Response to reviewer's comment

The answers from the authors are in red italic

Review #1 (RC1)

RC1.1: In this study, Jacopo Alessandri et al use the biogeochemical model BFM coupled to the ocean circulation model SHYFEM-MPI in an regional-unstructured-grid configuration of the North-West Adriatic, with a resolution that goes from 2km down to 300m on the coast, and compare it to their usual NEMO-BFM version (2km resolution).
Although the study is well done and shows that SHY-BFM has an improved biogeochemistry, lots of questions remain open, that prevent to really understand why it's better, and i think a major revision might be needed to fill all the gaps.

Response: *We thank the reviewer for the in-depth analysis and constructive comments. The doubts and questions raised are entirely reasonable and we have done our best to address all of them. Below we respond point by point; manuscript line numbers refer to the revised version unless stated otherwise. The text that was added to the manuscript is reported here between quotes (" "). Please note that we added a new figure in the manuscript (Fig. 3) so from figure 3 on they all shifted by 1 number, so the old Fig. 3 is now Fig. 4, Fig. 4 became Fig. 5 and so on.*

General comments.

RC1.2: My general feeling about the study is that, we miss a whole part of the study. Biogeochemistry is a slave of the physics, and we can't understand why BFM acts differently in SHY-BFM without a minimum evaluation of both SHY-BFM and NEMO-BFM physics. In particular things that will explain the differences we see: circulation changes, mixing, T-S maps...

Response: *We thank the reviewer for the comment. To address this issue, we added a new section (4.4.1 Surface circulation, temperature and salinity maps; lines 280-299) where we show the temperature and salinity maps, comparing them with the climatological values from EMODnet, where we also superimposed the SB circulation on the temperature field (Fig. 3). We added here the new figure.*

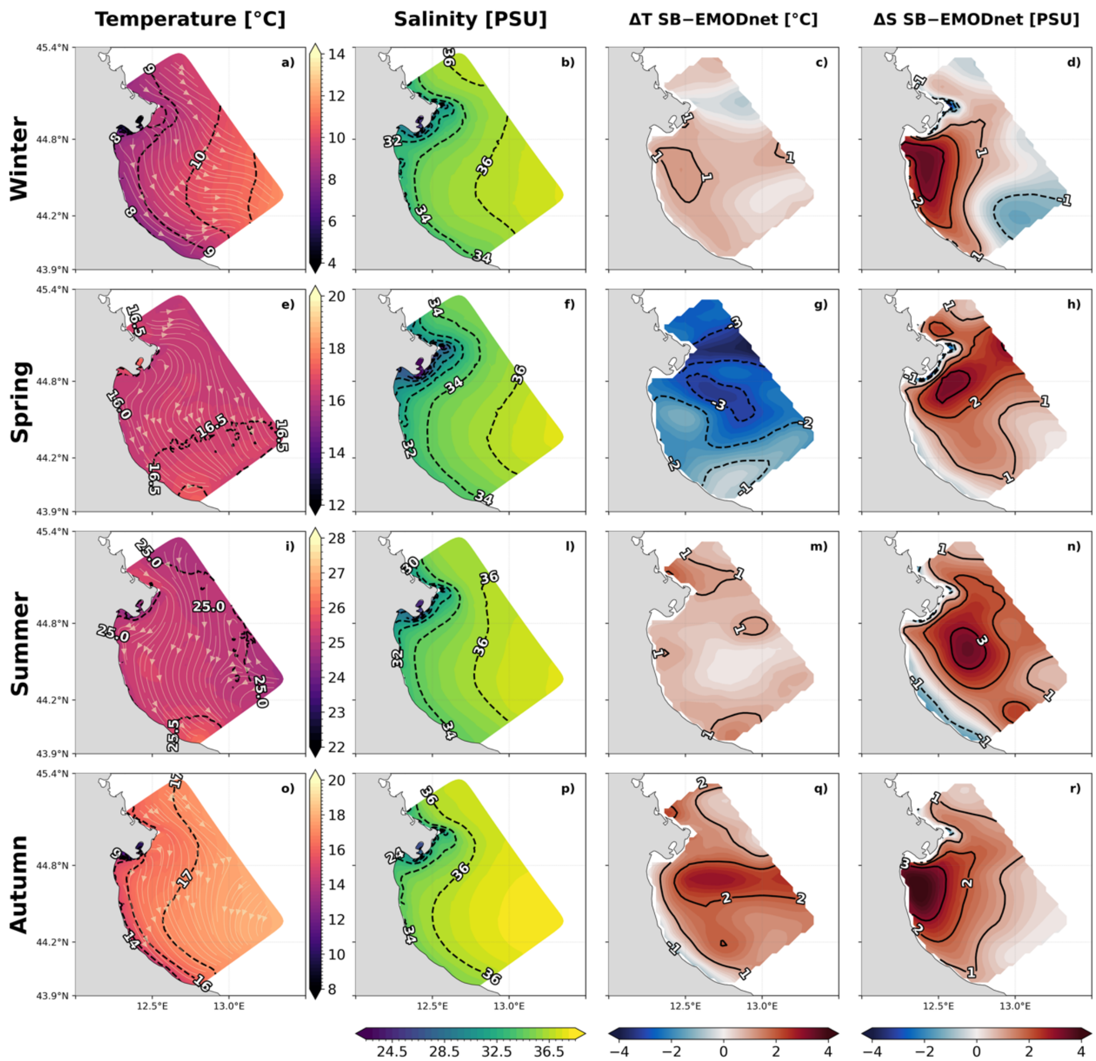

Figure 3: Seasonal surface maps of temperature with superimposed mean circulation (a, e, i, o) and salinity (b, f, l, p) for SB and differences against EMODnet climatology for temperature (c, g, m, q) and salinity (d, h, n, r).

We added the following text to this new section 4.4.1:

"Seasonal temperature and salinity surface maps are shown in Fig. 3, where also differences against EMODnet climatology were reported. Temperature ranges between a minimum of around 8 ℃ in winter (Fig. 3a), along the coast, to a maximum of 25-26 ℃ in summer (Fig. 3i). Stronger coast-to-offshore gradients are shown in winter (Fig. 3a) and autumn (Fig. 3o), with the shallow coast that is 3-4 ℃ colder than the offshore area. The differences against the climatology show in general a slight overestimation of temperature, except for spring (Fig. 3g), which shows temperature underestimation, with a maximum difference of more than -3 ℃ in front of the Po River. The maximum temperature overestimation is shown in autumn with almost 3 ℃ more than EMODnet in the central part of the domain (Fig. 3q).

Salinity maps show a constant sharp coast-to-offshore gradient that strengthen in Spring due to increased river discharge (Fig. 3f). The salinity differences show in general two different patterns.

In winter and autumn (Fig. 3d, r) the larger overestimation (more than 3 psu) is just in front of the ER coast, while in the south-east part of the domain the difference decreases or becomes even negative in winter (Fig. 3d). In spring and summer (Fig. 3h, n) the salinity is overestimated (from 1 to 3/3.5 psu) except than along the ER coast where a slight underestimation is shown (-0.5/-1 psu). Temperature and salinity maps for EMODnet climatology and NB are available in SI 2 (Fig. SI2.1; Fig. SI2.3). The seasonal mean surface circulation is superimposed to the temperature maps (Fig. 3a, e, i, o, u) to provide an indication of the circulation patterns in the area, that is mainly southward due to the wind and river forcing. Seasonal circulation maps for SB and NB and their comparison can be found in SI2 (Fig. SI2.6). In general, both SB and NB show consistent fields of circulation, temperature, salinity."

For a complete overview, as explained in the text we added also the temperature and salinity comparison for NB in the supplementary information 2 (SI 2) that we show here (Fig. SI2.3):

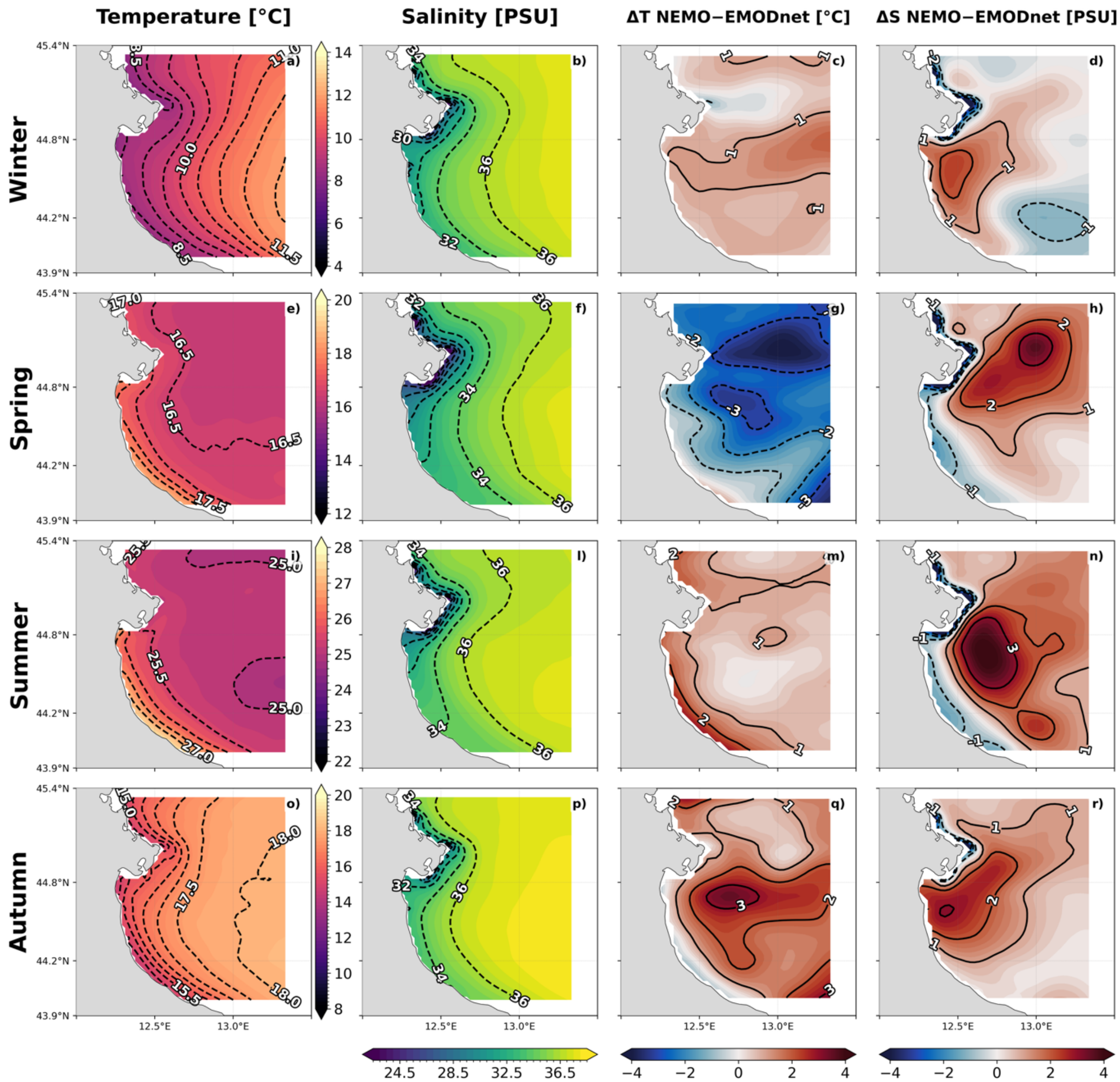

Figure SI2.3: Seasonal surface maps of temperature (a, e, i, o) and salinity (b, f, l, p) for NB and differences against EMODnet climatology for temperature (c, g, m, q) and salinity (d, h, n, r).

Moreover, there is already a comparison of temperature and salinity profiles in Fig. 7 (Fig. 6 of the old manuscript) that can help the comparison. Unfortunately, we did not have observations for the circulation in the area, so we cannot show a validation of the circulation in the manuscript, even though we added SB circulation on the temperature field in Fig. 3 to provide an indication of the circulation in the region. However, we understand that for a complete overview of the work, circulation maps may be very helpful, so we added a figure in SI2 with circulation for both SB and NB and the relative differences (Fig. SI2.6) that we show here.

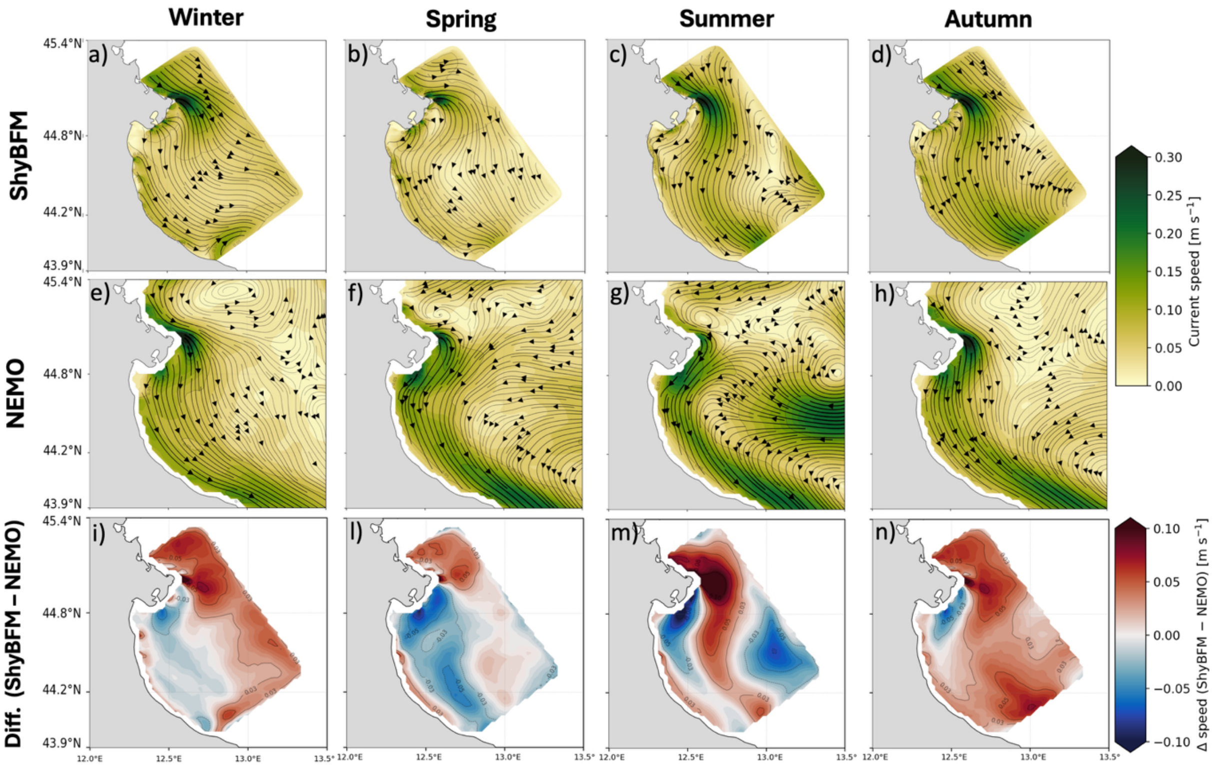

Figure SI2.6: Seasonal near-surface circulation for SB (a, b, c, d), NB (e, f, g, h) and speed difference (SB-NB; i, l, m, n).

The main southward circulation is well represented by both SB and NB, with some discrepancies in the offshore extent of the current maximum, which lies closer to the coast in NB than in SB, probably owing to a different representation of the river plumes. These circulation differences are nonetheless limited. Temperature and salinity biases show similar patterns for SB and NB, although the negative coastal salinity bias evident in NB (Fig. SI2.3h, n) is reduced in SB (Fig. 3h, n), bringing it closer to the climatology, possibly as a result of these circulation differences. Without dedicated sensitivity experiments, however, it is difficult to attribute differences in the biogeochemical variables between SB and NB to differences in the dynamics. Overall, the maps show that SB and NB produce consistent circulation, temperature and salinity fields.

Lastly, we added few sentences on temperature and salinity in the discussion (lines 485-497) that we report here:

"Temperature influences phytoplankton and zooplankton growth through the metabolic (Q10) dependence in BFM, yet the temperature differences in Fig. 3 do not map onto the chl-a differences in Fig. 5: the winter underestimation of chl-a coincides with a slight warm bias (~1 °C; Fig. 3c), while a much larger spring cold bias (~−3 °C; Fig. 3g) leaves the chl-a difference (Fig. 5e) essentially unchanged from the other seasons. This suggests that phytoplankton biomass here is controlled less by temperature than by river inputs and open-boundary conditions. Discrepancies in salinity (Fig. 3) can be attributed primarily to uncertainty in the prescribed river discharge, which sets the

freshwater input and hence the strength and extent of the low-salinity plume. In addition, biases in the simulated coastal circulation, which advects the plume southward along the shelf, may displace the freshwater signal relative to observations; however, in the absence of current measurements this contribution cannot be quantified directly. SB and NB show similar temperature and salinity patterns (Fig. SI2.3) and vertical profiles (Fig. 7), indicating that these features are largely inherited from the shared forcing and boundary conditions rather than introduced by the differences in the modelling framework (grid, coupling, numerics, etc.).”

RC1.3: Also we need some more information about NEMO-BFM. We have lots of details for the SHY-BFM configuration (which is good), but not much about the NEMO-BFM ER configuration it is compared to. We need to know what the differences are between both configurations, as some will explain the biogeochemical changes. In particular, are both configurations run with the same time step ? If everything is the same but SHY-BFM, please mention it in the simulation set-up. This has to be clear for the reader.

Response: *To avoid any misunderstanding: we did not run a dedicated ER configuration of NB; instead, we used NB output data from the Adriaclim project. That is why we reference to Mentaschi et al., 2024 and Verri et al., 2024 (Lines 215-216). Those are the reference papers for the data we used in this work to generate initial and boundary conditions and to compare seasonal cycles and the mean values of our model. However, we understand that more information is needed for the NB simulations as not all the information required can be retrieved from the papers. We added more details for NB in sections 4.2 (lines 214-222) that we report here:*

“The lateral and initial conditions were provided daily (except for sea level that was provided at 3 h frequency) by a historical simulation at 2 km resolution carried out for the entire Adriatic Sea with NEMO-BFM (Mentaschi et al., 2024; Verri et al., 2024) with a vertical grid composed by 120 z levels with layer thickness going from around 1 m in the surface to more than 50 m in the deepest levels at around 2500 m. First the physical component ran with a 120 s and 2 s timestep for the baroclinic and barotropic component respectively (NEMO uses the split-explicit time stepping method), then NEMO-BFM ran offline with a 600 s timestep using NEMO-TOP (NEMO TOP WG, 2018). More details about specific model configurations are summarized in table SI1.1 in the supplementary information 1 (SI 1)”

Moreover, we add the values of the biogeochemical parameters used for NB in table SI1.2 in the supplementary information 1 (SI1). So now it is possible to compare the BFM parameters used both in NB and SB. We also added a further table SI1 that summarizes the differences in the configuration between NB and SB (table SI1.1) that we show here:

Table SI1.1: Summary of the main characteristics of NB and SB model configuration.

Aspect	NEMO-BFM (NB)	ShyBFM (SB)
Physical model	NEMO v3.6 (Madec et al., 2024)	SHYFEM-MPI (Micaletto et al., 2022; Verri et al., 2023)
Grid type	Structured regular grid	Unstructured triangular finite-element (Arakawa-B-like)
Horizontal resolution	~2 km (uniform)	2 km offshore → 300 m at the coast
Domain	Whole Adriatic Sea; open boundary south of the Otranto Strait	Emilia-Romagna coastal subdomain (nested in NB)
Grid size	42214 active cells at the surface	15392 elements / 8142 nodes
Simulation period	1992-2020	2000–2009
Vertical coordinate	Free surface with 120 z-levels	Free surface with 43 z-levels
Vertical turbulence closure	TKE turbulence scheme	GOTM k-ε (Burchard et al., 1999)
Tracer advection scheme	MUSCL scheme for tracers; 2nd centered scheme for momentum	First-order upwind
Time step and output frequency	120 s for baroclinic and 2 s for barotropic mode. Output freq. at 3 h for surface variables, daily for 3D variables.	200 s with hourly output freq.
BGC coupling	Offline, one-way (BFM driven by NEMO-TOP transport)	Online; ADR module; synchronous source splitting
BGC state variables	51 pelagic	51 pelagic
Functional groups	4 phytoplankton, 4 zooplankton, 1 bacteria, DOM/POM	4 phytoplankton, 4 zooplankton, 1 bacteria, DOM/POM
Benthic treatment	Benthic-return closure	Benthic-return closure
BGC parameters	Adriatic-wide tuning (Mentaschi et al., 2024)	ER-specific re-tuning (parameter tables below)
Atmospheric forcing	WRF 6 km at 6 h output freq. (Verri et al., 2024)	WRF 6 km at 6 h output frequency (Verri et al., 2024)
River runoff	WRF-Hydro 600 m at hourly output freq. (Verri et al., 2024)	WRF-Hydro 600 m at hourly output freq. (Verri et al., 2024)
River chemical inputs	Inorganic N/P/Si (Ludwig et al., 2009) + DIC + Total Alkalinity for Po River	Inorganic N/P/Si (Ludwig et al., 2009 + ARPAE) + DIC + TA for Po River
Initial & lateral conditions	Med-CORDEX RCM; BGC initial cond. from CMS reanalysis	From NB (nesting)

The two models differ substantially and are not directly comparable in terms of numerical approach since NB is a structured-grid finite difference model while SB is an unstructured grid model with a finite element approach. Moreover, the scopes of the two configurations are also different since in NB the aim was to simulate the entire Adriatic Sea, while in SB we are interested in the ER area alone. Our main interest here is to validate the SB model against the climatology and to compare it with NB in terms of mean values and seasonal cycles. Understanding the spatial pattern is more complex because we do not have reference measurements for currents. However, *we added circulation streamlines superimposed to the temperature field in Fig. 3 and we added a more detailed circulation maps in the supplementary material (Fig. SI2.6) as shown in the answer to comment RC1.2. Moreover, the comparison of temperature and salinity maps with EMODnet for both SB and NB show similar patterns (compare Fig. 3 with Fig. SI2.3). We noticed that details of the vertical discretisation where missing also for SB, so we add the information in lines 209-210:*

"The vertical grid is composed by 43 z levels with 1 m thickness from the surface to 30 m depth, then increasing to 2 m up to the maximum depth of 56 m."

RC1.4: Finally, as you say in the text, the domain is very open, and hence strongly controlled by the boundary conditions. It would be interesting to know the boundary condition biases if there are any, as they explain some of the biases on the edge of the domain.

Response: *We agree with the reviewer. The biases in the boundaries are extremely important, especially in the northern part, where the flow is entering the domain. The bias of NB against climatology at the open boundary position is effectively the bias of the boundary conditions. We did not want to overload the manuscript with additional figures, so we quantified this in SI 2 (Fig. SI2.5) which show the differences of NB against EMODnet climatology, where for instance, is clear the overestimation of DIN (and of other variables) for NB, which is then inherited by SB more than internally generated. For a clearer comparison we also added the biogeochemical fields of NB in SI 2 (Fig. SI2.4). We specified this argument in section 5.1 (lines 434-440) that we report here:*

"Other discrepancies arise from the influence of the parent model that may be strong, particularly in the northern boundary where fluxes enter the domain following the main circulation and reducing the effectiveness of domain-specific parameterizations.
The effect of nutrient fluxes entering through the northern boundary is evident in Fig. 5, especially for DIN, but also for the other variables, where larger overestimations occur in the northern part of the domain and can be attributed to the parent model (NB) due to the southward main circulation (See Fig. SI2.5 for a comparison of NB against EMODnet climatology and Fig. SI2.6 for a circulation comparison)."

We added here Fig. SI2.4 and SI2.5:

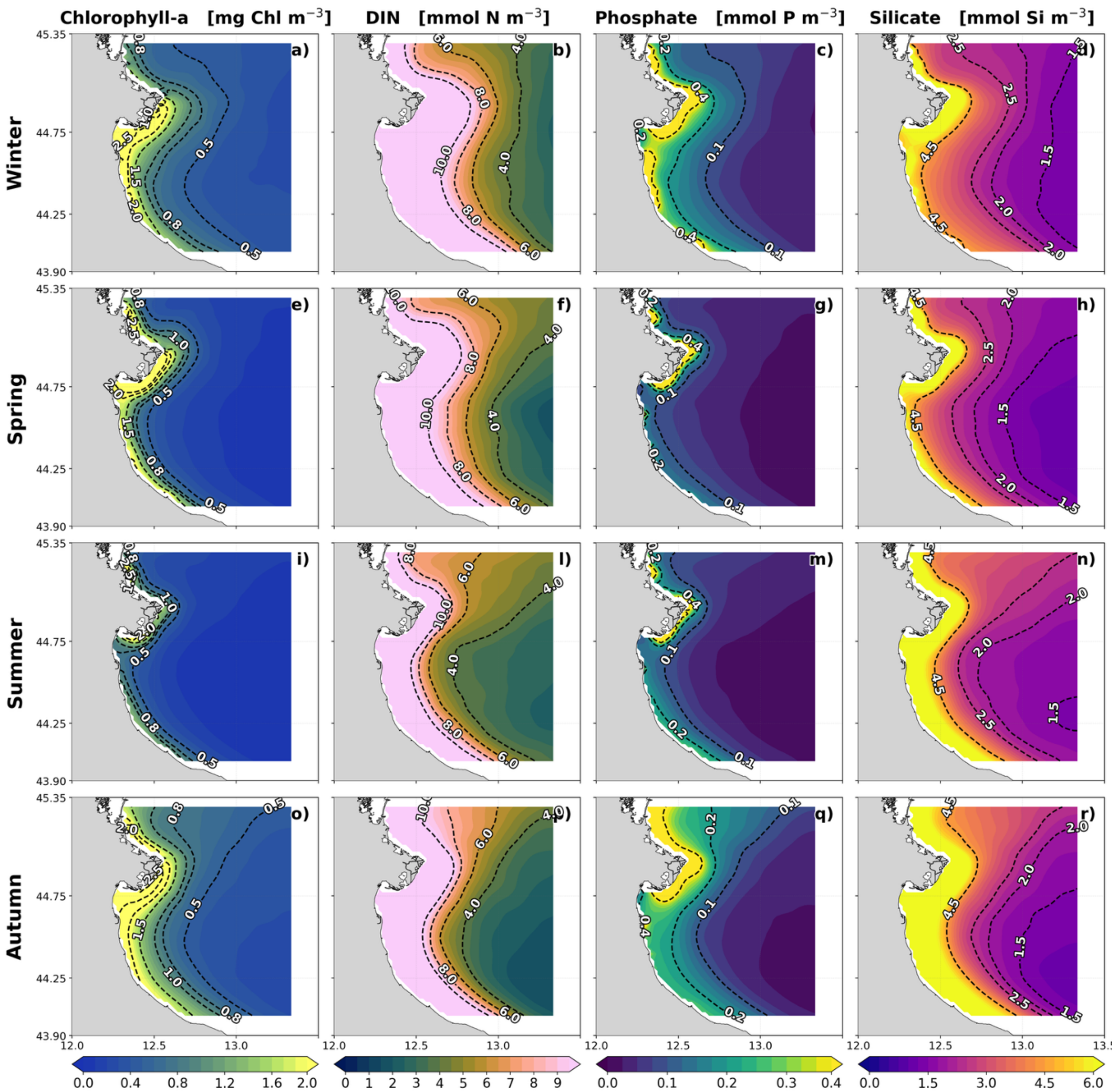

Figure SI2.4: Seasonal near-surface spatial distribution of chl-a (a, e, i, o), DIN (b, f, l, p), phosphate (c, g, m, q) and silicate (d, h, n, r) for NB.

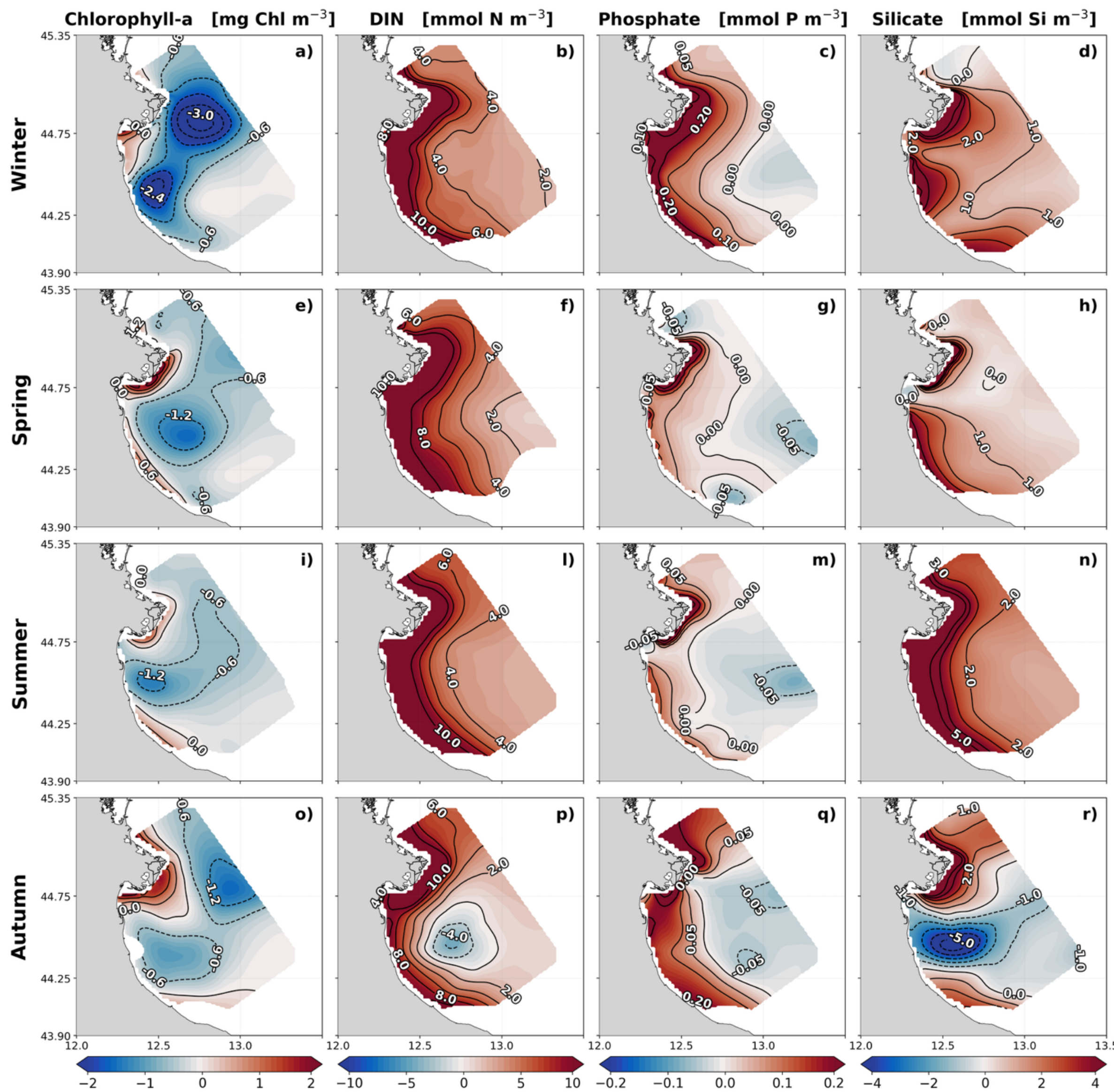

Figure SI2.5: Seasonal near-surface differences between NB and EMODnet of chl-a (a, e, i, o), DIN (b, f, l, p), phosphate (c, g, m, q) and silicate (d, h, n, r).

Specific comments (written while reading).

- Introduction

RC1.5: Line 79 : "And it is open-source". Looks like a late addition. It can be included in a better way to the sentence.

Response: *We now changed the sentence to this: "…,hereafter called ShyBFM (v1.0), an open-source system designed for efficient execution in a parallel MPI environment."*

RC1.6: In most of the paper, there are mentions of "The BFM" or "The SHYBFM". If it is "the

BFM model" or "module" Or something else, the "the" is OK, but it is not needed of it is just BFM.

Response: *We corrected this all along the paper.*

RC1.7: Line 81: "verified with the comparison with" - you can change to "compared to".

Response: *We modified the sentence accordingly to the reviewer suggestion.*

- The coupled physics-biogeochemistry system

RC1.8: Line 108-109: I thought BFM's benthic model was more complex than a "fixed quotes". That's surprising, and it will have consequences on the model results in the ER domain.

Response: *We agree with the reviewer that this is a limitation for a shallow area such the ER domain. Although BFM includes a dynamic benthic sub-model, the present ShyBFM configuration adopts a benthic-return closure (a constant rate of the deposited organic matter returned as a nutrient flux) in this first release. We specified this in lines 140-141:*

"In this first release of the code sediments are handled using a benthic return parameterization to account for the constant remineralization of deposited organic matter"

A work cited in the text (Scroccaro et al., 2022) used a more complex sediment model, but due to the lack of measurements of sediment variables in the area, there is high uncertainty in the initialization and in the parameter values for the benthic variables. This is the reason why we used a benthic return closure in this work. We stated the problem, with possible limitations in the discussion (section 5.1; lines 475-480):

"Moreover, the benthic processes may account for a large fraction of oxygen depletion in the bottom water (Seitaj et al., 2017) emphasizing the need to include benthic-pelagic coupling in coastal marine models. However, the use of more complex model should be supported by measurements of sediment variables that are lacking in the area, otherwise leading to high uncertainties in the benthic variables and their feedback to the water column. This is the main reason for the choice of a simpler benthic return closure in this first implementation of SB."

and we point out that the inclusion and validation of a more complex benthic dynamical model will be the topic of future research (lines 539-542):

"Future developments should incorporate higher-order advection schemes, the inclusion of ISM and CDOM for light absorption and more mechanistic sediment diagenetic modules, building on the unstructured framework, which already resolves the complex coastal geometry and cross-shelf gradients at variable resolution."

- Physical and BGC model component.

RC1.9: Are your configurations adapted for shelf specific dynamics, are tides or tide induced mixing included for example?

Response: *Yes, tides are included. They were added to the parent's model sea level in the pre-processing stage of ShyBFM using the TPXO tidal model. This is a relevant difference compared to NEMO-BFM and was clarified in section 4.2 (Lines 221-222):*

"Tides were added to the sea level boundary condition using the TPXO tidal model (Egbert and Erofeeva, 2002)."

Moreover, tides may be responsible for an increased mixing in the water column. We added a sentence about possible influence of tides on the mixing in section 5.1 (Lines 481-483):

"Tides can reach 1 m amplitude in northern Adriatic Sea and they can significantly enhance the mixing in water column, potentially explaining differences in stratification between SB and NB (Fig. 6)."

RC1.10: Table 2: It would be good to add information about the forcing in the table, like resolution, frequency, etc, lame for the river runoff/load. I know it is in the text, but it would help the reader.

Response: *We modified Table 2 giving more information on the forcing data and moving the period of simulation to the bottom row. We added three more columns with the variables used for each input dataset, resolution and output frequency:*

Table 2: Model forcing datasets and period of simulation.

	Datasets	Variables	Resolution	Output frequency
Bathymetry	EMODnet + multi beam	depth	250 m	-
Atmospheric Forcing	WRF surface variables (Verri et al., 2024)	Wind, T_{air}, T_{dew}, MSLP, S_w, Prec., TCC	6 km	6 h
Boundary and initial conditions	NEMO-BFM (Verri et al., 2024; Mentaschi et al., 2024)	Currents, T, S, sea level + biogeochemical var.	2 km	Daily for 3D var.; 3 h for 2D var.
Rivers runoff	WRF-Hydro (Verri et al., 2024)	River discharge	600 m	hourly
Rivers load	Ludwig et al. (2009) + ARPAE data	DIN, phosphate, silicate + DIC and TA for Po river	-	Annual data
Period of simulation	01 january 2000 – 31 december 2009			

We added a further sentence to define the atmospheric variables that are used for the simulation (lines 222-225):

"The atmospheric forcing is taken from the reconstruction of Verri et al. (2024) at 6 km resolution with the Weather Research and Forecasting (WRF) model (Skamarock and Klemp, 2008) at 6 hr frequency, from which wind components, air temperature (T_{air}), dewpoint temperature (T_{dew}), mean sea level pressure (MSLP), solar radiation, precipitation and total cloud cover (TCC) are considered."

- Simulation set-up

RC1.11: Don't you have Iron, DIC, DOM, Alkalinity from the rivers ? Or they are not considered important because of the open domain?

Response: *Iron is not included in our BFM configuration since in the Adriatic Sea it is not a limiting nutrient. This is a widely used choice for ecological models in the Adriatic Sea (e.g. Scroccaro et al., 2022, Mentaschi et al., 2024). In addition to DIN, phosphate and silicate, we have data for DIC and Alkalinity (no DOM) just for the Po River, while we miss those data for all the other rivers. We added this information in section 4.2 (lines 233-234):*

"Dissolved inorganic carbon (DIC) and total alkalinity (TA) data were available just for the Po River."

To answer the second question: they would be important but unfortunately we don't have those data. We acknowledge the lack and possible inaccuracies in river nutrient load data as a possible driving reason for the differences we observed against the climatology in lines 431-434:

"The surface comparison of chl-a with EMODnet (Fig. 5) shows similar patterns for spring, summer and autumn with a positive bias around the Po mouth and a negative bias along the coast. This pattern can be observed also in other variables of Fig. 5 and may result from uncertainties in the river nutrient loads."

The high uncertainty in land-borne river nutrient load is also stated by other works (e.g. Scroccaro et al., 2022) and reported in the discussion in lines 447-452 and 460-462.

"The coupled model of Scroccaro et al. (2022) reported a substantial overestimation of phosphate in the ER coastal area, where chl-a overestimation was also found, attributing this discrepancy to high uncertainty in land-borne river nutrient loads. Consistently, the comparison with EMODnet in Fig. 5 shows that the largest phosphate discrepancies occur around the Po mouth and along the coast, where several Apennine rivers discharge, supporting the role of uncertainty in river nutrient inputs."

"However, silicate loads are highly uncertain due to a lack of continuous measurements. Furthermore, riverine silicate inputs are often estimated using indirect methods (Ludwig et al., 2009), which are less reliable than direct observations."

Eventually, we stated in the conclusion, as one of the main future challenges, the improvement of the observational network, especially for river nutrient load (lines 543-548):

"Reducing uncertainties in coastal biogeochemical modelling also requires improvements in external forcing and in local observational networks: finer, kilometer-scale downscaling would better resolve coastal winds and air-sea fluxes at very high resolution, but is computationally very expensive (Denamiel et al., 2021), while denser in-situ networks are needed to better constrain river nutrient loads and boundary conditions. A higher frequency of river nutrient loads measurements would be of great benefit to generate a more consistent forcing and reduce uncertainty."

RC1.12: What are the initial conditions ? you say it in the abstract, but not here. Is the parent model (that provides Init and boundary conditions optimised for the region ?)

Response: *Yes, both physics and biogeochemical variables are Initialized from the parent model (NB). This is stated in line 214-216:*

"The lateral and initial conditions were provided daily (except for sea level that was provided at 3 h frequency) by a historical simulation at 2 km resolution carried out for the entire Adriatic Sea with NEMO-BFM (Mentaschi et al., 2024; Verri et al., 2024) with…"

The NB model was tuned for the Adriatic basin as whole (Mentaschi et al., 2024), i.e. balanced between oligotrophic open Adriatic Sea and the productive northern shelf, which is precisely why a coastal re-tuning was required for SB (section 4.3; lines 249-253).

"The NEMO-BFM model configuration from Mentaschi et al. (2024) was tuned for the entire Adriatic Sea. Since most of the area outside the northern Adriatic is oligotrophic, the parameters were chosen through an optimisation process that adjusted the values to be suitable for both oligotrophic and productive areas, such as the northern Adriatic Sea. In the testcase implemented here, a new parameter tuning was then necessary."

- Model Calibration.

RC1.13: Just to be clear, you've used NEMO-BFM on ER coastal region. what is in there ? what's the grid, domain, time-step ? what are the differences with shy-BFM ? We need some information about this NEMO-BFM run on ER domain.

Response: *We did not use NB specifically for this work in the ER coastal region, but we used the results of NB from the Adriaclim project. NB ran all over the Adriatic Sea (this is stated in Line 214).*

The detailed description of what was done for Adriaclim can be found in (Verri et al., 2024 and Mentaschi et al., 2024). As stated in the answer to comment RC1.3, to clarify the differences among NB and SB we add more information on NB in section 4.2. Moreover, now the SI 1 document has a table with the biogeochemical parameters of both NEMO-BFM and SB (Table SI1.2, that we will include in the revised SI1 document) and a further table where models' characteristics are summarized (Table SI1.1) showed in the answer to comment RC1.3.

- Model evaluation.

RC1.14: Are both Shy-BFM and NEMO-BFM using the new parameters ?

Response: *No, the new parameters were used only for SB. No new simulation was done with NB. The list of the parameter used by NB for the Adriaclim project (Mentaschi et al., 2024) is reported in SI 1(Table SI1.2) together with the new parameters used by SB and will be included in the revised SI 1 document.*

RC1.15: Fig 3. numbers are too little. we can't see them without zooming in.

Respnse: *We increased the readability of Fig. 4 (Fig. 3 in the old manuscript) increasing the size of the colorbar labels and changing the style and size of the contour labels. We applied the same corrections also to Fig. 5 (Fig. 4 in the old manuscript). This is the new figure:*

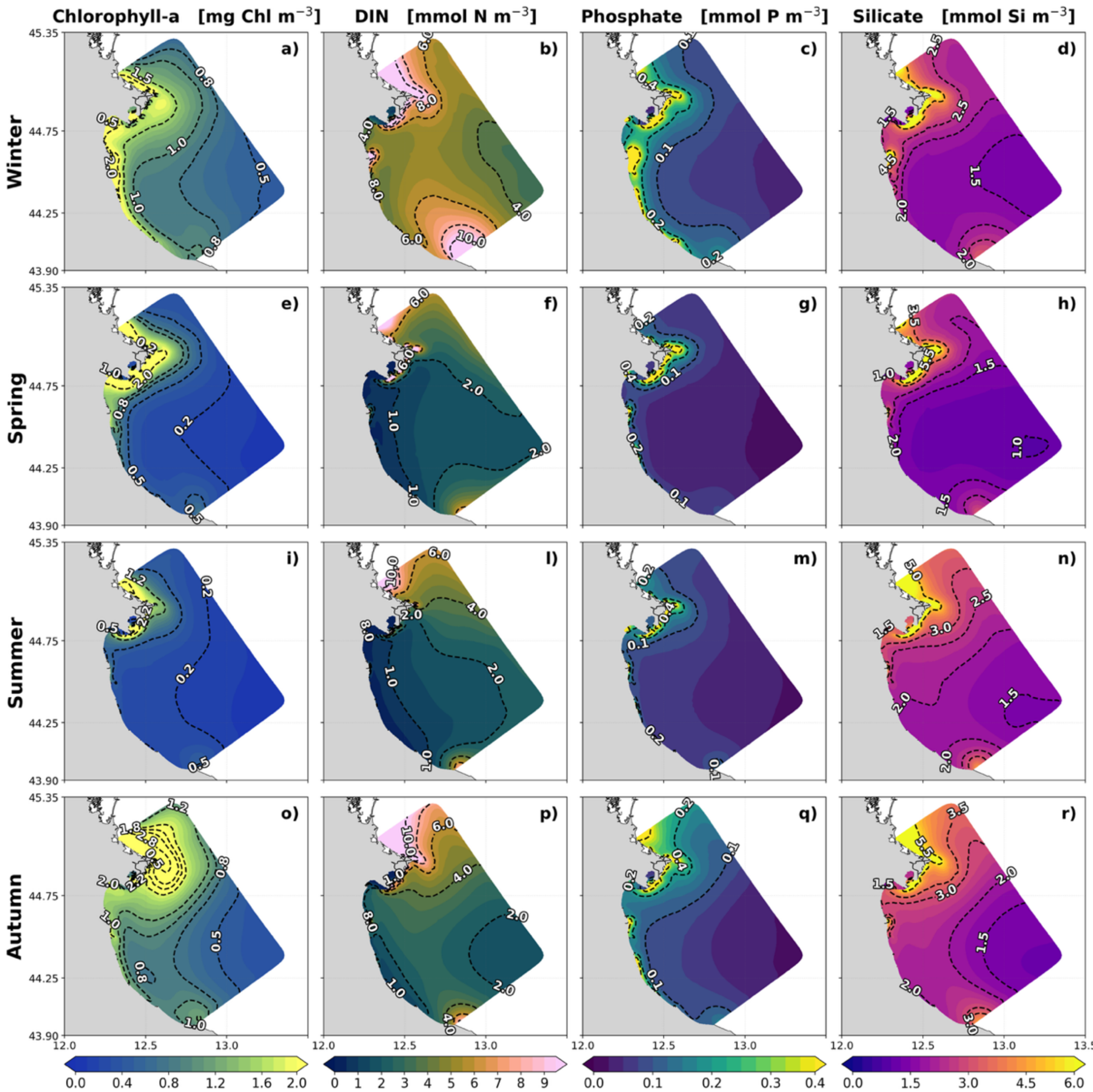

Figure 4: Seasonal near-surface spatial distribution of chl-a (a, e, i, o), DIN (b, f, l, p), phosphate (c, g, m, q) and silicate (d, h, n, r) for SB.

- Here again, i think we miss important information.

RC1.16: Before evaluating the biogeochemical response to this new unstructured-grid. we have to know about the dynamics, and its answer to SHY-BFM. The BGC changes will mostly be in response to changes in the dynamics. And to (better) understand what's happening, we need to know them.

Response: *We agree with the reviewer the need to evaluate the dynamics to better understand the biogeochemical response. Since we do not have observations for currents in the area we couldn't put in the manuscript a comparison with measured data, however we added a new* *section 4.4.1 with temperature and salinity maps for SB (Fig. 3) and the difference against EMODnet where we superimposed the circulation pattern of SB to the temperature field to provide an indication of the circulation patterns (See the answer to RC1.2). We also added circulation seasonal maps for SB, NB and their differences in the supplementary information (SI2; Fig. SI2.6, see RC1.2). We add a sentence on the possible influence of tides in the mixing (see answer to RC1.9). plot of T and S for NB where also added in SI2 (Fig. SI2.3, see RC1.2). A discussion on temperature and salinity was carried out in lines 484-496 as stated in the answer to comment RC1.2, where we also speculate that differences in the salinity field can also arise from biases in the circulation. Fig. SI2.6 show some slightly differences in the circulation between SB and NB. Despite the differences highlighted by the comparison, both SB and NB show consistent fields for circulation, temperature and salinity.*

RC1.17: Also, the domain is very open. it must be very Boundary conditions dependant. So, although you show Shy-BFM improves the BGC in the overall domain, it would be good to have an idea of how controlled by the boundary conditions your run is. for example, the North of the domain must mainly be controlled by the BC. Those BC are from another NEMO-BFM run, how different are they from the climatology?

Response: *We agree with the reviewer that the control of the boundary conditions is strong, especially in the northern boundary, since in the ER coastal area the main current is southward. We stated this in lines 434-440 (see RC1.4) adding a reference to fig. SI2.5 where the difference between NB and EMODnet climatology is shown for the biogeochemical variables and helps to understand the influence of the parent model (NB) on SB (see RC1.4).*

RC1.18: Suggestion: it could be good to add the Boundary Conditions (or the parent model results) around the model results in Fig 3 and 4. Highlighting the ER region, but so that we know that the high DIN at the north of the domain are (or not) from the BC.

Response: *We made the plots suggested by the reviewer:*

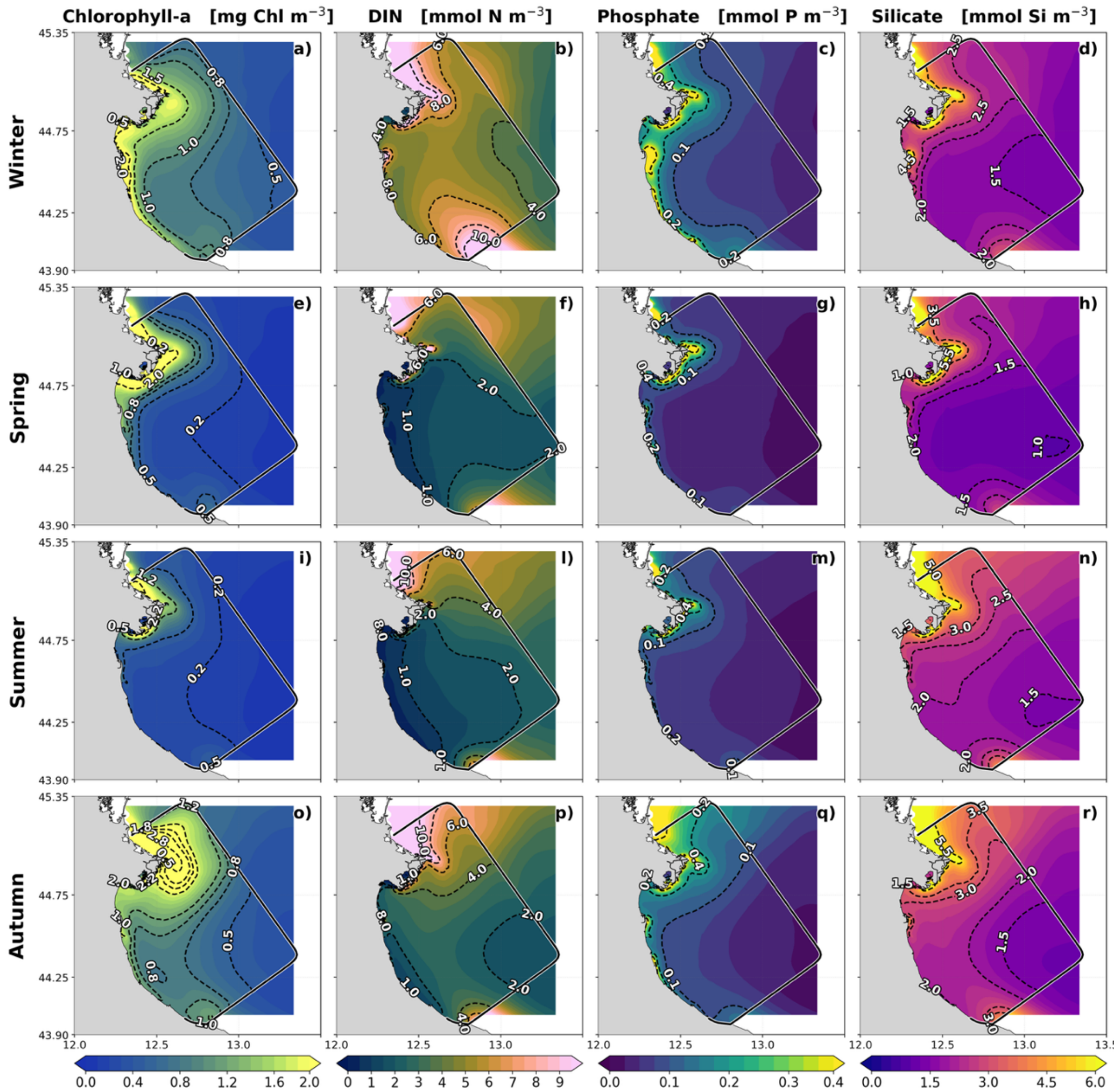

Figure 4: Seasonal near-surface spatial distribution of chl-a (a, e, i, o), DIN (b, f, l, p), phosphate (c, g, m, q) and silicate (d, h, n, r) for SB surrounded by NB values. The thick black line is the boundary of SB .

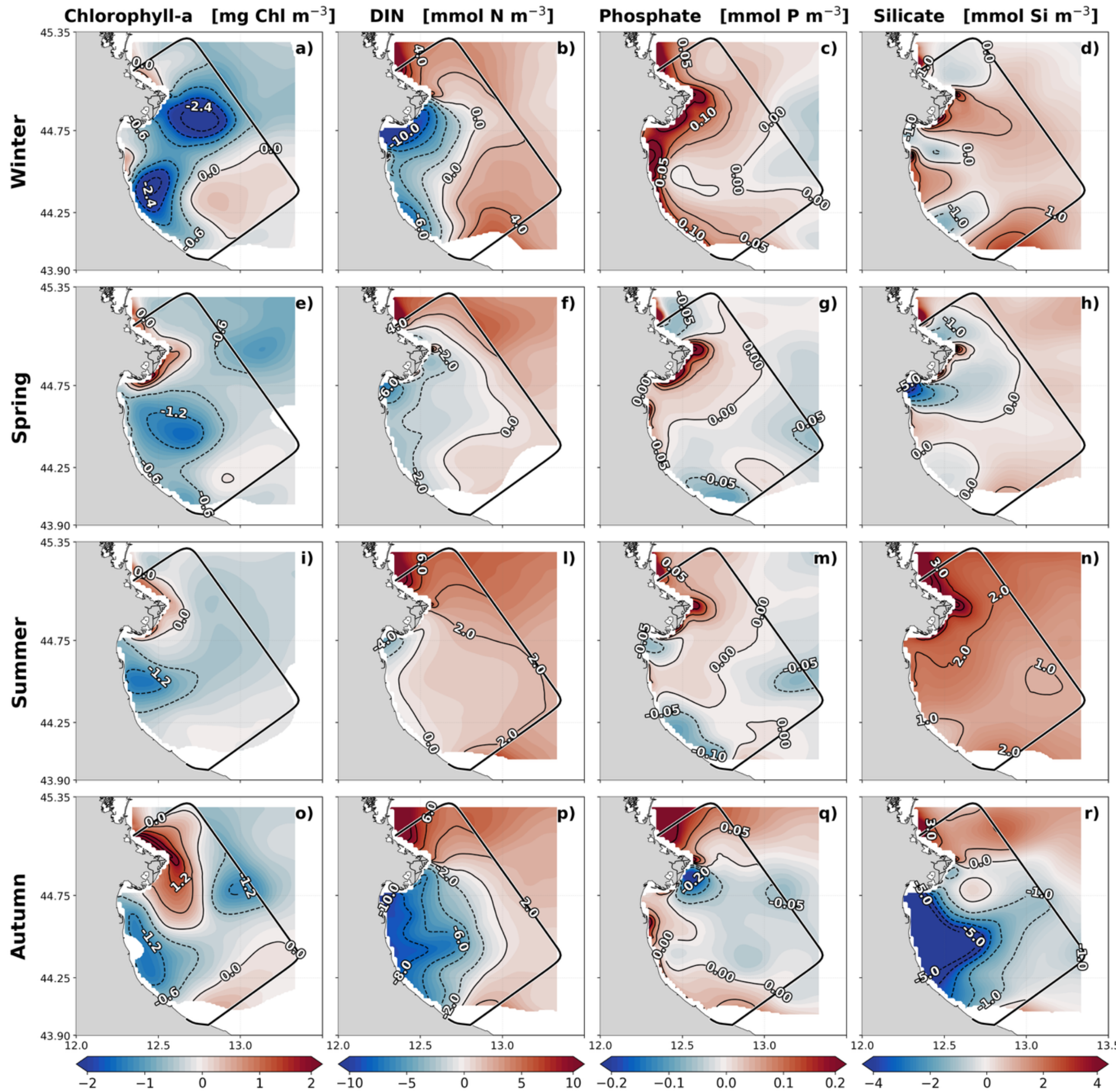

Figure 5:Seasonal near-surface differences between SB and EMODnet of chl-a (a, e, i, o), DIN (b, f, l, p), phosphate (c, g, m, q) and silicate (d, h, n, r) surrounded by the NB-EMODnet differences. The thick black line indicates the SB boundary

The plots show the biogeochemical variables of SB surrounded by the NB fields separated by a thick black line that highlight the SB boundary (Fig. 4). The same plot was done for the differences (Fig. 5). We understand that this plot can be helpful in highlighting the influence of the parent model (NB) on the child model (SB), but we believe that including these plots in the manuscript could be misleading for the reader. We prefer to keep in the manuscript surface map comparison against EMODnet climatology and include NB maps in SI2 (Fig. SI2.4; Fig. SI2.5; see RC1.4).

RC1.19: line 330: good oxygen at the surface: this has to be, as it's in equilibrium with the atmosphere. It would be worrying if not.

Response: *Yes, indeed. We slightly modified the sentence (line 367-368):*

"As expected by air-sea equilibrium, surface oxygen is well reproduced (Fig. 7a, d, g, l) but the performance degrades rapidly with depth."

RC1.20: Fig 7. : Shy-BFM looks better, with more variability. I would suggest to improve the shaded colours transparency, or the shaded colours themselves. we don't see the green shade when bellow the orange one.

Response: *We improved Fig. 8 (Fig. 7 in the old manuscript) readability using a lighter orange shade and adding circles in the green shaded area. Now the shaded areas are more distinguishable even when they are superimposed. Here is the new figure:*

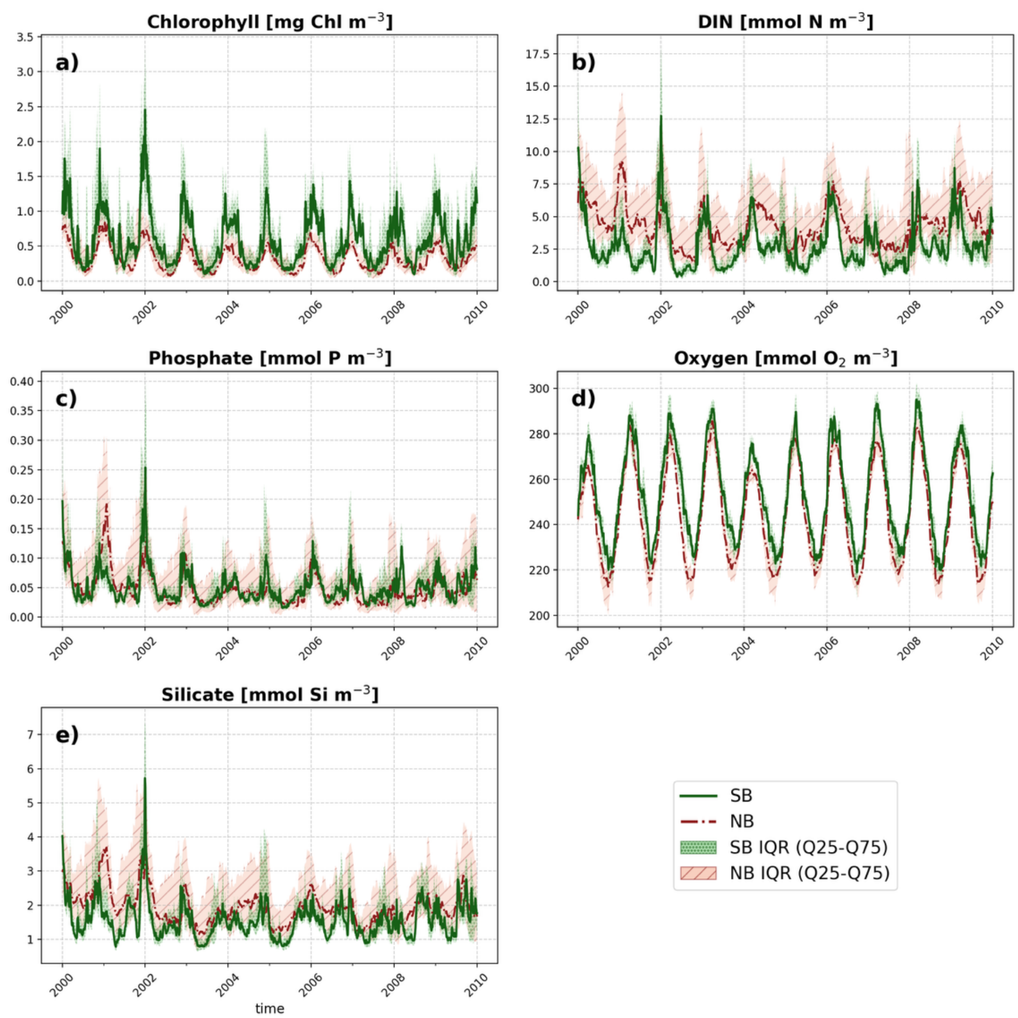

Figure 8. Daily median values for SB (green thick line) and NB (red thick dotted line), for the 10 years simulation, integrated over the domain between the surface and 30m depth: chl-a (a), DIN (b), phosphate (c), oxygen (d) and silicate (e). Light green with circles and light red hatched shaded areas indicate the spatial IQR for each modelling system, respectively.

- Discussion :

RC1.21: Line 431 : you talk about ISM, while i always heard of the importance of CDOM in coastal regions. I see a Paper by Alvarez et al., 2023, modelling CDOM with a 1D version of BFM. does your version of BFM include the impact of CDOM on light absorption ?

Respnse: *No, the current ShyBFM optics represent neither ISM nor CDOM light attenuation. The CDOM light absorption module implemented in Alvarez et al., 2023, is not part of the standard BFM v5.3 used here. We agree with the reviewer that in a river influenced coastal system like the northern Adriatic Sea, both ISM and CDOM optical effects are likely important. We extended the discussion including the importance of CDOM in coastal areas adding the Alvarez et al., (2023) reference. We stated the limitation of our model and identify the inclusion of CDOM as a future development:*

In section 4.2 Simulation set-up in lines 244-247:

"It is worth mentioning that in the current implementation there is no light attenuation due to inorganic suspended matter (ISM), nor light absorption by chromophoric dissolved organic matter (CDOM), posing some limitations to ShyBFM as it will be stressed in the discussion."

In section 5.1 Model performance in lines 465-469:

"The CDOM could be also responsible for a sgnificant fraction of light absorption (Álvarez et al., 2023; Campanelli et al., 2017) in coastal areas, but it is not considered in the configuration used here. This limitation is particularly relevant for the considered testcase, which is characterized by potentially high ISM and CDOM loads from the Po River, affecting phytoplankton photosynthetic processes (Bignami et al., 2007; Penna et al., 2004)"

And lines 473-475:

"Both ISM and CDOM omissions likely contribute to the vertical profile discrepancies reported here. The inclusion of optical formulation accounting for CDOM (Álvarez et al., 2023) is identified as a future development"

In the Conclusions in lines 529-531:

"An overestimation of oxygen concentration was identified, possibly linked to the absence of CDOM and sediment-induced light attenuation along the water column."

And lines 539-542:

"Future developments should incorporate higher-order advection schemes, the inclusion of ISM and CDOM for light absorption and more mechanistic sediment diagenetic modules, building on the unstructured framework, which already resolves the complex coastal geometry and cross-shelf gradients at variable resolution."

RC1.22: What is the computational cost of SHY-BFM compare the NEMO-BFM ?

Response: *We added details of the computational cost in the discussion (lines 513-516):*

"In terms of computational cost, SB required around 695 core-hours per simulated year with 36 MPI processes, while NB used around 1728 core-hour per simulated year with 288 MPI processes. This means a wall clock of around 19 h for SB and 6 h for NB per simulated year. NB was almost 3 times faster but used around 2.5 more computational resources compared to SB."

- After reading questions :

I am sorry but reading your paper rises lots of questions. You might want to include some of your answers in the paper. It would be good if you do, i understand if you don't :

RC1.23: Why this approach rather than working on other mechanisms that would (also) improve the model in a shelf region (and probably be less computationally expensive), like improving the benthic model ? or changing the vertical coordinates ?

Response: *We believe that the unstructured framework and process improvements are more complementary rather than alternative. The unstructured grid approach addresses a problem that neither a better benthic closure nor a different vertical coordinate can solve on a structured mesh: explicit representation of complex coastal geometry, river mouth and the cross-shelf gradient at a variable resolution (down to ~300 m) while retaining basin-scale forcing through the open boundary. We stated the main advantages of unstructured grids in the discussion in lines 404-408:*

"Unstructured grid modelling can accurately describe complex coastal morphologies and transitional environments such as estuaries, lagoons and salt marshes, where key biogeochemical processes often occur (Bonamano et al., 2024; Cravo et al., 2024; Newton et al., 2014). This improves the representation of coastal ecosystems by enabling these environments to be included in the computational domain. The flexibility of the mesh enables changes in resolution in areas with larger spatial scales (e.g. offshore areas)."

We agree that benthic model and other process improvements are valuable and we present them as a priority for future developments, to be pursued on top of the unstructured framework. We specified this in the conclusion in lines 539-542.

""Future developments should incorporate higher-order advection schemes, the inclusion of ISM and CDOM for light absorption and more mechanistic sediment diagenetic modules, building on the unstructured framework, which already resolves the complex coastal geometry and cross-shelf gradients at variable resolution."

Moreover, the developments of the SHYFEM-MPI and BFM coupling is a part of multiple efforts made at CMCC to build a digital twin for the coastal ocean. A useful example could be the development of a sediment transport model (ongoing work) that is carried out for SHYFEM-MPI or the z implementation (Verri et al., 2023). Once the sediment transport model will be integrated within ShyBFM we will be able to account for the light attenuation due to ISM.*

RC1.24: Any plans for further improvements ? Any idea how to improve the river nutrient inputs ? any data from land/river models ?

Response: *We already stated some planned developments including a higher-order advection scheme for the biogeochemical tracers' transport, the inclusion of ISM and CDOM for light absorption and the inclusion of more mechanistic sediment-diagenesis modules (lines 539-542, see RC1.23). Moreover, the improvement of the observational networks, especially for rivers would be another major improvement (Conclusions; lines 543-546):*

"Reducing uncertainties in coastal biogeochemical modelling also requires improvements in external forcing and in local observational networks: finer, kilometer-scale downscaling would better resolve coastal winds and air-sea fluxes at very high resolution, but is computationally very expensive (Denamiel et al., 2021), while denser in-situ networks are needed to better constrain river nutrient loads and boundary conditions."

In many parts of the manuscript (lines 431-434; 447-452; 460-462; see RC1.11) we identified possible discrepancies between SB and the climatology due to uncertainty in river nutrient loads. Specifically for nutrient inputs we would suggest an increase in the frequency of the observations to generate a more consistent forcing and reduce uncertainty. We added this comment in the conclusions, lines 546-548:

"A higher frequency of river nutrient loads measurements would be of great benefit to generate a more consistent forcing and reduce uncertainty."

At the local level, there is a modelling chain for hydrological forecast managed by the ARPAE (the regional agency for environmental protection and energy) but those data are used only *at the institutional level for the early warning systems, they are not open source and are constrained just to river discharge.*

RC1.25: The atmospheric forcing at 6km (which is already great) sounds like a limitation when running with 300m resolution at the coast. Is there a way (that's probably a whole project) to downscale those around the coast to a finer resolution ?

Response: *We agree with the reviewer. The difference in resolution at the coast between the atmospheric and the ocean model could be a limitation. However, we think that the 6 km WRF reconstruction (Verri et al., 2024) was the most consistent choice, since it was the output of the AdriaClim project and it was the same forcing used also by NB (hence reducing uncertainty due to a different forcing). A finer, kilometer-scale atmospheric downscaling would better resolve coastal winds and air-sea fluxes at very high resolution but is computationally very expensive. We found an article on this (Denamiel et al., 2021; https://doi.org/10.5194/gmd-14-3995-2021) that is now cited in the manuscript. We add a comment on this in the conclusion, lines 543-546 (see RC1.24).*

RC1.26: Zenodo - Please, give a minimum instruction on how to run Shy-BFM. Giving the code is nice, but please, explain how to use it.

Response: *We already put a quickstart manual in the supplementary material and now we added the manual also in the Zenodo repository (https://zenodo.org/records/21359516). You will find in the repository a new file called SHYBFM_manual.pdf with instructions to compile and run the model.*