The Mediterranean analysis and forecasting physical system for the Copernicus Marine Service: description and skill assessment

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OUTLINE

- Mediterranean Forecasting System overview in the CMEMS framework
  - System description
    - Main differences between actual and previous modeling system
    - Major impacts of the implemented modifications on the new system
  - System validation with in-situ, satellites and climatological datasets
  - Overview of future upgrades
  - Summary & Conclusions
CMEMS Med-MFC is one of the 7 CMEMS MFCs

A consortium of 3 research institutes:
CMCC (Leader of the consortium and responsible for the Physical product)
OGS (Responsible for the Biogeochemical product)
HCMR (Responsible for the Wave product)

http://marine.copernicus.eu/
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.
Temporal resolution:
Forecasts: 3hrs for the first 3 days and 6 hours for the next 7 days
Analysis: 6 hours time resolution

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

Land river runoff:
vertical boundary condition for 39 major rivers (previous version 7) with annual mean discharge > 50 m3/s using climatological monthly mean seasonal cycle values
The Dardanelles inflow is parameterized through a river-like parametrization

Lateral Boundary conditions in the Atlantic:
Daily NRT analyses and forecasts from Global Ocean Forecasting System (GLO-MFC) @ 1/12° horizontal resolution, 50 vertical levels:
- Flather boundary condition (Flather, 1976) is applied to barotropic velocities
- Orlansky npo boundary condition (Orlanski, 1976) is applied to tracers and baroclinic velocities
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

The assimilated data are:

- **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
  - XBT

SLA data assimilated in 2016-2017

ARGO data assimilated in 2016-2017

Non-solar heat flux correction is achieved through satellite SST nudging
The data are assimilated weekly with a daily analysis window.

**ANALYSIS**: Each Tuesday → simulation for the previous 2 weeks with ECMWF analysis atmo. forcing + assimilation correction

**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**: Computed for next 10 days forcing the numerical model with ECMWF forecast fields
# Med-Currents Analysis and Forecast system description

## Main differences between actual and previous modeling

<table>
<thead>
<tr>
<th>Previous system EAS1</th>
<th>Actual system EAS3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feature</strong></td>
<td></td>
</tr>
<tr>
<td>1/16° (5-6km) hor</td>
<td>1/24° (4-5km) hor</td>
</tr>
<tr>
<td>72 vert lev</td>
<td>141 vert lev</td>
</tr>
<tr>
<td>NEMO v3.4 linear free-surface Z coord.</td>
<td>NEMO V3.6 non-linear free-surface Z* coord</td>
</tr>
<tr>
<td>7</td>
<td>39</td>
</tr>
<tr>
<td>1.2e-5 / 1.2e-6 [m2/s]</td>
<td>1.2e-6 / 1.0e-7 [m2/s]</td>
</tr>
<tr>
<td>-6.e8 / -1.e9 [m4/s]</td>
<td>-1.2e8 / -2.e8 [m4/s]</td>
</tr>
<tr>
<td>300sec</td>
<td>240sec</td>
</tr>
<tr>
<td>SDN Clim T/S</td>
<td>WOA-V2 Winter Clim T/S</td>
</tr>
<tr>
<td>From modified DBDB1 1min</td>
<td>From modified GEBCO 30arc-sec</td>
</tr>
</tbody>
</table>

### Common parameterizations

- Air-sea fluxes: MFS bulk formulae described in Pettenuzzo et al. (2010)
- Advection scheme for active tracers: mixed up-stream/MUSCL
- Vertical diffusion and viscosity terms: Function of the Richardson number as parameterized by Pacanowsky and Philander (1981)
Net transport at Messina Strait (2015-2016) = -0.051 Sv

In-situ obs
EAS1: RMS=4.84, Bias=0.06 cm
EAS3: RMS=4.28, Bias=0.05 cm

Impacts due to increased resolution

MESSINA STRAIT

EAS1 (1/16o)
EAS3 (1/24o)

Sea Level comparison

In-situ obs
EAS1: RMS=5.66, Bias=0.06 cm
EAS3: RMS=4.28, Bias=0.02 cm

Reggio Calabria, Sea Level [cm]
In-situ obs
EAS1: RMS=4.84, Bias=0.06 cm
EAS3: RMS=4.28, Bias=0.05 cm
Impacts due to increased resolution

**Gibraltar Mean Flux [Sv]**

<table>
<thead>
<tr>
<th></th>
<th>EAS 1</th>
<th>EAS 3</th>
<th>Soto-Navarro et al., 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net</td>
<td>0.03</td>
<td>0.04</td>
<td>0.038 ± 0.007</td>
</tr>
<tr>
<td>Eastward</td>
<td>1.20</td>
<td>0.90</td>
<td>0.81 ± 0.06</td>
</tr>
</tbody>
</table>

**In-situ obs**

- **EAS1**: RMS=5.04, Bias=-0.15 cm
- **EAS3**: RMS=4.82, Bias=-0.18 cm

**Sea Level comparison**

- **Algeciras**: RMS=5.04, Bias=-0.15 cm
- **EAS1**: RMS=4.82, Bias=-0.18 cm
- **Tarifa**: RMS=5.83, Bias=-0.01 cm
- **EAS3**: RMS=5.68, Bias=0.01 cm
Quasi-Independent Validation: MISFITS

Time Series of Temperature RMS misfits at 30 & 600m depth

T RMS at 30m depth

T RMS at 600m depth
Quasi-Independent Validation: MISFITS

Time Series of Salinity RMS misfits at 30 & 600m depth

S RMS at 30m depth

S RMS at 600m depth
Quasi-Independent Validation: MISFITS

Temperature RMS misfits [deg C]

Salinity RMS misfits [PSU]

SLA RMS misfits [cm]

T & S error
- Larger error during summer
- Larger error at thermocline, that decreases at lower layers
Quasi-Independent Validation: MISFITS

Spatial Variability of RMS misfits in 2016-2018

Temperature RMS misfits at 8m [degC]
Salinity RMS misfits at 8m [PSU]
SLA RMS misfits [cm]

Temperature RMS misfits at 30m [degC]
Salinity RMS misfits at 30m [PSU]

N. ARGO Observations
N. SLA Observations
Quasi-Independent Validation SST: model VS. satellite L4 data

Satellite SST Annual Mean (2016)

Perc diff: (Model- Satellite SST)/Satellite SST

SST BIAS at midnight

SST is not assimilated but it is used to correct Heat fluxes by relaxation.

\[ Q_{corrected} = Q_{forc} + \frac{dQdSST}{\rho C_p} (SST_{model} - SST_{observation}) \]

Data assimilation of ARGO and SLA improves midnight SST values
CLIMATOLOGY*: Houpert et al., 2015
Monthly gridded climatology produced using MBT, XBT, Profiling floats, Gliders, and ship-based CTD data from different database in the Med. 1969 - 2013

Validation: Mixed Layer Depth
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
The actual Mediterranean Sea Analysis and Forecast operational system has been presented highlighting major upgrades with previous version.

The increased resolution provides better prediction of fluxes at Gibraltar strait, allows to resolve the Messina Strait circulation.

The increased n. of river inputs provides better representation of surface salinity next to river mouths as well as the volume salinity in the Mediterranean Sea.

The model validation assessment is performed regularly and shows:

- improvements in terms of Temperature and Salinity with respect to the previous system;
- the model ability to correctly represent the time and spatial variability of the major physical parameters.

A continuous upgrade of the system is foreseen in order to improve the quality of the analysis and forecasting system and provide state of the art product to the users.
Thanks