

Evolution of the Black Sea Physical Analysis and Forecasting System within CMEMS

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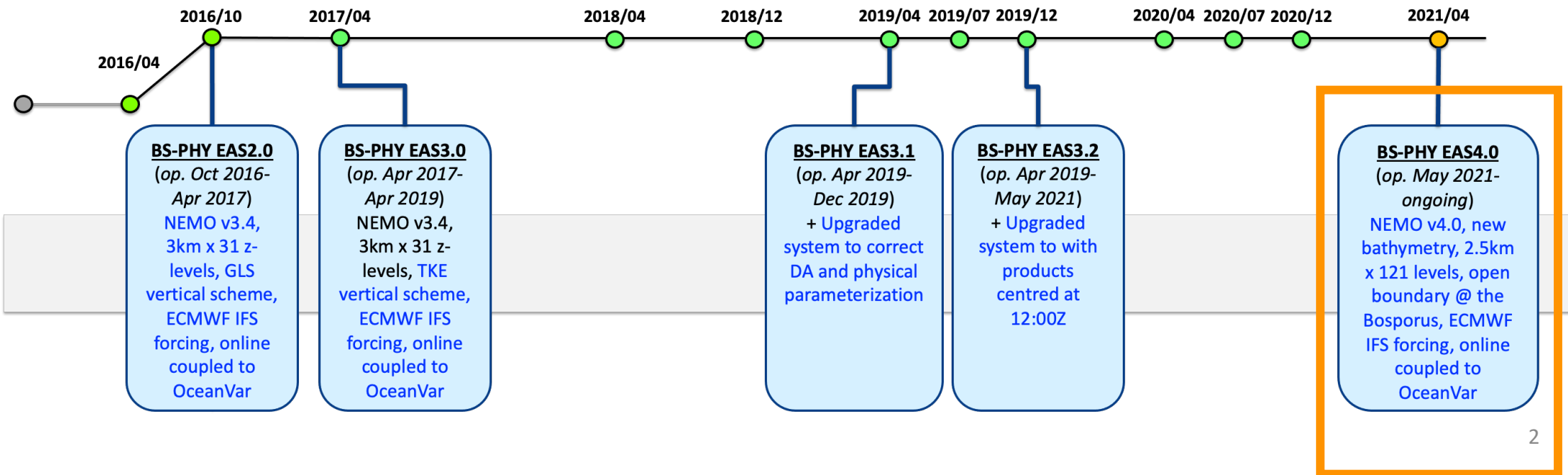
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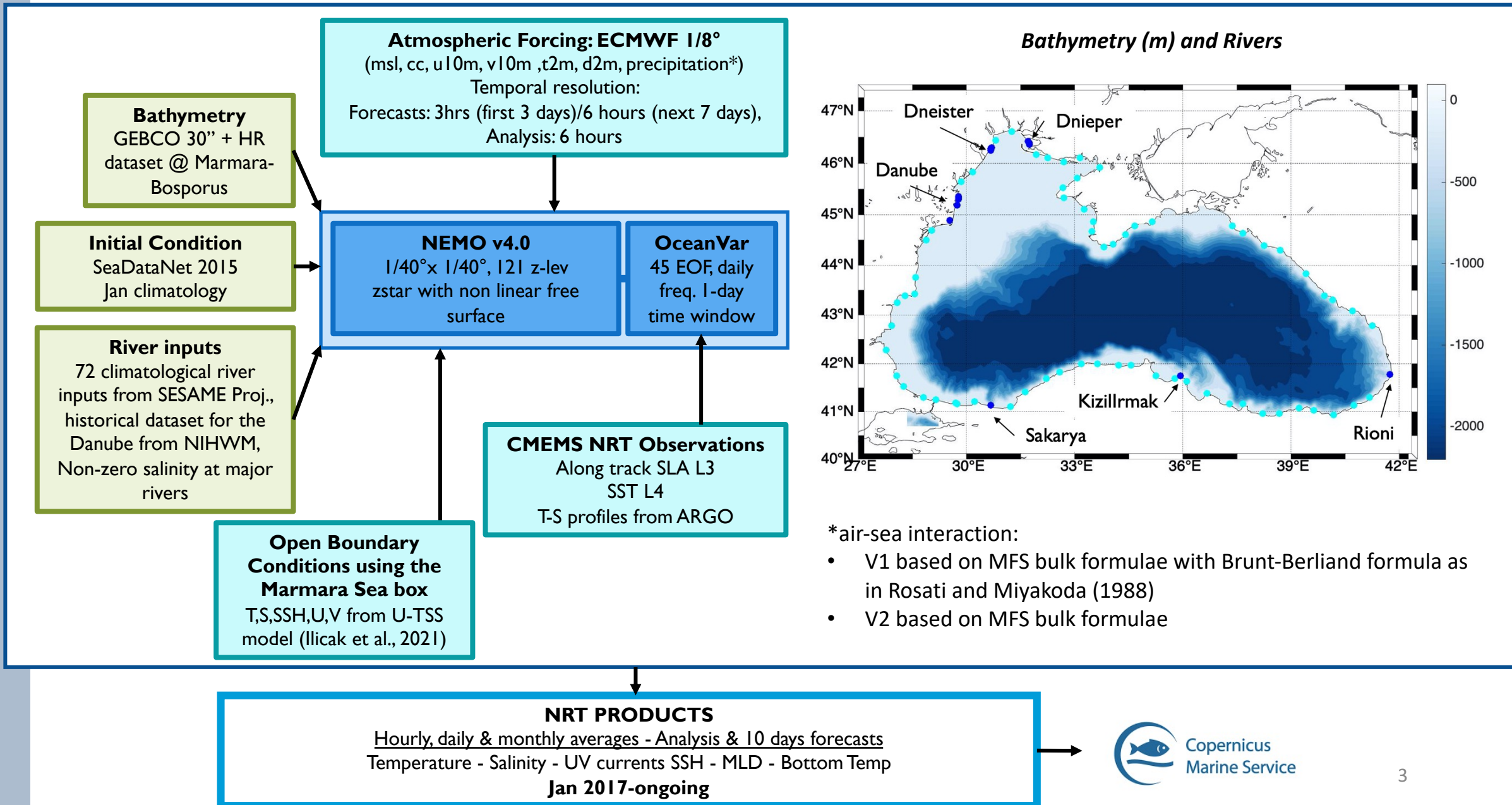
Credits: NASA

The BS-PHY in CMEMS: A successful story

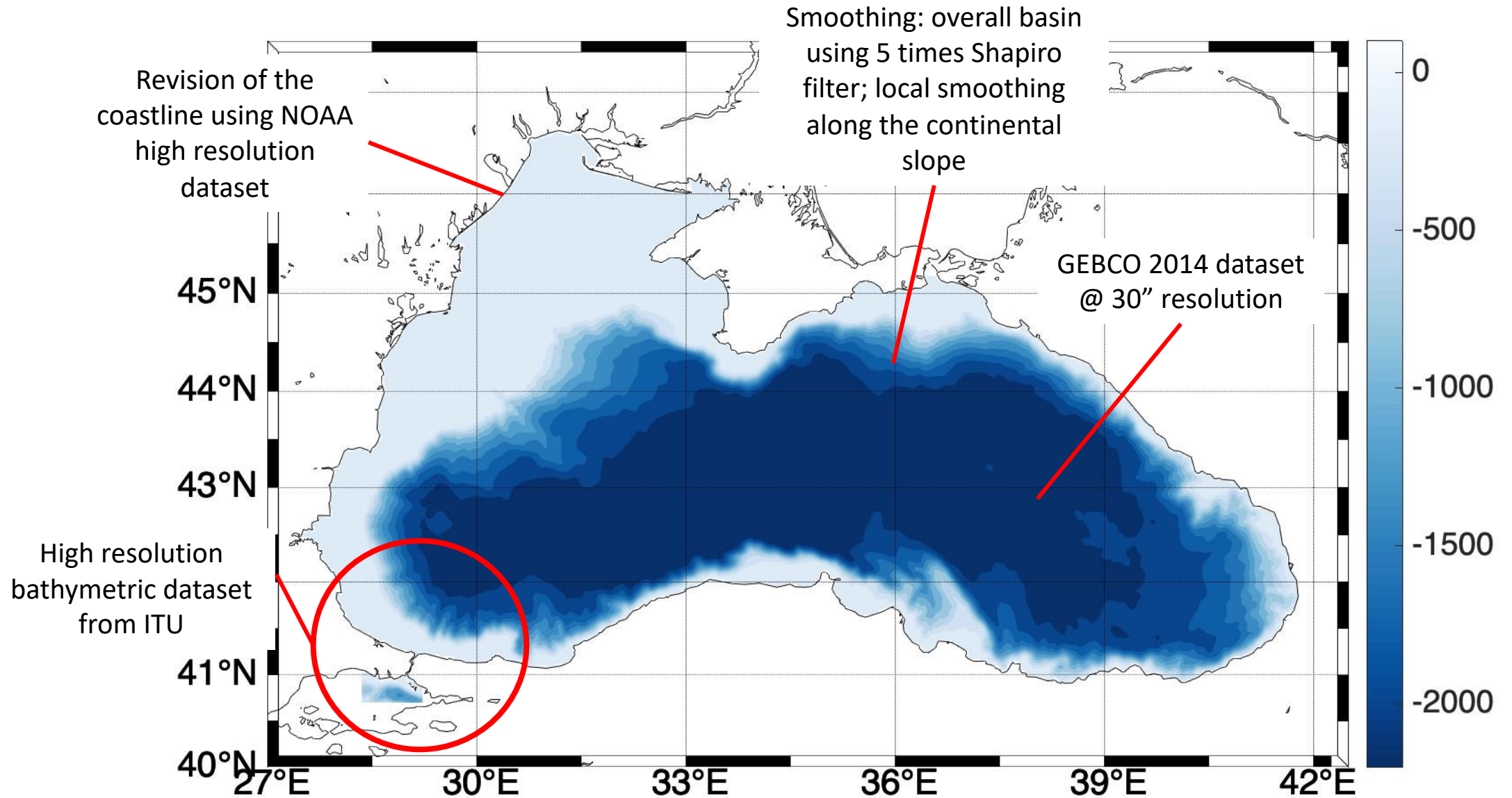
- Reconstructing and predicting the Black Sea ocean state is a challenging objective that primarily concerns the development of the numerical hydrodynamics to simulate the complex dynamics of this large estuarine basin
- In the framework of Copernicus Marine Environment and Monitoring Service (CMEMS), the BS-PHY is the Physical core of the Black Sea Monitoring and Forecasting Center (BS-MFC), devoted to provide analysis and forecasting fields for the essential ocean variables in the Black Sea. It is working operational since 2016
- Improving the quality of analysis and forecasting fields for the Black Sea through
 - Increased vertical resolution
 - The optimal interface with the Mediterranean Sea
 - Better representation of rivers
 - Upgrades in data assimilation scheme



The BS-PHY EAS4 modelling system: an overview



The Black Sea bathymetry @ 2.5 km resolution: actions



The Danube and its representation in the BS-PHY EAS4



- The Danube River has the greatest delta among the European rivers
- Delta is distributed along 204 km of Romanian coastline and the Danube floodplain occupies around 3500 km²
- The main arms are 3:
 - Chilia arm, subdivided into 3 sub-arms, the southern one located in Romanian territory
 - Sulina arm
 - Sfintu Gheorge (St. George) arm

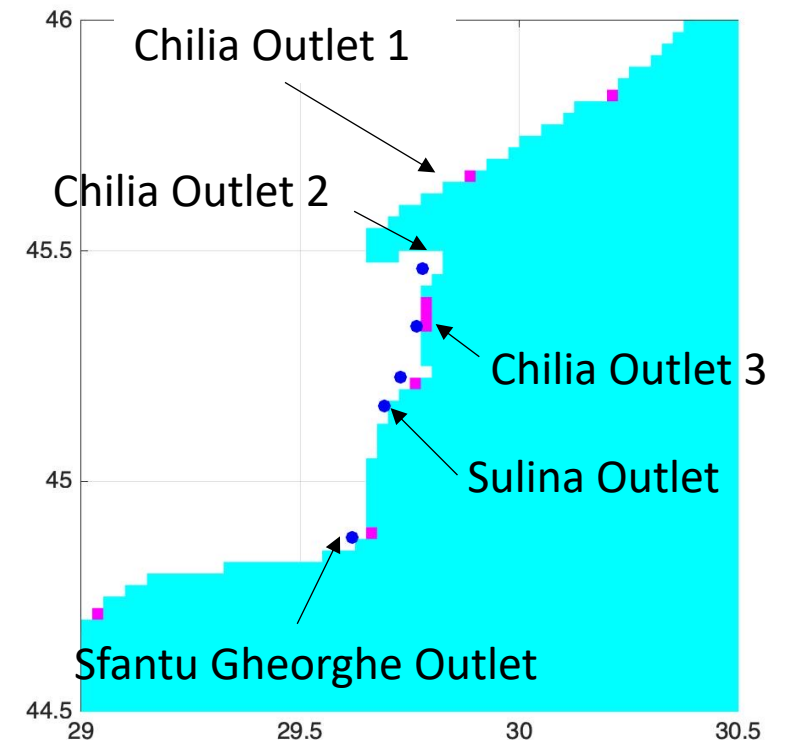
The Danube and its representation in the BS-PHY EAS4

Considering high variability of the Danube arms (some of them have important variations under certain periods) NIHWM proposes to compute contributions in the following way:

- Main input data: Discharges at Danube - Isaccea and Tulcea Arm - Tulcea (converted from water levels using the existing rating curves)
- $Q_{\text{Chilia Arm}} = (Q_{\text{Isaccea}}) - (Q_{\text{Tulcea}})$
- $Q_{\text{Chilia_1}} = 0.22 * Q_{\text{Chilia Arm}}$
- $Q_{\text{Chilia_2}} = 0.42 * Q_{\text{Chilia Arm}}$
- $Q_{\text{Chilia_3}} = 0.36 * Q_{\text{Chilia Arm}}$
- $Q_{\text{Sulina}} = 0.20 * Q_{\text{Isaccea}}$
- $Q_{\text{Sfantu Gheorghe}} = (Q_{\text{Tulcea}}) - (Q_{\text{Sulina}})$

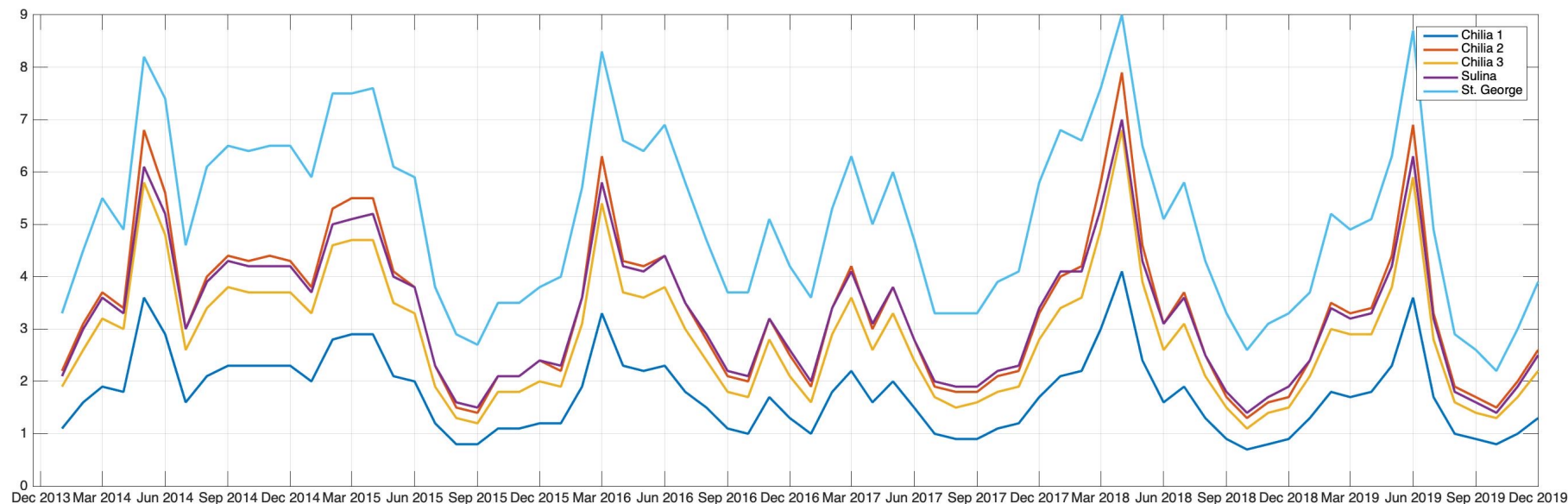
In the figure on the right:

- **Purple square**: river grid points in bs-nrt
- **Blue dots**: location of the 3 branches as provided by NIHWM



The Danube and its representation in the BS-PHY EAS4: discharge

- **Evaluating NIHWM interannual dataset for the Danube** – In the figure below, we see the Danube hydrograph for the 5 outlets – 3 for Chilia, 1 for Sulina and 1 for St. George – in the period 2014-2019

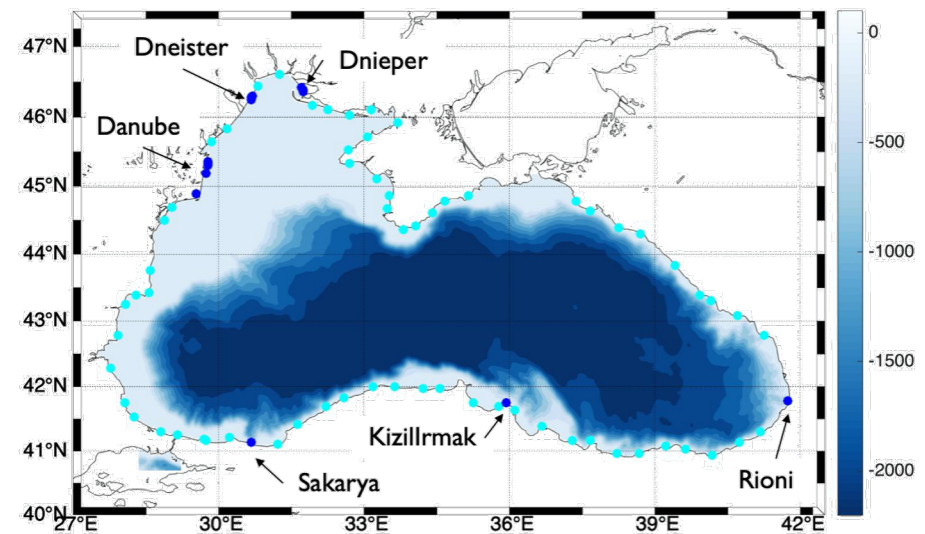
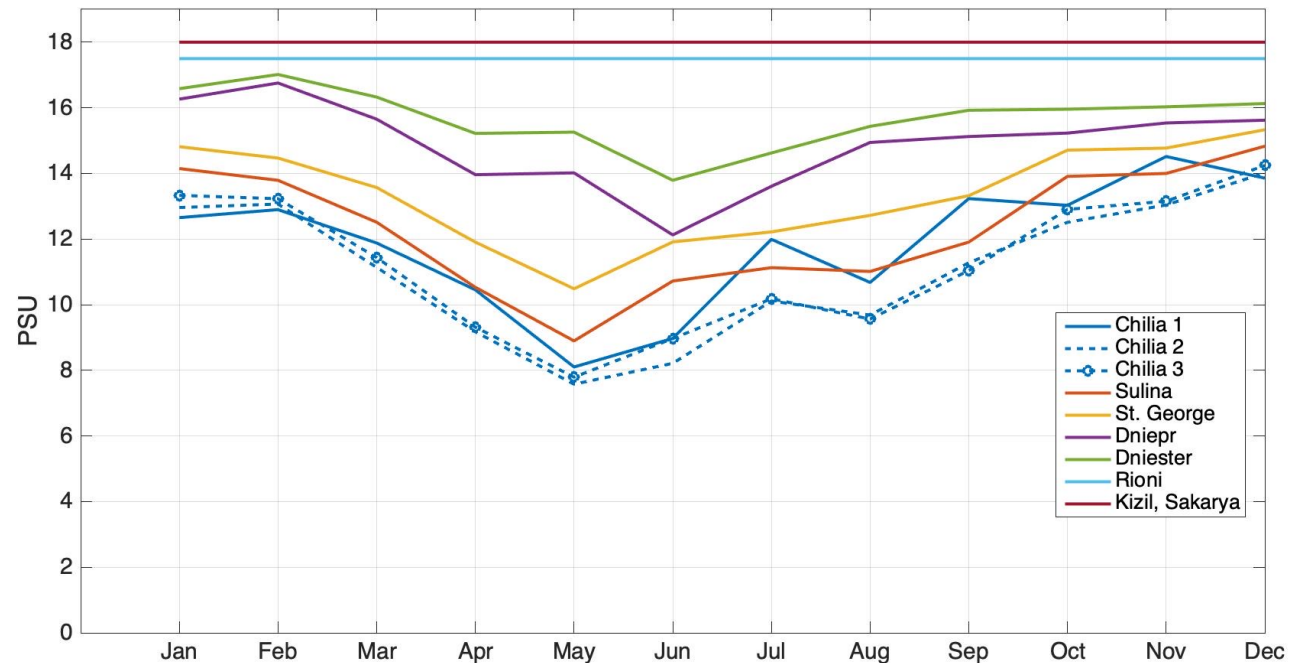


Outlet/km 3/yr >	SESAME	CL 1980- 2014	CL 2014- 2019	2014	2015	2016	2017	2018	2019
Chilia	105	109	96	117	95	98	77	100	88
Sulina	40	40	39	47	39	41	33	41	35
St. George	57	53	63	70	61	65	54	64	53
TOTAL	202	202	198	234	195	204	164	205	176

The Danube and its representation in the BS-PHY EAS4: discharge

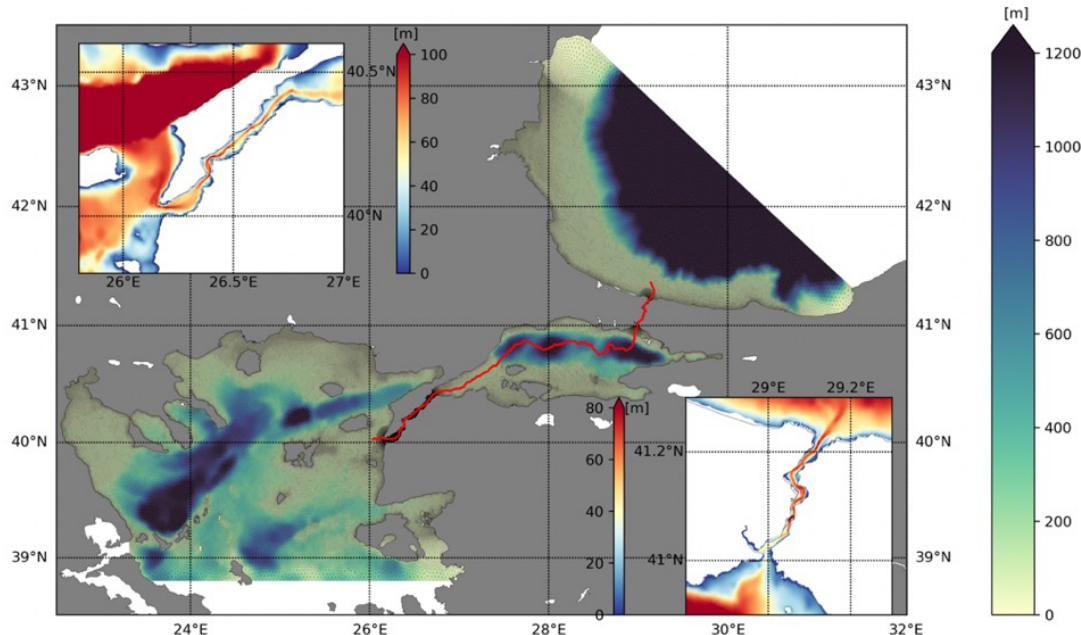
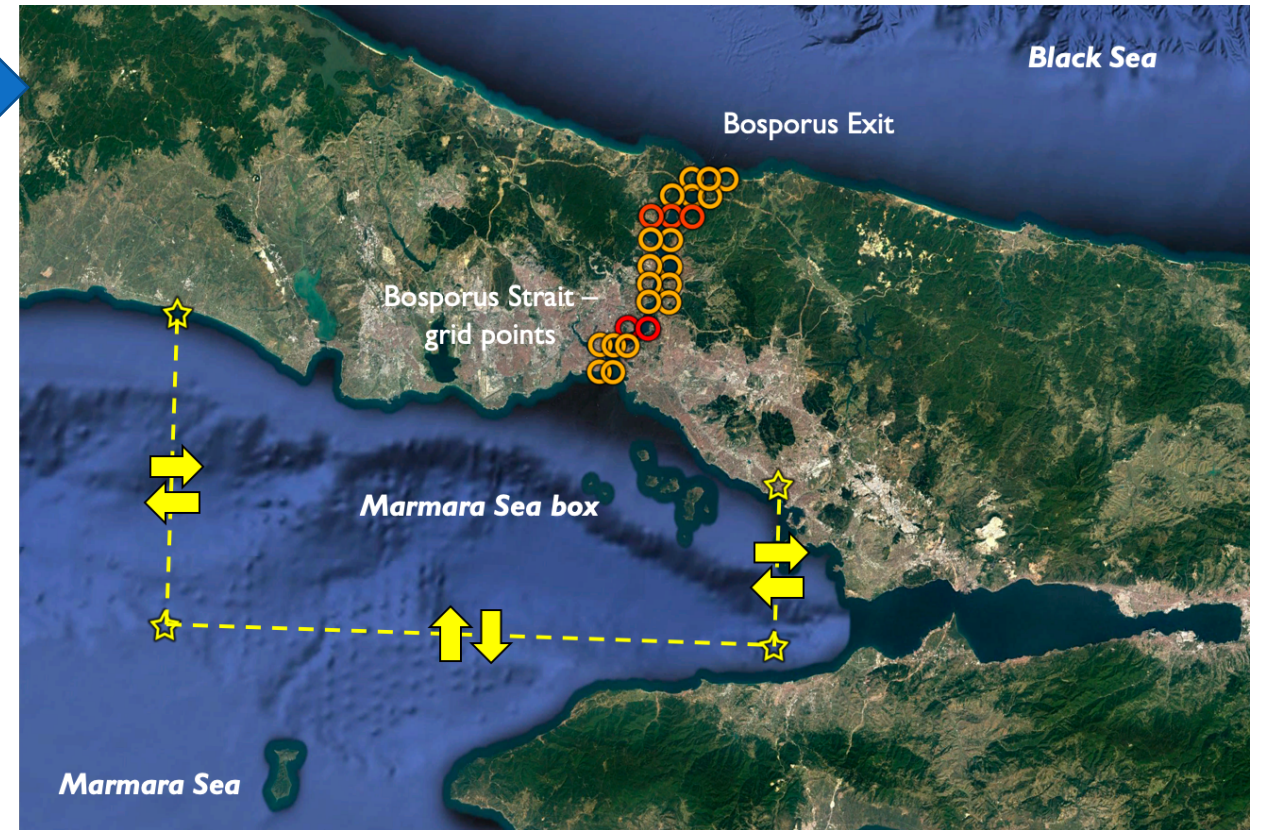
- **Representing the salinity for the main BS rivers:**

- Zero salinity for all the 72 rivers
- Providing monthly salinity climatologies for the Danube, Dniester and Dniepr and constant monthly values for Rioni, Kizilirmak, Sakarya (since no variation from SDN) (figure below). Values estimated from SDN15 monthly climatology for salinity (1997-2015), while Rioni 17.5 PSU, Kizilirmak 18 PSU, Sakarya 18 PSU



The Lateral Open Boundary Conditions in the BS-PHY EAS4

- The Marmara Sea “box” as optimal interface between Mediterranean and Black Seas
- The **Unstructured Turkish Straits System** (U-TSS) developed for the Marmara Sea with 2 open boundaries in the 2 regional basins (Ilıcak et al. 2021)
 - Based on SHYFEM (System of Hydrodynamic Finite Element Modules)
 - Resolution between 500 meter in the deep to 50 meter in the shallow areas to resolve the Turkish Straits, and 93 geopotential

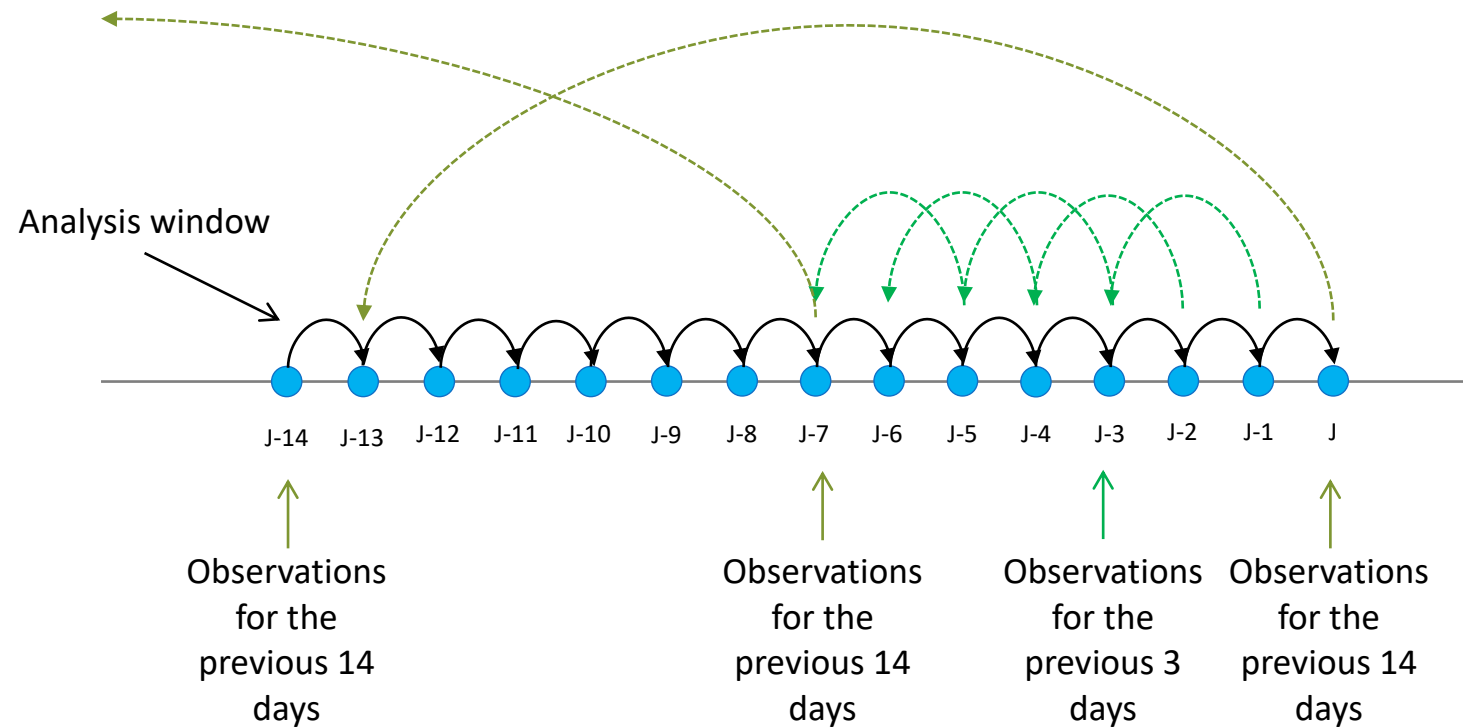


U-TSS high resolution monthly climatological T, S, SSH, U, V to BS-PHY EAS4

- 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: 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
- Assimilated observations are:
 - T/S profiles from ARGO provided by the CMEMS INS TAC (higher quality)
 - Along track Sea Level Anomaly from satellites such as Altika, Cryosat2, Jason2-3, Sentinel3A-3B (L3) provided by CMEMS SL TAC
 - Sea Surface Temperature from satellite provided by CMEMS SST TAC
- 45 spatially varying 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

BS-PHY EAS4 processing system



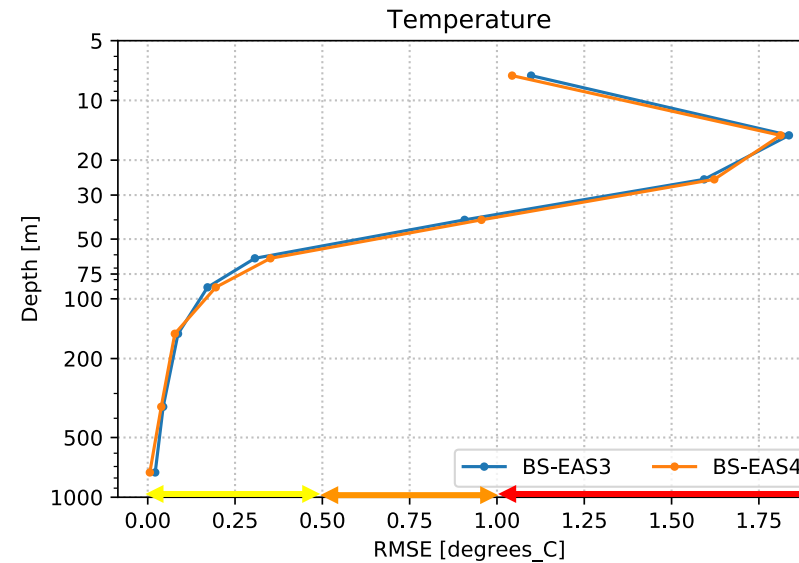
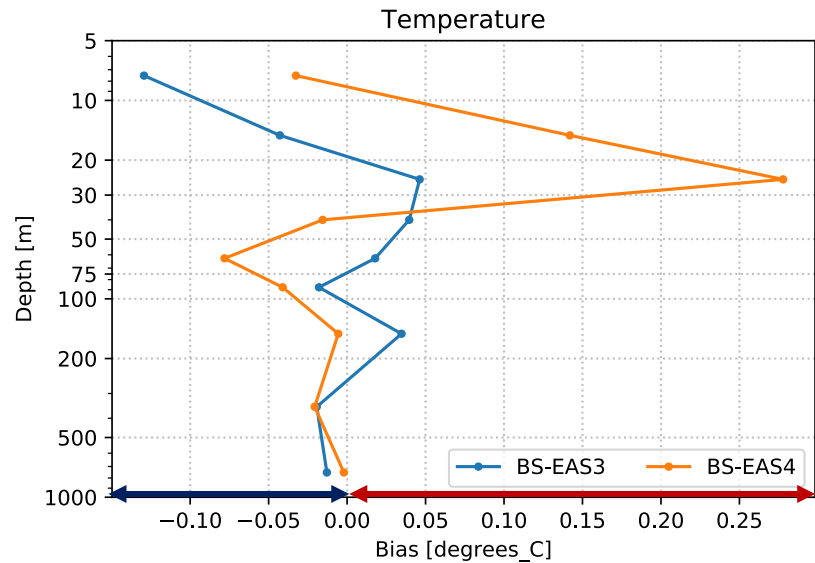
Analysis: every day, a simulation + assimilation correction is performed using ECMWF analysis fields. BS-PHY implements 2 cycle:

- **Daily cycle:** redoing analyses for the previous 3-days with available observations
- **Weekly cycle:** redoing analyses for previous 14 days with newly high quality observations

Simulation: every day, the initial condition for the forecast cycle is generated by a model simulation for the previous 24 hours and forced by ECMWF analysis atmospheric fields

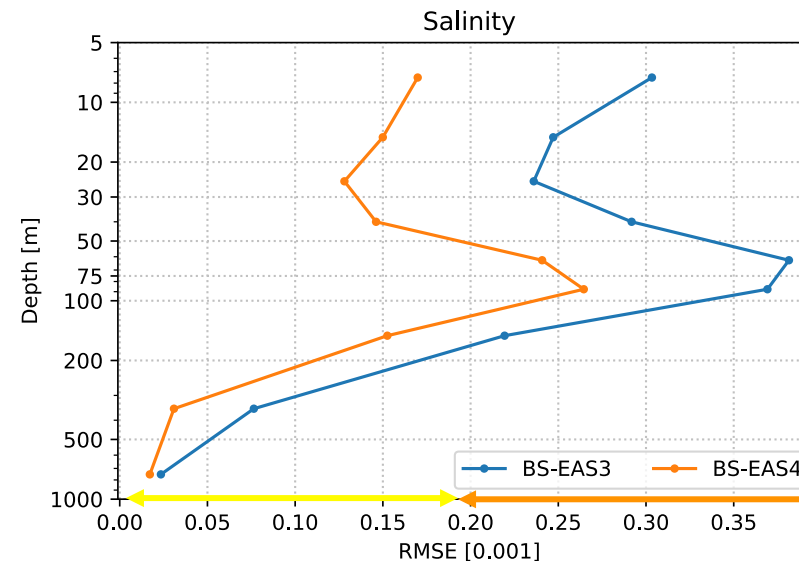
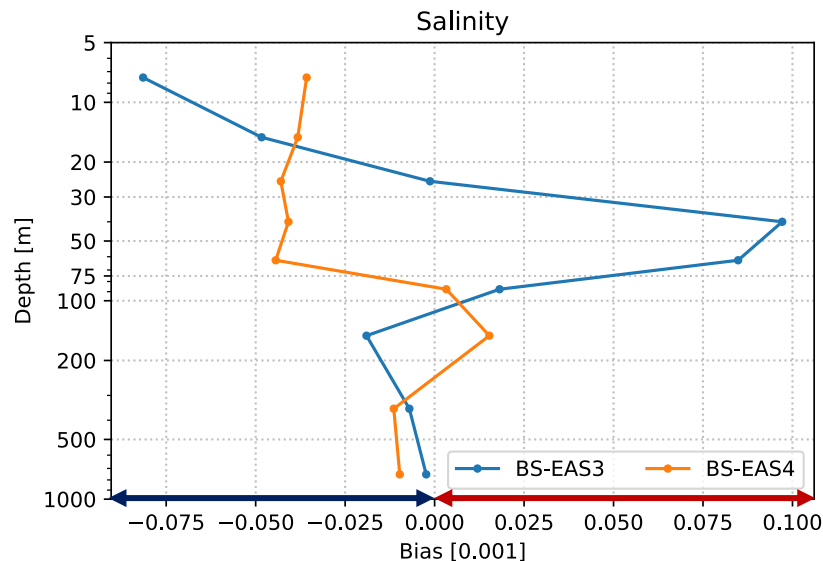
Forecast: computed for the next 10 days, using ECMWF forecast atmospheric fields

T-S Estimated Accuracy Numbers using ARGO insitu profiles



Temperature

- EAS3 and EAS4 show similar error, with slight improved performances of EAS4 at the subsurface (5-10 m: EAS4 with $\sim 1.3^{\circ}\text{C}$ vs EAS3 with $\sim 1.1^{\circ}\text{C}$)
- EAS3 is colder than EAS4



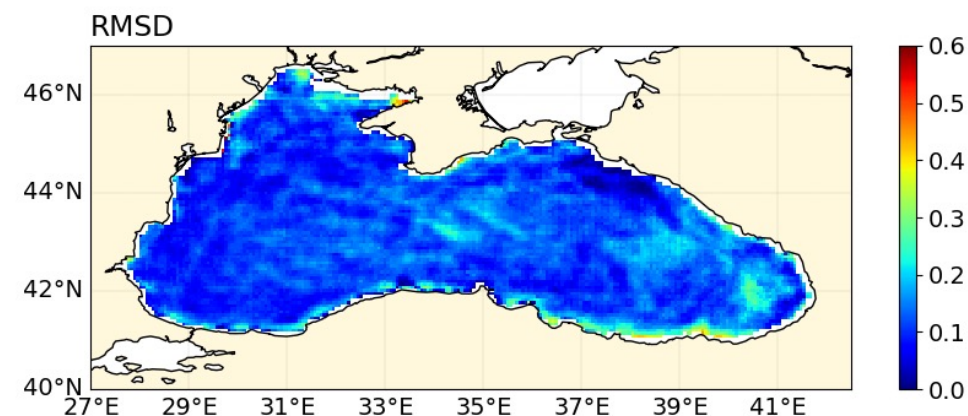
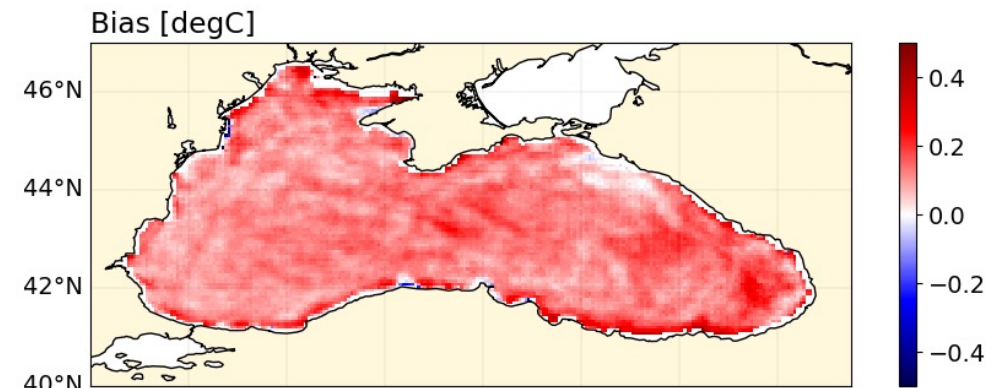
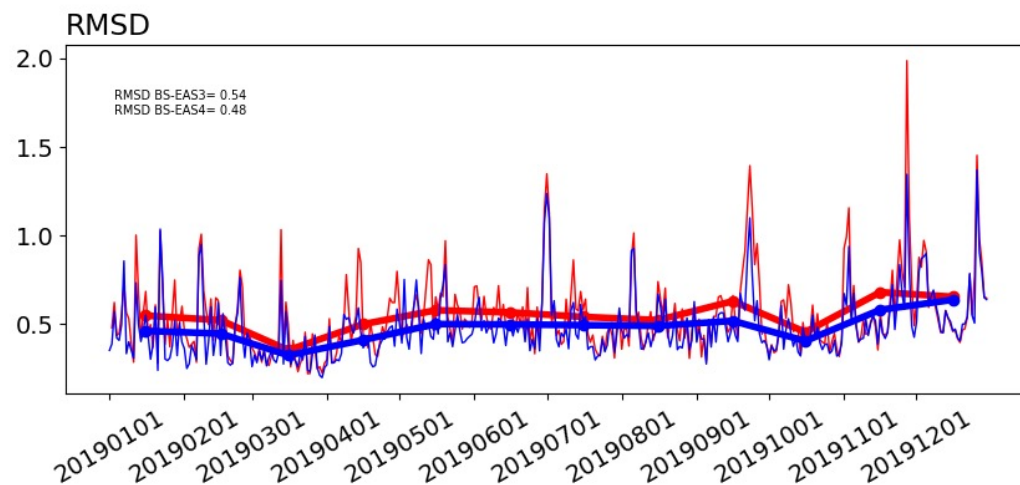
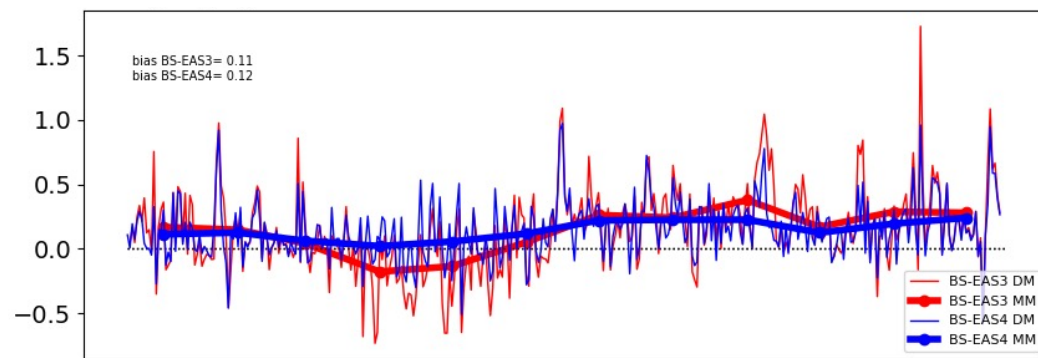
Salinity

- EAS4 is significantly improving salinity with reducing the error almost half with respect to EAS3
- Quasi-zero BIAS is given by EAS4

Positive effect of:

- OBC
- River runoff

SST timeseries and spatial distribution of Estimated Accuracy Numbers computed using SST satellite data



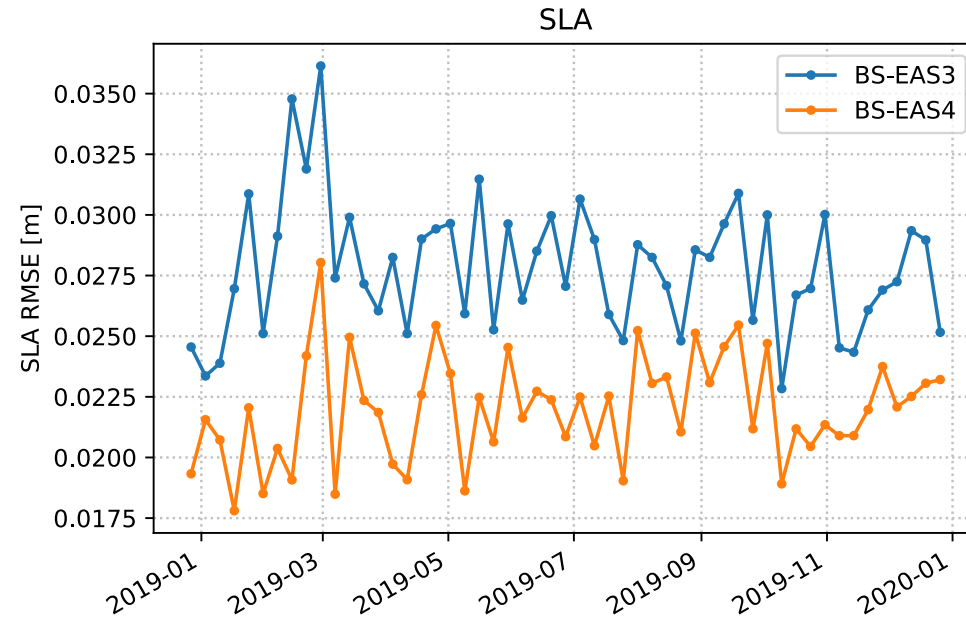
Sea Surface Temperature

- EAS3 and EAS4 show similar error (EAS4 is still slightly better)
- SST error over 2019 shows higher error (up to 0.3°C) in the Eastern basin, in the area of the Batumi gyre, and along the Bulgarian-Romanian coastline

SLA Estimated Accuracy Numbers timeseries using all available SLA L3 data

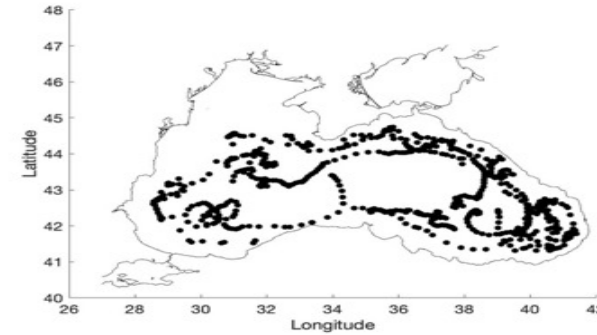
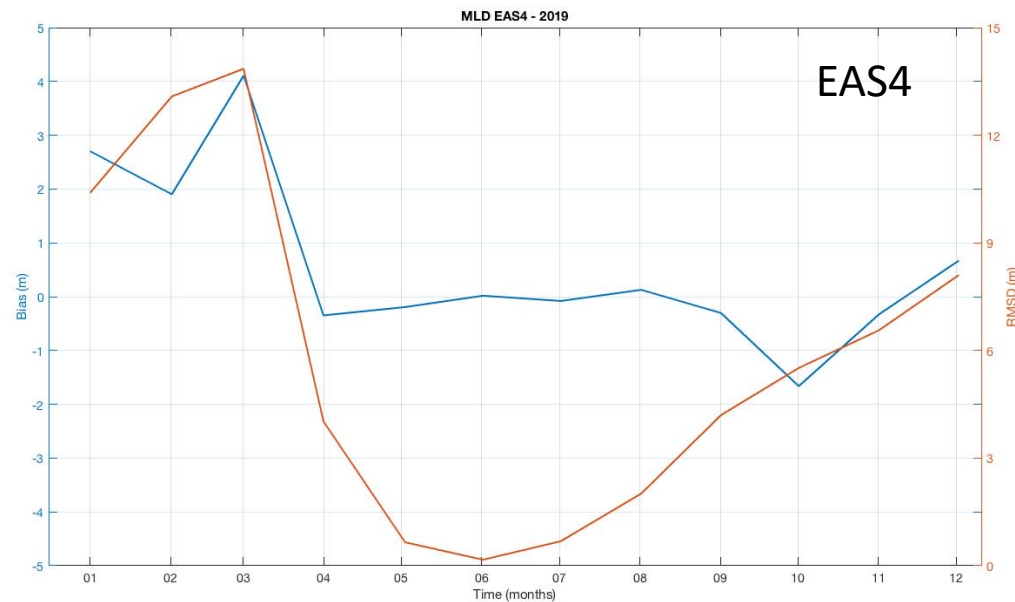
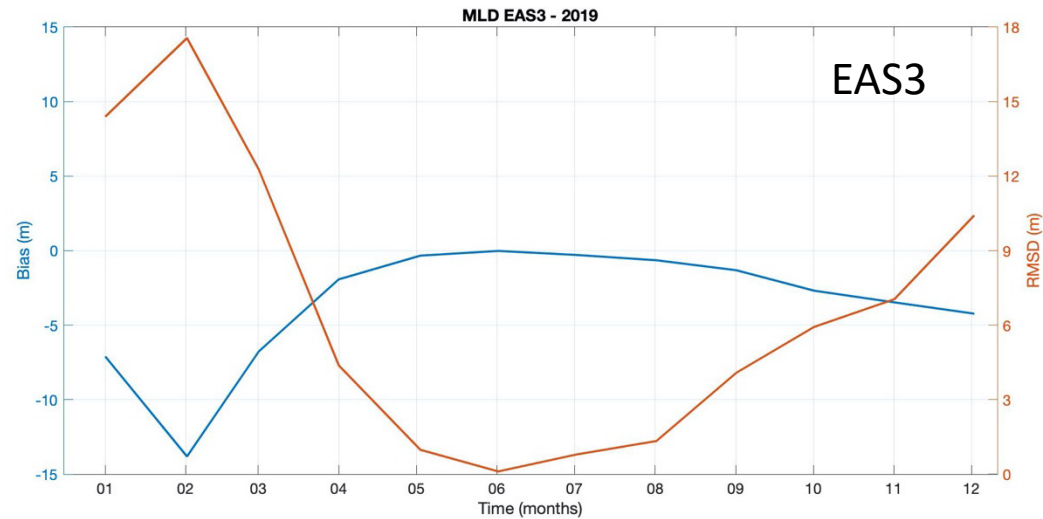
Sea Level Anomaly

- 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



RMSD [cm]		BIAS* [cm]	
BS-PHY EAS3	BS-PHY EAS4	BS-PHY EAS3	BS-PHY EAS4
3.2	2.2	0.000	0.000

Mixed Layer Depth

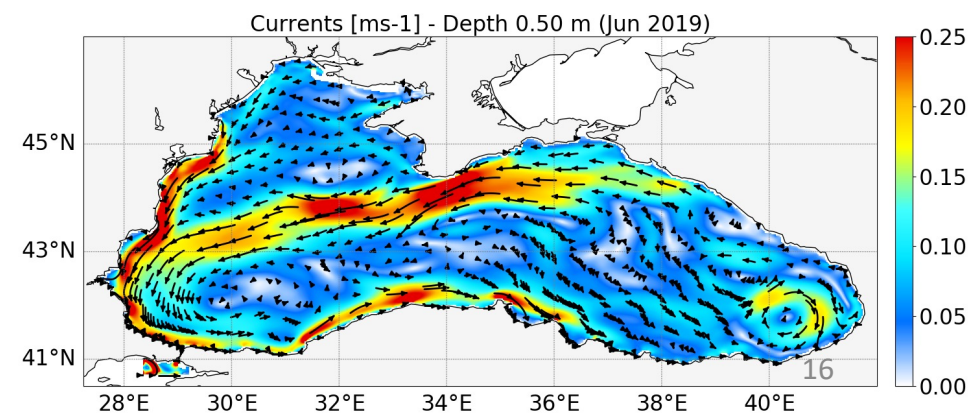
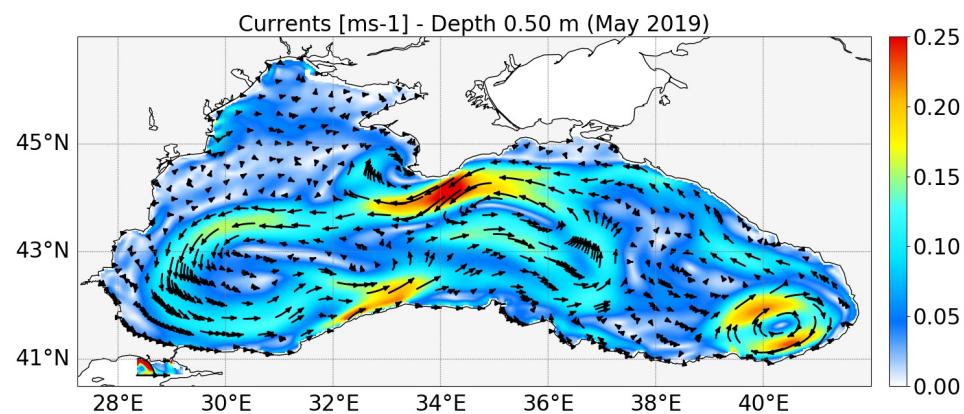
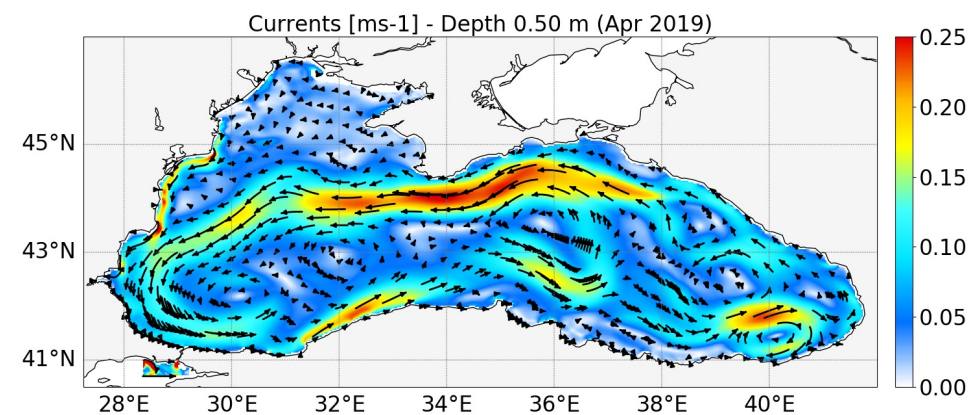
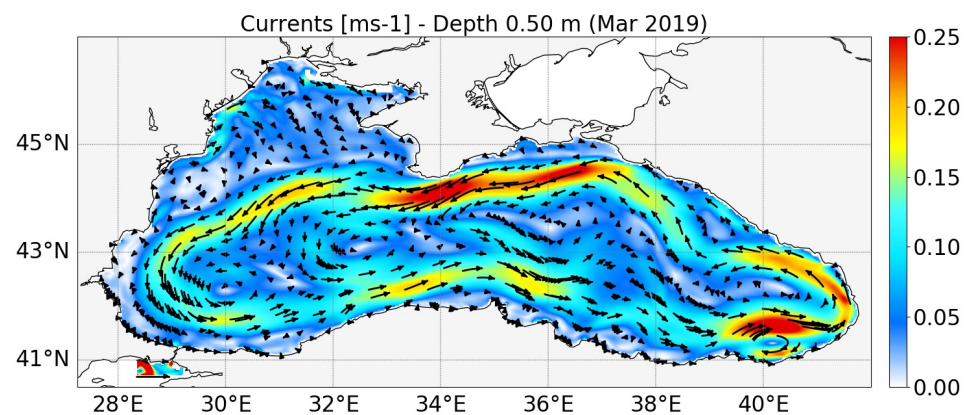
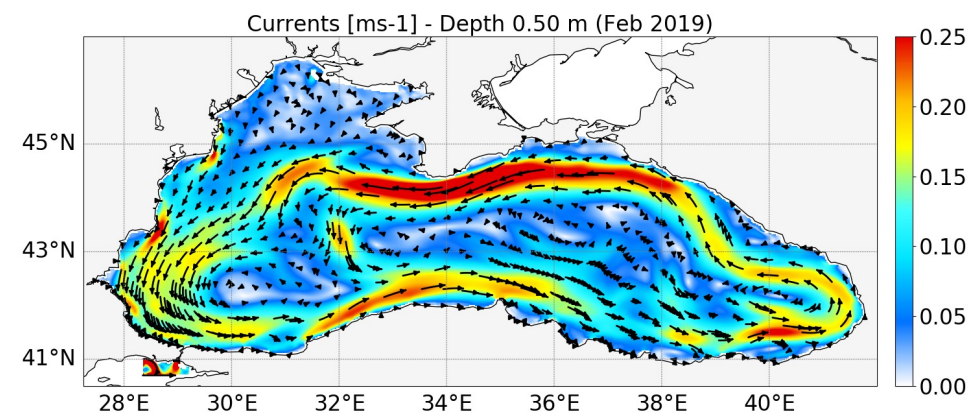
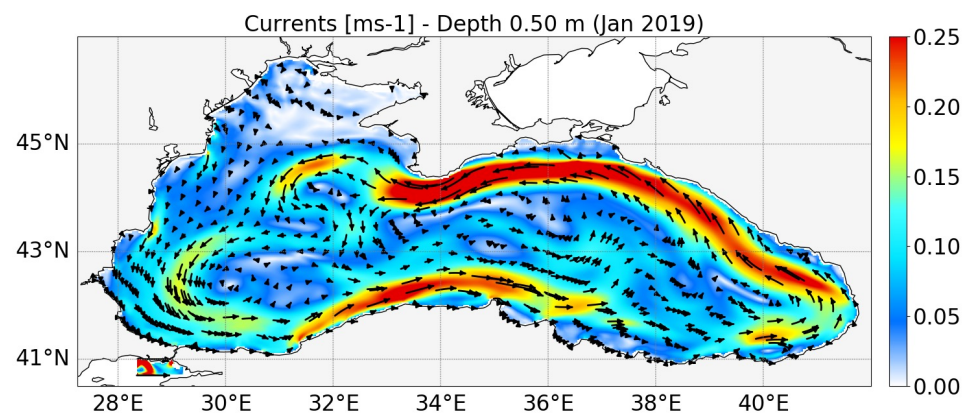


Monthly evolution of the mixed layer depth in 2019 as given by the BS-PHY EAS3 (top) and BS-PHY EAS4 (below) at basin scale at ARGO location.

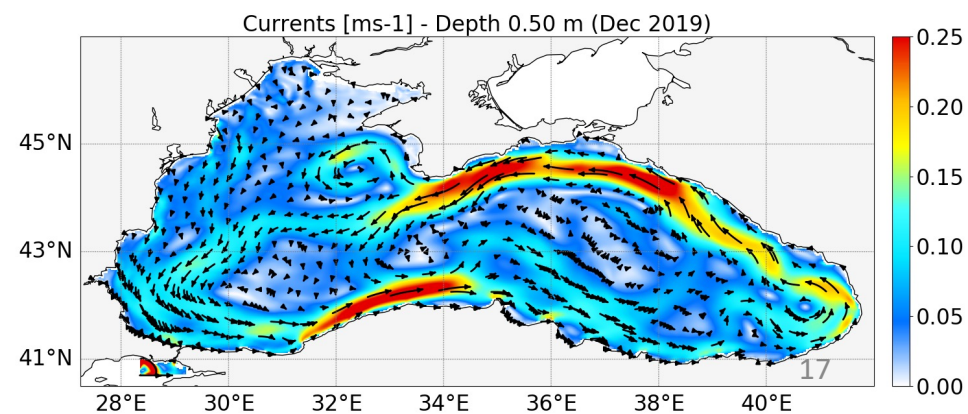
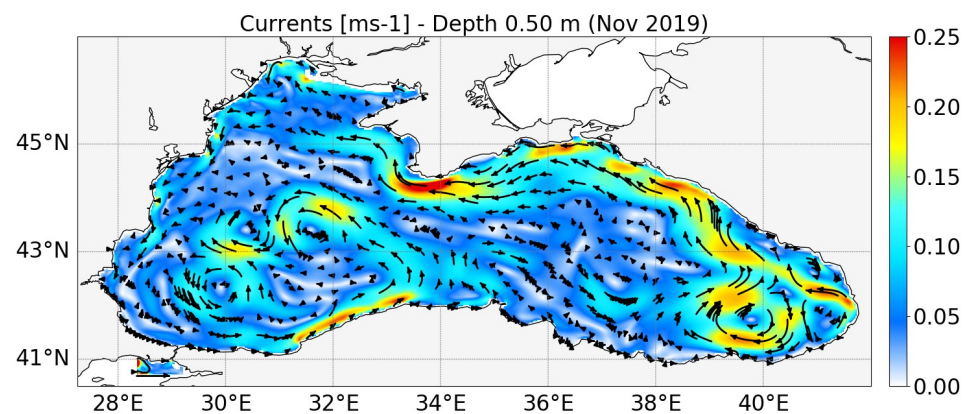
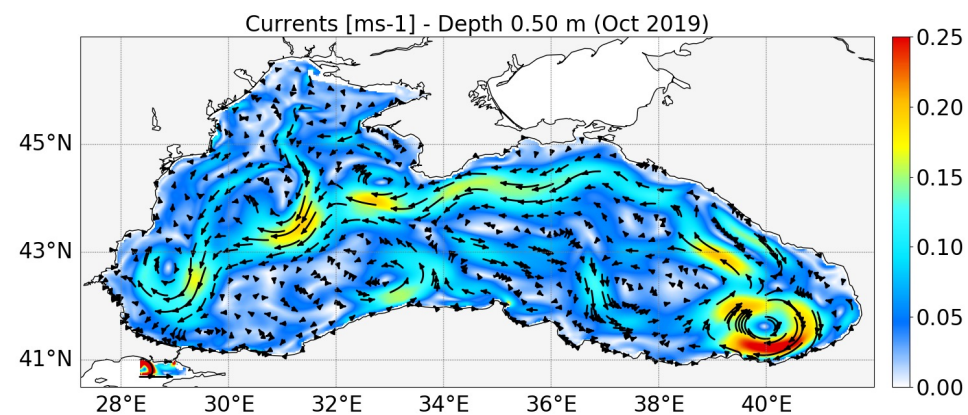
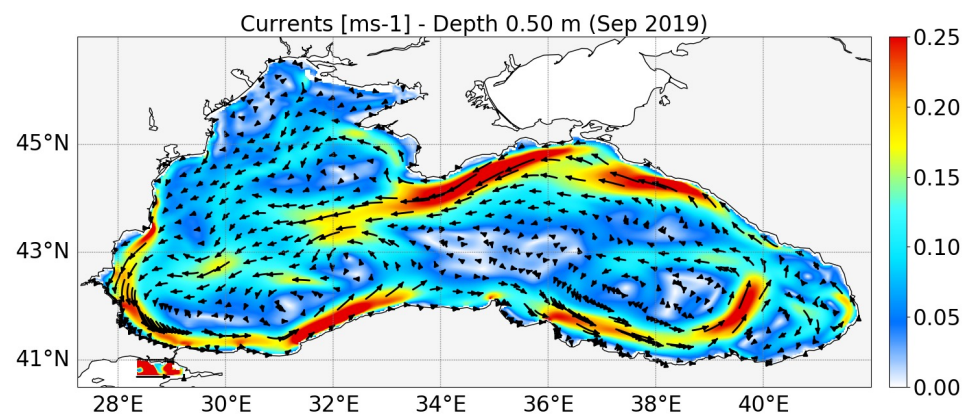
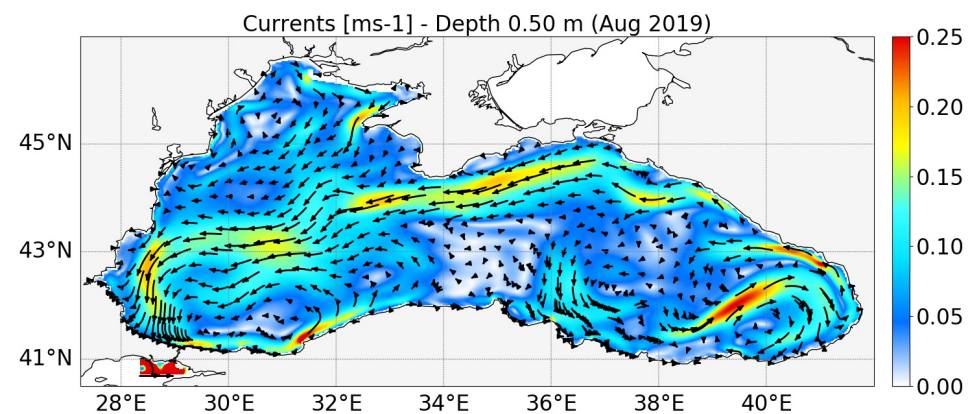
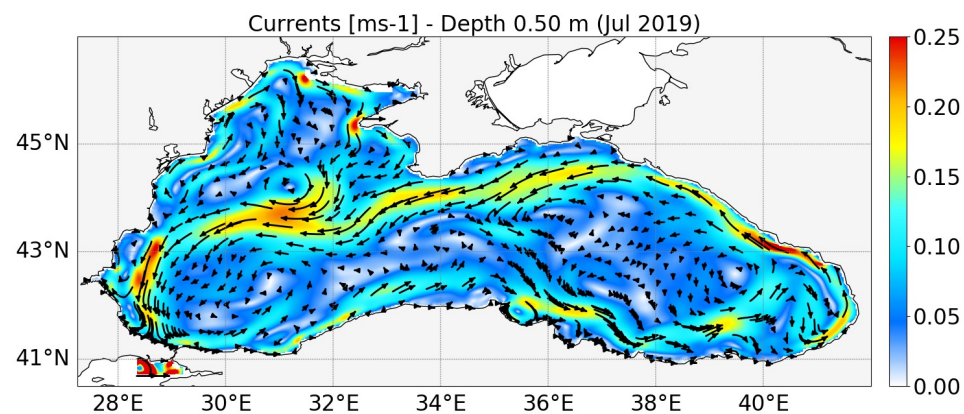
Both metrics have been computed using ARGO T/S at the closest location to the selected point.

The new system is able to provide better estimation of the mixed layer depth and in good agreement with literature.

Surface Currents in 2019



Surface Currents in 2019



Summary

- The new Black Sea Analysis and Forecasting system (EAS4) setup and pre-qualification has been presented, with focus on major upgrades with respect to previous version
 - Model bathymetry and spatial grid
 - Hydrodynamical model and data assimilation scheme
 - Lateral Open Boundary Conditions at the Marmara Sea for the optimal interface with the Mediterranean Sea
 - River runoff with focus on the Danube River
- Implementation of open boundary conditions at the Marmara Sea box, revisions of river runoff representation and increased vertical levels have significantly improved the quality of the BS-PHY analysis product especially in salinity and in the representation of the subsurface temperature. Also SLA is characterized by satisfactory skills
- The evaluation 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 and submesoscale eddies



Thank you!