A baroclinic tidal forecasting model for the Mediterranean Sea - First validation results

Anna Chiara Goglio (1), Emanuela Clementi (1), Massimiliano Drudi (1), Alessandro Grandi (1), Rita Lecci(1), Valentina Agresti(2), Simona Masina (1), Giovanni Coppini(1), Nadia Pinardi (1,3)

[1] {CMCC: Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy };
[2] {Ricerca sul Sistema Energetico - RSE S.p.A., Italy};
[3] {Department of Physics and Astronomy, University of Bologna, Italy};

INTRODUCTION

In the framework of the Copernicus Marine Environment Monitoring Service (CMEMS) Mediterranean Analysis and Forecasting Physical System (MedFS), a specific modeling upgrade has been carried out by including the main lunisolar tides.
The first results of baroclinic tidal model experiments are presented together with their validation with respect to insitu and satellite data as well as comparing with available literature studies.

The Numerical Modeling System

Initial Conditions
WOA winter climatologies
System initialization on Jan/2015

Boundary conditions
Atlantic:
daily GLO-MFC AN/FCST (1/12°res.)
Dardanelles:
daily GLO-MFC AN/FCST (1/12°res.)
& Maderich et al., 2015.

Land river runoff:
39 rivers discharge: Q > 50m^3/s
(climatological data)

Bathimetry
modified GEBCO 30arc-sec

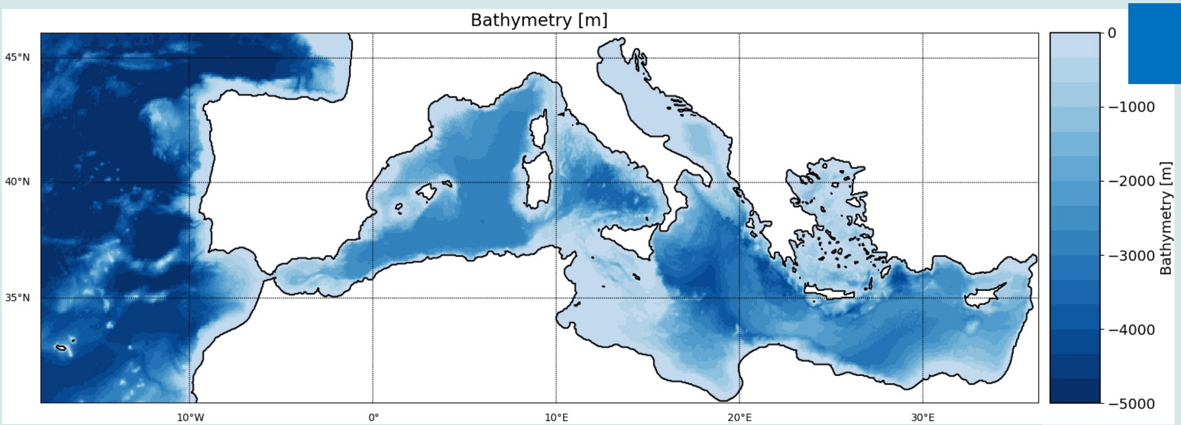
Tidal Forcings

Atlantic boundary:
- **FES2014 downscaled tidal elevations**
- **FES2014+TUGOm downscaled tidal velocities** (http://sirocco.omp.obs-mip.fr/ocean_models/tugo)

Atmospheric Forcings

ECMWF 1/8° analysis fields time resolution 6 hrs:
- mean sea level pressure (MSLP)
- cloud cover
- 2m relative humidity
- 2m air temperature
- 10m zonal and meridional wind components
- Precipitation

Parameterizations:
- Air-sea fluxes: MFS bulk formulae [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)



NEMO v3.6 Circulation modeling system
1/24° hor. Res - 141 vert. levels
[Clementi et al., 2017]

OUTPUTS:

Daily fields:
- ✓ Temperature (3D)
- ✓ Salinity (3D)
- ✓ Currents (3D)
- ✓ SSH (2D)
- ✓ Mixed Layer Depth (2D)
- ✓ Bottom Temperature (2D)

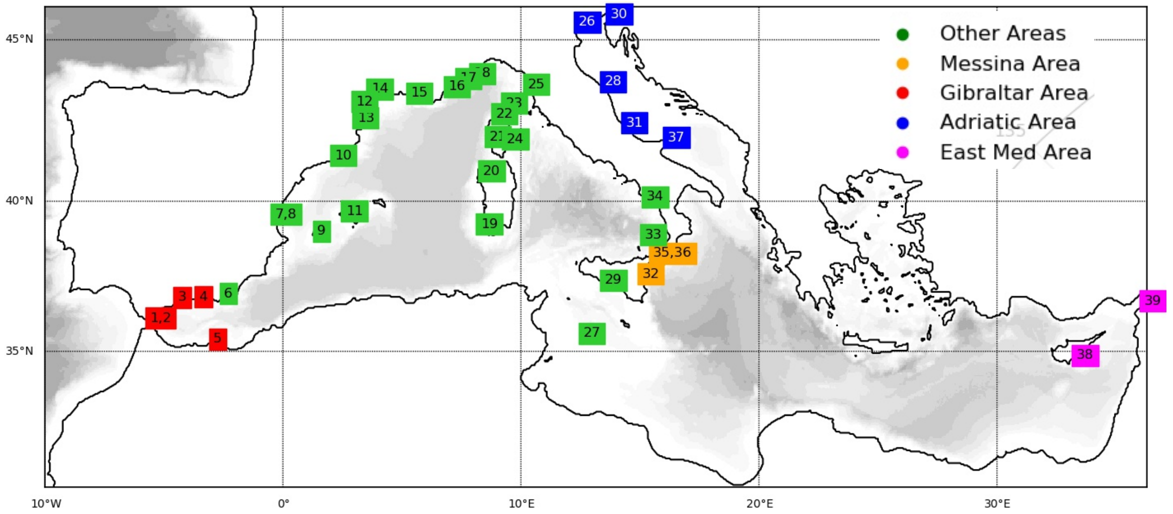
Hourly fields:
- ✓ SSH (2D)
- ✓ Sfc Currents (2D)

Run Settings and Validation Dataset

Model Settings

Model Run	Tidal potential (key_tides)	Tidal boundary forcings	Tidal components	Time integration scheme	Time filter	Time-step Internal /External		Bottom turbulent kinetic energy background	Integration period
Control run	✗	✗	✗	Forward	Boxcar over 2*nn_baro steps	**240 s**	**2.4 s**	2.5e-3 m^3/s^2	2015-2019
Tidal run	✓	✓	8 components: M2, S2, K1, O1, N2, Q1, K2, P1	Centered	Boxcar over nn_baro steps	**120 s**	**2.0 s**	0 m^3/s^2	2015-2019

Validation dataset: available Tide-Gauges



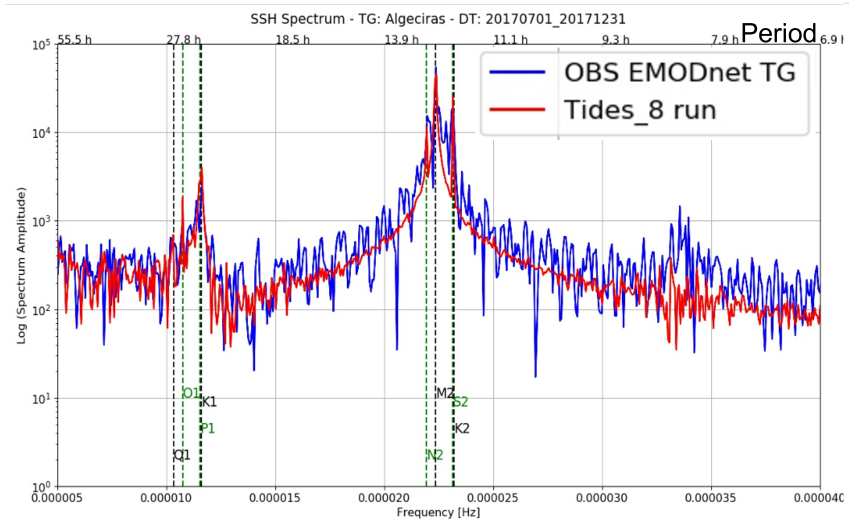
#	Name	Longitude	Latitude	Source
1	Tarifa	-5.60361	36.0064	EMODnet
2	Algeciras	-5.39833	36.1769	EMODnet
3	Malaga	-4.417	36.712	EMODnet
4	Motril	-3.524	36.72	EMODnet
5	Melilla	-2.918	35.291	EMODnet
6	Almeria	-2.478	36.83	EMODnet
7	Valencia	-0.33	39.46	EMODnet
8	Sagunto	-0.206	39.634	EMODnet
9	Ibiza	1.44972	38.9111	EMODnet
10	Barcelona	2.163	41.342	EMODnet
11	PalmadeMallorca	2.6375	39.5603	EMODnet
12	PortLaNouvelle	3.06410	43.01471	EMODnet
13	PortVendres	3.10730	42.52010	EMODnet
14	Sete	3.70170	43.40000	EMODnet
15	Marseille	5.35370	43.27850	EMODnet
16	LaFigueirette	6.93377	43.48353	EMODnet
17	Monaco	7.42370	43.73300	EMODnet
18	Imperia	8.01694	43.88111	ISPRA
19	carloforte	8.30500	39.13556	ISPRA

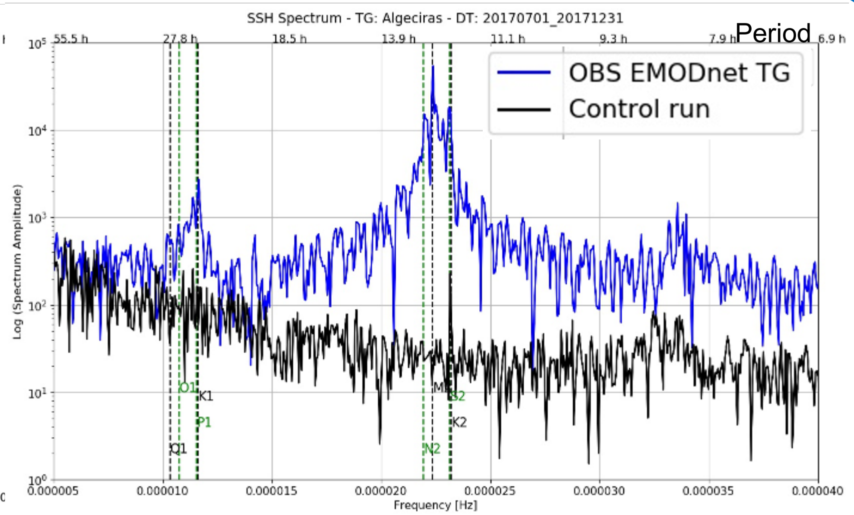
#	Name	Longitude	Latitude	Source
20	Portotorres	8.40667	40.84722	ISPRA
21	Ajaccio	8.76290	41.92270	EMODnet
22	IleRousse	8.93524	42.63960	EMODnet
23	Centuri	9.34983	42.96578	EMODnet
24	Solenzara	9.40383	41.85686	EMODnet
25	Livorno	10.28806	43.54222	ISPRA
26	Venezia	12.42361	45.42361	ISPRA
27	Lampedusa	12.61000	35.49139	ISPRA
28	Ancona	13.50833	43.62694	ISPRA
29	Portoempedocle	13.52528	37.28806	ISPRA
30	Trieste	13.76250	45.64389	ISPRA
31	Ortona	14.40667	42.35583	ISPRA
32	Catania	15.08472	37.49139	ISPRA
33	Ginostra	38.784	15.1933	EMODnet
34	Palinuro	15.27111	40.01694	ISPRA
35	Messina	15.55917	38.18639	ISPRA
36	Reggiocalabria	15.64389	38.11861	ISPRA
37	Vieste	16.16944	41.89806	ISPRA
38	Zygi	33.34023	34.72632	EMODnet
39	Iskenderun	36.17676	36.59423	EMODnet

SSH Harmonic Analysis Validation

Local Spectral Analysis

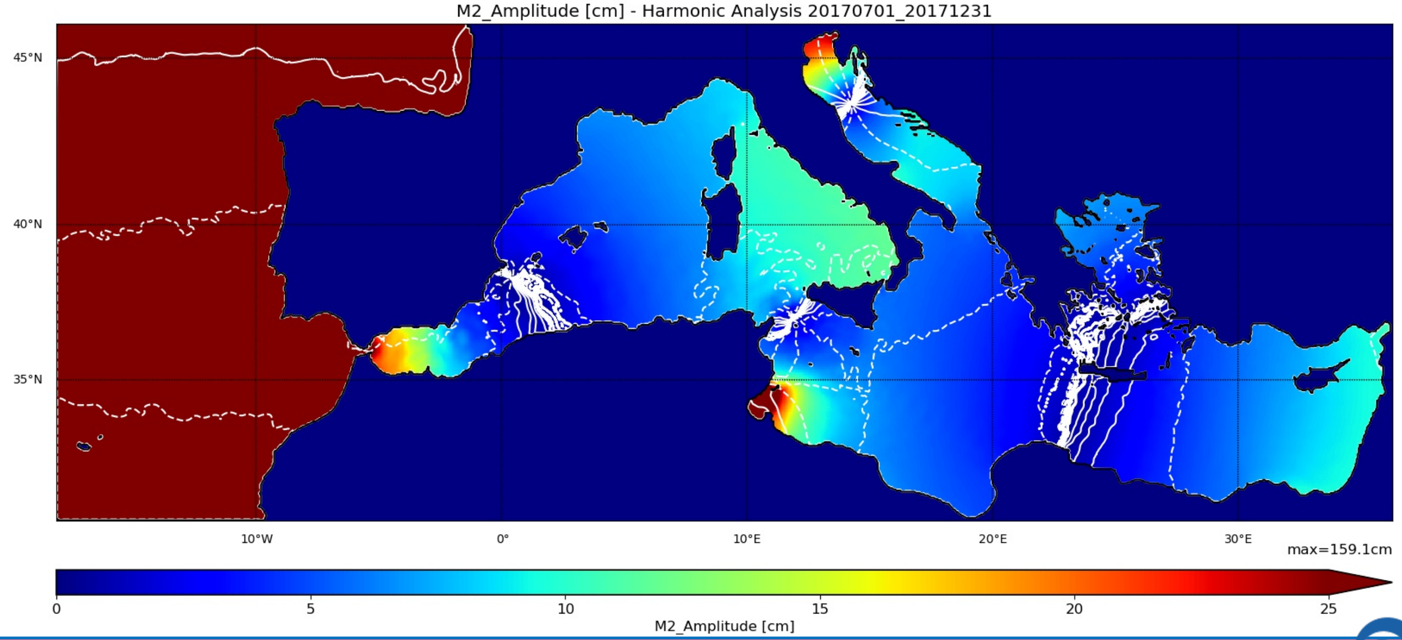
Spectrum (tidal frequency range) of 6 months samples of hourly SSH values in Algeciras TG location (Gibraltar area) for tidal run (red line) and control run (black line) compared to the observed one (blue lines)



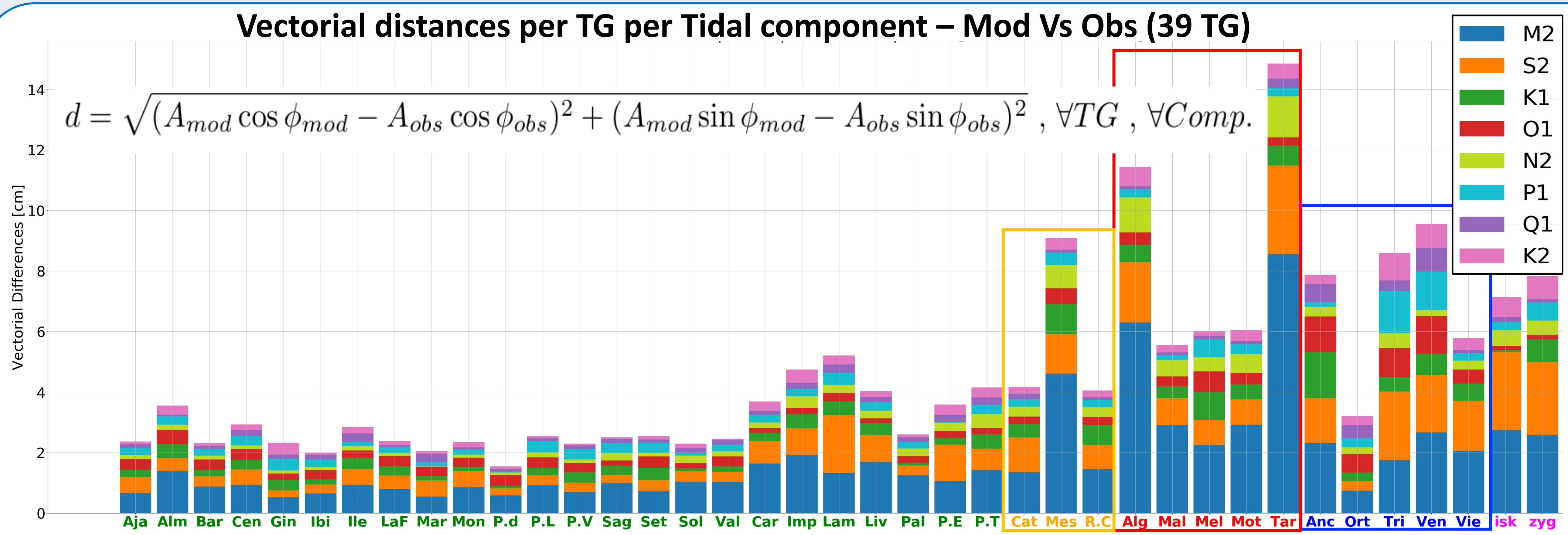


Areal Harmonic Analysis

Map of amplitude (colors) and phase (white solid contours for positive values and dashed for negative ones, interval 20°) of the main semidiurnal tidal component M2 computed on a 6 months period with the Salish-Sea-Project Fit method [https://salishsea-meopar-docs.readthedocs.io/en/latest/tidalcurrents/tidal current tools.html]



SSH Harmonic Analysis Validation



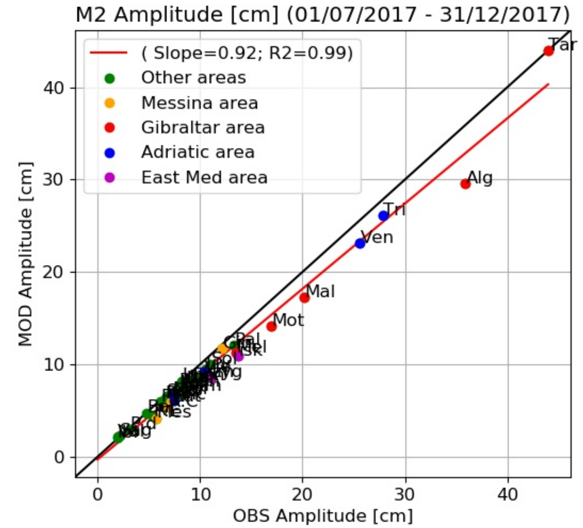
Vectorial distances between model and TG harmonic analysis results computed on a 6 months period [Foreman et al.; 1993]

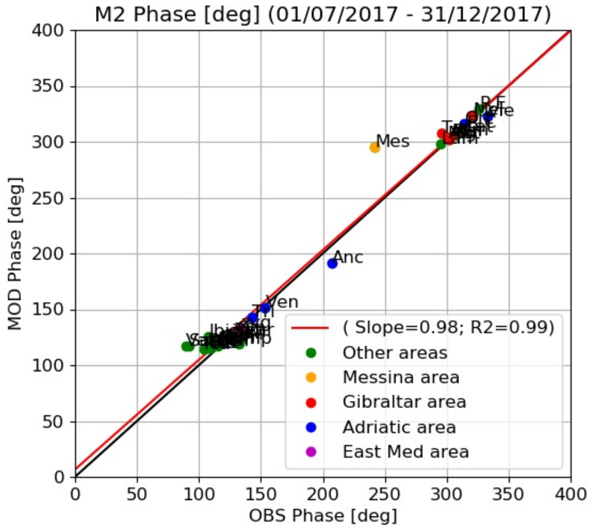
Mean and Max Vectorial distances per Tidal component – Mod Vs Literature (15 TG)

Vectorial distances (15 TG)	M2		S2		K1		O1	
	Mean d	Max d	Mean d	Max d	Mean d	Max d	Mean d	Max d
TIDAL RUN	**1.57 cm**	**2.9 cm (Malaga)**	**1.09 cm**	**2.3 cm (Trieste)**	**0.47 cm**	**1.5 cm (Ancona)**	**0.48 cm**	**1.24 cm(Venezia)**
[Tsimplis et al.; 1995]	1.75 cm	4.0 cm (Malaga)	1.21 cm	3.9 cm (Trieste)	1.48 cm	4.5 cm (Trieste)	0.46 cm	1.0 cm (Ancona)

SSH Harmonic Analysis Validation

Amplitude and Phase Linear regressions – Mod Vs Obs



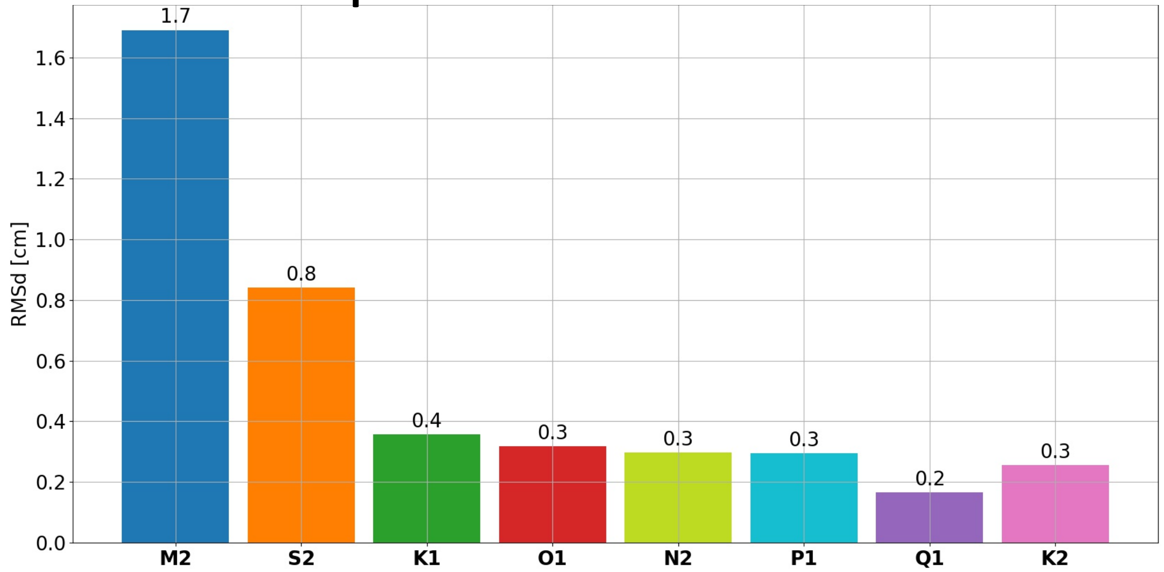


Tidal components	Amplitudes Slope	Amplitudes R^2	Phases Slope	Phases R^2
M2	0.92	0.99	0.98	0.99
S2	0.90	0.99	0.98	0.99
K1	1.02	1.00	0.97	0.99
O1	0.83	0.96	1.09	0.96
N2	0.93	0.99	0.98	0.99
P1	0.99	0.99	1.01	0.99
Q1	0.54	0.89	1.00	0.84
K2	0.88	0.98	0.98	0.99

Table: Linear regression parameters for amplitudes and phases for each tidal component in respect to observed data

Plots: Linear regressions for amplitudes and phase respectively of the main tidal component M2

Root Mean Square distance – Mod Vs Literature

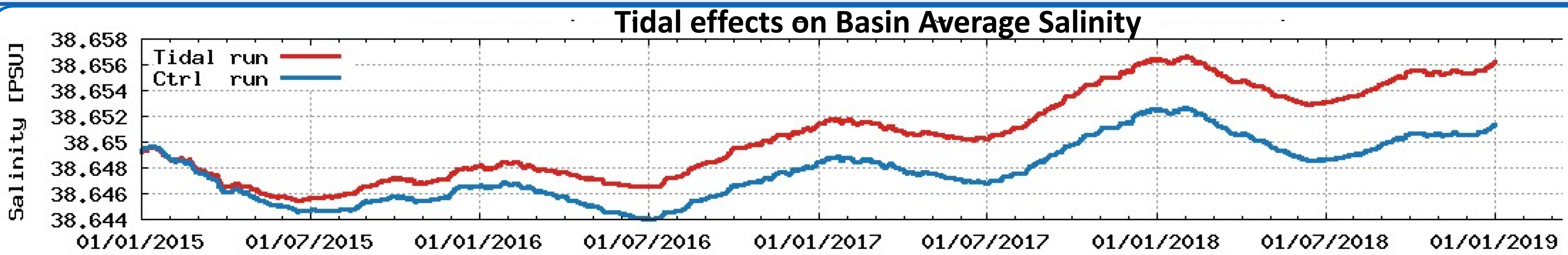


$$RMSd = \sqrt{\frac{1}{2N_{TG}} \sum_{TG} [(A_{mod} \cos \phi_{mod} - A_{obs} \cos \phi_{obs})^2 + (A_{mod} \sin \phi_{mod} - A_{obs} \sin \phi_{obs})^2]} \; , \forall Comp.$$

MED RMSd [cm]	M2	S2	K1	O1
TIDAL RUN	**1.7**	**0.8**	**0.4**	**0.3**
[V. Agresti; 2010]	2.1	1.0	0.9	0.3
[V. Agresti; 2010 - Barotropic model]	2.2	1.0	1.7	0.9

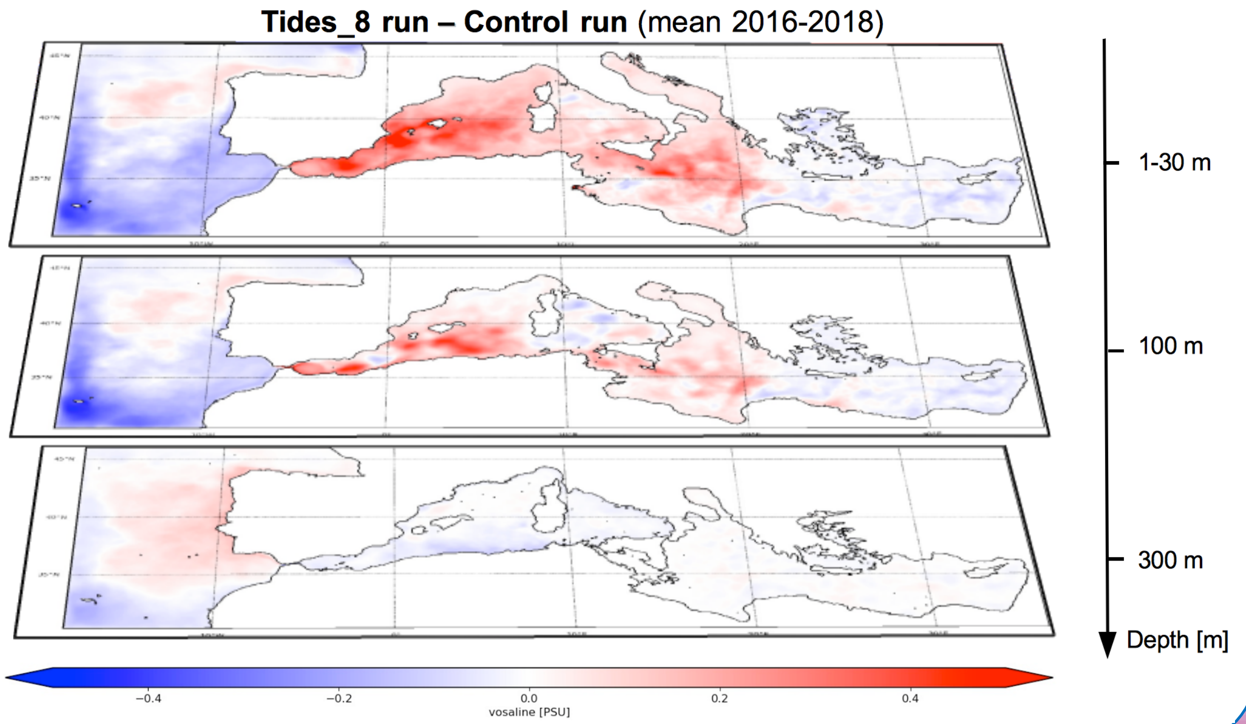
Root Mean Square distance comparison with literature for the first 4 tidal components computed on a 6 months period

Effects of Tides on Tracers

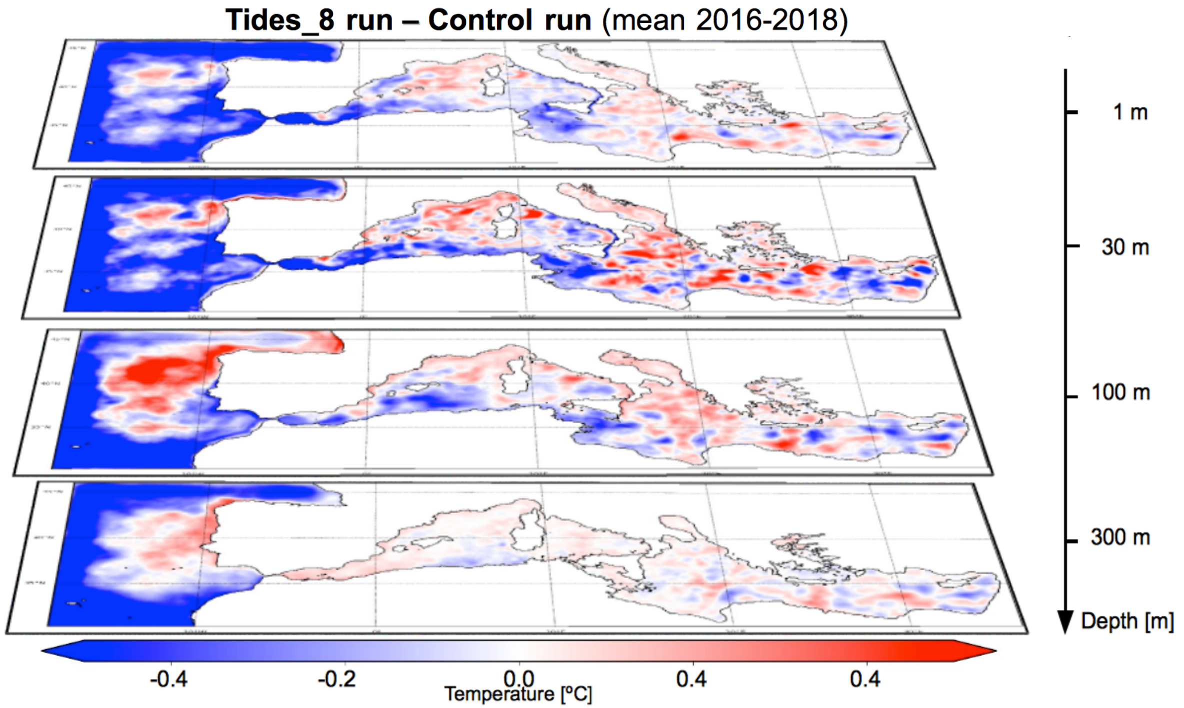


Basin avg salinity time series and difference maps between tidal and control runs for tracers

Tidal effects on *Salinity* at different depths



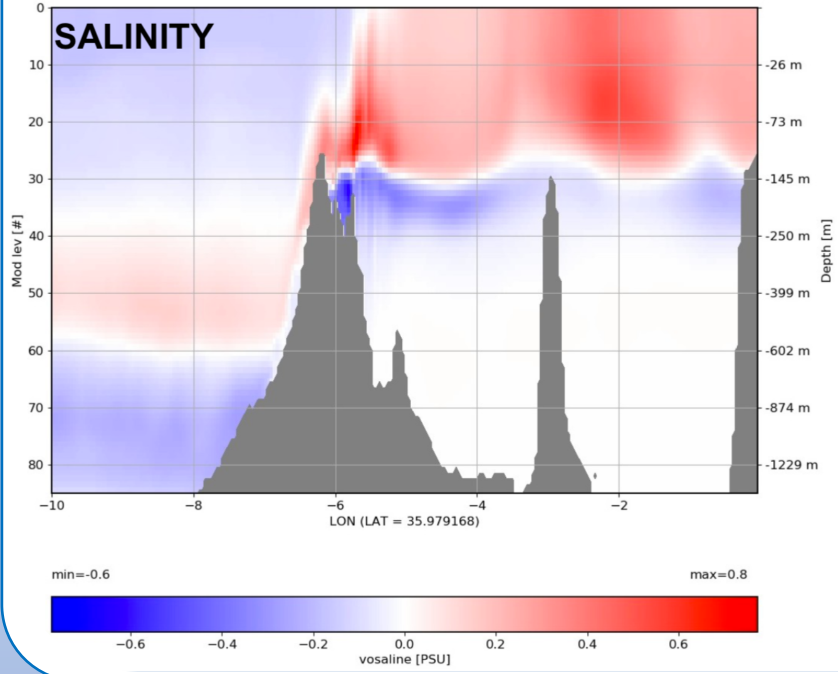
Tidal effects on *Temperature* at different depths



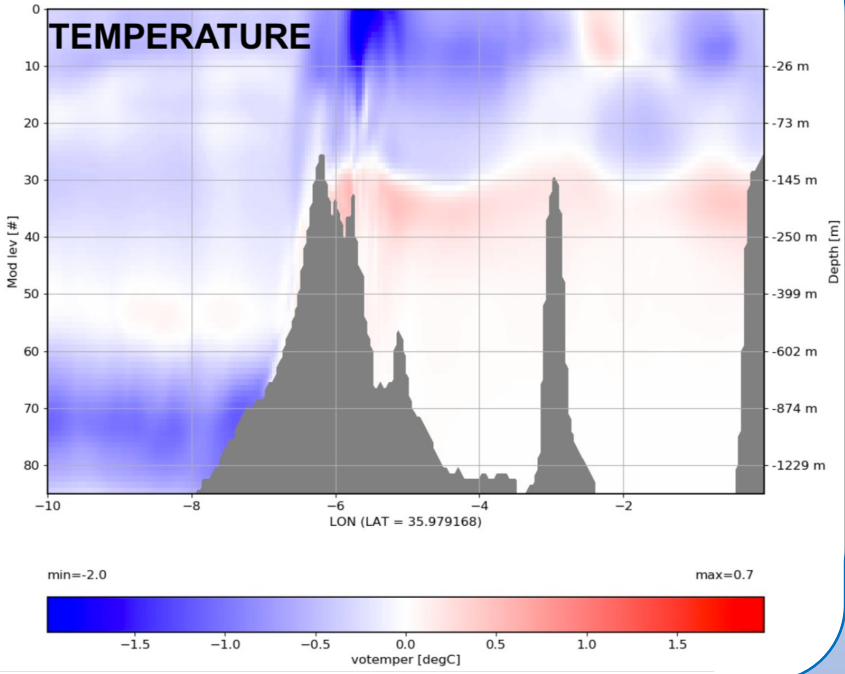
Effects of Tides on Gibraltar Strait

Tidal effects on Tracers in Gibraltar Strait

MOD **tides** – MOD Control run
(mean 2016-2018)



MOD **tides** – MOD Control run
(mean 2016-2018)



Sea Level Differences In Gibraltar

Fig: Gibraltar strait

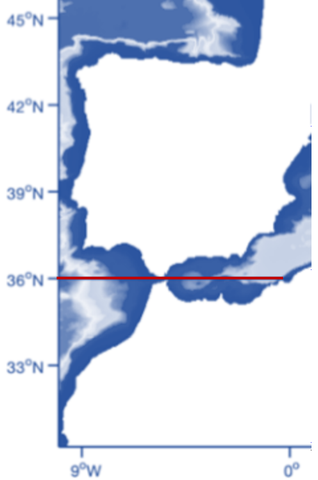


Table: Mean **Sea Level** differences between Atlantic Box and Mediterranean Sea for control and tidal runs compared to satellite data

ΔSSH (2016-2018) Atl Box – Med Sea	Control	Tidal	ΔSSH Tidal - Control
EAS5 MODELS	9.4 cm	8.9 cm	-0.5 cm
SATELLITE	6.0 cm	3.2 cm	-2.8 cm

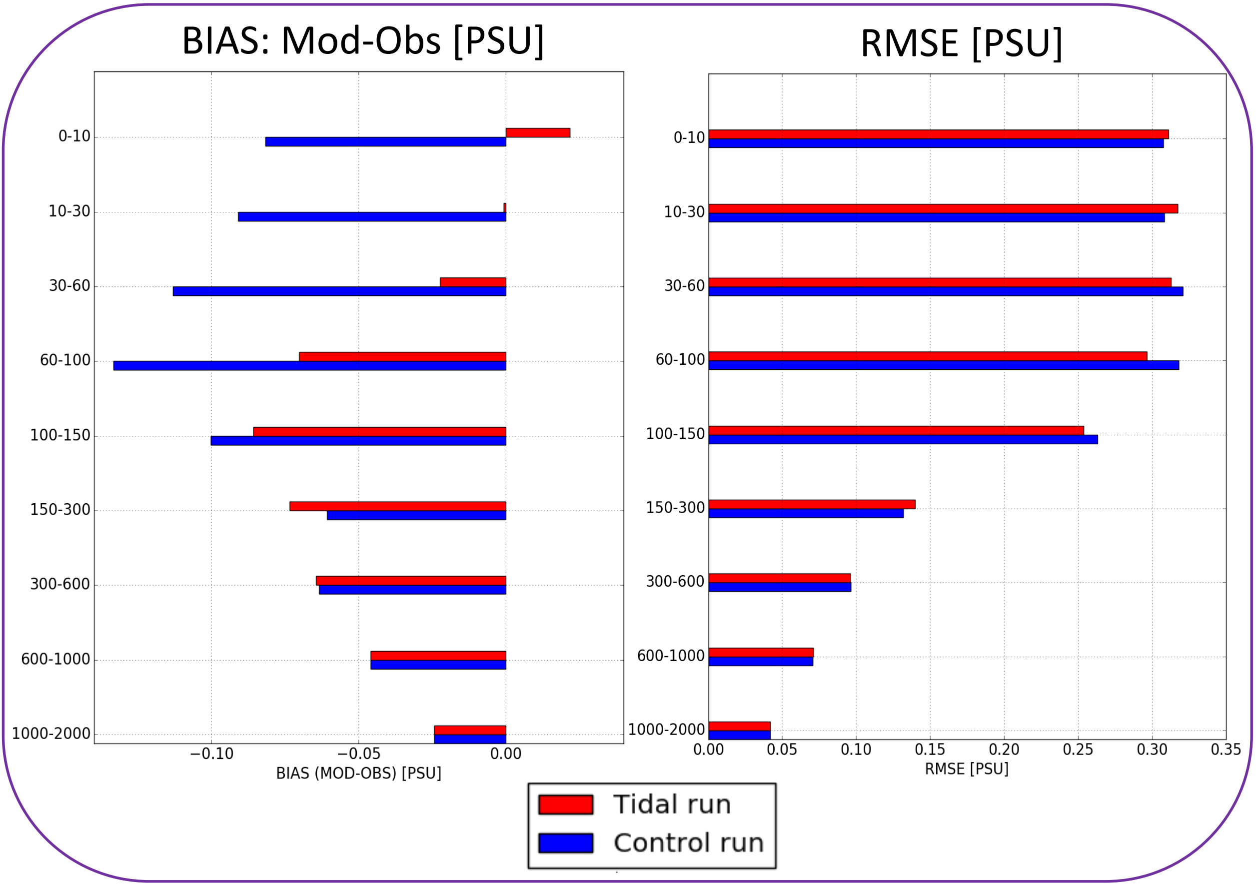
Gibraltar Transports: comparison between yearly tidal and control model runs, data and literature

	Obs	EAS5 (1/24°)		Tidal simulations in Literature
	Soto Navarro et al. 2015	Tidal run	Control run	V. Agresti 2018
NET	0.038 ± 0.007 Sv	0.037 Sv	0.032 Sv	0.041 Sv
EASTWARD (incoming)	0.81 ± 0.05 Sv	0.99 Sv	0.88 Sv	0.95 Sv
WESTWARD (outgoing)	0.78 ± 0.05 Sv	0.96 Sv	0.85 Sv	0.91 Sv

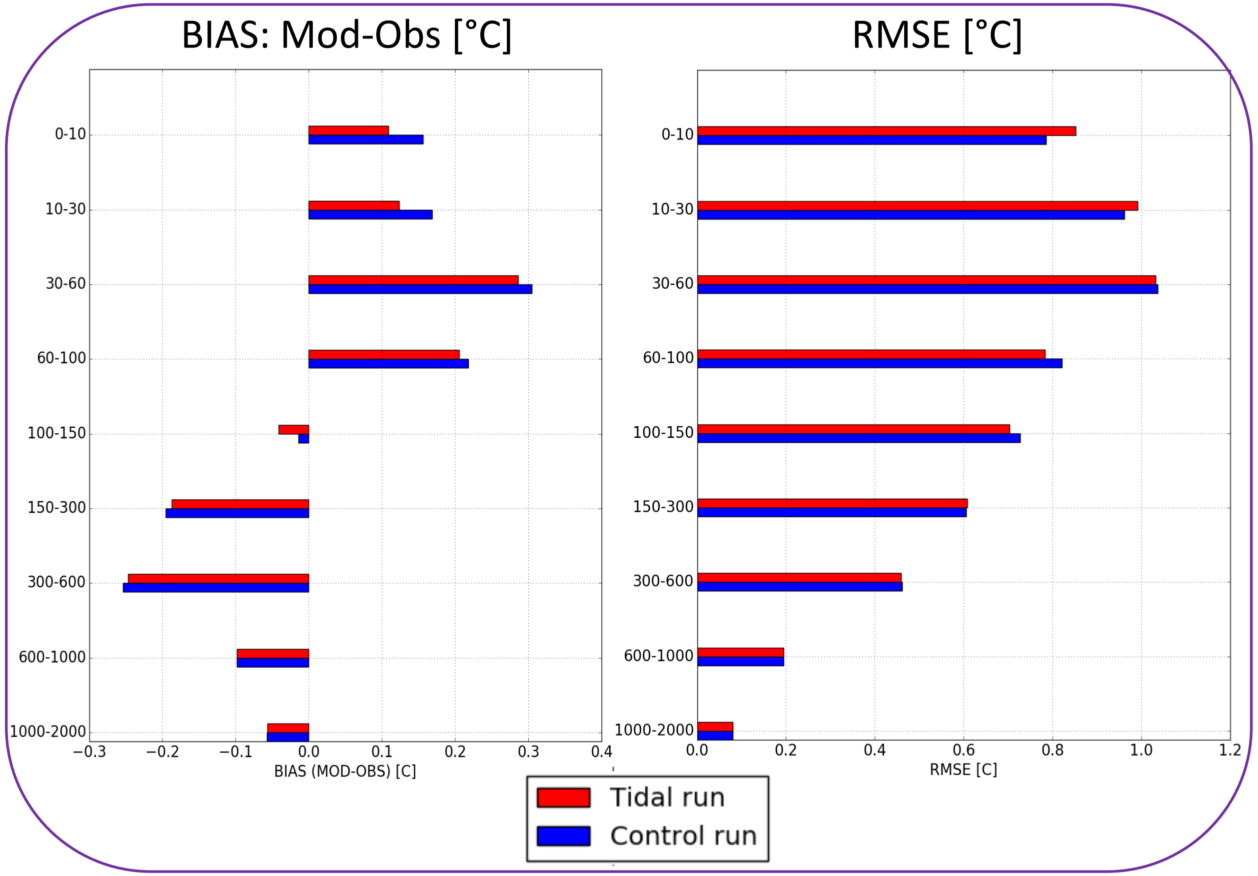
Skill Assessment of Model Runs

Model comparison with CMEMS INSITU Temperature and Salinity profiles

Salinity



Temperature



Bias (model outputs – observed values) and Root Mean Square Error with respect to the available INSITU data for salinity and temperature averaged on basin layers in the period 2016-2018 for tidal and control model runs

Conclusions and References

TIDAL MODEL VALIDATION RESULTS

- **Model SSH shows a good agreement** with tide-gauges data and literature in terms of amplitudes (mean amplitude bias lower than 1 cm) and phases (mean phase bias lower than 15°)
- Major differences are found in Gibraltar strait area and Adriatic Sea region where the tidal amplitudes are underestimated by the model (up to 6 cm) and in Messina strait area where the phase shows a higher bias (up to 90°)

- Tidal simulations show a **saltier and colder upper layer** with respect to the control run, expecially in Alboran Sea. The same behaviour is found in literature [Harzallah et al.; 2014] and does not improves significantly the model skills in terms of Estimate Accouracy Numbers, namely bias and rmse in respect to INSITU and satellite data
- Gibraltar **net transport is close to the observed value** but **easward and westward components appears to be enhanced** with respect to control run and measurements

REFERENCES

- **Clementi et al. 2017;** *Coupling hydrodynamic and wave models: first step and sensitivity experiments in the Mediterranean Sea*
- **Agresti 2018**; *Effect of tidal motion on the Mediterranean Sea general circulation*
- **Tsimplis et al. 1995**; *A two-dimensional tidal model for the Mediterranean Sea*
- **Soto-Navarro et al. 2015**; *Evaluation of regional ocean circulation models for the Mediterranean Sea at the Strait of Gibraltar: volume transport and thermohaline properties of the outflow*
- **Foreman et al. 1993**; *A finite element model for tides and resonance along the north coast of British Columbia*
- **Harzallah et al. 2014**; *Mass exchange at the Strait of Gibraltar in response to tidal and lower frequency forcing as simulated by a Mediterranean Sea model*