Responses to the Referee#1 Comments and Suggestions

Journal: Ocean Sciences (OS)
Manuscript number: egusphere-2025-606
Manuscript title: Modelling river-sea continuum: the case of the Danube Delta

The original Reviewer's comments and suggestions are shown in regular typeface, while our responses are shown in italics. The line and figures numbers we use refer to the revised document.

R1.1 The manuscript "Modelling river-sea continuum: the case of the Danube Delta", by Ferrarin et al., describes a new model configuration for the river-lagoon-sea interconnections in the Danube Delta Region. The model is first validated under current conditions and then used to explore the temporal and spatial variability of oceanographic parameters and three alternative reconnection options.

Evaluation: overall the manuscript covers and interesting topic in a region and type of system that could be extrapolated to other similar systems. The manuscript also does a good job (through visuals) at showing the spatial and temporal variability of oceanographic parameters. However, there are questions about the datasets used, the validation of the model results and the interpretation of results could be strengthened. The manuscript would benefit from some reorganisation since the findings and the implications are difficult to follow beyond the focus on the local issue. The scientific questions and relevance are not clearly articulated in the Introduction and some of them appear further down in the Methods. New results are presented in the Discussion and on the other hand the results of the study (both those in the result section and those in the discussion section) are not put into the broader context and remain descriptive. Perhaps the validation should go in supplementary materials and the result figures currently in the discussion (11-14) could be presented in the Results section highlighting how they relate to current understanding of this type of systems. The Conclusion restates the local findings and should be strengthen by highlighting why or how this piece of work is of general interest.

Response. We thank the referee for the in-depth and useful review. We appreciate the comments and we will improve the manuscript in accordance with all suggestions. In particular, all results will be presented in the "Results" section, while the interpretation of our findings within a broader context will be included in the "Discussion and Conclusions" section.

R1.2 The modelling system and Numerical experiments. Significant details on the datasets and the modelling system need to be included without these details it would be difficult to reproduce the results and to evaluate the validity of the numerical modelling: What is the bathymetric resolution of the different datasets? In coastal environments the bathymetry has a non-negligible impact on the obtained results. What is the temporal resolution of the Black Sea lateral boundary condition? Some of the datasets are only available upon request so it will be challenging to reproduce these results. What is the temporal resolution of the model outputs?

Response: We thank the reviewer for highlighting this issue. In the revised version of the manuscript we will include more details about the modelling application setup. In particular, for the bathymetric dataset we will specify that:

- *the 2022 European Marine Observation and Data Network dataset (EMODnet Bathymetry Consortium, 2022) for the shelf sea on a regular grid of 1/16*1/16 arc minutes, ca. 115 metre grid;*
- *the 2024 dataset for the Razelm Sinoie Lagoon System acquired on (mostly West-East-oriented) transects spaced 450 m apart on average and covering the whole system. The distance between two points within each transect is ∼1 m.*
- *three separate multibeam datasets (provided at a ∼1 m resolution) for the main river branches: the 2023 dataset for Chilia; the 2019 dataset for Sulina; the 2016-2017 dataset for Sf. Gheorghe. Available sparse data was used for some secondary branches and small channels.*

The choice of saving daily model results was made to limit the volume of model output and is justified by the fact that the boundary conditions for the Black Sea and the Danube River river have a daily frequency.

R1.3 The numerical experiments: it is not clear for which period are the what-if scenarios run (L126). Please clarify whether it is 2015-2019 or 2018.

Response. We will add a sentence to specify that the period, parametrization, forcing and boundary conditions considered in the what-if numerical experiments are the same adopted in the reference run.

R1.4 L123 highlights why this study matters and yet it only appears here. This should we moved to the Introduction section.

Response. According to the reviewer's suggestion, the mentioned reference, and the related sentence, will be moved to section 1.1.

R1.5 L131 you refer to four datasets not three.

Response. We will correct the text accordingly.

R1.6 The model validation: my main concern is the lack of validation data in terms of the water division in the lower parts of the delta river network and salinity on coastal areas.

Response. We acknowledge the reviewer's concerns; however, the area of interest is poorly monitored. Limited spatial and temporal coverage of existing monitoring networks, along with restricted (freely) available data, are critical issues in the Danube Delta. To address this, we reached out to various authorities and research centers to gather data on bathymetry, river discharge, water level, temperature, and salinity for use in the development and validation of our model. We utilized all available datasets, and while we agree that validation could be further enhanced, we believe the results demonstrate the robustness of our model. We hope this modelling effort will encourage more effective data sharing among institutions and contribute to advancing research in this ecologically significant transitional environment.

R1.7 Fig 2. What are the red circles and the black diamonds in Fig2b and 2c? There is no legend for those. There might be a typo on the x and y axis of Fig 2b and Fig 2c, shouldn't it be "m^3/s" instead of "m"?

Response. The figure's caption will be improved by adding the following sentence "The black diamonds, the red circles and the red lines in panels b and c represent the scatter *data, the 5 to 99th percentiles and the line of best fit, respectively." We will also correct the unit on panels b and c.*

R1.8 The validation data for sea level and sea temperature is relatively far from the zone of interest where the manuscript focuses. Why is the validation for sea level done for mean sea level and not at the time the measurements are collected? Does the validation improve when done for mean daily values or is it that the model output are daily values? This is not clear. Validation of sea level is quite poor at times (e.g. differences of over 0.1m for 0.7m variation in sea level Fig.3). The reasons (L171) for the poor fitting should be better explained/explored, does the bathymetry play a role as well in this? Why are results not presented as scatter plots?

Response. See the response to comment R1.6 regarding the validation. The sea level and sea temperature validation has been performed on daily values because this is the model output frequency (see the response to comment R1.1). It is worth noting that the tide in the area of interest is negligible and therefore the sea level oscillations are mostly influenced by the open sea conditions and wind and pressure associated with atmospheric perturbations having a typical time scale of 1-10 days.

We decided to present the sea level validation as a timeseries instead of a scatter plot to visualise the amplitude and duration of the sea level variability in the area of interest. The results of the statistical analysis are reported in the text (please note that reperforming the validation, we modified some values).

As mentioned in the manuscript, the SHYFEM model's performance is strongly related to the capacity of the Black Sea Physics Reanalysis (hereinafter BLKSEA) in reproducing sea level oscillations. To better explore this dependence, we reported in Fig. 1 both the timeseries of the sea level simulated by our SHYFEM application and by the Black Sea Physics Reanalysis.

The figure clearly shows the strong dependency of the SHYFEM results on the imposed boundary conditions. However, the statistical analysis reported in Table 1 demonstrates that SHYFEM is performing slightly better than BLKSEA. This is due to the higher resolution of the SHYFEM model application at the coast, which allows to represent coastal dynamics better.

Table 1: Statistical analysis (in terms of centered RMSE, BIAS and R) of simulated sea temperature at the monitoring stations.

Station	**RMSE (cm)**		**CC**	
	SHYFEM	BLKSEA	SHYFEM	BLKSEA
Constanta	6.5	7.6	0.66	0.58
Mangalia	7.8	8.3	0.55	0.51

Unless specifically requested by the reviewer, we do not intend to include a validation of the Black Sea Physics Reanalysis in our manuscript, either in the form of time series figures or statistical metrics in the text.

R1.9 Similarly for the sea surface temperature, why is the validation for Constanta not shown in Fig. 4 while data is available? Temperature is usually a minor part in estuarine dynamics with most of the density gradient being driven by salinity differences. However, here the validation is presented in terms of temperature and yet you focus later on salinity results, are there no data available in terms of salinity? There are 6 satellite control SST points,

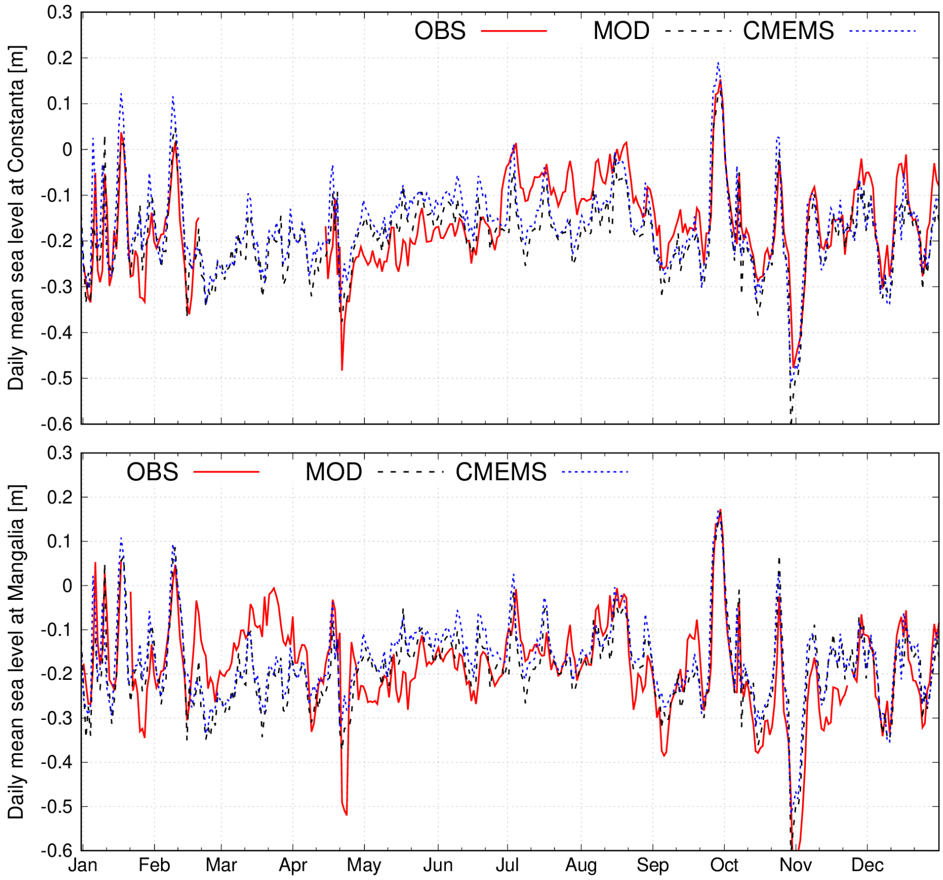

Figure 1: Observed (red line) and simulated (black dashed line) sea levels at Constanta (top panel) and Mangalia (bottom panel) for year 2017.

however a single set of statistical parameters are given in L182. What are the implications of comparing averaged daily values with specific timings in the satellite data?

Response: The validation for Constanta was not presented to limit the number of panels in Fig. 4. The results of the statistical analysis reported in Table 1 demonstrate the good performance of the model at all three sea temperature monitoring stations. We can include the timeseries of the sea temperature in Constanza, if required by the reviewer.

We are aware that salinity plays a major role in driving estuarine dynamics but, unfortunately, the area of interest is poorly monitored and, to our knowledge, no salinity observing stations exist (see the response to comment R1.6).

Satellite sea surface temperature values are provided at midnight to reduce the errors related to the impact of diurnal warming on the skin-to-bulk temperature conversion. Water temperature values were extracted from the simulation results in the surface layer at the location and time corresponding to the satellite SST data. Due to the limited number of available values at each control point, we prefer to apply the statistical analysis to a dataset containing all samples.

R1.10 I think that if this validation section could go into supplementary materials to streamline the paper.

Response: This paper presents the first comprehensive modelling study of the Danube Delta, and we believe the validation must be presented in the main text.

R1.11 Table 1 could include the statistical analysis for all the validation datasets (i.e. also include sea level and satellite SST) and not just temperature for monitoring stations.

Response: Following the reviewer's suggestion, we will included a table reporting the statistical analysis for all the validation datasets (e.g., Table 2) at the beginning of the "Model validation" section.

Table 2: Statistical analysis of simulated river discharge, sea level, sea temperature and sea surface temperature.

Variable	**Station**	**N data**	**RMSE**	**BIAS**	**CC**	**SLOPE**
River discharge	Chilia	120	158	-46	1.00	0.90
(m^3 s^{-1}	Tulcea	120	158	43	1.00	1.10
Sea level	Constanta	624	6.5	-	0.66	0.70
(cm)	Mangalia	722	7.8	-	0.55	0.62
Sea Temperature	15360	972	1.7	0.2	0.98	1.08
(°C)	Constanta	966	1.6	-0.4	0.97	0.98
	Mangalia	908	1.5	-0.2	0.97	0.96
SST (°C)	Razelm Sinoie	135	1.0	0.3	0.97	0.99

R1.12 Water division: water division is only validated in the upper part of the delta, and only temperature values are shown for a point in the vicinity of the outlets. Without discharge measurements in the network or temperature or salinity in the outlets it is difficult to assess how well or bad the model is performing. The water division is likely to influence the coastal dynamics and the plumes observed. These results also don't seem to be further explored in the paper.

Response: The numerical model application has been designed to resolve the more relevant water courses and can therefore be used to estimate the water discharge distribution in the delta. We believe that, even if only partially validated, the results presented in section 3.2 and Fig. 5 provide significant insights on the river-sea dynamics which are worth publishing. See also the response to comment R1.6 regarding the validation.

We will include the following paragraph in section 3.3 to highlight the influence of the water division on the plume dynamics: "In front of the Danube Delta, the general coastal circulation (determined averaging the values over the whole simulated period) reflects these processes with the several branches of the multiple-mouth delta forming separated freshwater plumes having shape and dimension defined by amount of water carried out by the different river branches and the coastline characteristics (Fig. 4a). Indeed, the largest plume is found south of the Sulina mouth, where the 5 km long artificial jetty enhances the offshore spread of riverine waters and creates a well-defined recirculation structure. It has to be noted that this plume is reinforced by the freshwater discharged by the nearby Chilia mouth. Well-defined plumes can be also recognized out of the Sf. Gheorghe, Novo Stambul and Potapov mouths. On average, the region of freshwater influence (ROFI; Simpson et al., 1993) associated with the Danube River extends for about 15 km offshore the river mouths. As illustrated in Fig. 4d, the freshwater inputs determine a stratified water column along the coast with Black Sea waters (defined here as having salinity higher than 16 g L^{-1}) located on average below 5 to 10 m from the surface."

R1.13 Spatial and temporal variability of coastal dynamics. L216 please define the scales of variability you refer to in the text. Here it is implicit you are considering seasonal scales as per your figure 6.

Response: We will modify the sentence to clarify that we are here presenting the results for two specific events having different hydro-meteo-marine conditions: (1) a summer event with peak river discharge (13000 m^3 s^{-1}) and calm weather (16 June 2019), and (2) an autumn event with low river discharge (2400 m^3 s^{-1}) and windy (northerly) conditions (11 November 2019). The seasonal scale analysis is reported in Fig. 7.

R1.14 L234 there is no correlation calculated here, suggest change "are highly correlated" to "can be explained by".

Response: We will correct the text following the reviewer's suggestion.

R1.15 River lagoon connectivity: Over which period are calculated the averages and estimates in L241 to L249?

Response: We will specify that unless otherwise specified, the reported values refer to averages over over the whole 2015-2019 simulation period.

R1.16 what causes the difference in WRT in the different years in L253 to L256? Are the weather regimes very different? Is it the different river discharge? It would be good to further explore the reason for these differences.

Response: We found an error in the WRT values reported in the original manuscript: the minimum (181 days) and maximum (333 days) basin-wide WRT values are found in 2018 and 2017, respectively. To further explore the role of forcing on the WRT computation, we analysed the characteristics of river discharge and wind in different years. The main findings are reported in the following sentences, which will be included in the revised manuscript: "The spatial and temporal variability of river, ocean and meteorological conditions affects the river-lagoon-sea fluxes as well as the internal mixing in the lagoons, and consequently the WRT computation. Indeed, the difference in WRT across the different years primarily reflects the freshwater input into the lagoons that mainly drives the river-lagoon-sea fluxes and therefore the flushing of the lagoon waters. Indeed, the minimum (181 days) and maximum (333 days) basin-wide WRT values are found in the flood (2018) and drought (2017) years, respectively (Fig. 2). A secondary, but not negligible, role is played by the wind which, in 2018 was characterized by frequent and intense Northerlies that enhanced internal mixing and favored the outflow from the lagoon towards the sea."

R1.17 L259 The sense of the gradient and the number of days seem reversed.

Response: We will correct the sentence as "... a marked east-to-west WRT gradient (from 50 to more than 300 days) is evident ...".

R1.18 Assessment of lagoon-sea reconnection solutions L270 please indicate for which period where the what if scenarios run.

Response: We will indicate the 2015-2019 period. See the response to comment R1.3.

R1.19 You could combine Fig. 8 and Fig. 9 and present current Fig. 9 as differences with respect to the reference run instead of absolute values. That way the differences would be more easily perceived.

Response: Following the reviewer's suggestion, we created a figure (included in this document as Fig. 2) presenting the results of the reference simulation as absolute values and of the reconnection scenarios as differences with respect to the reference run. In the revised version of the manuscript, we will replace Fig. 8 and remove Fig. 9.

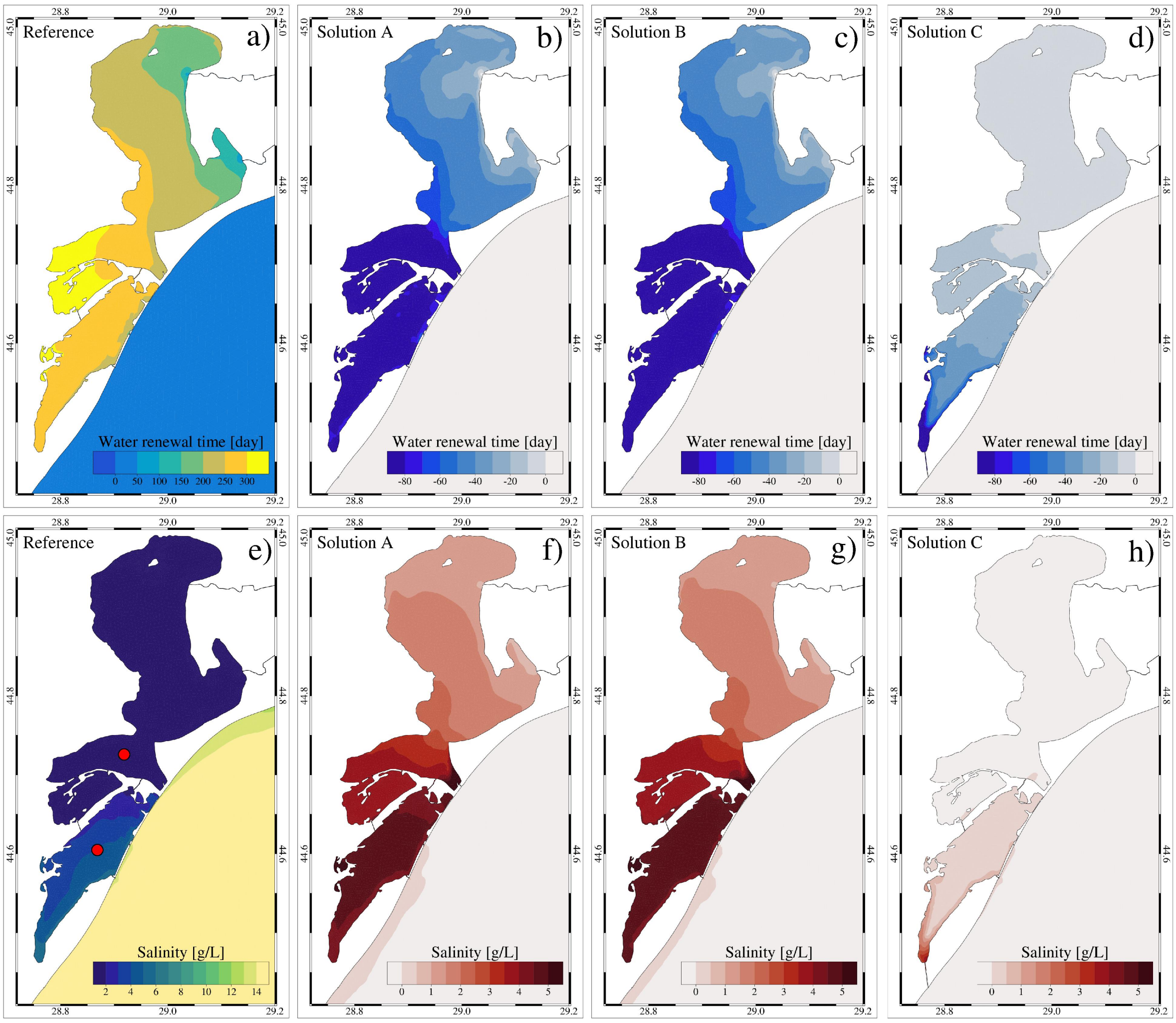

Figure 2: Average water renewal time and salinity over the Razelm Sinoie Lagoon System for the reference simulation (as absolute values) and the reconnection scenarios A, B and C (as difference with respect to the reference run). The red dots in panel *e* indicate the location of the two control points where the salinity timeseries were extracted (Fig. 10).

R1.20 L277-282: please point to table 2

Response: We will add the reference to Table 2.

R1.21 Fig 10, please change the colours they're not very colour blind friendly particularly sol.A and sol. B.

Response: Following the reviewer's suggestion, we changed the lines' colours in the mentioned figure (included in this document as Fig. 3).

R1.22 Discussion. The discussion further presents new results (there are 4 results figures in this section) and while they are interesting, they're not put in context or related to similar systems. I believe the discussion would be strengthened if these new 4 figures were moved into the results section and the results were further discussed and contextualised in the discussion. It is difficult to see what is of interest beyond the regional area and what learnings could be taken to other regions.

Response: Following the reviewer suggestion, all results will be presented in the "Results" section, while the interpretation of our findings within a broader context will be included

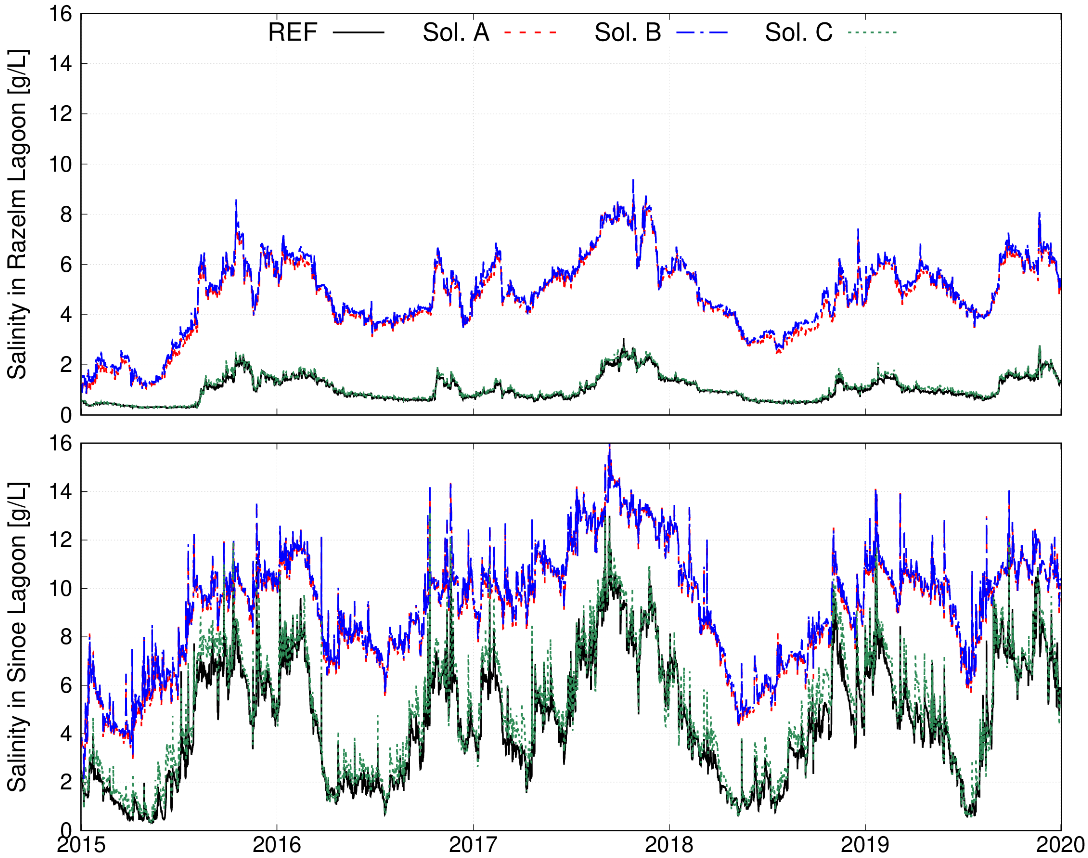

Figure 3: Timeseries of modelled salinity extracted in the control points in the Razelm (top panel) and Sinoie (bottom panel).

in the "Discussion and Conclusions" section.

R1.23 L305-309: I believed this is the first time that stratification is mentioned in the manuscript. So far, the analysis has been limited to the surface. Beside there is no reference to the different wind regimes, could you please elaborate on its influence on the circulation and vertical mixing patterns? Fig 6b and 6c correspond to surface salinity and currents.

Response: We will move these results and the related figure in section 3.2. Moreover, to investigate the influence of river discharge and wind on the coastal dynamics, we added to Fig. 6 (here Fig. 4) the plots of salinity along transect N-S. Such a figure, as well as the following text will be included in the revised version of the manuscript.

"As illustrated in Fig. 4d, the freshwater inputs determine a stratified water column along the coast with Black Sea waters (defined here as having salinity higher than 16 g L^{-1}) located on average below 5 to 10 m from the surface. During peak river flow and northerly conditions, vertical mixing processes near the coast occupy the whole water column (Fig. 4e). On the contrary, during low river discharge, the surface coastal dynamic is mainly driven by the wind. The autumn event presented in Fig. 4c is characterized by a general northward surface transport of saline waters with the ROFI limited to river plumes extending north-eastward for a few km from the river mouths. During such an event, the water column in front of the delta is well mixed except for a surficial 2 m thick layer in front of the main river branches (Fig. 4f)."

R1.24 L306 This is the first reference to the stratification of the water column and the stratification has not been shown anywhere in the paper, please point the reader to the figures

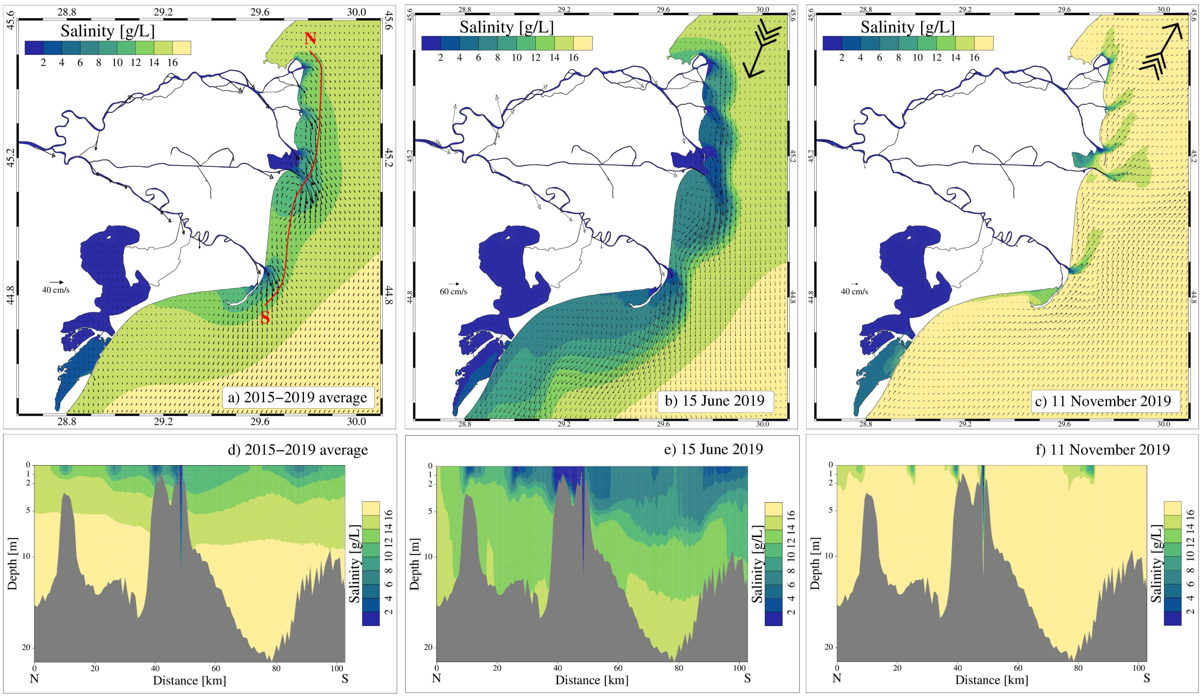

Figure 4: Surface salinity and current velocity maps, and N-S salinity transects: a) and d) average values over the 2015-2019 period; b) and e) instant values on 15 June 2019; c) and f) instant values on 11 November 2019. The arrows in the top right corner of panels b and c indicate the wind direction.

as needed or rephrase.

Response: We will rephrase this sentence. See also the response to comment R1.23.

R1.25 L309 Fig6b and 6c only show surface, not vertical processes as indicated, please rephrase. The wind regimes are not shown anywhere in the paper so it is difficult to follow the reasoning.

Response: We will rephrase this sentence. The wind arrows have been included in the figures Fig. 4b and c. See also the response to comment R1.23.

R1.26 L315 Upwelling is wind driven although it may interact with river plumes. You may wish to clarify the reasoning in this paragraph.

Response: We will change the mentioned sentence as "The presented analysis indicate that these peculiar structures are generated by upwelling processes induced by the action of southerly winds blowing along the coastline and interacting with the river outflow."

R1.27 L325 is the first reference to salt intrusion, there is no previous information or profile to assess the type of salt intrusion. You could include a profile along the main branches in Fig., 12.

Response: We will remove the section describing saltwater intrusion since it does not add significant advancements for this specific study area.

R1.28 Fig 13, please change the colours. Sol. A and Sol. B are difficult to distinguish. It is not clear how or where the differences are calculated. Is this over the whole lagoon? Is it the differences between two points one in the lagoon and one at sea?

Response: Following the reviewer's suggestion, we changed the lines' colours (included in this document as Fig. 5). We corrected the figure's caption to clarify that the image represents the average (over 2015-2019 period) water levels along the AB transect crossing the Razelm Sinoie Lagoon Systems and indicated with a red line in the right panel.

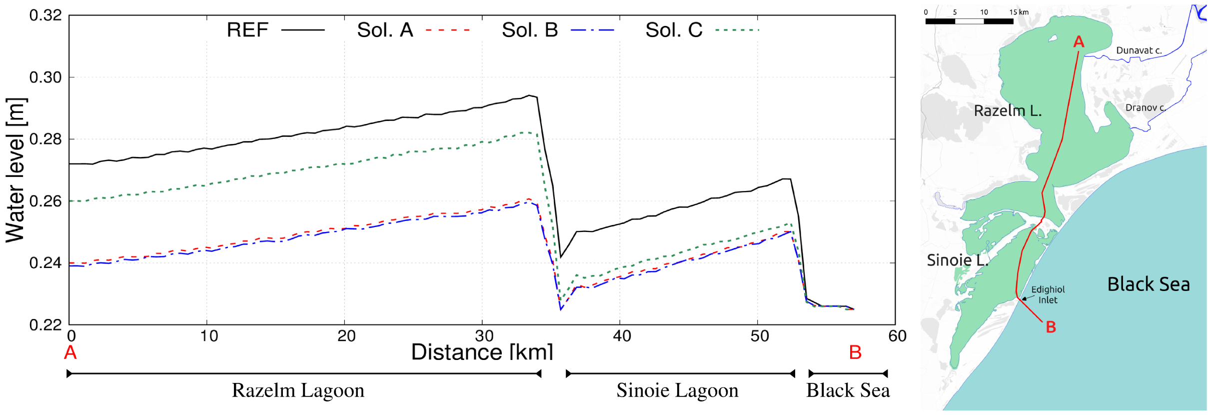

Figure 5: Average (over 2015-2019 period) water levels along the AB transect crossing the Razelm Sinoie Lagoon Systems indicated with a red line in the right panel. Background: ©OpenStreetMap contributors 2024; distributed under the Open Data Commons Open Database License (ODbL) v1.0.

R1.29 L337 please clarify what you mean by hydraulically limited here. You again refer to the wind here, but you do not present any information about the wind. You could include wind information in the figure in the same way that you include the river discharge.

Response: We will modify the sentence as "The water level jumps between the two lagoons and between the Sinoie Lagoon and the open sea indicate that the water exchange between the different water bodies is limited by the transport capacity of the narrow and shallow connecting canals (Canal 2, Canal 5, Edighiol and Periboina inlets)."

As mentioned in section 1.1, the two major wind regimes characterizing the study area are from north-east, being the most intense, and south-south-west, that can drive alongshore water and sediment transport (Dan et al., 2009). To provide more information about the wind variability, we included the wind speed and direction in Fig. 14 (see the response to comment R1.30).

R1.30 L340. Fig14 would benefit from including wind regime.

Response: Following the reviewer's suggestion, we included the wind speed and direction in Fig. 14 (included in this document as Fig. 6.)

R1.31 L345-347 please clarify what you mean by with hydraulically controlled.

Response: The mentioned sentence will be modified as "It must be noted that the water flux is not linearly dependent on the water level gradients confirming that the flow between the lagoon and the sea is limited by the transport capacity of the Edighiol and Periboina inlets (ad example at the beginning of March)."

R1.32 Conclusions. The conclusion could be strengthened by highlighting why or how this work is relevant beyond the study area at present it just restates what the paper does, and it is difficult to see why it would be of interest of the broader community beyond the study area. Could this be further explored?

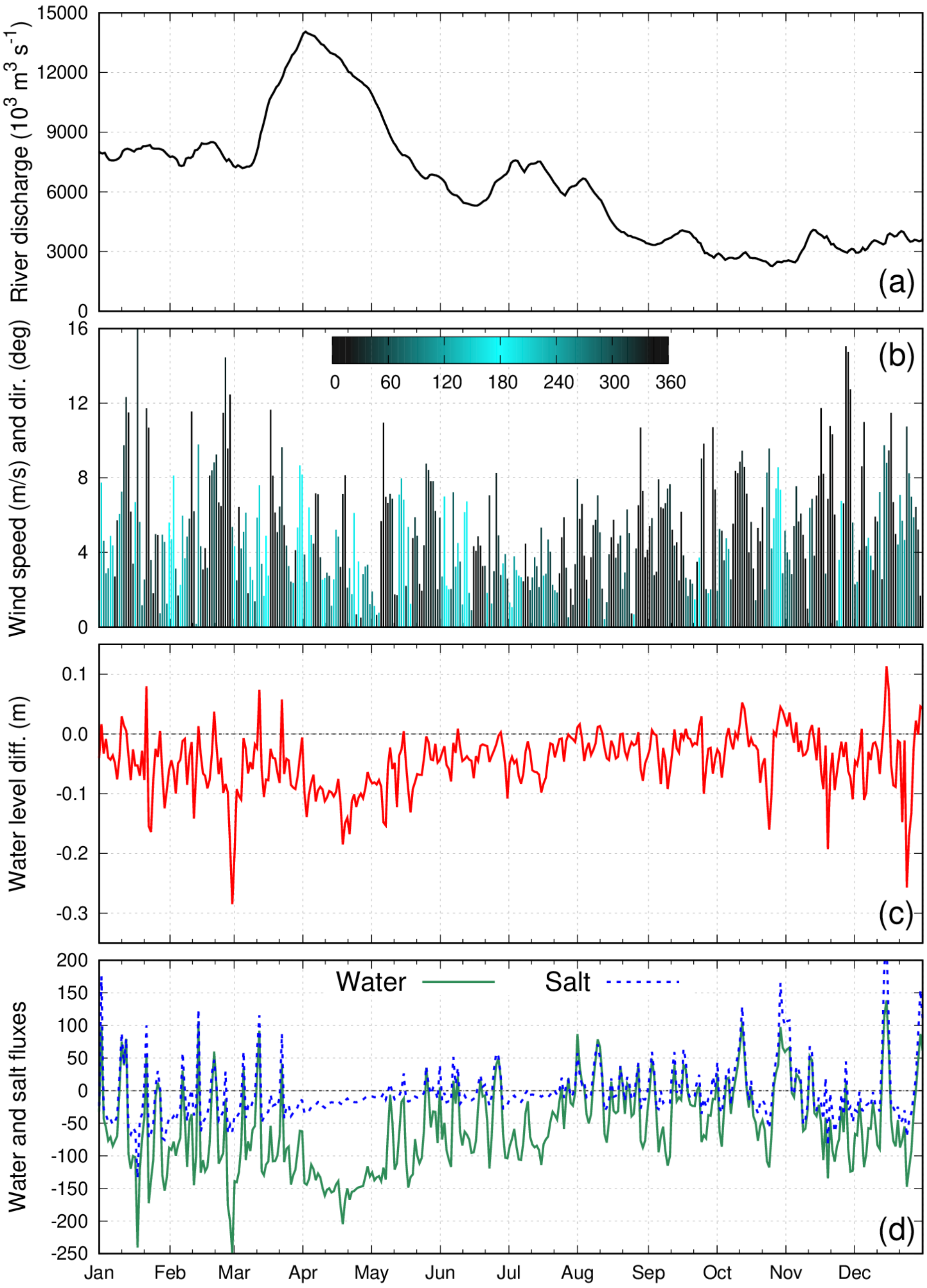

Figure 6: (a) daily values for the year 2018 of Danube River discharge; (b) water level difference between the lagoon and the sea; (c) wind speed (y-axes) and direction (colour); (d) sea-lagoon water (m^3 s^{-1}) and salt (10^3 kg s^{-1}) fluxes (positive values indicate inflow into the lagoons while negative values indicate outflow from the lagoon to the sea).

Response: As mentioned in the response to comment R1.22, the interpretation of our findings within a broader context will be included in the "Discussion and Conclusions" section.

R1.33 L382 "four lagoon-sea reconnections" I believe you explore 3 different options.

Response: We will correct the text.

References

Dan, S., Stive, M., Walstra, D.-J. R., and Panin, N.: Wave climate, coastal sediment budget and shoreline changes for the Danube Delta, Mar. Geol., 262, 39–49, https://doi.org/10.1016/j.margeo.2009.03.003, 2009.

EMODnet Bathymetry Consortium: EMODnet Digital Bathymetry (DTM 2022), https://doi.org/10.12770/ff3aff8a-cff1-44a3-a2c8-1910bf109f85, 2022.

Simpson, J. H., Bos, W., Schirmer, F., Souza, A., Rippeth, T., Jones, S., and Hydes, D.: Periodic stratification in the rhine ROFI in the North Sea, Oceanologica Acta, 16, 23–32, 1993.