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Black Sea Production Centre

BLKSEA_ANALYSISFORECAST_PHY_007_001

Issue: 3.1

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CHANGE RECORD

When the quality of the products changes, the QuID is updated and a row is added to this table. The third column specifies which sections or sub-sections have been updated. The fourth column should mention the version of the product to which the change applies.

Issue	Date	§	Description of Change	Author	Validated By
2.0	31 January 2017	all	Creation of the document for V3	S. Ciliberti	
	1 February 2017	all	Revision	E. Peneva, A. Storto	
2.1	24 February 2019	all	General revision of the text. Updated BS-PHY NRT system and product quality	S. Cilberti	Mercator Ocean
2.2	08 September 2019		Including quality control after BS-PHY processing system upgrade. First draft highlighted in yellow in Section VI.2	S. Ciliberti, E. Jansen, L. Stefanizzi	
	26 September 2019	$VI	Updated statistics and addition of MLD evaluation in Section VII	L. Stefanizzi, E. Jansen, S. Ciliberti	E. Peneva
3.0	15 January 2021	all	New product	S. Ciliberti, E. Jansen, D. Azevedo, L. Stefanizzi, S. Causio, M. Ilicak	E. Peneva
	21 April 2021	all	Revision of plots	S. Ciliberti	E. Peneva
3.1	10 September 2021	$II. 1.1, $VI	Updated upstream data and updated statistics observations)	S. Ciliberti, E. Jansen, D. Azevedo, L. Stefanizzi, S. Causio	E. Peneva

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APPLICABLE AND REFERENCE DOCUMENTS

	Ref	Title	Date / Version
[DA1]	CMEMS-BS-PUM-007-001	Black Sea Physics Analysis and Forecast Product User Manual	Jan 2021 / 3.1

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I EXECUTIVE SUMMARY

I.1 Product covered by this document

BLKSEA_ANALYSISFORECAST_PHY_007_001 is the Black Sea Near Real Time (NRT) nominal product of the physical component, at 1/40° (~2.5 km) horizontal resolution and 121 vertical levels. It provides everyday analysis and forecast of the Black Sea essential variables. BS-NRT is based on the NEMO model (v4.0) for the hydrodynamical core, online coupled to OceanVar, a 3DVAR scheme for the assimilation of near-real-time in-situ temperature and salinity profiles as well as satellite altimetry tracks and sea surface temperature.

I.2 Summary of the results

The quality of the BLKSEA_ANALYSISFORECAST_PHY_007_001 near real time product is assessed over the period 2018-2020, by evaluating temperature, salinity, sea surface height, currents, mixed layer depth against available in-situ and satellite observations, climatological datasets as well as the inter-comparison with the previous NRT system.
The main results of the BLKSEA_ANALYSISFORECAST_PHY_007_001 quality assessment are summarized below:
Temperature: Temperature predictions of the BS-EAS4 model are compared to both satellite and in-situ data. For the satellite data the uppermost model level, at a depth of 0.5m, is compared to L3 satellite SST observations. The SST bias of BS-EAS4 varies from approximately 0.1°C in winter up to 0.25°C during the summer months, with RMSD values of 0.3°C and 0.5°C respectively. The comparison to in-situ temperature observations uses observations obtained from ARGO profiling floats. The evaluation is performed at different levels and the average RMSD over the year 2019 ranging from a maximum of 1.8°C around the thermocline (10-30m) to below 0.1°C for depths greater than 100 m. The temperature bias is quite good below 0.1°C, with a maximum of 0.27°C between 20 and 30 m.

Salinity: Salinity is evaluated using the in-situ observations from ARGO profiling floats, using the same method as for temperature. The RMSD for salinity is approximately 0.15 PSU at the upper levels, reaching a maximum of 0.25 PSU between 50 and 100 m depth. Below 200 m is less than 0.03 PSU. Bias values are generally slightly negative but never larger than 0.05 PSU.

Currents: The validation of the currents at present includes only qualitative analysis with the 2D maps at different reference depths for the 2019. The simulated mean current for the period is consistent with the known main cyclonic RIM current.

Sea Surface Height: Sea surface height is evaluated by comparing the sea level anomaly (SLA) to satellite altimetry data. The comparison is performed along the tracks of the satellite and uses an unbiasing procedure that removes the mean value along the track. The RMSD values for SLA are relatively stable throughout the year and fluctuate between approximately 1.9 and 2.4 cm with an average of 2.16 cm.

Mixed Layer Depth: The mixed layer predicted by BS-EAS4 model was compared to observations and climatological values from Houpert et al (2015) and Kara et al. (2009). The results show that the model is able to accurately represent the depth, spatial distribution and seasonal variability of the mixed layer in the region. The mixed layer given by the model is shallower than the climatological values and compared to observations has a maximum bias of ~ 20 meters in average. Monthly skills are good with RMSD lower than 15 meters.

I.3 Estimated Accuracy Numbers

Estimated Accuracy Numbers (EAN) are computed using the daily outputs of the BS-PHY NRT, produced by BS-PHY EAS4 system, and comparing them to available observations. Root mean square differences (RMSD) and bias are estimated over the pre-qualification period, here 2019.

EAN are computed for:

- Temperature;
- Salinity;
- Sea Surface Temperature (SST);
- Sea Level Anomaly (SLA) (Note that the comparison of SLA for the model and observations includes a bias removal so the value here should always be 0)

Used observations are listed in Table 1.

Table 1 - Quasi-independent observations used for the EAN computation and validation

Temperature	INSITU_BS_NRT_OBSERVATIONS_013_034 from CMEMS
Salinity	INSITU_BS_NRT_OBSERVATIONS_013_034 from CMEMS
SST	SST_BS_SST_L3S_NRT_OBSERVATIONS_010_013 from CMEMS
SLA	SEALEVEL_EUR_PHY_L3_NRT_OBSERVATIONS_008_059 from CMEMS

Temperature (in °C)

Layer (m)	BS-PHY EAS4	
	bias	**RMSD**
5-10	-0.016	0.99
10-20	0.169	1.82
20-30	0.276	1.67
30-50	0.007	0.97
50-75	-0.065	0.33
75-100	-0.040	0.16
100-200	0.001	0.08
200-500	-0.016	0.03
500-1000	-0.002	0.01

Salinity (in PSU)

Layer (m)	BS-PHY EAS4	
	bias	RMSD
5-10	0.006	0.17
10-20	0.004	0.15
20-30	0.000	0.13
30-50	0.003	0.16
50-75	-0.008	0.25
75-100	0.010	0.26
100-200	-0.020	0.15
200-500	-0.024	0.04
500-1000	-0.011	0.02

SST (in °C)

BS-PHY EAS4	
bias	RMSD
0.12	0.48

SLA (in cm)

Note that the comparison of SLA for the model and observations includes a BIAS removal so the value here should always be close to zero.

BS-PHY EAS4	
bias	RMSD
~0	2.2

II PRODUCTION SYSTEM DESCRIPTION

Production centre name	BS-PHY
Production system name	Black Sea Analysis and Forecasting EAS4 System
Producer	CMCC – Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici (Italy)
CMEMS product name	BLKSEA_ANALYSISFORECAST_PHY_007_001
Variables	Temperature (3D), Salinity (3D), Meridional and Zonal Currents (3D), Sea Surface Height (2D), Mixed Layer Depth (2D), Seabed Temperature (2D)
Frequency of model output	daily (24h) averages, hourly (1h) averages, monthly averages
Geographical coverage	27.25°E → 41.1°E; 40.5°N → 47.0°N
Horizontal resolution	1/40° (~2.5 km)
Vertical coverage	From surface to 2200 m (121 vertical unevenly spaced levels)
Length of forecast	10 days for the daily mean fields, 5 days for the hourly mean fields
Frequency of product release	Daily
Period	Timeseries from Jan 2019

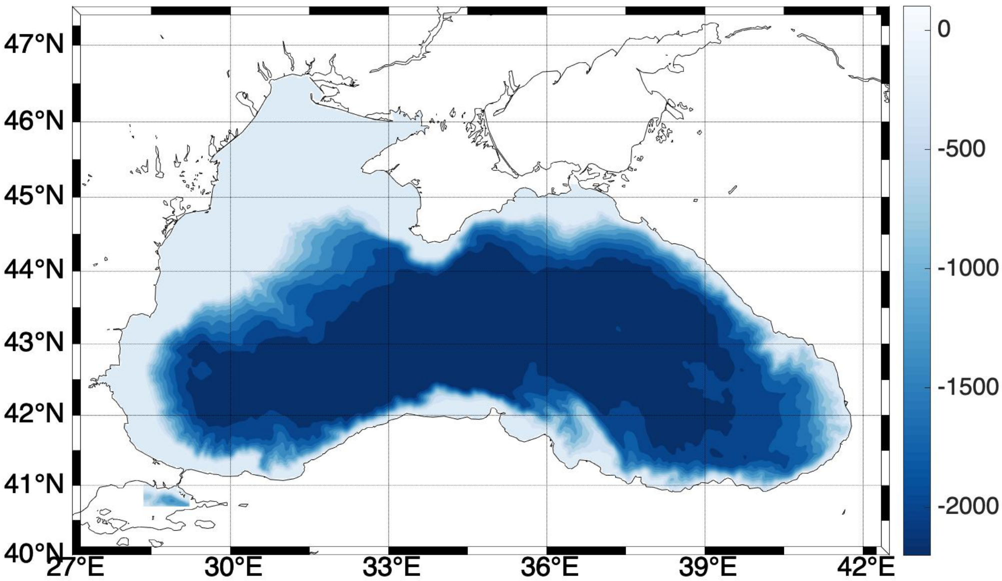


Figure 1 – BS-NRT bathymetry (m) and spatial domain

Details about the production system and processing chain are reported in [DA1].

II.1 Description of the BS-PHY EAS4 model system

The BS-PHY NRT is providing analysis and forecast fields of the main physical parameters in the Black Sea since 2016. EAS4 system configuration is implemented over the Black Sea domain, including part of the Marmara Sea as originally implemented in Gunduz et al. (2020), at about 2.5 km horizontal resolution and 121 vertical levels. EAS4 implements open boundary conditions through the Marmara Sea box by using high resolution fields provided by a novel implementation of an unstructured grid model in the Marmara Sea called Unstructured Turkish Strait System (U-TSS). U-TSS, developed by ITU and CMCC, is considered the optimal interface between the Black Sea and the Mediterranean Sea. In the next subsections, the BS-NRT circulation model component and the data assimilation scheme are described. Additionally, the U-TSS model setup and validation is introduced and described in details (as part of the upstream data validation).

II.1.1 Circulation model component

BS-NRT core model is based on NEMO ocean model, version 4.0 (Madec et al., 2019). The code is developed and maintained by the NEMO Consortium.
NEMO has been implemented in the Black Sea at 1/40° x 1/40° horizontal resolution and 121 unevenly spaced vertical levels, with time step of 200 sec. The model covers the whole basin except the Azov Sea and includes a portion of the Marmara Sea for the optimal interface with the Mediterranean Sea through the Bosporus Strait.
The NEMO model solves the primitive equations using a time-splitting technique to explicitly resolve the external gravity waves with non-linear free surface formulation and time-varying vertical z-star coordinates.
Bathymetry. The bathymetric source is provided by gridded GEBCO 30" resolution (https://www.gebco.net/) combined with a high resolution dataset for the Bosporus Strait and the Marmara Sea. This dataset has been provided by Prof. E. Özsoy in the frame of CMEMS BS-MFC Phase 1 (2016-2018) contract and extensively described in Gürses (2016). Once acquired, an optimal barycentric interpolation method has been used to interpolate the high-resolution scattered dataset on the regular spatial grid. The coastline has been revised to account and proper represent the coastal peculiarities and structures available in the Black Sea, by using the NOAA shoreline dataset (https://www.ngs.noaa.gov/CUSP/).

Rivers representation. The process of the coastline revision included a remapping of the river locations according to the new bathymetric dataset. A total number of 72 rivers are included in the BS-NRT model, where the Danube, the Dnieper, the Rioni, the Dniester, the Sakarya and the Kizilirmak are the major ones (Figure 2). A dedicated study has been made for the Danube: a new setup represents the Danube by using 5 grid points, distributed among the three main branches: Chilia, Sulina, St. George (Figure 3).
The distribution of the Danube river discharge among the 5 grid points accounts that the Chilia branch is the greatest one with three sub-arms. One located in the Southern in the Romanian territory, while the other two are part of the Ukraine. The Sulina and the St. George are included in the bigger Danube floodplain, which occupies around 3500 km^2. The distribution of the Danube River discharge through the 3 main branches follows Panin (2000), in which the Chilia spreads 52% of the total discharge, while the remaining 48% is distributed between the Sulina (20%) and the St. George (28%) branches, respectively.

Physical parameterization. A 4th order Flux Corrected Transport (FCT) scheme is used for active tracers advection (Zalesak, 1979). Laplacian operator is used for lateral diffusion for tracers, with spatial varying diffusion coefficients (12-26 m2/s). Laplacian operation is also used for lateral diffusion of momentum, with spatial varying viscosity coefficients (220-444 m2/s). The vertical eddy viscosity and diffusivity coefficients are computed from a TKE turbulent closure model (Blanke and Delecluse, 1993; Madec et al., 1998). Vertical background viscosity and diffusivity values are set to 1.2e-5 m^2/s and 1.0e-6 m^2/s respectively. A non-linear drag coefficient is adopted and the model uses vertical partial cells to fit the bottom depth shape. No-slip boundary conditions are allowed at the land boundaries with increased values along the Bosporus Strait.

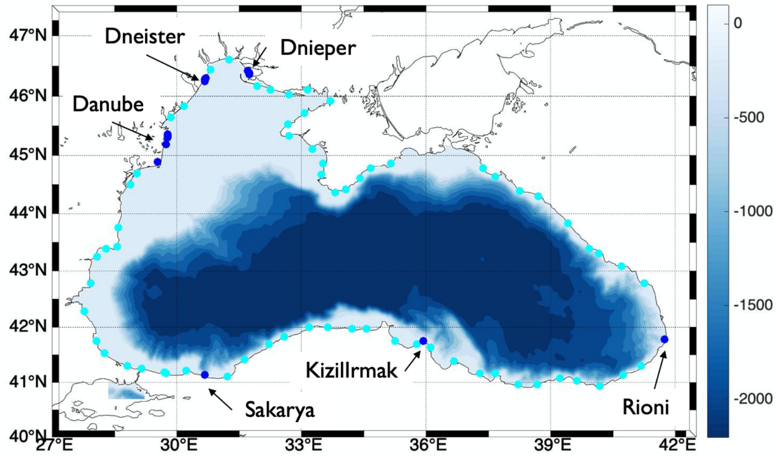


Figure 2 - Distribution of rivers in the Black Sea basin as represented in BS-NRT: minor ones are in cyan, major ones are in dark blue

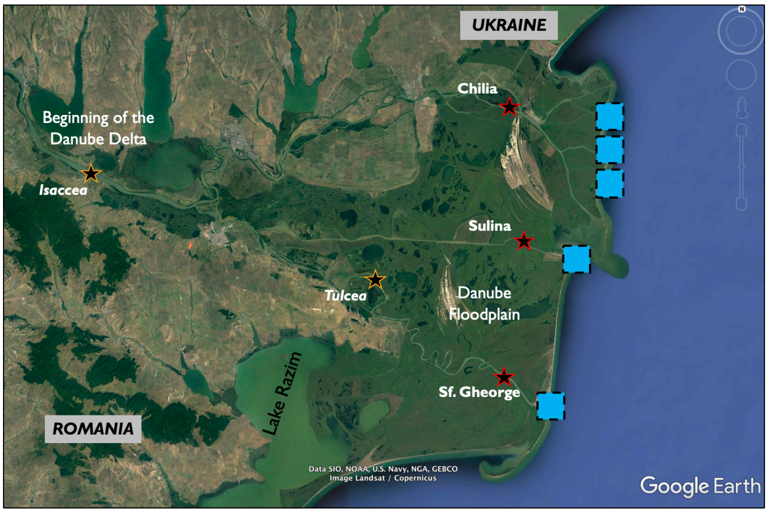


Figure 3 – The Danube Delta: the Chilia, the Sulina and St. George arms (with red labeled stars) and the sea-grid points representation in the BS-NRT model

Initial conditions. The pre-operational run has been initialized using 3D temperature and salinity climatological fields produced within the framework of SeaDataNet FP6 Project (Simoncelli et al., 2015).

It is the combination of the January climatology for the Black Sea with the corresponding one from the Mediterranean Sea which includes the Marmara Sea.

Surface boundary conditions.

Air-sea interaction. The model is forced by momentum, water and heat fluxes interactively computed by bulk formulae using the 1/8° horizontal-resolution operational analysis and forecast fields from the European Centre for Medium-Range Weather Forecasts (ECMWF) at highest available time frequency (3 hours for the first 3 days of forecast, 6 hours for the following 7 days of forecast and for the analysis). The water balance is computed as Evaporation minus Precipitation and Runoff. Evaporation is derived from the latent heat flux, precipitation is provided by ECMWF as daily averages; Precipitation fields over the basin are from ECMWF as well. The atmospheric fields - zonal and meridional components of 10 m wind (ms^{-1}), total cloud cover (%), 2 m air temperature (K), 2 m dew point temperature (K) and mean sea level pressure (Pa) - are used for computing the momentum, heat and water fluxes at the air-sea interface based on the Black Sea bulk formulae (Ciliberti et al., 2021 - in preparation).

Runoff. Monthly mean river discharge provided by the SESAME project (Ludwig et al., 2009) is applied to the Black Sea rivers as in Figure 2 except the Danube, for which interannual river discharge from 1980 to 2019 provided by the National Institute of Hydrology and Water Management (NIHWM, partner of the BS-MFC Consortium) is used. The Danube dataset consists of historical discharge for the 5 outlets and for the Isaccea and Tulcea stations (Figure 3). NIHWM suggests to compute water discharge Q (km3/year) in the following way:

- Q @ Chilia arm as difference of Q @ Isaccea and Q @ Tulcea stations
- Q @ Chilia 1st arm is equal to 22% of total Q @ Chilia arm
- Q @ Chilia 2nd arm is equal to 42% of total Q @ Chilia arm
- Q @ Chilia 3rd arm is equal to 36% of total Q @ Chilia arm
- Q @ Sulina is equal to 20% of total Q @ Tulcea station
- Q @ St. George is equal to difference between Q @ Tulcea station and Q @ Sulina arm

The BS-NRT uses daily discharges for the Danube River using the historical interannual dataset until July 2020 and the daily observations onwards. The Killworth correction (Killworth, 2006) was applied to all the 72 rivers in order to change their runoff frequency from monthly to daily. The Danube hydrograph for the 5 outlets over the period 2017-2020 accounted for the BS-NRT system is shown in Figure 4.

Regarding salinity at the river mouths, BS-NRT uses zero salinity for all rivers excepts the major ones – Danube, Dniepr, Dniester, Rioni, KizilIrmak, Sakarya – for which monthly climatological salinity values from SeaDataNet are imposed as shown also in Figure 5 (Simoncelli et al., 2015).

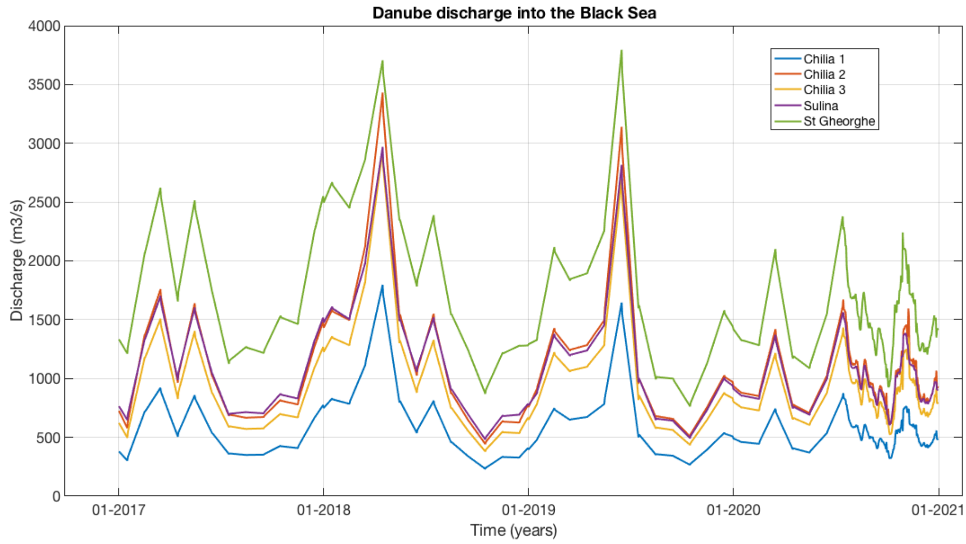


Figure 4 - Daily discharges for the Danube outlets: NIHWM interannual dataset from January 2017 until June 2020 and daily observations from July 2020 onwards as accounted in the BS-NRT model

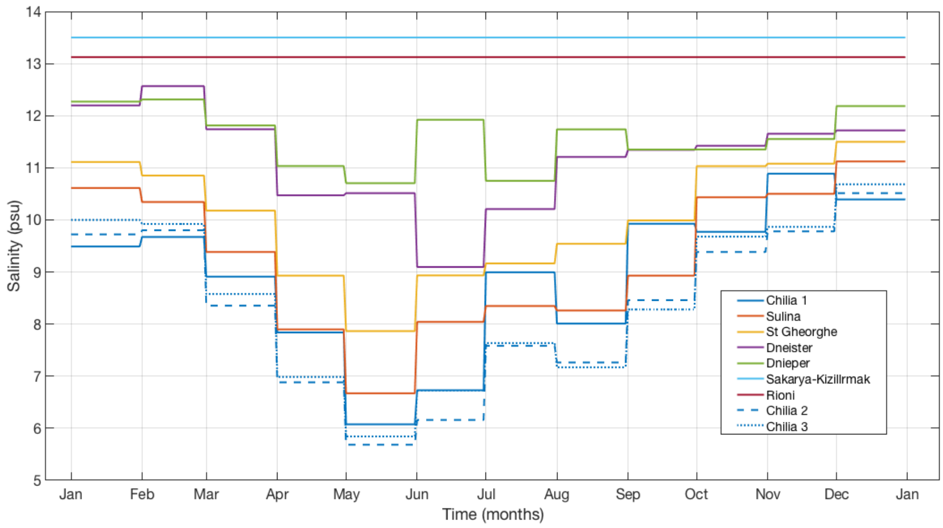


Figure 5 - Monthly climatological salinity values at daily frequency from SeaDataNet as imposed in the BS-NRT major river mouths

Lateral open boundary conditions. The BS-NRT implements lateral open boundary conditions to the Black Sea through the Marmara Sea box (Figure 6), which provides monthly climatological temperature, salinity, U and V velocity components and sea surface height over the 3 open sides from the Unstructured Turkish Strait System model (U-TSS), whose general setup is described in Section II.1.3. Flather's condition is applied for the barotropic component, while Orlanski radiation scheme is applied for tracers and baroclinic components as implemented in NEMO v4.0. Ad hoc interfaces between U-TSS and BS-NRT have been developed in order to reshape U-TSS model solution for BDY module as implemented in NEMO v4.0.

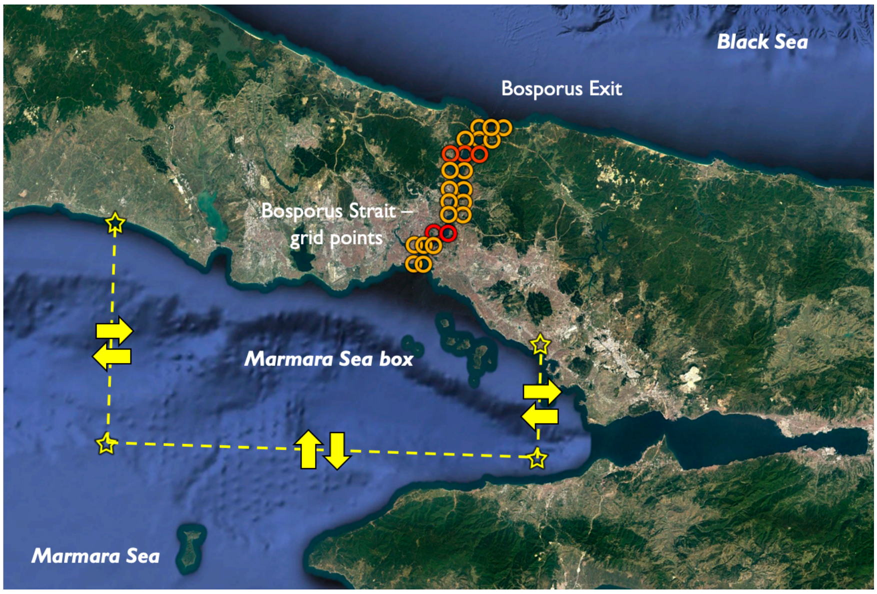


Figure 6 - Representation of the Marmara Sea box and the Bosporus Strait in the BS-NRT

II.1.2 Data assimilation scheme

The Data Assimilation (DA) system is based on a 3D variational scheme, implemented in the OceanVar software (Dobricic and Pinardi, 2008; Storto et. al. 2011). In this scheme, corrections to the model state are calculated by minimising a cost function that takes into account the model background state, the observations and their respective error covariance.

The background covariance matrix is modelled using a set of empirical orthogonal functions (EOF) that provide a variable transformation to pre-condition the cost function minimisation. The system uses a spatially varying set of 45 EOF to describe the covariance of sea surface height and temperature and salinity in the water column. The EOF are derived from a 10-year integration of the hydrodynamical core without DA. To account for seasonal variability the EOF have a monthly time dependence. Horizontal correlations are modelled through a third-order recursive filter (Farina et al., 2015), specified as a function of the distance from coast, ranging approximately from 9 to 27 km.

The observational error covariance matrices are spatially varying and include a depth and (monthly) time dependence where appropriate. The matrices have been calculated by a series of experiments in which the error is iteratively updated using the method of Desroziers et al., 2015.

The DA system assimilates temperature and salinity measured by ARGO profiling floats and satellite sea level anomaly (SLA). The assimilation of SLA imposes local hydrostatic adjustments as multi-variate balance between the sea level innovation and vertical profiles of temperature and salinity (Storto et al., 2011). The DA system runs with a daily frequency and uses a 24-hour assimilation time window.

II.1.3 The high resolution Marmara Sea model setup and validation

To provide lateral boundary conditions for the BS-PHY EAS4, we have developed a new high-resolution model for the Marmara Sea including the Bosporus and Dardanelles Straits using the Shallow Water Hydrodynamic Finite Element Model (SHYFEM) and called U-TSS (Unstructured Turkish Strait System, Ilicak et al. 2021). SHYFEM uses unstructured finite element grid in the horizontal and hydrostatic approximation with depth integrated shallow water equations in the vertical. The new model has a resolution between 500 meter in the deep to 50 meter in the shallow areas to resolve the Turkish Straits, and 93 geopotential coordinate levels in the vertical (Figure 7). The same bathymetry used in BS-PHY EAS4 has been also employed in this model. Initial conditions of temperature and salinity fields are provided from the model used in Aydogdu et al. 2018. We used April averaged temperature and salinity fields from that study since it showed the minimum bias compared to observations. We conducted a 4-year simulation run between 2016 and 2019 using 2D daily field of sea surface height, 3D daily fields of u- and v- velocity, temperature and salinity as lateral boundary conditions from BS-PHY EAS3 for the Northern boundary and Med-PHY EAS4 (Clementi et al., 2019) for the Southern boundary. Atmospheric boundary conditions from the ECMWF dataset are applied at every 3 hours using bulk formulae. We used k-epsilon vertical mixing scheme with Canuto-A stability function which was proven to give better results in density driven flows (Ilicak et al. 2008). Smagorinsky type dynamical momentum closure scheme is also used in the horizontal. We chose nondimensional Smagorinsky constant as 2.2 to reduce the numerical mixing in the model which was suggested by Ilicak et al. 2012. Total variation diminishing (TVD) scheme is used for tracer advection to ensure conservation properties.

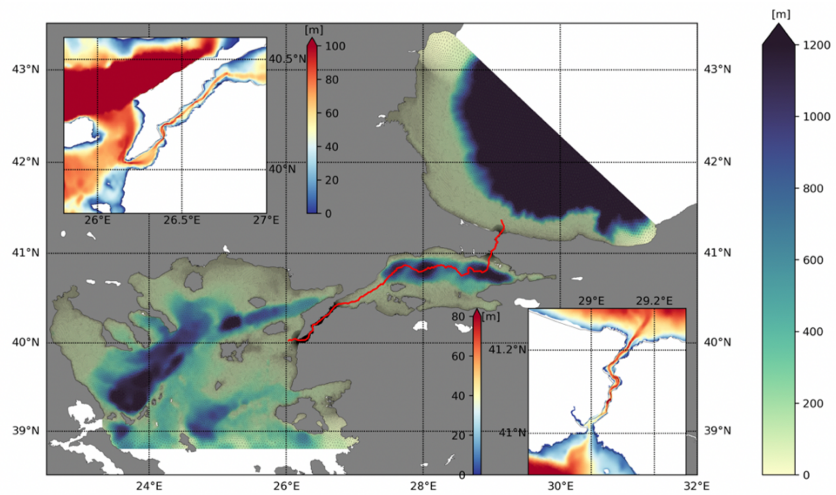


Figure 7 - U-TSS spatial domain and bathymetry (m)

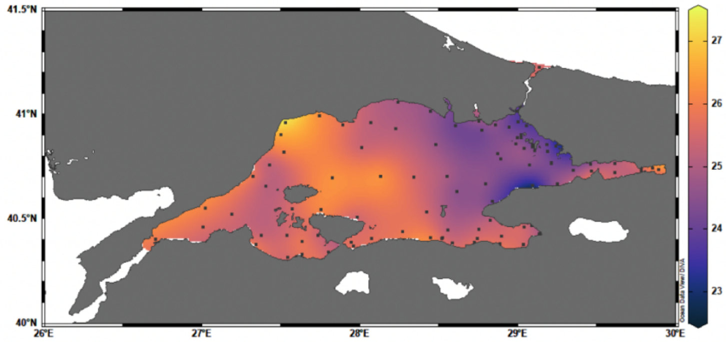


Figure 8 - U-TSS sea surface temperature (°C) 2D map and observations (black dots) in Aug 2017

U-TSS has been validated against the seasonal in situ observational data. Temperature and salinity fields obtained from four different cruises in 2017 and 2018 that covers the whole Marmara Sea have been used for observation. Figure 8 shows the August 2017 cruise sea surface temperature field interpolated over the Marmara Sea. The black dots represent station locations. Temperature and salinity bias computed in the vertical at each station for different cruises are shown in Figure 9. The maximum bias occurs at around halocline depth between 20 to 30 meters. The model is approximately 1°C colder than observations below 40 meter, however we believe this is due to the initial conditions. RMSD profile also shows that mixed layer interface is very challenging to represent correctly in the Marmara Sea. Maximum salinity bias and RMSD in the new U-TSS are around 3 PSU which is a significant improvement then previous studies.

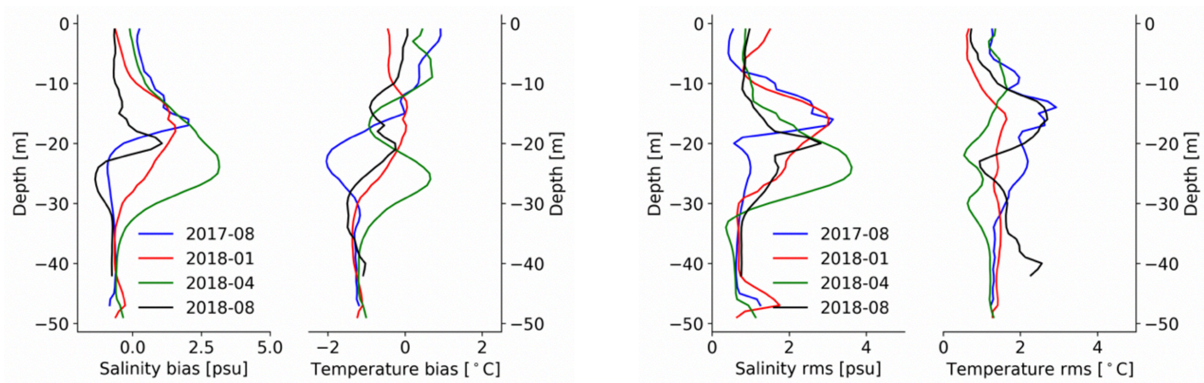


Figure 9 - bias (left) and RMSD (right) for salinity and temperature computed using U-TSS and available observations in the Marmara Sea

II.2 Upstream data

The BS-PHY EAS4 system implements interfaces for the operational (O)/static (S) access of the following list of upstream data:

- Bathymetry (S): GEBCO 30” for the overall basin; high resolution bathymetric dataset provided by ITU for the Marmara Sea and the Bosporus Strait;
- Atmospheric Forcing (O): ECMWF analysis and forecast atmospheric fields at 1/8° horizontal resolution and 3-6 hours frequency, distributed by the Italian National Meteo Service (USAM/CNMA);
- Land Forcing (S): monthly climatological discharge from SESAME project for all rivers; regarding the Danube, we use historical interannual dataset provided by the NIHWM. Zero salinity for all rivers except the major ones which uses monthly climatological salinity values provided by SeaDataNet v1.1;
- Lateral Open Boundary Conditions (S): from U-TSS – T, S, SSH, U, V – at very high spatial resolution and 92 vertical levels;
- Data assimilation (O):
    - Temperature and Salinity vertical profiles from CMEMS INS TAC
        - INSITU_BS_NRT_OBSERVATIONS_013_034
    - Satellite along track Sea Level Anomaly (SLA) from CMEMS SL TAC
        - SEALEVEL_EUR_PHY_L3_NRT_OBSERVATIONS_008_059
    - Satellite Sea Surface Temperature (SST) from CMEMS SST TAC
        - SST_BS_SST_L3S_NRT_OBSERVATIONS_010_013

III VALIDATION FRAMEWORK

A pre-operational run for BS-PHY NRT EAS4 system has been run from 01/01/2017 to 31/12/2020. It is the baseline for the operational launch of the production which will start officially since May 2021 CMEMS release.

Pre-qualification has been carried out over 1 year period - 01/01/2019 to 31/12/2019 - based on CLASS1, CLASS2 and CLASS4 metrics, including transports at the Bosporus Strait. Performances have been assessed by using external products: quasi-independent satellite and in-situ observations have been used to assess the skill of temperature, salinity and sea level anomaly; climatological datasets have been used to assess the quality of the temperature and salinity. Finally, literature and previous studies have been used to evaluate the other variables, such currents and mixed layer depth, where no observations are available for a direct comparison. Quasi-independent data are all the observations which have been assimilated by the system (in-situ T/S, SLA, SST). Diagnostic in terms of RMSD between model output and observation and/or bias are computed.

The metrics used for the validation procedure are listed in

Name	**Description**	**Ocean parameter**	**Supporting reference dataset**	**Quantity**
NRT evaluation of BS-PHY using INS semi-independent data: Estimate Accuracy Numbers				
T/*S*-<X-Y>m-D-CLASS4-PROF-RMSD-Jan2019-Dec2019	Temperature/ *Salinity* vertical profiles comparison with CMEMS INS TAC data at 9 layers for the Black Sea basin.	Temperature /*Salinity*	ARGO floats from the CMEMS INS TAC product: INSITU_BS_NRT_OBSERVATIONS_013_034	Profiles of temperature/*salinity* daily RMSD between model and in-situ observations, averaged over the qualification testing period (Jan-Dec 2019). This quantity is evaluated on the model analysis. The statistics are defined for all the Black Sea and are evaluated for 9 different layers (0-10, 10-20, 20-30, 30-50, 50-75, 75-100, 100-200, 200-500, 500-1000 m). Together with the time series, the time (2019) average RMSD value is reported in tables.
T/*S*-<X-Y>m-D-CLASS4-PROF-BIAS- Jan2019-Dec2019	Temperature/ *Salinity* vertical profiles comparison with CMEMS INSITU TAC data at 9 layers for the Black Sea basin.	Temperature /*Salinity*	ARGO floats from the CMEMS INS TAC product: INSITU_BS_NRT_OBSERVATIONS_013_034	Profiles of temperature/*salinity* daily mean differences between model and in-situ observations averaged over the qualification testing period (Jan-Dec 2019). This quantity is evaluated on the model analysis. The statistics are defined for all the Black Sea and are evaluated for 9 different layers (0-10, 10-20, 20-30, 30-50, 50-75, 75-100, 100-200, 200-500, 500-1000 m). Together with the time series, the time (2019) average BIAS value is reported in tables.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of BS-PHY using SAT semi-independent data: Estimate Accuracy Numbers				
SLA-D-CLASS4-ALT-RMSD-Jan2019-Dec2019	Sea level anomaly comparison with CMEMS Sea Level TAC (satellite along track) data for the Black Sea basin.	Sea Level Anomaly	Satellite Sea Level along track data from CMEMS SL TAC product: SEALEVEL_EUR_PHY_L3_NRT_OBSERVATIONS _008_059	Time series of Sea Level daily RMSD between model and satellite observations averaged over the qualification testing period (Jan-Dec 2019). This quantity is evaluated on the model analysis. The statistics are defined for all the Black Sea basin. Together with the time series, the time (2019) average RMSD value is reported in tables.
SST-D-CLASS4-RMSD-Jan2019-Dec2019	Sea Surface Temperature comparison with SST CMEMS SST TAC L3 data for the Black Sea basin.	Sea Surface Temperature	SST satellite data from CMEMS SST TAC L3 product: SST_BS_SST_L3S_NRT_OBSERVATIONS _010_013	Time series of Sea Surface Temperature daily RMSD between model and satellite observations averaged over the qualification testing period (Jan-Dec 2019). This quantity is evaluated on the model analysis. The statistics are defined for all the Black Sea basin. Together with the time series, the time (2019) average RMSD value is reported in tables.
SST-D-CLASS4-BIAS-Jan2019-Dec2019	Sea Surface Temperature comparison with SST CMEMS SST TAC L3 data for the Black Sea basin.	Sea Surface Temperature	SST satellite data from CMEMS SST TAC L3 product: SST_BS_SST_L3S_NRT_OBSERVATIONS _010_013	Time series of Sea Surface Temperature daily difference between model and satellite observations averaged over the qualification testing period (Jan-Dec 2019). This quantity is evaluated on the model analysis. The statistics are defined for all the Black Sea basin. Together with the time series, the time (2019) average BIAS value is reported in tables.
Name	**Description**	**Ocean parameter**	**Supporting reference dataset**	**Quantity**
NRT evaluation of BS-PHY using INS and SAT semi-independent data. Weekly comparison of misfits				
T/*S*-<X-Y>m-W-CLASS4–PROF-RMSD-BS-Jan2019-Dec2019	Temperature (*Salinity*) vertical profiles comparison with assimilated CMEMS INS TAC data at 5 specified depths.	Temperature (*Salinity*)	ARGO floats from the CMEMS INS TAC product: INSITU_BS_NRT_OBSERVATIONS_013_034	Time series of weekly RMSD of temperature/*salinity* misfits (observation minus model value transformed at the observation location and time). Together with the time series, the average value of weekly RMSD is evaluated over the qualification testing period (2019). The statistics are defined for all the Black Sea and are evaluated at five different depths: 8, 30, 150, 300 and 600 m.
SLA-SURF-W-CLASS4-ALT-<PLAT>- RMSD-BS-Jan2019-Dec2019	Sea level anomaly comparison with assimilated CMEMS SL TAC satellite along track data for the Black Sea basin.	Sea Level Anomaly	Satellite Sea Level along track data from CMEMS SL TAC product: SEALEVEL_EUR_PHY_L3_NRT_OBSERVATIONS _008_059	Time series of weekly RMSD of sea level anomaly misfits (observation minus model value transformed at the observation location and time). Together with the time series, the average value of weekly RMSD is evaluated over the qualification testing period (2019). The statistics are defined for all the Black Sea and are evaluated for the different assimilated satellites.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of BS-PHY using INS semi-independent data. Depth-Time monthly comparison of misfits (Hovmoller diagrams)				
T/*S*-<X-Y>m-M-CLASS4–HOV-RMSD-BS-Jan2019-Dec2019-HOV	Temperature/ *Salinity* depth-time comparison with assimilated CMEMS INS TAC between 0 and 500m	Temperature/ *Salinity*	ARGO floats from the CMEMS INS TAC product: INSITU_BS_NRT_OBSERVATIONS_013_034	Depth-Time (Hovmoller diagram) of monthly RMSD temperature/*salinity* misfits (observation minus model value transformed at the observation location and time) evaluated over the qualification testing period (2019). The statistics are averaged over the whole Black Sea and are defined between 0 and 500m depth.
Name	**Description**	**Ocean parameter**	**Supporting reference dataset**	**Quantity**
NRT evaluation of BS-PHY using T/S independent data. Daily comparison with moorings				
T/*S*-SURF-D-CLASS2-MOOR - Jan2019-Dec2019	Temperature/ *Salinity* comparison using CMEMS INS TAC	Temperature /*Salinity*	ARGO floats from the CMEMS INS TAC product: INSITU_BS_NRT_OBSERVATIONS_013_034	Time series of daily sea surface temperature./salinity of in-situ observations and model outputs evaluated over the qualification testing period (2019). This quantity is evaluated on the model analysis.

Name	Description	Ocean parameter	Supporting reference dataset	Quantity
NRT evaluation of BS-PHY using Climatological dataset				
MLD-D-CLASS1-CLIM-MEAN_M-BS	Mixed Layer Depth comparison with climatology from literature in the Black Sea	Mixed Layer Depth		Comparison of climatological maps form model outputs and a climatological dataset
SBT-D-CLASS1-CLIM-MEAN_M-BS	Bottom Temperature comparison with a climatological dataset in the Black Sea	Sea Bottom Temperature		Comparison of climatological maps form model outputs and SeaDataNet climatology for the area with topography < 1500m

IV VALIDATION RESULTS

IV.1 Sea surface temperature and sea surface salinity

IV.1.1 CLASS4 metrics based on satellite SST observations

Figure 10 provides bias and RMSD - CLASS4 metrics - calculated by comparing BS-PHY EAS4 daily analysis fields against satellite SST L3 observations (Table 1) on 2019: performances are also evaluated with respect to the previous system BS-PHY EAS3. BS-PHY EAS4 provides an average bias of 0.12°C and a RMSD of 0.48°C: the new system is accordance to the previous EAS3, even slightly better (average bias of 0.11°C and a RMSD of 0.54°C). The new system has new physics which is not exactly comparable to BS-PHY EAS3; additionally, BS-PHY EAS4 first level is at 0.5 m depth, while BS-PHY EAS3 one is deeper, at 2.5 m: this setup, combined to air-sea physics and light penetration parameterization may justify the spread and the warmer predicted surface waters. The new system is capable to better represent surface dynamics thanks also to higher vertical resolution and seasonal signal in the bias is quite evident.

To understand the spatial distribution of the same metrics, we provide 2D maps for BS-EAS4 averaged over 2019 in Figure 11 (top panel for *bias*, bottom panel for RMSD): higher error (up to 0.3°C) is located in the Eastern basin (where the Batumi gyre is generally located) and along Bulgarian-Romanian coastline. The lowest error is located along the Turkish coastline and Synop peninsula, the Crimean peninsula and the Russian South-Eastern coastline.

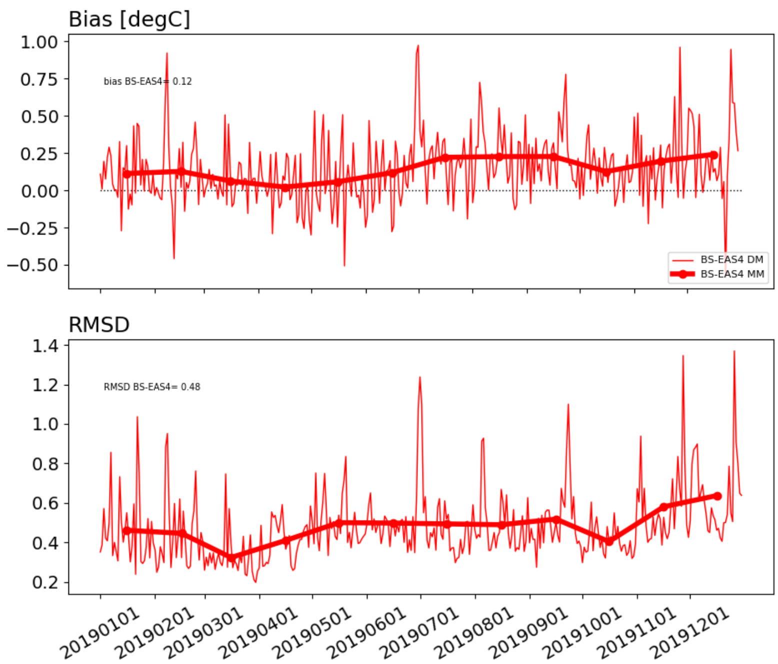


Figure 10 - BIAS (top panel, SST-D-CLASS4-BIAS-Jan2019-Dec2019) and RMSD (bottom panel, SST-D-CLASS4-RMSD-Jan2019-Dec2019) timeseries of BS-PHY EAS4 and BS-PHY EAS3 against SST L3 data in 2019

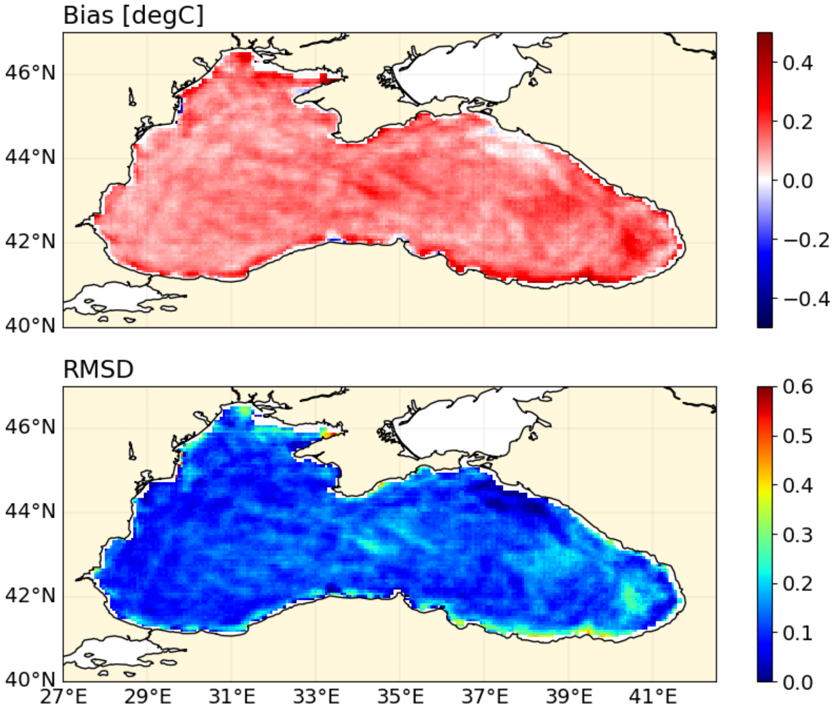


Figure 11 – 2D map BIAS (top panel) and RMSD (bottom panel) for Sea Surface Temperature using BS-PHY EAS4 analysis fields and satellite SST L3 observations on 2019

IV.1.2 CLASS2 metrics using available moorings observational data

For the pre-qualification period, we compared BS-PHY EAS4 hourly analysis fields against observations from operational moored buoys and shore stations from GTS operating during 2019. The list of stations, provided by the BS INS TAC, is reported in Table 2: they are mainly distributed along the Bulgarian coastline.

Table 2 - List of Black Sea moorings provided by the BS INS TAC and operating in 2019

Type	Platform name	Lon	Lat	Parameter
Moored buoys	EUXRo01	44,7	30,779	TEMP, PSAL
	EUXRo02	44,318	30,417	TEMP, PSAL
	EUXRo03	43,98	29,936	TEMP, PSAL
	15360	45,2	29,7	TEMP
	15480	44,2	28,6	TEMP
Shore stations from GTS	15428	44,7	29	TEMP
	15499	43,8	28,6	TEMP
	15552	43,2	28	TEMP
	15655	42,5	27,5	TEMP
	15428	44,7	29	TEMP

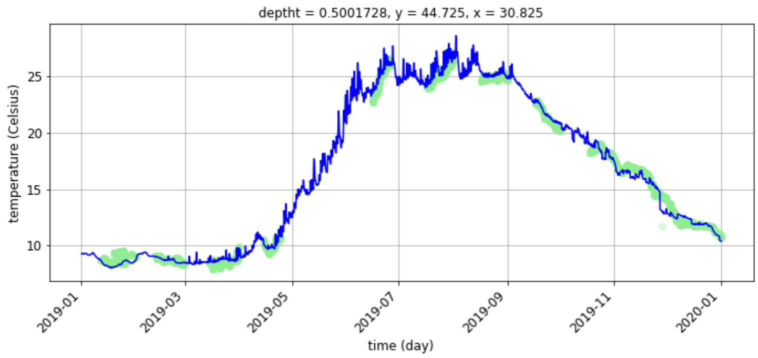


Figure 12 - CLASS2 SST comparison BS-PHY EAS4 daily analysis at hourly frequency vs EUXRo01 station observations in 2019 (T-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

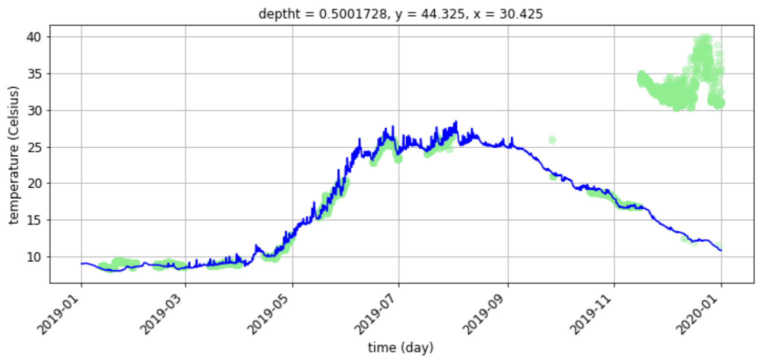


Figure 13 - CLASS2 SST comparison BS-PHY EAS4 daily analysis at hourly frequency vs EUXRo02 station observations in 2019 (T-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

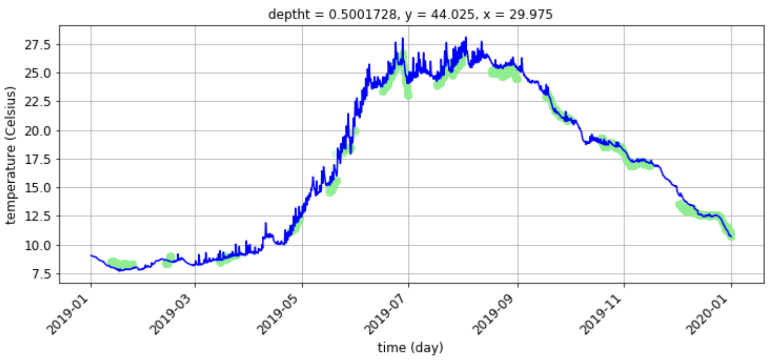


Figure 14 - CLASS2 SST comparison BS-PHY EAS4 daily analysis at hourly frequency vs EUXRo03 station observations in 2019 (T-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

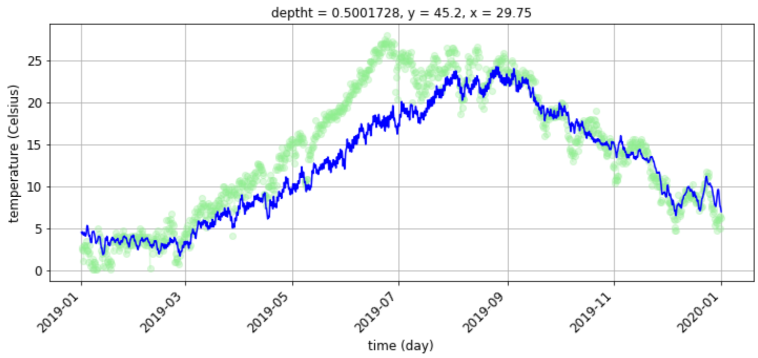


Figure 15 - CLASS2 SST comparison BS-PHY EAS4 daily analysis at hourly frequency vs 15360 station observations in 2019 (S-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

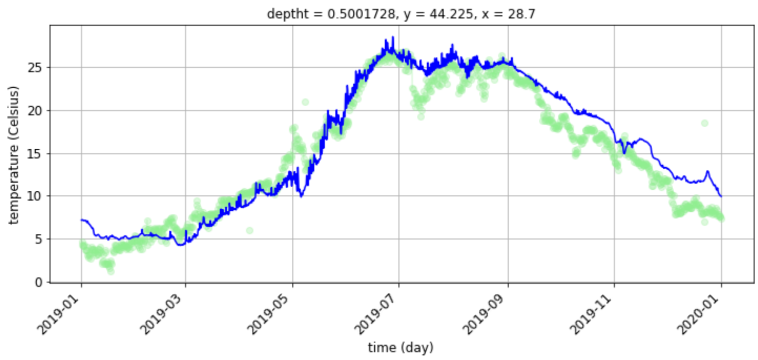


Figure 16 - CLASS2 SST comparison BS-PHY EAS4 daily analysis at hourly frequency vs 15480 station observations in 2019 (S-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

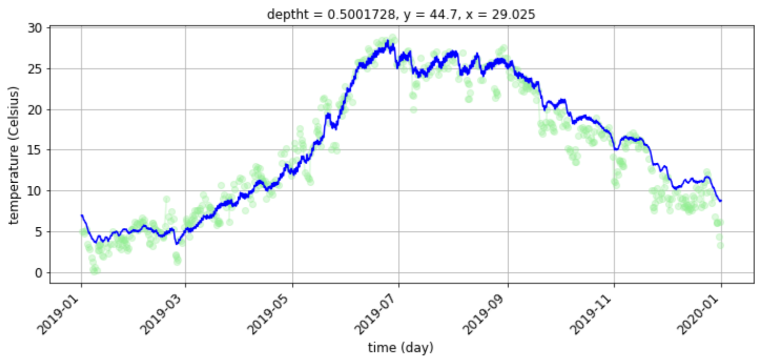


Figure 17 - CLASS2 SST comparison BS-PHY EAS4 daily analysis at hourly frequency vs 15428 station observations in 2019 (S-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

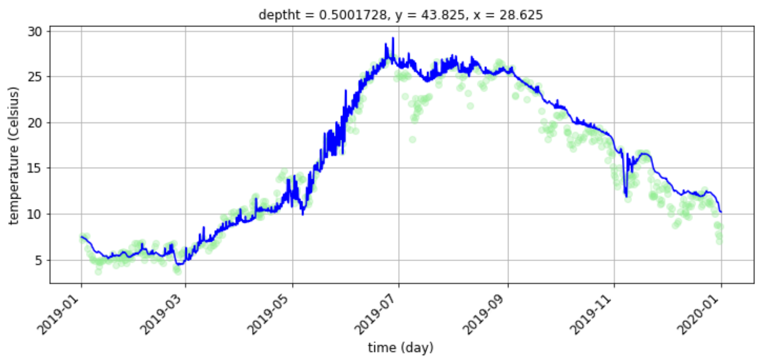


Figure 18 - CLASS2 SST comparison BS-PHY EAS4 daily analysis at hourly frequency vs 15499 station observations in 2019 (S-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

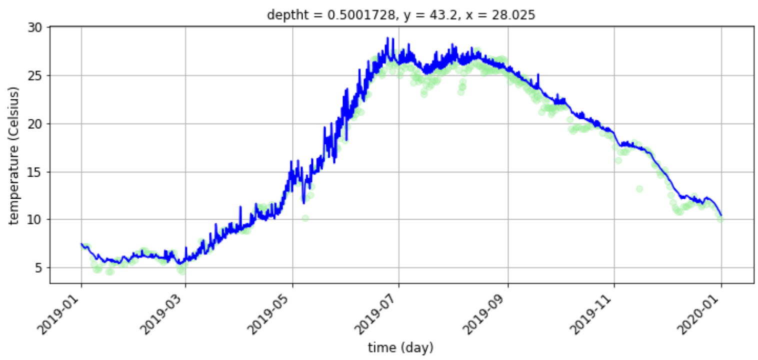


Figure 19 - CLASS2 SST comparison BS-PHY EAS4 daily analysis at hourly frequency vs 15552 station observations in 2019 (S-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

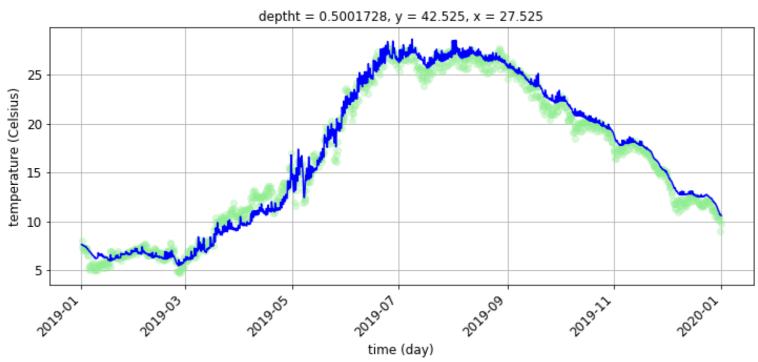


Figure 20 - CLASS2 SST comparison BS-PHY EAS4 daily analysis at hourly frequency vs 15655 station observations in 2019 (S-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

From Figure 12 to Figure 20, we provide the overlapping timeseries from BS-PHY EAS4 daily analysis at hourly frequency (blue line) at the closest station location and observed SST (green dots): the agreement between model and observations is quite satisfactory and seasonal signal is well reproduced.

Regarding sea surface salinity, we provide analogous overlapping timeseries in Figure 21 to Figure 23: the model well captures salinity signal at EUXRo stations locations, however during Spring-Summer period observations provides higher peaks of salinity corresponding to period of lower precipitation and river inflow that the system seems not to well reproduce. It suggests more advanced river modelling solutions especially close to the Danube River region of freshwater influence.

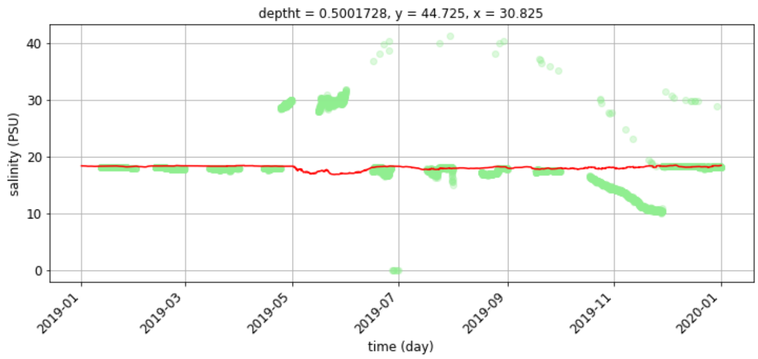


Figure 21 - CLASS2 SSS comparison BS-PHY EAS4 daily analysis at hourly frequency vs EUXRo01 station observations in 2019 (S-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

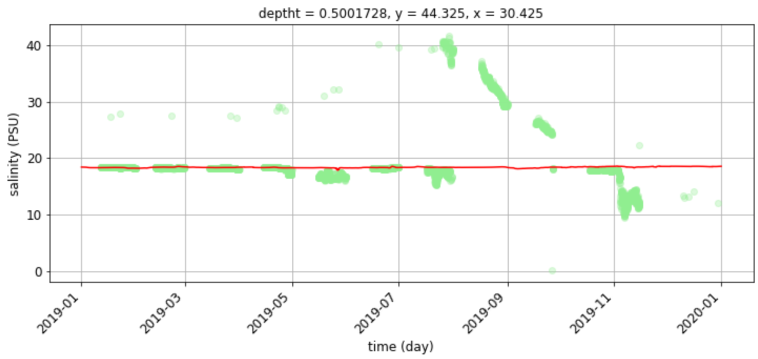


Figure 22 - CLASS2 SSS comparison BS-PHY EAS4 daily analysis at hourly frequency vs EUXRo02 station observations in 2019 (S-SURF-D-CLASS2-MOOR -Jan2019-Dec2019)

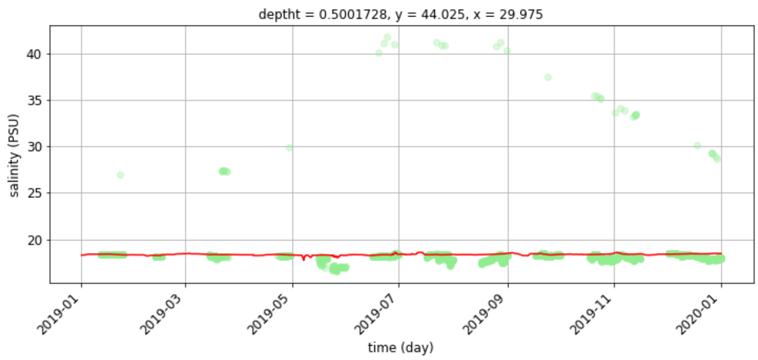


Figure 23 - CLASS2 SSS comparison BS-PHY EAS4 daily analysis at hourly frequency vs EUXRo03 station observations in 2019 (S-SURF-D-CLASS2-MOOR -Jan2019-Dec2019).

IV.2 Temperature

Water column properties predicted by BS-PHY EAS4 are evaluated starting from the validation of 3D temperature. Table 3 summarize RMSD of temperature misfits at reference depths for the whole pre-qualification period - i.e. 2019, computed by using the analysis of BLKSEA_ANALYSISFORECAST_PHY_007_001 and ARGO T profiles (quasi-independent validation). Evolution in time of the same metric is represented in Figure 24. The error is characterized by a seasonal variability, with the highest error concentrated during summer/fall seasons (maximum errors up to 3.0°C-3.5°C) as shown in Figure 24 at 8 and 30 m reference depths. In general the region of the water column where the thermocline is located experiences higher error than the intermediate-deep levels, where the error is extremely low.

Table 3 - RMSD of temperature misfits in 2019 at reference depths

Depth (m)	RMSD misfit (°C)
8	0.75
30	1.0
150	0.06
300	0.03
600	0.06

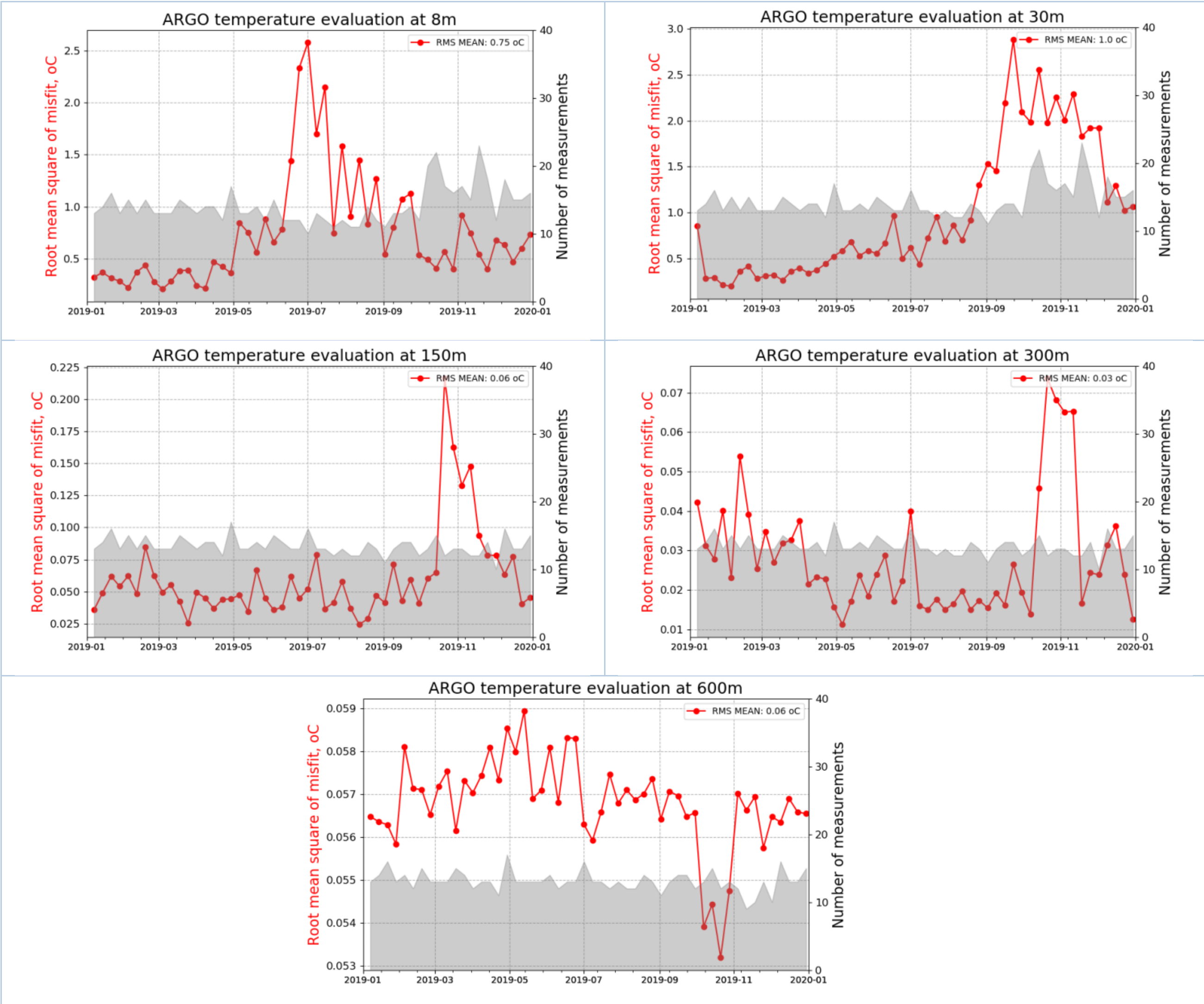


Figure 24 - Time series of weekly RMSD of temperature misfits (red solid line) and number of observed profiles (grey shaded area) at 8, 30, 150, 300 and 600 m (T-<X-Y>m-W-CLASS4–PROF-RMSD-BS-Jan2019-Dec 2019). Reference depth on top of each plot.

IV.3 Salinity

Table 4 summarize RMSD of salinity misfits at reference depths for the whole pre-qualification period - i.e. 2019, computed by using the analysis of BLKSEA_ANALYSISFORECAST_PHY_007_001 and ARGO S profiles (quasi-independent validation). Evolution in time of the same metric is represented in Figure 25. Salinity error is below 0.5 PSU in the upper layer and around 0.1 PSU at the corresponding region of the thermocline (i.e. ~ 30 m). Performances are quite improved thanks to the open boundary condition that is providing to the Black Sea, through the Marmara-Bosporus system, a better representation of the Mediterranean saltier inflow.

Table 4 - RMSD of salinity misfits in 2019 at reference depths

Depth (m)	RMSD misfit (PSU)
8	0.14
30	0.11
150	0.12
300	0.03
600	0.01

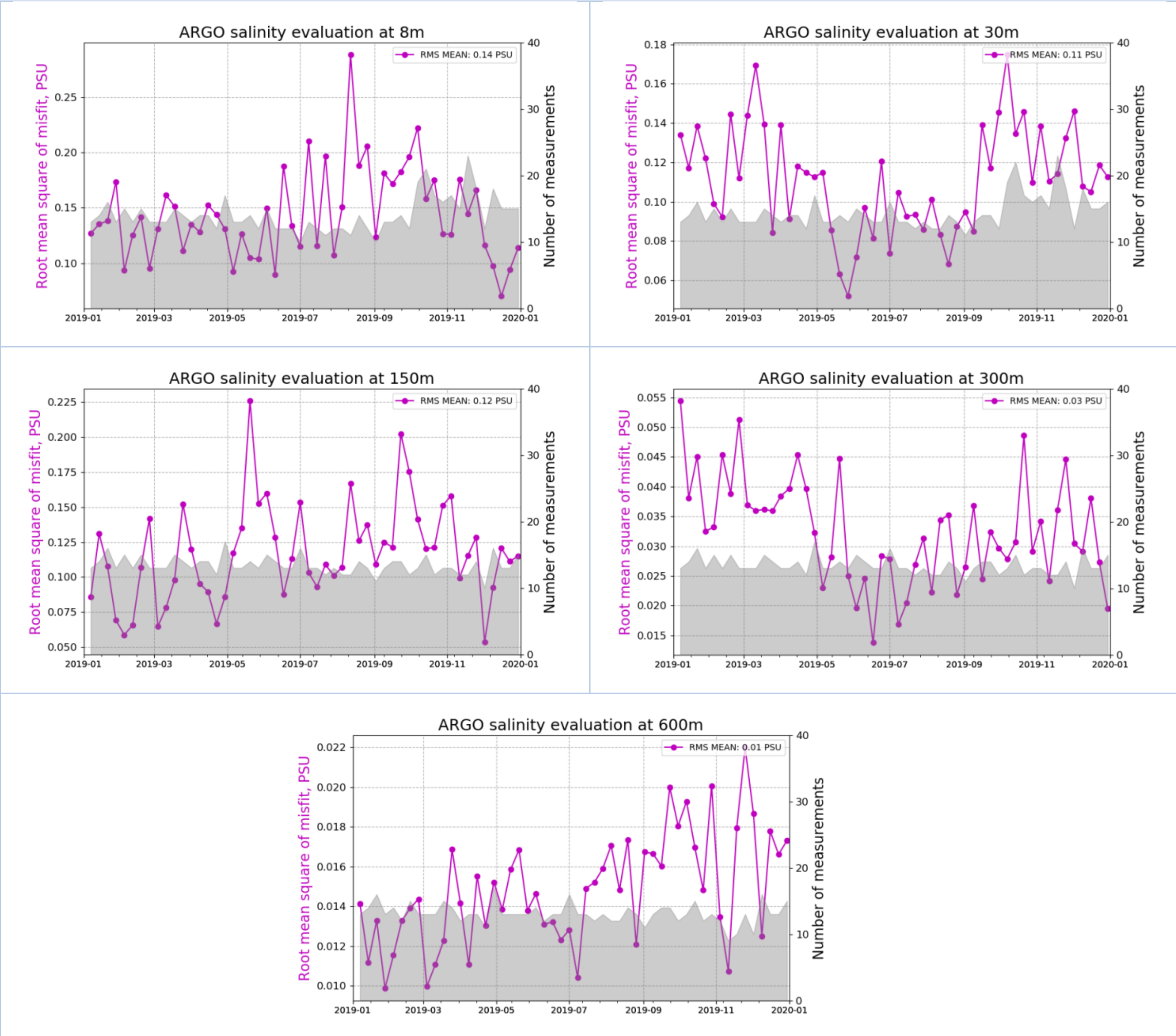


Figure 25 - Time series of weekly RMSD of temperature misfits (red solid line) and number of observed profiles (grey shaded area) at 8, 30, 150, 300 and 600 m (S-<X-Y>m-W-CLASS4–PROF-RMSD-BS-Jan2019-Dec 2019). Reference depth on top of each plot.

IV.4 Sea Level Anomaly

Table 5 provides RMSD of sea level anomaly misfits for the whole pre-qualification period - i.e. 2019, computed by using the analysis of BLKSEA_ANALYSISFORECAST_PHY_007_001 and available satellite along track sea level anomaly observations (Table 1). Evolution in time of the same metric is shown in Figure 26 for all satellite and in Figure 27 for each reference platform. BS-PHY EAS4 provides an overall error of about 2.16 cm in the whole basin. Considering each reference platform singularly, the error is quite stable and around 2.0 cm, with the only exception of CryoSat2, for which BS-PHY EAS4 gives an error of about 2.4 cm at basin scale.

Table 5 - RMSD of sea level anomaly misfits in 2019

Platform	RMSD misfit (cm)
All	*2.16*
Altika	2.06
CryoSat2	2.39
Jason2	2.23
Jason3	2.09
Sentinel-3A	2.01
Sentinel-3B	2.09

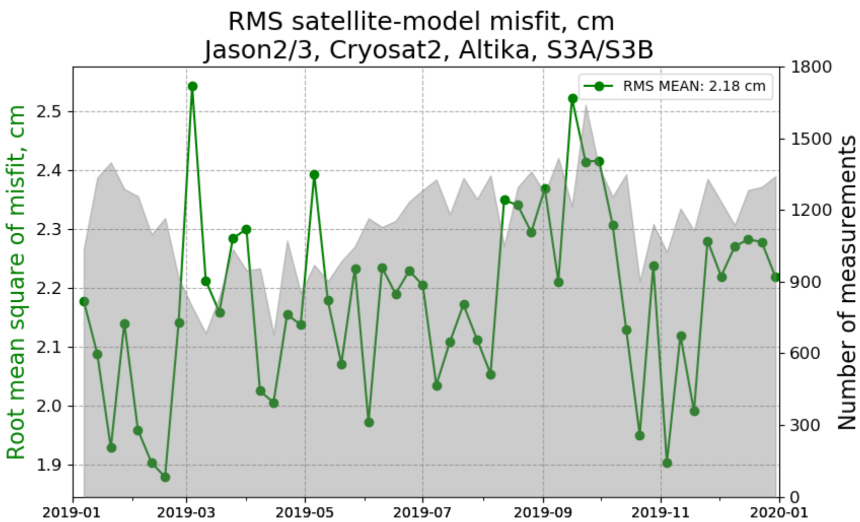


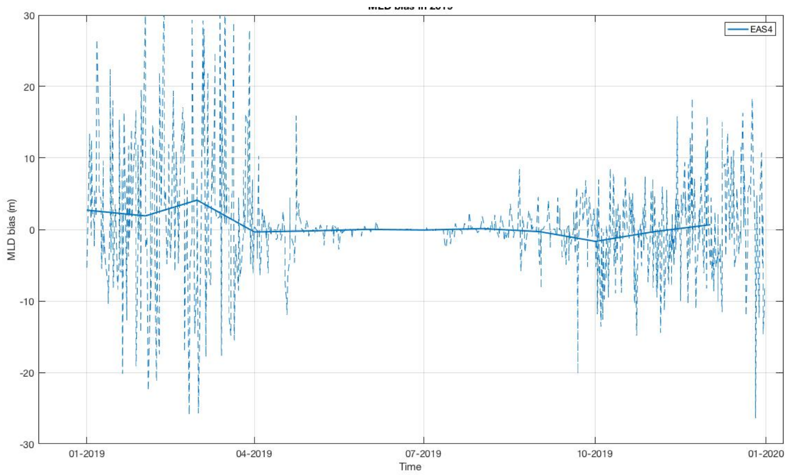
Figure 26 - Time series of weekly RMS of misfits along SLA data track for all the satellites (shaded areas in the figure) (SLA-SURF-W-CLASS4-ALL-RMSD-BS-Jan2019-Dec2019).

Figure 27 - Time series of weekly RMS of misfits along SLA data track from each satellites: Altika, Cryosat, Jason2, Jason3, Sentinel-3A and Sentinel-3B and corresponding number of assimilated data (shaded areas in the figures) (SLA-SURF-W-CLASS4-ALT-<PLAT>-RMSD-BS-Jan2019-Dec2019). Reference satellite on top of the plot.

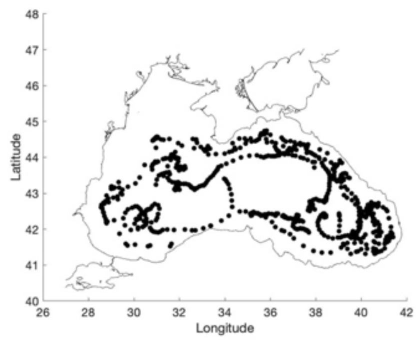
IV.5 Mixed layer depth

The mixed layer depth is computed within the model using the density criteria. It is defined as the depth where the density increase is greater than 0.01 kg/m3 compared to the density value at a reference depth of 10 m. For the validation and assessment of the quality of the mixed layer variable, we take advantage of all observations and climatological data at disposal.

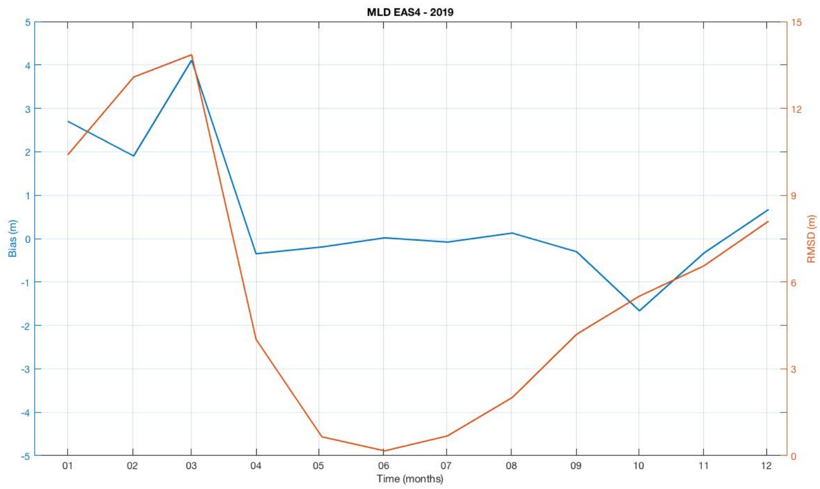
Using the temperature and salinity from the ARGO floats (Table 1) and spatially reported in Figure 28b, we follow the same procedure for estimation of the mixed layer as used by the model. The higher bias between model and observations occurs in Winter/Spring with daily values of +/- 20 meters (Figure 28a), monthly maximum bias of -5 m and RMSD of 15 m (Figure 28c).



(a)



(b)



(c)

Figure 28 - a) Mixed layer depth daily and monthly bias from mode BS-EAS4 compare to ARGO floats, b) the spatial location of the floats in 2019 used in the computation of bias and RMSD, c) mixed layer bias and RMSD from model compared with ARGO floats.

The observations dataset is still sparse in the region moving in the influence area of the RIM current (in Figure 28b) and therefore we complement the validation with climatological values found in the literature. Houpert et al. (2015) provides a monthly gridded climatology produced using MBT, XBT, Profiling floats, gliders and ship-based CTD. The temperature profiles cover the period from 1969-2012 and both the Mediterranean Sea and western Black Sea regions. Figure 29 to Figure 31 show the 2D maps of climatological MLD (left panel) and the MLD as given from BS-PHY EAS4 (right panel). Unlike the climatology, the model results consider the average over the month for the year 2019 and therefore shows more variability of the mixed layer values. Despite the clear differences, quantitatively it is noticeable that the model BS-PHY EAS4 is capable of reproducing the location of the deeper mixed layer in the central Black Sea region for late Spring (Figure 29), and around the Bosporus and western coastline for Autumn (Figure 30) and Winter (Figure 31). The model mixed layer has shallower values than the climatology that can be due the comparison between different time periods, the 44-year climatology to 2019, or the mixed layer method chosen. The density criteria used by the model gives lower values in comparison to the temperature method used in by Houpert et al. (2015).

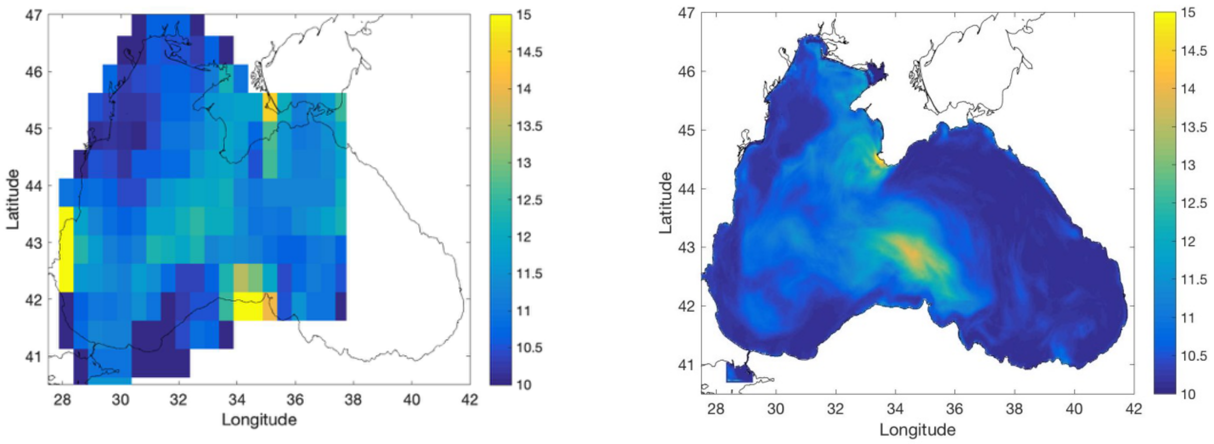


Figure 29 - Mixed layer depth values comparison May climatology from Houpert et al. (2015) (on the left) with BS-PHY EAS4 May 2019 (on the right).

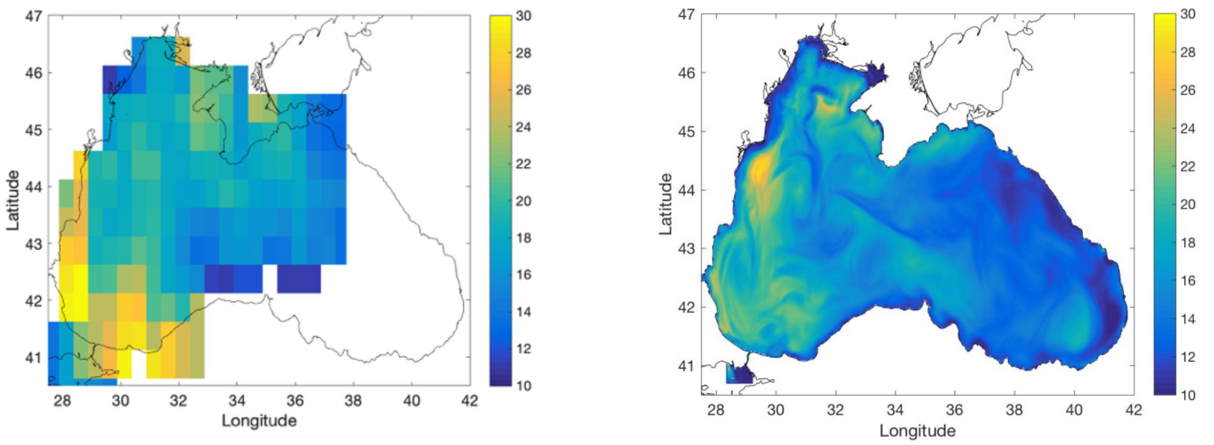


Figure 30 - Mixed layer depth values comparison October climatology from Houpert et al. (2015) (on the left) with BS-PHY EAS4 October 2019 (on the right).

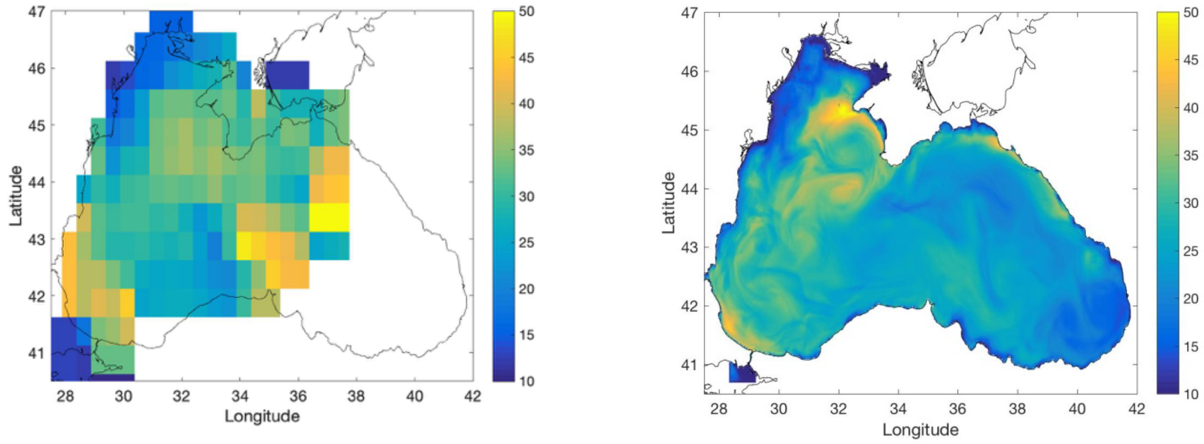


Figure 31 - Mixed layer depth values comparison December climatology from Houpert et al. (2015) (on the left) with BS-PHY EAS4 December 2019 (on the right).

In the work of Kara et al. (2009), a time series of monthly mean climatological mixed layer depth using observations done in the Black Sea at a location 43ºN, 30ºE is provided. Considering different criteria for computing the mixed layer, the results summarize as the following: from January to March the mixed layer between 70 and 40 meters, in April drops to 20-30 meters, from May to August between 10-15 meters and from September to December the mixed layer increases from 20 to 40 meters. Figure 32 shows the monthly evolution of the mixed layer depth in 2019 as given by the BS-PHY EAS4, at the same location in Kara et al. (2009). Despite the underestimation of the winter mixed layer (~20 m) in BS-PHY EAS4 model, the time evolution and depth values of the model mixed layer are in good agreement with Kara et al. (2009).

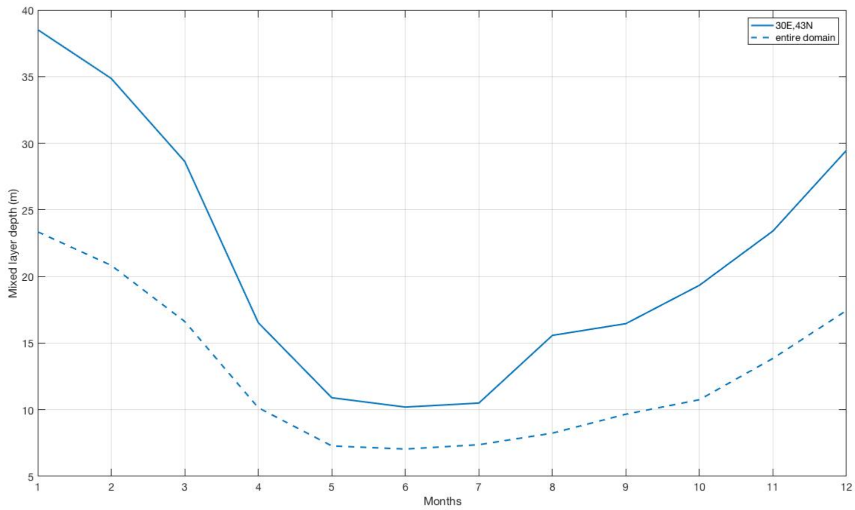


Figure 32 - Monthly mixed layer depth values in 2019 at the location 43ºN, 30ºE (continuous line) and average over the entire domain (dashed line).

IV.6 Currents

The Black Sea mean circulation at the surface, whose typical pattern is shown in from Ozsoy and Ünlüata (1997) as in Figure 33, during the pre-qualification period - i.e. 2019, is shown Figure 34. Due to missing data over the overall period, it is quite difficult to perform a quantitative validation: we can rely only on literature contributions (Ozsoy and Ünlüata (1997), Staneva et al. (2001), Ivanov and Belokopytov (2013)) that describes the Black Sea circulation peculiarities.

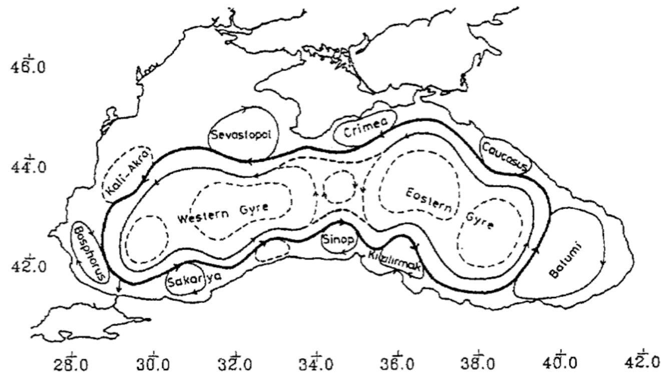


Figure 33 - General circulation of the Black Sea as proposed by Ozsoy and Unluata (1997) using the observations available until the study conducted.

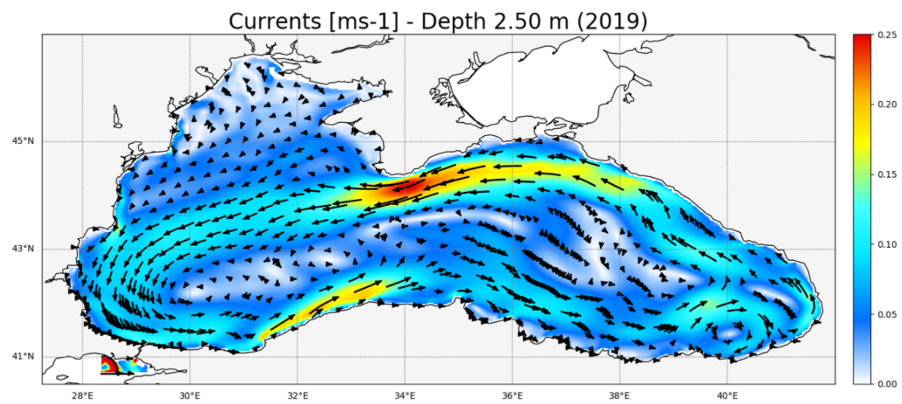


Figure 34 - 2D map of BS-PHY EAS4 circulation at surface in 2019

BS-PHY EAS4 reproduces in 2019 some peculiar circulation patterns, such as the Rim current that develops along the continental slope, the Batumi gyre and the Western gyre. Figure 35 to Figure 37 show the 2D circulation maps at from 50 to 900 m depth: the persistency of the Rim current is well shown also in the subsurface and intermediate layers, while very low circulation is reproduced at deepest levels.

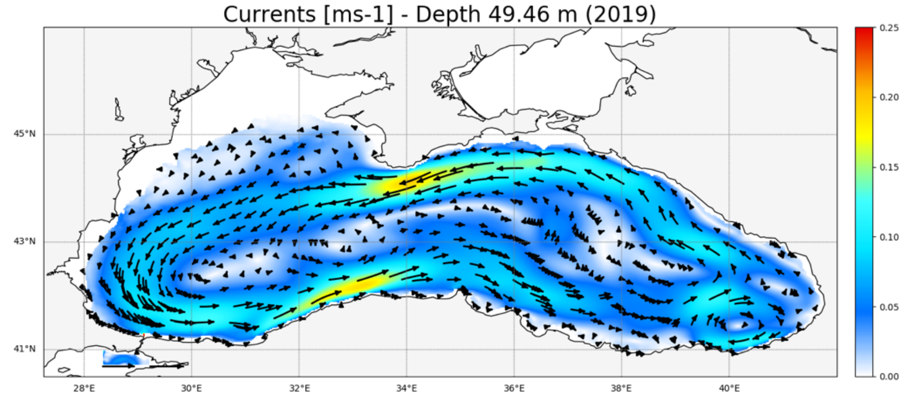


Figure 35 - 2D map of BS-PHY EAS4 circulation at ~50 m in 2019

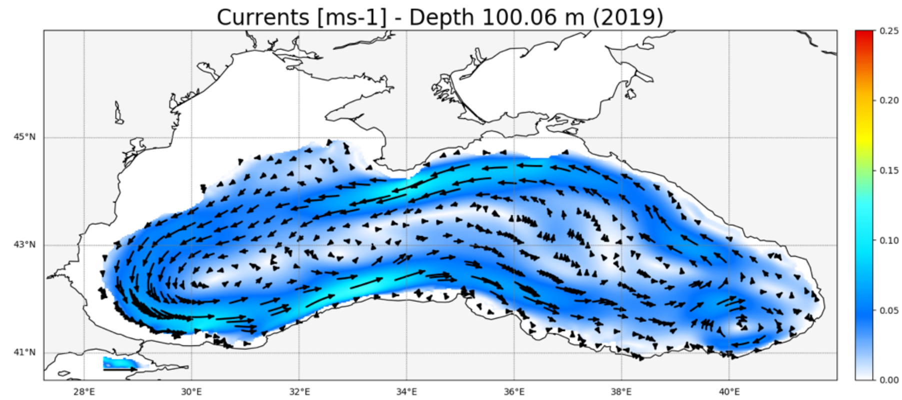


Figure 36 - 2D map of BS-PHY EAS4 circulation at ~100 m in 2019

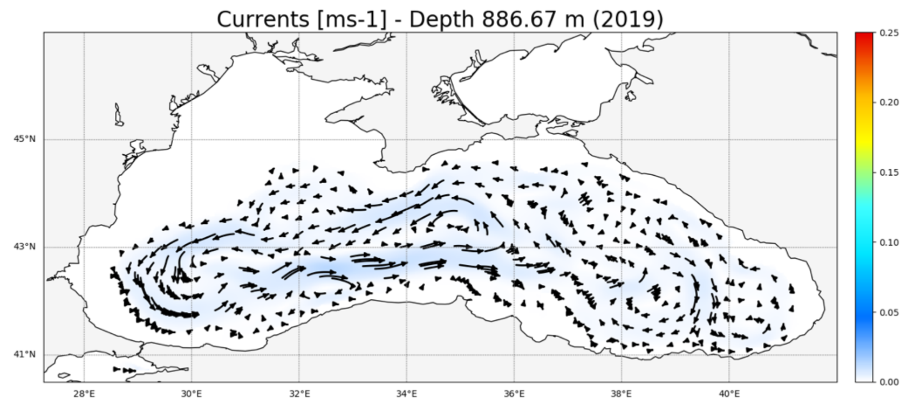


Figure 37 - 2D map of BS-PHY EAS4 circulation at ~1000 m in 2019

The Bosporus Strait is extremely important in controlling the interaction between the Mediterranean Sea and the Black Sea through the Marmara Sea. A two-layer flow is established at the Bosporus exit, ruling the Black Sea (Peneva et al., 2001): this exchange is crucial for the freshwater balance in the Black Sea with a net transport across the Bosporus Straight of about 300 km3/year (Ünlüata et al., 1990; Besiktepe, 1994). BS-PHY EAS4 is able to reproduce the overall net exchange through the Bosporus Strait. In particular, in the pre-qualification period, the annual inflow (e.g., lower transport, represented by Mediterranean waters into the Black Sea) is equal to -418 km^3year^{-1}, while the outflow (e.g., upper transport, from the Black Sea to the Mediterranean Sea) is equal to 299 km^3year^{-1}: the net is equal to -119 km^3year^{-1}, which is lower than what provided in Ünlüata et al. (1990): it deals with water budget conditions, in particular the role of lower total precipitation from ECMWF over the considered pre-qualification period.

Table 6 - BS-PHY EAS4 transports and comparison with literature values

Transports at the Bosporus Strait (km^3year^{-1})	**BS-PHY EAS4**		
	Net	**Inflow**	**Outflow**
2019	-119	-418	299
Ünlüata et al. (1990)	-300	-653/-603	353/303

V SYSTEM'S NOTICEABLE EVENTS, OUTAGES OR CHANGES

Date	Change/Event description	System version	other
2018	Change in the horizontal resolution of the atmospheric forcing data: ECMWF analysis and forecast product resolution was enhanced double (from ~25 to ~12.5 km)	EAS3	
Apr 2019	Revision of BS-PHY NRT data assimilation component and physical core	EAS3	
Sep 2019	Updated processing system to have products centered at 12:00 UTC	EAS3	
Jan 2021	New BS-PHY NRT system with increased vertical resolution and open boundary conditions for the Bosporus Strait	EAS4	Timeseries availability from 01/01/2019
Sep 2021	**The Danube River historical observation at daily frequency including forecast data**	**EAS4**	**(Redelivery of) timeseries availability from 01/01/2019**

VI QUALITY CHANGES SINCE PREVIOUS VERSION

2017-2019: The evolution from BS-Currents V2.2 to V3 has seeing some improvements in the modelling configuration, related in particular on the model core version (NEMO v3.4 to v3.6) and vertical mixing scheme (GLS to TKE). The model setup in V3 is demonstrating to represent better the thermohaline stratification – the CIL is much more persistent in time also with respect to the previous V2.2. The EANs computed for V3 shows some improvements with respect to V2.2 BS-Currents especially in the intermediate layer. A more detailed view of the general assessment of the NRT BS-Currents will be provided once completed also the metrics for 2016.

Jan 2021: new core model based on NEMO v4.0 and upgraded data assimilation scheme, with increased spatial resolution (from 31 vertical levels to 121 ones, horizontal resolution at about 2.5 km) and optimal interface with Mediterranean Sea through open boundary conditions for the Bosporus Strait. In the incoming sections, we present the main differences among the BS-PHY EAS3 (operational from 2019) and BS-PHY EAS4.

The Sep 2021: upgrade of the system to use the Danube River historical daily observations from Jul 2020 and forecast data. The new timeseries accounts for the assimilation of the recovered SST satellite data.

Table 7 summarizes the main differences between EAS3 and EAS4 systems for BS-PHY NRT.

Table 7 - Differences between CMEMS BS-PHY EAS3 and EAS4 systems

	CMEMS BS-PHY NRT EAS3	CMEMS BS-PHY EAS4
Hydrodynamical core model	NEMO v3.4	NEMO v4.0
Spatial grid	1/27° x 1/36° horizontal resolution and 31 levels; the spatial grid covers the Black Sea basin only	1/40° x 1/40° horizontal resolution and 121 levels; the spatial grid covers the Black Sea and a portion of the Marmara Sea for ingest-ing LOBC
Initial conditions	January monthly climatology from Si-monov and Altman, 1991	January monthly climatology from SeaDa-taNet v1.1 2015 (Simoncelli et al. 2015)
Bosporus Strait – boundary condi-tions	Closed configuration: the Bosporus Strait is modelled as a surface boundary condition (two layers flow as inverse river)	Open boundary conditions at the Marmara Sea box for the optimal interface between Med and BS. It uses U-TSS high resolution T, S, SSH, U, V interpolated at 1/40º spatial grid and 121 levels
River runoff	72 rivers with monthly climatological discharge and zero salinity	72 rivers with monthly climatological dis-charge except the Danube, which uses histori-cal interannual discharge provided by NIHWM; imposed zero salinity for all rivers excepts the major ones – Danube, Dniepr, Dniester, Rioni, KizilIrmak, Sakarya – which in-gest non-zero salinity from SeaDataNet monthly climagological salinity values
Data Assimila-tion	OceanVar scheme using 15 EOF	OceanVar scheme using 45 EOF assimilating SST satellite data (from CMEMS [SST-328])

VI.1 BS-PHY: EAS3 vs EAS4 from the model setup perspective

In this section, we provide a description of BS-PHY EAS4 performances with respect to BS-PHY EAS3, by referring to EAN: they have been computed by using analysis for both BS-PHY EAS3 and EAS4 against observations – insitu T/S profiles and along track SLA as reported in Table 1 – in the pre-qualification period 2019.

Figure 38 show temperature and salinity EAN – bias and RMSD – with respect to ARGO T/S vertical profiles. Considering temperature, both BS-PHY EAS3 and EAS4 show quite similar error (Figure 38b), while bias is quite different due to the different physical parameterization adopted by the two systems. BS-EAS3 has slightly lower error at the surface: this is a point for EAS4 and in particular for the need to improve the air-sea interaction and light penetration parameterization, for example.

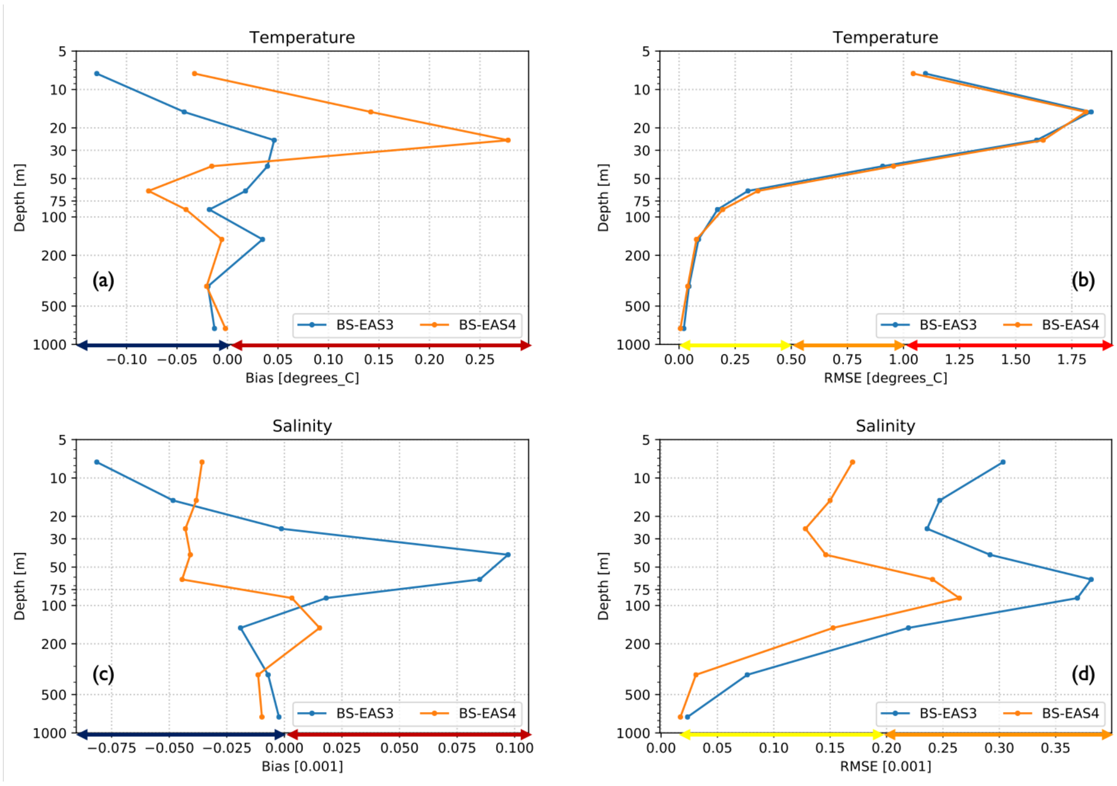


Figure 38 – EAN for temperature (bias (a) and RMSD (b)) and salinity (bias (c) and RMSD (d)) basin averaged profiles for assigned layers in 2019.

BS-PHY EAS4 has the best performance in terms of salinity with respect to EAS3: this is due to 1) the effect of the open boundary condition at the Marmara Sea box that, through the Bosporus Strait, provides a quite good representation of the Mediterranean waters influence (saltier and warmer waters through the lower layer) and 2) the improved representation of the river runoff inputs, in particular the Danube and the major ones for which a non-zero salinity is imposed. Even in terms of bias, the BS-PHY EAS4 provides the lower value per layer especially in the halocline region.

Figure 39 shows the EAN for sea level anomaly for the BS-PHY EAS3 and EAS4: the new system significantly improves the accuracy of the analysis, with a gain of around 1 cm.

Error! Reference source not found. shows the EAN for sea surface temperature for the BS-PHY EAS3 and EAS4: the new system improves a bit the accuracy of the analysis as well, with a gain of around 0.05ºC in average.

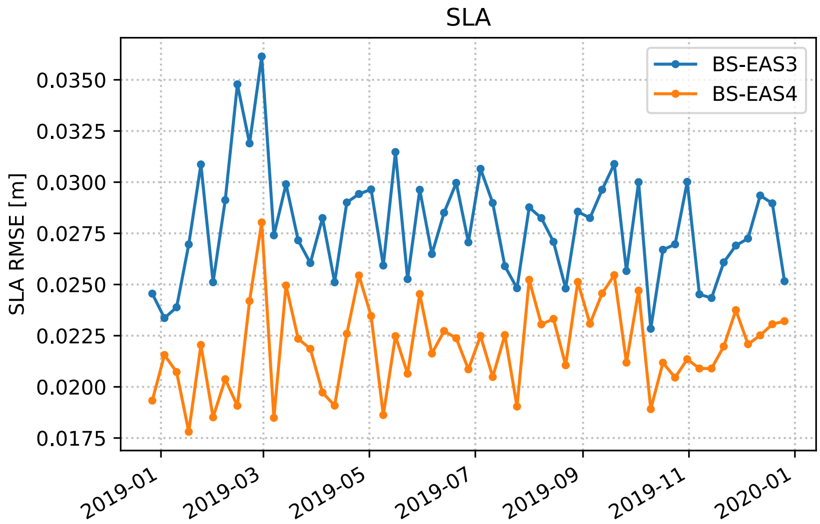


Figure 39 – EAN for sea level anomaly (RMSD) at basin scale in 2019.

The next figure shows the comparison EAS4 against SST L3 observations from CMEMS [SST-328]. Considering Figure 40, we indicate with EAS4.0 the system as in May 2021 EIS, with EAS4.1 the run performed by assimilating the timeseries. EAS4 after assimilating the new SST timeseries (e.g. EAS4.1) slightly improves skills but not significantly (from Oct 2019).

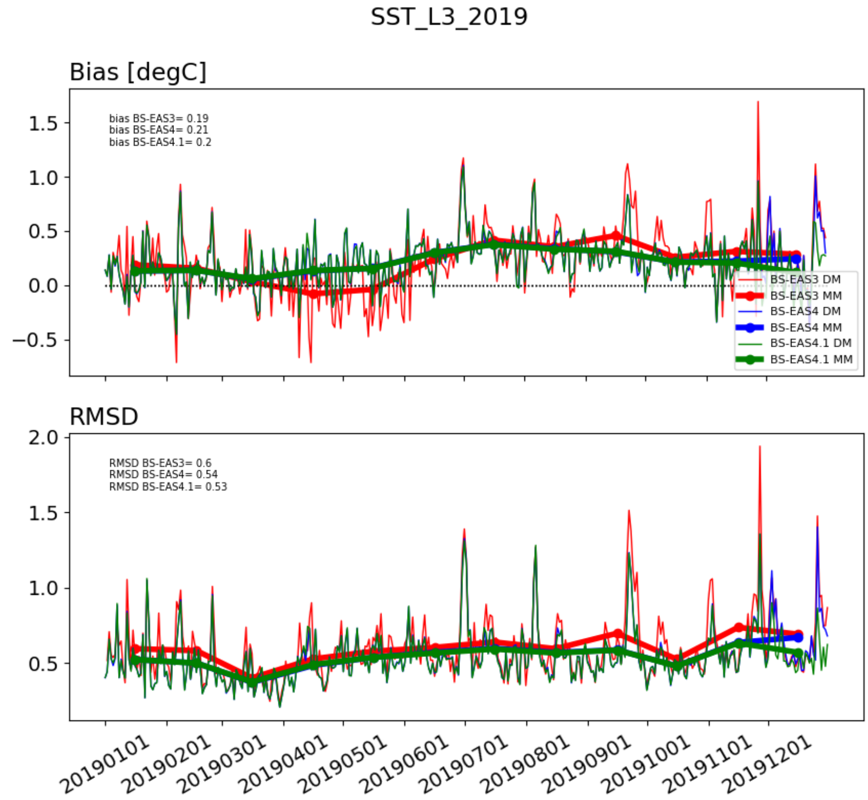


Figure 40 – EAN for sea surface temperature (bias on top and RMSD on bottom) at basin scale in 2019.

VI.2 The role of historical daily observed discharge at the Danube River

The Danube runoff strongly influences the Black Sea dynamics and therefore a better representation of the discharge variability will represent an improvement in the current system.

The Killworth correction was applied to all the 72 rivers represented by the BS-PHY NRT system (Killworth, 2006). Specifically for the Danube, the following settings have been used:

- From Jan 2017 to Jun 2020: monthly historical observations provided by NIHWM are provided at daily frequency with Killworth correction;
- From Jul 2020, daily observations operationally provided by NIHWM are used, including forecast data for the production of the Black Sea forecasting system.

As seen in Figure 4, the years 2017, 2019 and 2020 show a decrease in the runoff, namely 20%, 14% and 25% with respect to the climatological value. To evaluate the impact of the changes described in 2020 and beginning 2021 we compared the model sea surface temperature with a moored buoy next to Sulina (platform 15360 – see Table 2 and Figure 41). Figure 42 show the comparison of SST a) from analysis of EAS4.0 (blue) and EAS4.1 (orange) and b) observations at mooring location as in Figure 41 (black crosses). In the summer months there is a clear reduction in the SST bias from EAS4.1 of more than 3ºC.

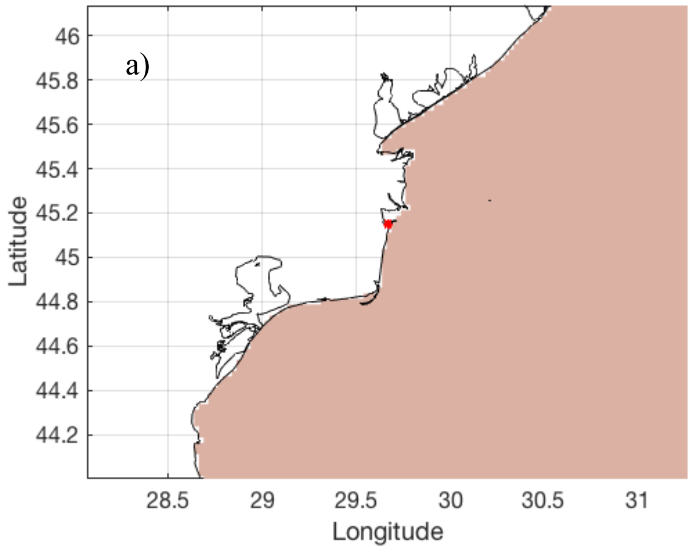


Figure 41 – Location of mooring ID=15360 at the Sulina branch in the Danube Delta.

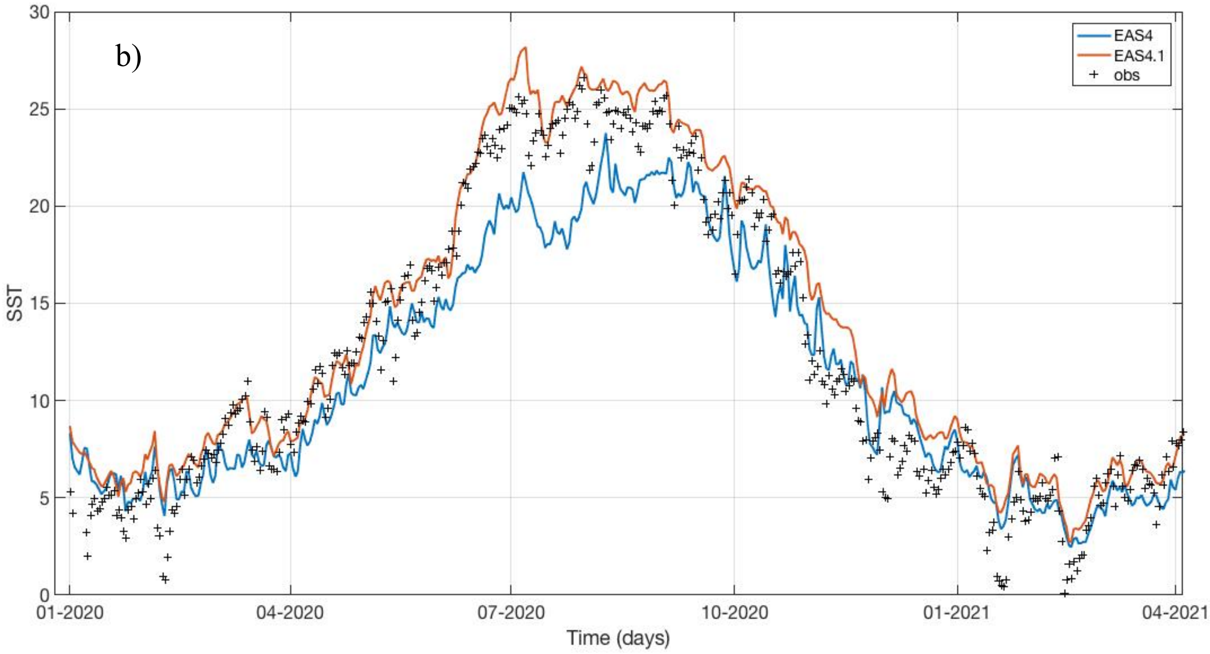


Figure 42 - Sea surface temperature comparison between EAS4.0 (blue), EAS4.1 (orange) and observations (black crosses) at the mooring location.

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