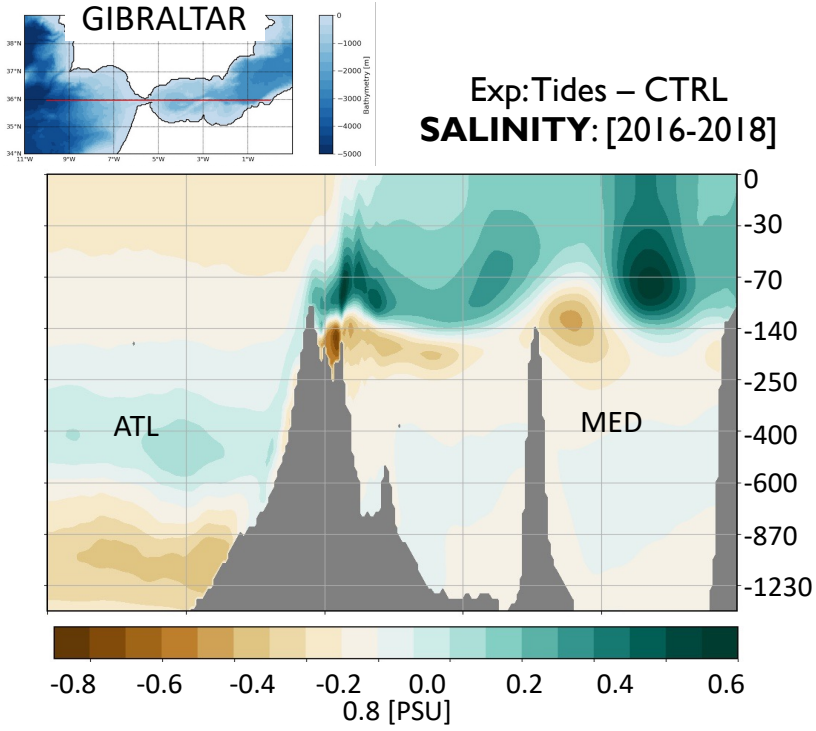
From the May 2021 CMEMS delivery → new system including tides

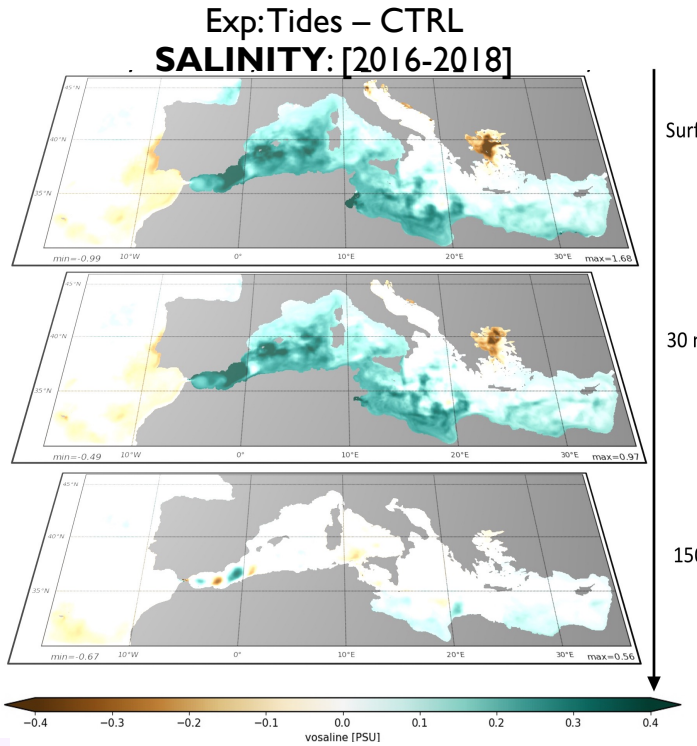
- ✓ 8 tidal components are included: M2, S2, N2, K2, K1, O1, Q1, P1
- ✓ Tidal BDY in the Atlantic from FES2014 (SSH) + TUGO (UV)
- ✓ Assimilation of tidal signal from SLA satellite data





Tidal impact on tracers content





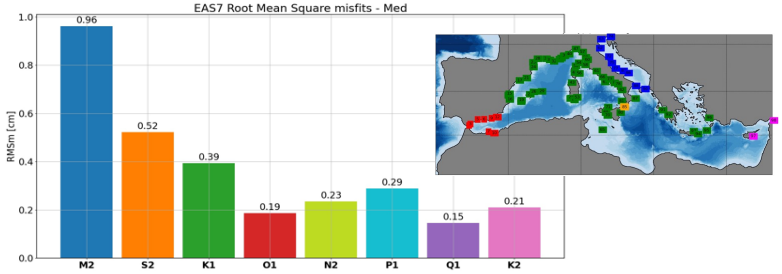
When tides are explicitly represented, salinity increases in the Mediterranean Sea, especially in the surface layers

This increase is mainly due to a change of the salt flux at the Gibraltar strait

Latest modeling upgrades & Validation

1. Add a topographic wave drag (TWD) parametrization: momentum sink due to dissipative waves generated by tides over rough topography in the open ocean (Shakespeare, 2020)

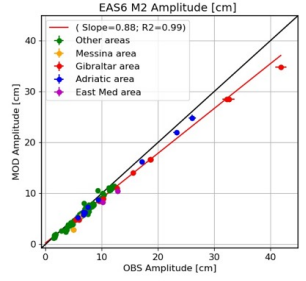
Model SSH VS. Tide Gauges: Harmonic Analysis

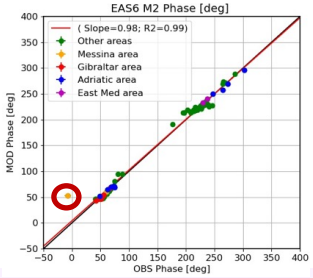


Mean Vectorial distances	M2	S2	K1	O1
EAS7 (new system)	1.10 cm	0.67 cm	0.59 cm	0.27 cm
Tsimplis et al., 1995	1.60 cm	0.98 cm	1.35 cm	0.41 cm
Palma et al., 2020	1.53 cm	0.86 cm	1.34 cm	0.71 cm

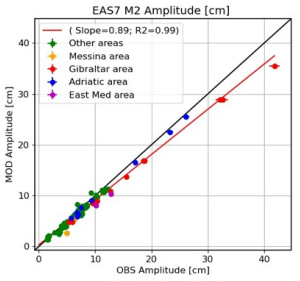
$$RMSd = \sqrt{\frac{1}{2N}\sum_{n}^{N}[(A_{mod}\cos\phi_{mod} - A_{ref}\cos\phi_{ref})^2 + (A_{mod}\sin\phi_{mod} - A_{ref}\sin\phi_{ref})^2]}$$

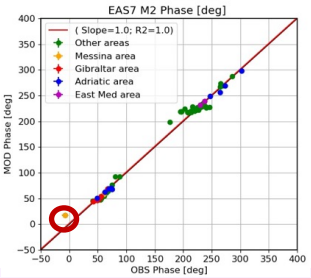
EAS6: BEFORE





EAS7: AFTER



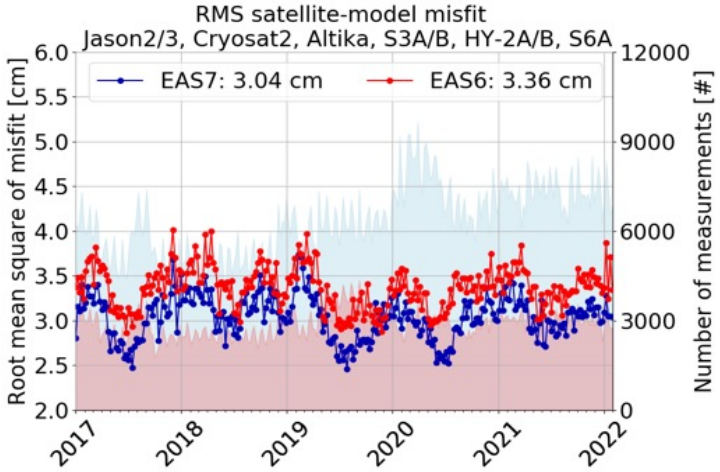


Tidal amplitudes and phases are correctly represented by the model when compared to tide gauges
Improvements especially at Messina Strait

Latest modeling upgrades & Validation

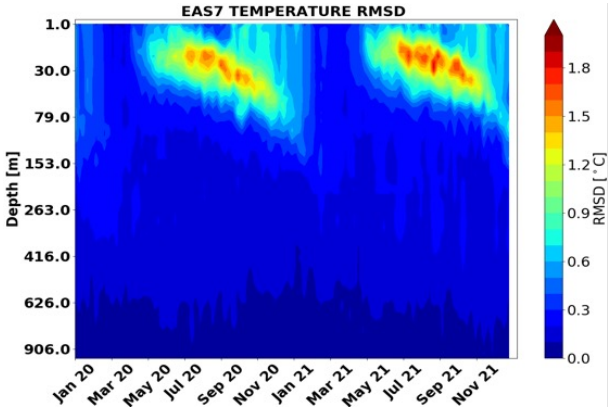
2. Assimilation of new available SLA Altimeter data Sentinel-6A, HY-2A/B + Assimilation at observations resolution (7km) + new MDT

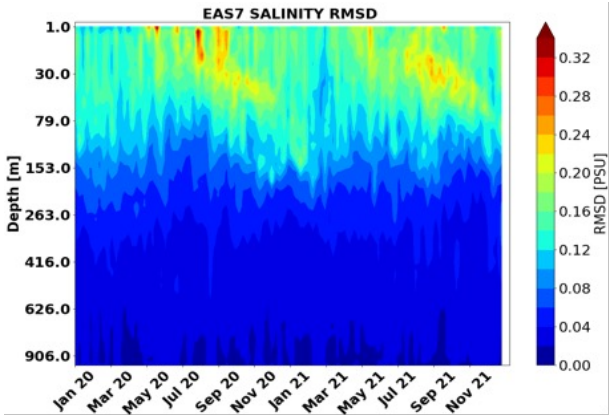
Model Sea Level Anomaly VS. Altimeter data: RMS misfits



Huge increase of assimilated SLA along track data
10% reduction of the SLA RMSD

Latest modeling upgrades & Validation





Model 3D Temperature and Saliniity VS *Insitu* observations

System version	T [°C] 8 m	T [°C] 30 m	T [°C] 150 m	T [°C] 300 m	T [°C] 600 m
EAS7 (new)	0.56±0.20	0.78±0.42	0.25±0.06	0.18±0.04	0.11±0.02
EAS6 (old)	0.54±0.20	0.78±0.44	0.26±0.06	0.19±0.04	0.11±0.02

System version	S [PSU] 8 m	S [PSU] 30 m	S [PSU] 150 m	S [PSU] 300 m	S [PSU] 600 m
EAS7 (new)	0.17±0.03	0.16±0.04	0.09±0.02	0.047±0.008	0.029±0.005
EAS6 (old)	0.17±0.03	0.17±0.03	0.10±0.02	0.048±0.004	0.029±0.005

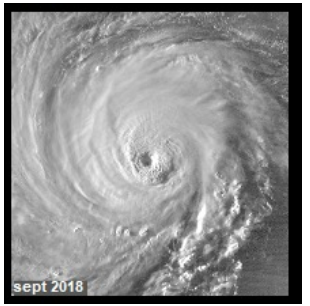
New modelling upgrades produced a slight reduction of the Temperature and salinity RMSD

Case study: Medicane Ianos

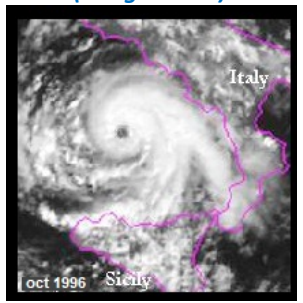
The Mediterranean Sea is one of the most cyclogenetic regions in the world

- Tropical-like cyclones generating in this region are known as ***medicanes*** or ***Mediterranean hurricanes***
  - cloudless "eye" at the centre of a spiral cloud coverage
  - cyclonic systems with symmetric, warm core structure
  - typical size of the order of 300 Km in diameter
  - more frequent during autumn and winter
  - are characterized by a combination of intense winds, heavy precipitation and enhanced ocean waves
- Such warm cores have been shown to form due to the process of warm seclusion or due to the development of deep convection close to the cyclone's centre→ similar to tropical cyclones

Tropical cyclone
(image NASA)



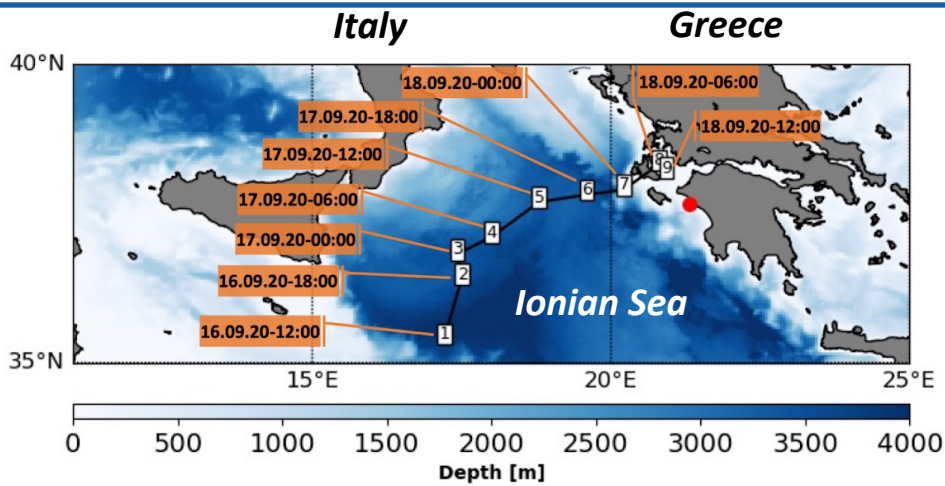
Medicane
(image NASA)



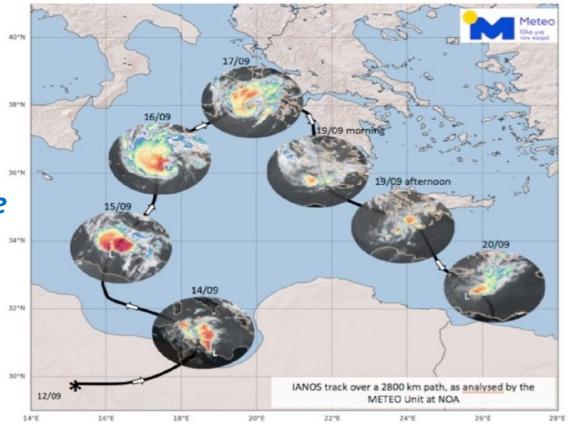
While cyclones have devastating effects when passing over coastal areas, over the ocean they might have a positive effect by enhancing productivity in oligotrophic areas

Case study: Medicane Ianos

- A record Mediterranean tropical-like cyclone
- 14th to 20th September 2020
- Impacting Ionian Sea & Greece
- Wind speeds up to 110 km/h, torrential rain and flooding → damages and death
- One of the strongest such storms recorded since 1969 (beginning of satellite observations) in terms of duration and intensity



Investigating the cyclone impacts by using observational data may have some obvious limitations → 3D ocean models can provide insights on its evolution and on the coupling mechanisms driving ecosystem productivity



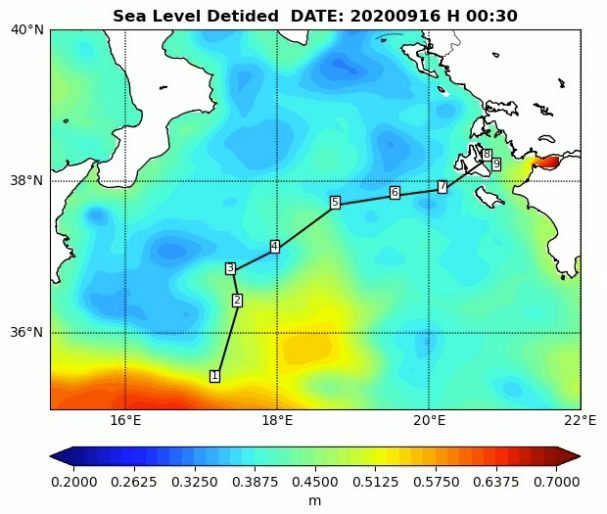
Ianos track as analyzed by the METEO unit of IERSD/NOA

Med-MFC numerical analysis data are used to analyse Ianos impacts on the physical, wave and biogeochemical upper layers fields

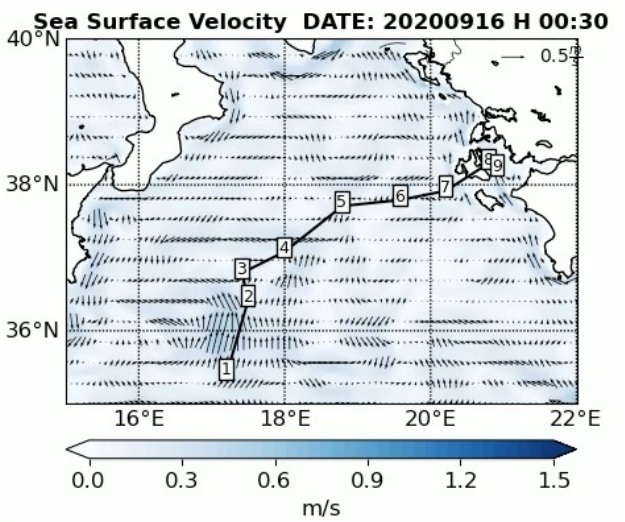
Case study: Medicane Ianos

Medicane Ianos: rare Mediterranean tropical-like cyclone impacting Greece on 17-20 Sept. 2020

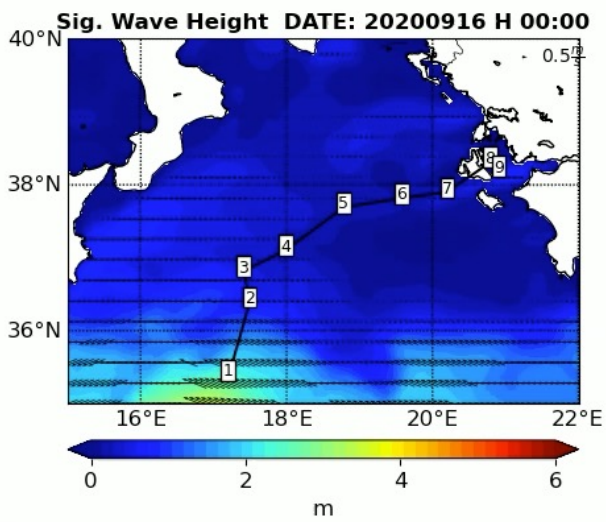
SEA LEVEL



SURFACE CURRENTS



SIG. WAVE HEIGHT



Impact of Medicane Ianos' passage clearly captured by hydrodynamic and wave models

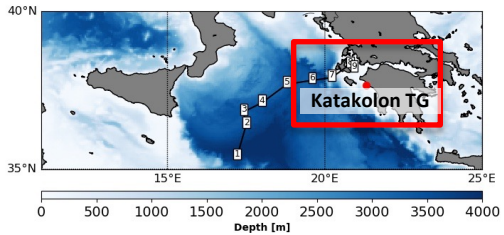
→ increase of the sea level and significant wave height

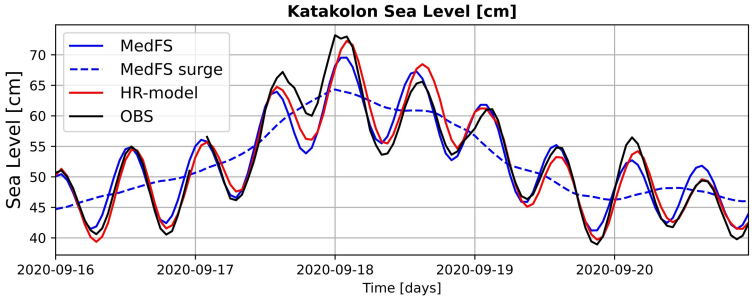
→ intensification of the surface currents

along the Medicane path

Case study: Medicane Ianos

SEA LEVEL VALIDATION



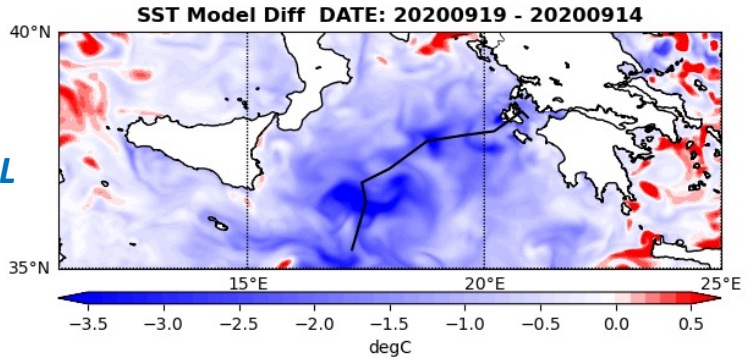


- Model hourly sea level in agreement with observations @ Katakolon TG
- Model Underestimation ~ 4 cm at peak

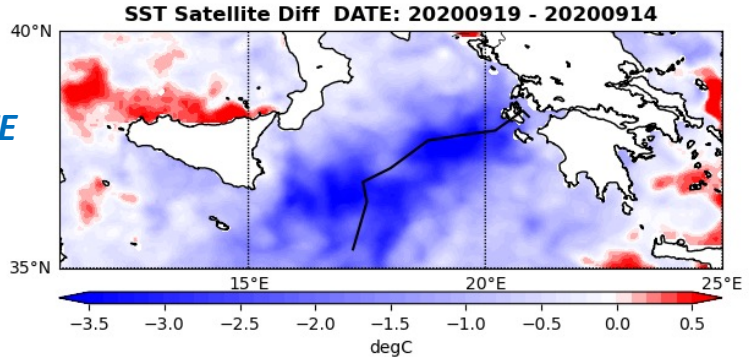
- MedFS used to force high res. (3km to 100m) unstructured grid model (based on the SHYFEM) → reduced error at peak

SST VALIDATION

MODEL



SATELLITE



- SST decrease around -3.5 °C
- MedFS shows some underestimation compared with the satellite L4 SST dataset

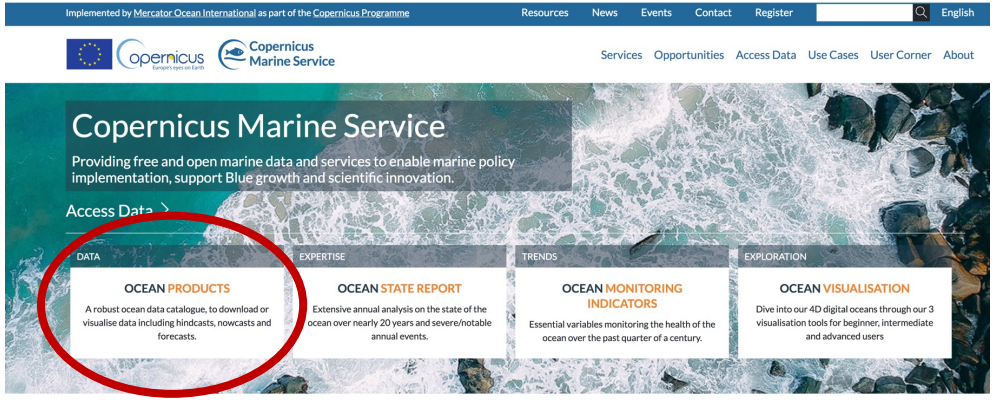
Copernicus Marine Med-MFC future evolutions

	2023	2024

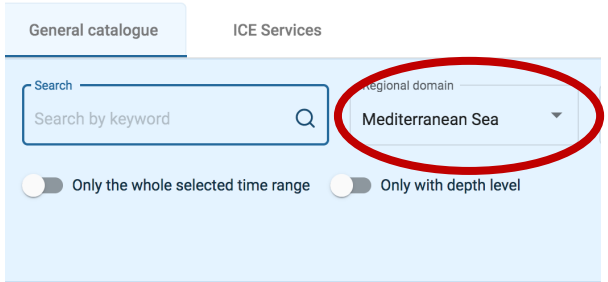
Model	• Delivery of an improved NEMO-WW3 system:
	  • Updated version of NEMO 4.2
	  • Updated version of WW3 6.07
	  • Modified vertical mixing scheme
	  • Use higher frequency river data (EFAS NRT)
		• Dardanelles LOBC from U-TSS
		• Estuary box model for major rivers
		• Improved representation of air-sea fluxes

Data Assimilation	• Update OceanVar for NEMO4.2 • Assimilation of gliders • Assimilation of 5Hz SLA data • Assimilation in the Atlantic-box (only insitiu)	• Use of L3s SST data (relaxation or assimilation) • Shorter assimilation cycle • Revision of the analysis definition
Catalogue	Revision of SSH de-tiding + UV de-tiding with Doodson filter	Operational high-frequency 3D interfaces between coastal models & regional MFC

Copernicus Marine Med-PHY Products



Med-MFC products are operationally produced, constantly updated and freely available through the Copernicus Marine Service website catalogue



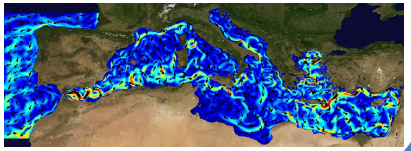
2 Numerical Modeling Products

- **Near Real Time Products**
  Analysis and Forecast
- **Multi-Year Products:**
  Reanalysis

Copernicus Marine Med-PHY Reanalysis System

OGCM: NEMO v3.6

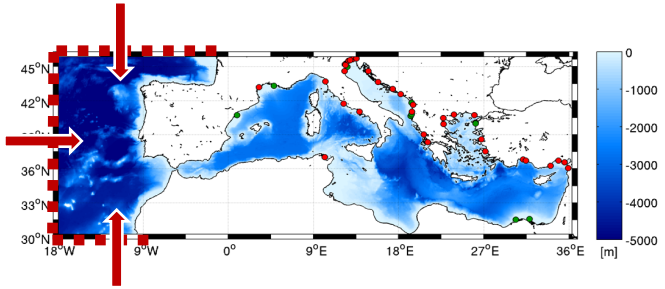
Hor. Res. = 1/24° (~4 km)
Vert. Res. = 141 z* vertical



DATA ASSIMILATION OceanVar
3D-VAR Ocean variational data assimilation scheme
Satellites SLA and T/S insitu reprocessed observations are jointly assimilated
Non-solar heat flux correction is achieved through satellite SST

EXTERNAL FORCING FIELDS
INITIAL CONDITIONS 1985: World Ocean Atlas Winter climatology
ECMWF **ERA5 1-hour 1/4°** atmospheric fields
39 major river inflows (climatological data)
1 lateral open boundary:
Atlantic Ocean nested into the Global CMCC CGLORS-v5 system

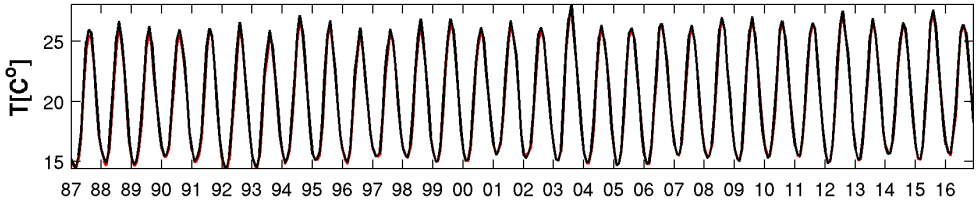
Lateral Open Boundary (LOBC) in Atlantic from CMCC Global Reanalysis



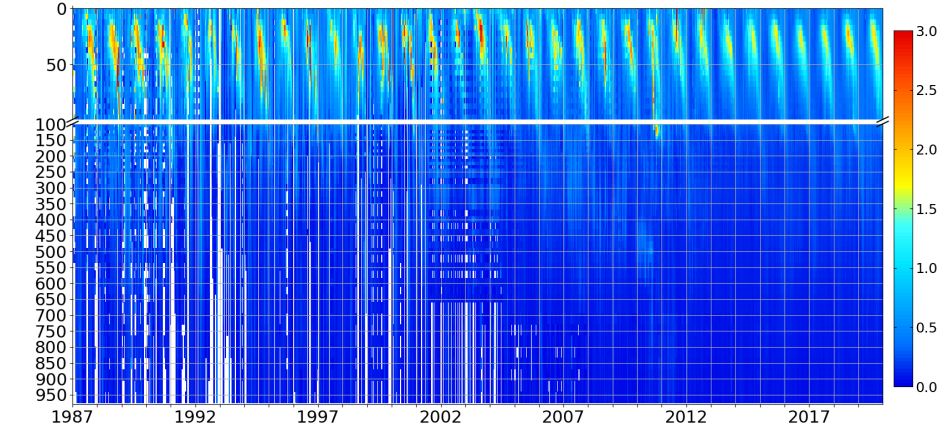
Copernicus Marine Med-PHY Reanalysis System Validation

Sea Surface Temperature Model Reanalysis: 20.3 °C

Sea Surface Temperature Satellite obs.: 20 °C

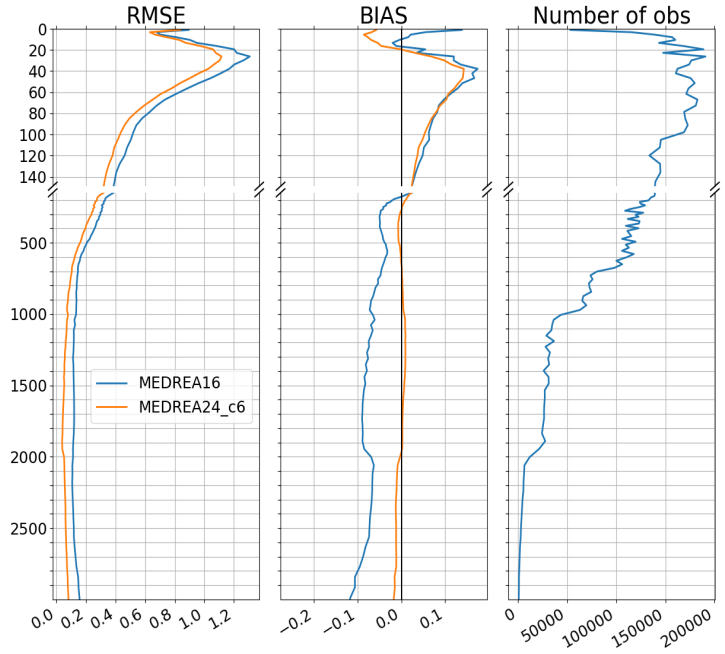


Temp. RMSD wrt insitu Obs.



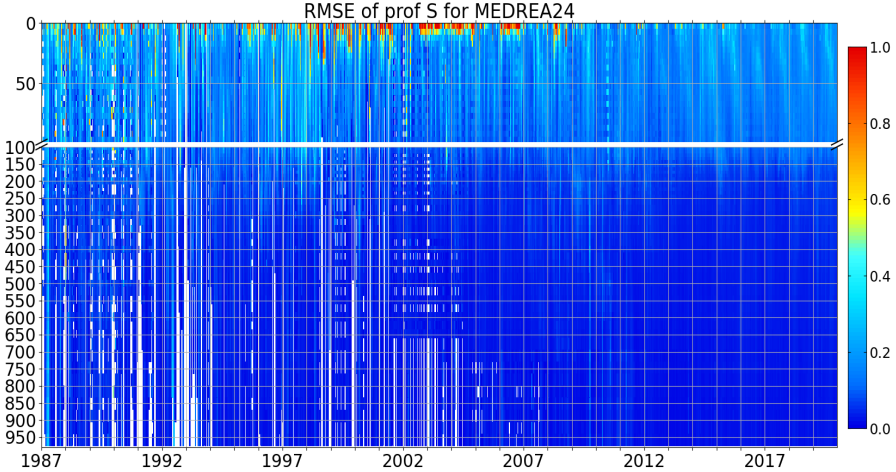
Temp. RMSD wrt insitu Obs.

Old (MEDREA16) VS New Reanalysis (MEDREA24)



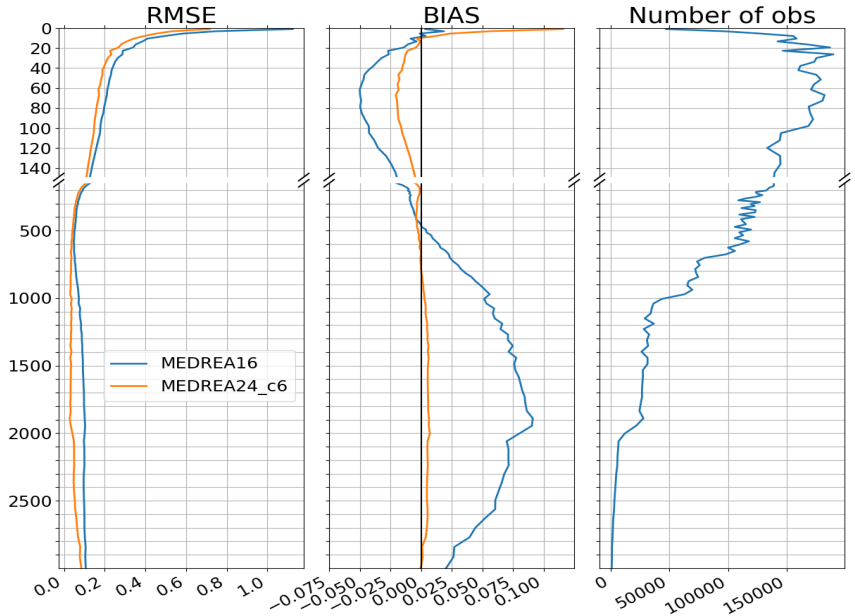
Copernicus Marine Med-PHY Reanalysis System Validation

Sal. RMSD wrt insitu Obs.



Sal. RMSD wrt insitu Obs.

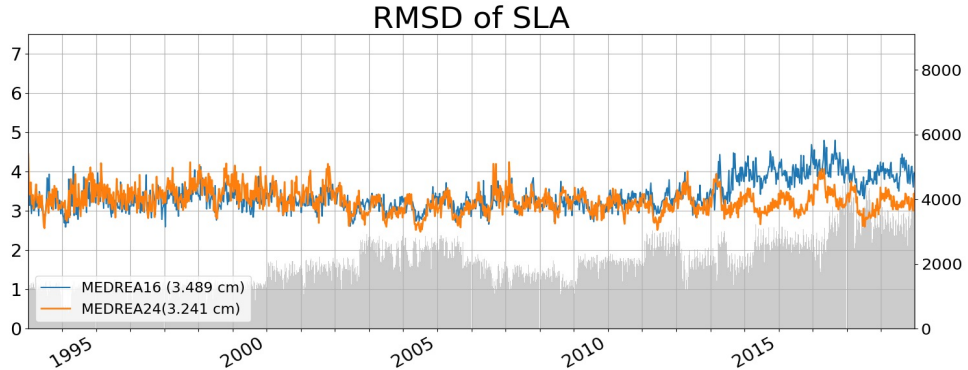
Old (MEDREA16) VS New Reanalysis (MEDREA24)

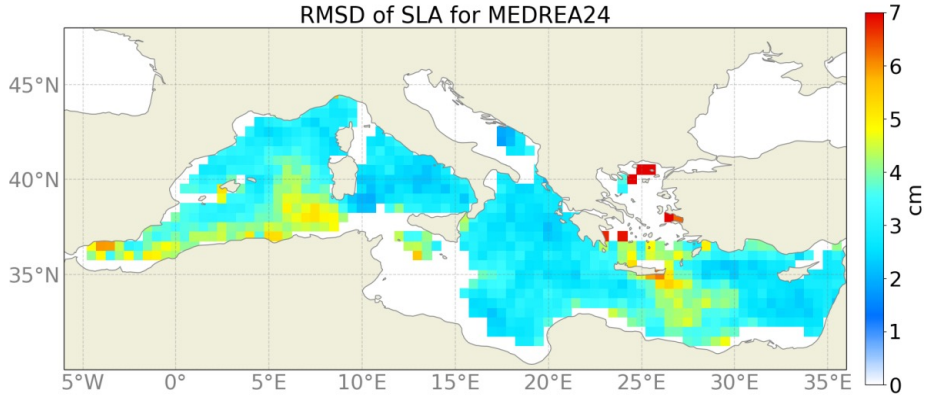


Copernicus Marine Med-PHY Reanalysis System Validation

SLA Model VS. Satellite Obs.

Old (MEDREA16) VS New Reanalysis (MEDREA24)

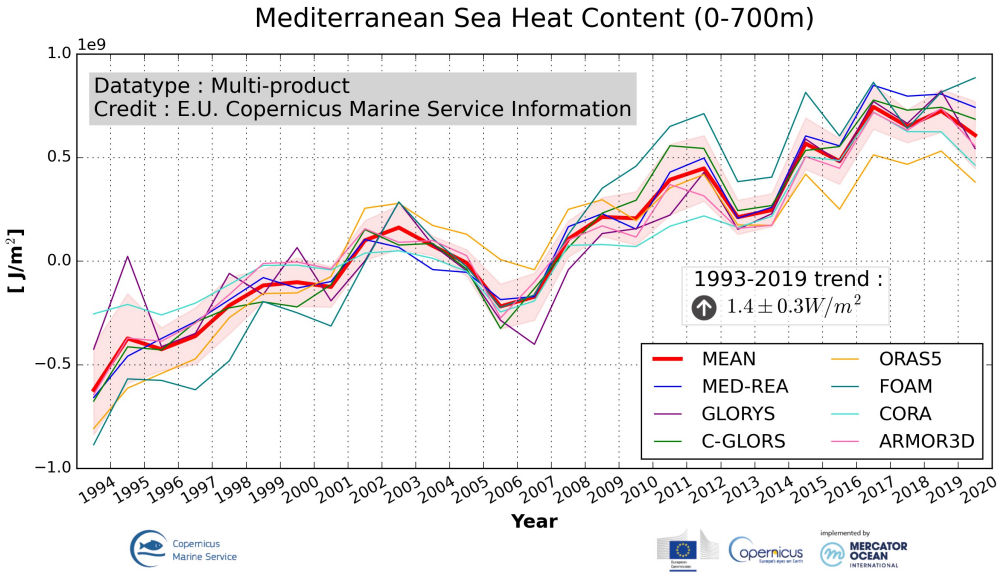




Copernicus Marine Med-PHY Ocean Monitoring Indicators

Ocean reanalyses are used to evaluate Ocean Monitoring Indicators

Ocean Monitoring Indicators (OMIs) are key variables used to track the vital health signs of the ocean and changes in line with climate change.



Conclusions

- The **Mediterranean Sea operational system** within the Copernicus Marine Service is **constantly ameliorated** following users' needs in order to improve the product accuracy
- **Recent system upgrades** (to become the official operational system from 29/November/2022) consist in the improvement of the tidal representation, assimilation of 7km SLA data, and of new satellite missions available (Sentinel-6A, HY2A/B), use of a new MDT
- **The system has been validated** comparing model daily analyses fields with respect to Copernicus Marine satellite and insitu observations. **Major improvements** are achieved in representing the Sea Level Anomaly in the whole domain and the tidal phase in the Messina strait. Temperature and salinity mean skill is slightly improved.
- The model is able to **represent extreme events** such as Medicane Ianos and its impact on the surface dynamics
- The Mediterranean Sea **Reanalysis** provides a reliable representation of the ocean state variables evolution and can be successfully used to evaluate **ocean monitoring indicators** in the basin

Thanks

Emanuela Clementi
emanuela.clementi@cmcc.it

cmcc
Centro Euro-Mediterraneo
sui Cambiamenti Climatici