#Reviewer 4

We thank the reviewers for their valuable comments, which have been essential in improving our study. In response to feedback from several reviewers, we have optimized the parameterization of the advection-dispersion module, allowing us to use a more realistic dispersion coefficient. In the new version of the article, as detailed in the responses to the questions, we have provided a more precise explanation of the dispersion coefficient used. Additionally, a new section (Section 3.1) has been added, where we justify in detail the need to include sinks, as well as provide a thorough description of the sink parameter. All the results presented in the article have been updated to reflect the new simulations performed with the improved model version. Although these new simulations do not alter the results or discussion presented, they contribute to greater clarity and precision in the presentation of the findings.

This is a valuable manuscript that helps to gain insight on salt transport processes in well-mixed estuaries, such as the Guadalquivir estuary. The effects on salt distribution due to natural and anthropogenic freshwater outtakes from the estuary is addressed. The topic is relevant as higher salt intrusion in estuaries is expected in the actual global warming and freshwater supply reduction context.

My overall impression is positive, although the manuscript requieres a major revision before I could recommend publication.

Thank you for your kind words and the suggestions you provided. Please find each of them answered below.

My major concerns are regarding the usage of terms, discrepancies between model output and observations, and citations. Please see specific comments below.

1. **I think that not all the discrepancies should be attributed to withdrawals. Evaporation rates could be particularly important during the dry season.**

Thank you for your valuable comment.

We agree that not all discrepancies in the observed salinity should be attributed solely to withdrawals. Evaporation rates, especially during the dry season, are indeed an important factor to consider. Natural processes such as evaporation can contribute to a reduction in water volume, potentially increasing salinity levels.

Considering only natural effects, such as evaporation or the small natural channels present in the estuary, would not generate a sufficient volume reduction to account for the high salinity range observed along the river during the different campaigns. It is therefore necessary to include anthropogenic processes such as water withdrawal for agricultural, industrial and urban activities, illegal wells, the creation of secondary channels and the reduction of marshes, among others. All these processes (both natural and anthropogenic) together lead to a reduction in water volume, which could be responsible for the high salinity concentrations observed in the inner part of the estuary. The parameter δ is a key factor in quantifying the effect of extractions and minor contributions to water volume along the river. In other words, it represents all the natural and anthropogenic processes that can affect the volume of water, such as agricultural abstraction, industrial use, small side channels and evaporation. δ represents an average value between these two actions, and for our study it was positive, indicating that on average extractions exceed the contributions from smaller channels that drain into the main channel.

Similarly, we have revised Sections 4.1 and 4.2 (now Sections 3.5.1 and 3.5.2, following your suggestion), referring to the moments of maximum salinity at high-water slack and minimum salinity at low-water slack.

2. **If not considered, uncorrected phase lags (which are related to those of the tides) in modeled and observed salinity yield also deviations. As the oceanographic vessel travelled upstream (How much time took the vessel to complete one survey?), the tide propagates and at different locations of the estuary the moment of the tide is different. I think the authors didn't mention whether along-channel modeled salinity is plotted at a given simulation time or at the time the salinity measurement was taken at each location. The authors should discuss that.**

Thank you for your comment.

You are absolutely correct that the tide exhibits a phase lag at different points in the estuary, and this must be accounted for in salinity measurements.

In Fig. R1, we present the time series of current velocity, tidal height, and salinity (all simulated from the model for MG1) at three different points (4 km, 40 km and 80 km form the mouth). As can be seen, the phase lags in both the tide and salinity are accounted for in our simulations. As you rightly pointed out, the tidal wave will exhibit a phase lag as it moves upstream. This aspect was included when we force the model in a section near Bonanza, specifying an appropriate temporal variation of the salinity calculated as a function of the current (u) in this section and derived from the available observations.

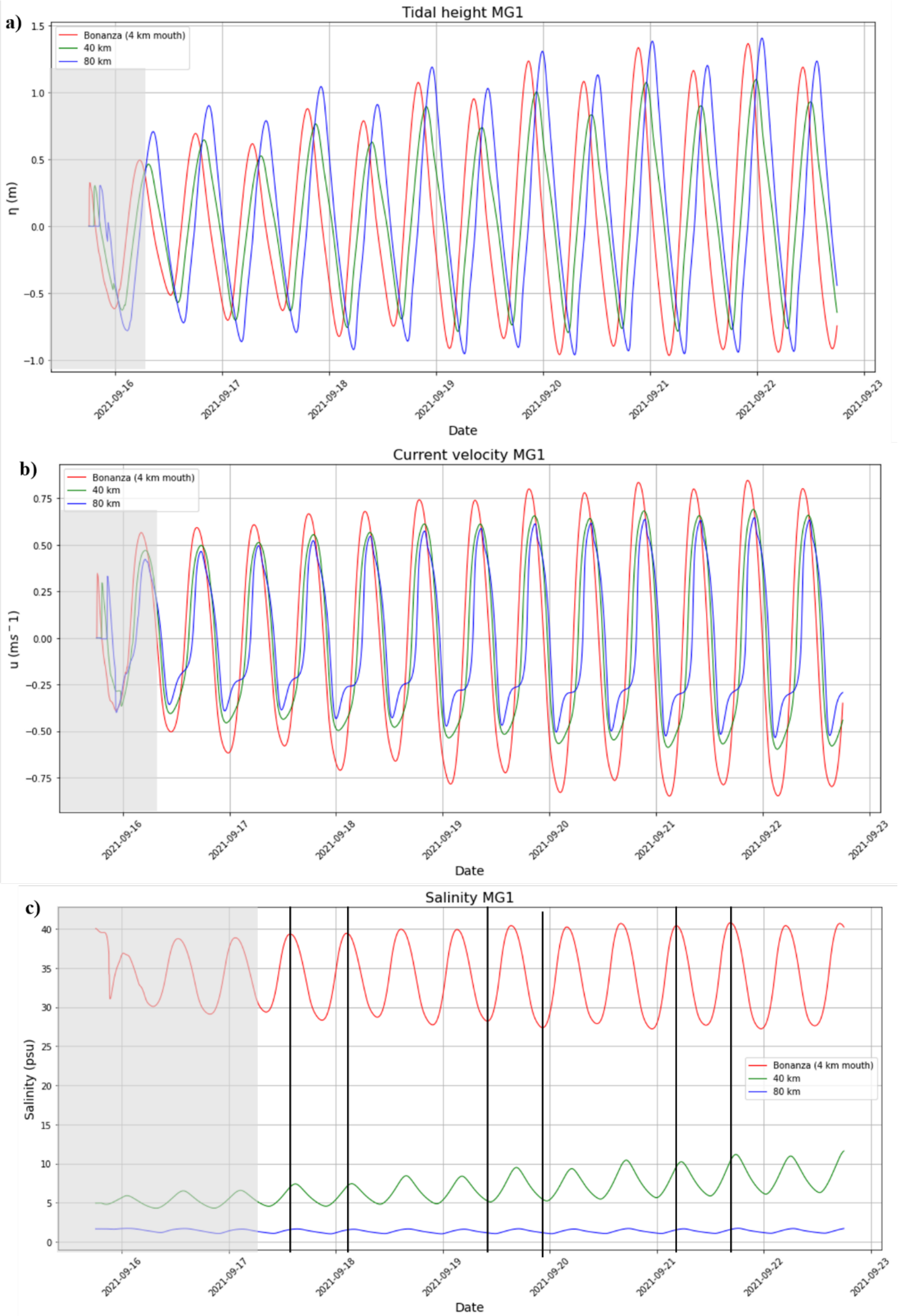

Figure R1. Time series of 7 days of simulation for tide height (a), current velocity (b), and salinity (c) at three sections of the estuary: 4 km from the mouth (red line), 40 km from the mouth (green line), and 80 km from the mouth (blue line). The model stabilization period is indicated by a grey rectangle.

Regarding the simulations presented with the data obtained from the thermosalinograph as the vessel traveled upstream/downstream through the estuary, we are using the same time instances as the observations (Fig R2a). In Figure R2b, represents the comparison between the observation points and the model simulation points, measuring the spatial differences in meters. In other words, it shows the discrepancy in the location between the observed data points and the model simulation points, based on the spatial distance. These differences arise because the model's spatial resolution is 25 m, meaning we do not have the exact position of the vessel in the simulation. Instead, we use the nearest point to the vessel's location.

Figure R2c shows the coordinates of each observed point (vessel data) and the corresponding modelled points. Although only the information for MG1 is shown, it is important to note that for each observation presented in the article, the same time instant was used. Our model has a very high temporal resolution (dt= 1 second), which allows us to select the same sampling instants. Similarly, at the spatial level, our model has a spatial resolution of 25m, which enables us to almost exactly select the same observed points. The small discrepancies between both datasets may also be due to the georeferencing of the model, which was carried out through the digitization of the main channel from nautical charts.

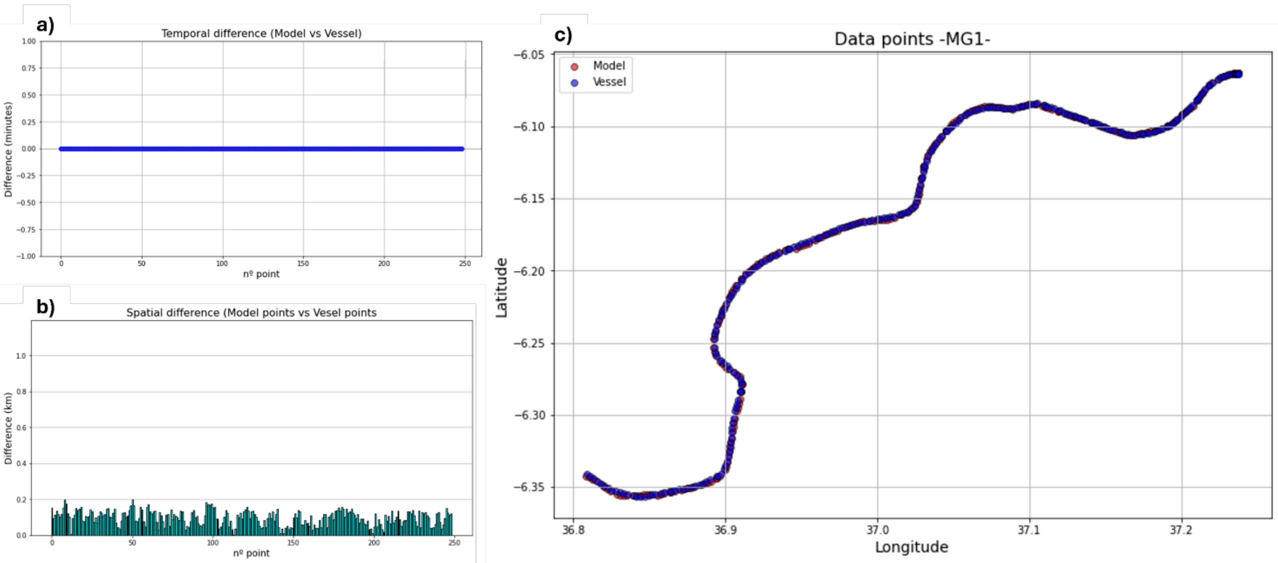

Figure R2. (a) Temporal difference at each point between simulation and observation data. (b) Spatial difference between observation points locations and simulation points. (c) Map of observation data (vessel trip data) locations in blue, with red dots representing model data locations at each point. This information corresponds to MG1 campaign.

Regarding the time it takes for the vessel to complete its journey, it varies in each case and does not cover a significant temporal range.

In the following table, we summarize the information about the vessel trips for each campaign, titled "vessel trips" in the manuscript. Although the temporal coverage may not be extensive, it allows us to validate the model both in time and space simultaneously. Subsequently, validation is performed using fixed stations (presented in supplementary material as SM4, SM5, SM6). For the MG3 -down- campaign, it has been divided into two parts, as on the 20th, the sampled points were closest to the head. Between the measurements taken on July 20, 2022, and July 21, 2022, sampling was conducted at a fixed station (see SM4b).

MG	Start Date	End Date	Elapsed Time (hours)
MG1	2021-09-20 14:35:00	2021-09-20 18:45:00	4.17
MG2	2022-01-31 16:13:00	2022-01-31 23:58:00	7.75
MG3 Up	2022-07-19 11:23:00	2022-07-19 16:35:00	5.2
MG3 Down (1)	2022-07-20 17:08:00	2022-07-20 19:09:00	2.02
MG3 Down (2)	2022-07-21 19:23:00	2022-07-21 21:18:00	1.92
MG4 Up	2023-10-17 09:57:00	2023-10-17 16:17:00	6.33
MG4 Down	2023-10-18 07:42:00	2023-10-18 11:09:00	3.45

We have revised the text, as you correctly pointed out that it was not clear that we are comparing the same time instances and approximately the same locations. Thank you for your valuable feedback. We have included the necessary clarifications to enhance understanding in Line 231.

Line 288 (Revised version of the manuscript):

“It should be noted that the simulations presented in this figure represent the simulated salinity concentration generated by the model at each time instance of the observations, corresponding to the nearest possible point to the sampling location of the vessel”.

Line 373:

“Fig. 3 shows the behavior of the longitudinal observations collected demonstrating the high accuracy of the simulations (including *δ)* in replicating the observed data and demonstrating a robust fit across all campaigns. It is important to note that the simulations presented in this figure represent the simulated salinity concentration generated by the model at each time instance of the observations, corresponding to the nearest possible point to the sampling location of the vessel (Fig. SM1).”

3. **Regarding terms usage, some of the them are inappropriate (salt wedge/front) for this estuary during low riverflows. Besides, higher/Lower salt intrusions do not occur at maximum flood/ebb.**

Thank you, we have corrected this by using the precise terms suggested by all the reviewers (Horizontal salinity gradient and salt/saline intrusion). Similarly, it is indeed the case that the salinity maxima and minima do not occur at maximum flood and ebb, as there is a phase lag between them. We did not mean to imply that the maxima occur at maximum flood/ebb, but rather that they occur just after (given the phase lag between salinity and velocity). We have corrected this wording in the text to avoid confusion.

Section 3.3, now renumbered as Section 3.4, has been revised. We have updated the tidal moments and selected neap and spring tides to clarify and simplify the analysis. The text has been modified accordingly. Please see below:

“3.4. Tidal cycle dynamics.

Once the reliability of the model had been confirmed by the results of the experimental validation presented in the previous sections, it was used to simulate the dynamic of the saline intrusion during a spring-neap tidal cycle. To do this, we conducted a simulation extended over 15 days (15/07/2022-30/07/2022) using the same model configuration presented in section 3.1 for the MG3 campaign. This period was selected because it comprised records of observations distributed throughout the spring-neap tidal cycle, allowing for the validation of the simulations. A spin-up of 3 days is necessary to stabilize the initial conditions and achieve realistic outputs.

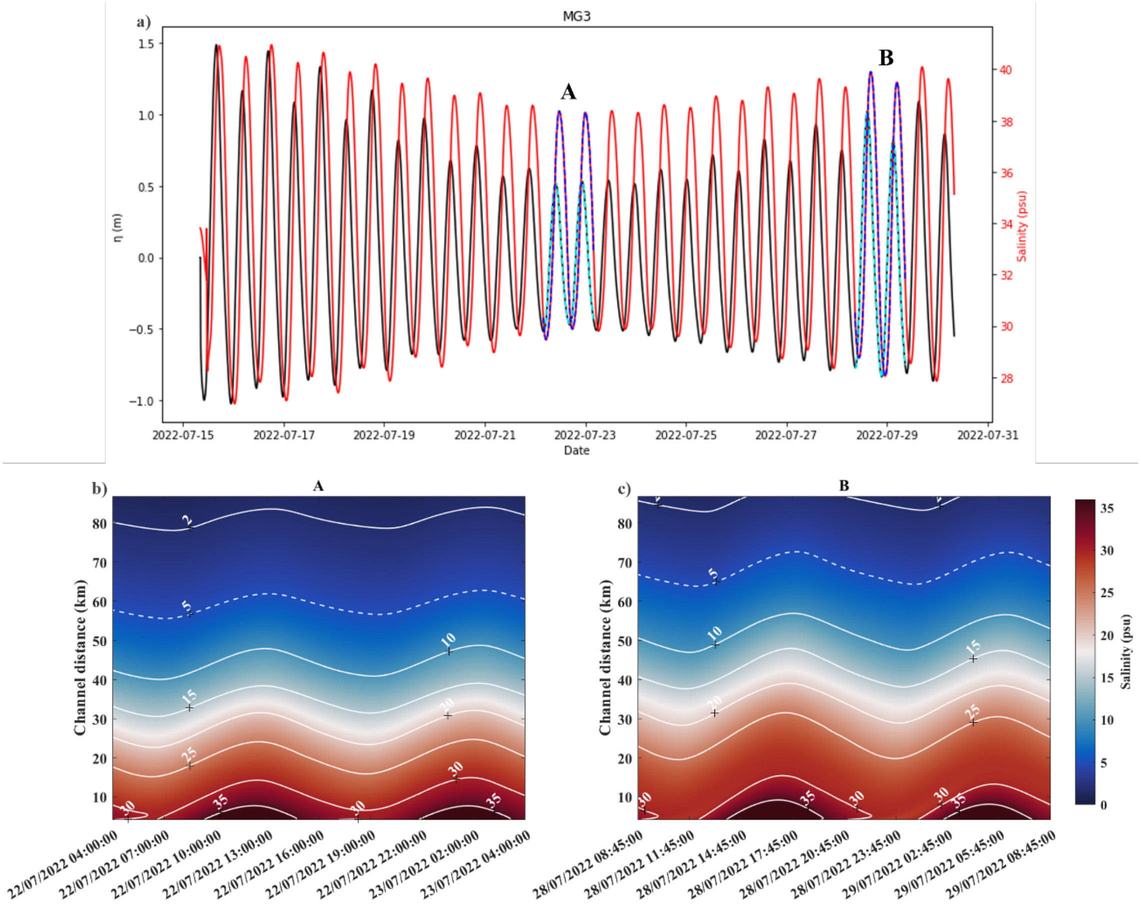

Figure 1: (a) Superposition of tidal height (m) and salinity (psu) simulated time series at Bonanza section throughout 15 days of July 2022. Dashed lines indicate the selected 24 h periods referred to in (b) and (c); Hovmöller diagrams of simulated salinity variation over these two daily cycles (24 h) during neap tides(b) and spring tides (c) along the Guadalquivir estuary. Isohalines are represented as white lines.

We focused on two 24-hour periods to describe the dynamics of the horizontal salinity gradient during different phases of the semi-diurnal cycle (Fig. 5a). To account for water volume In Figure 5a, it can be observed that the maximum salinity levels occur near the high-water slack, while the minimum salinity levels are recorded around the low water slack. Figure 5b shows the progression of the saline intrusion during neap tides (A). Using the 5 psu isohaline as the boundary for the horizontal salinity gradient, it can be seen that the maximum salinity extends up to 63 km from the mouth, while the minimum values of this isohaline do not exceed 56 km. In contrast, during spring tides (B) (Figure 5c), as expected, higher salinity values are observed throughout all sections of the estuary compared to neap tides. The 5 psu isohaline extends up to 72 km from the mouth, while the minimum values do not exceed 65 km. This shows a difference of approximately 5-8 km between the moments of maximum and minimum intrusion, being this displacement higher for spring tides than neap tides.

In the same way, when comparing the behavior during spring tides to neap tides, we can observe a difference of 8 km between the minimum values and up to 10 km between the maximum values. Therefore, there is an oscillation of approximately 10 km between spring and neap tides. During spring tides, the horizontal salinity gradient reaches higher concentrations further upstream compared to neap tides, where both the maximum and minimum salinity values are lower. This finding is consistent with the results suggested by Díez-Minguito et al. (2013), who documented a net displacement of approximately 10 km between spring and neap tides.

These results suggest that the constant anthropogenic pressure on the estuary has caused a change in saline intrusion, resulting in higher salinity levels upstream of the river compared to the records of previous studies, such as that of Fernández-Delgado et al. (2007). In this study, it was found that over a six-year period (1997–2003), the 5 psu isohaline boundary was located near 25 km at low tide and at 35 km at high tide. The 18 psu isohaline limit was also found to be 5 km and 15 km upstream of the river mouth at low and high tides, respectively."

Similarly, we have revised Sections 4.1 and 4.2 (now Sections 3.5.1 and 3.5.2, following your suggestion), referring to the moments of maximum salinity at high-water slack and minimum salinity at low-water slack.

4. **Please check references out, too. I think a few of them are not appropriate or out of place.**

Done, thank you for the suggestion.

Specific comments:

Abstract

L13. (there exists advective and diffusive transport)

Done, thank you

L15. I agree with one of the other reviewers. There is no salt wedge or salt front in the GRE during low riverflows. Please use salt intrusion or saline intrusion. Salt wedge typically occurs in highly stratified estuaries. Change here and elsewhere. Salt front may form after high freshwater discharges near the mouth.

Done, thank you. We have modified all terminology including salt intrusion and horizontal salinity gradient.

L17. Water withdrawal or sink term or outflow?

We have modified for sink, we are referring to δ parameter which has been called "sink" in the manuscript.

Introduction

L28. Perhaps Miranda et al. 2017 is much more "physical" than "biological". I suggest to change citation here.

Done, we have rewritten the sentence and eliminated the citation:

"These coastal areas are typically described as highly productive zones, where nutrients from the land are incorporated into a transitional system between fresh and sea waters"

L29. + freshwater discharge + tides + wind

Done, thank you

L32. I think is better here to cite a general reference on ecological systems better than Donázar-Aramendía et al., (2019), which is somehow more "local".

Done, we have changed for a more general reference

Boehlert, G. W., & Mundy, B. C. (1988). Roles of behavioral and physical factors in larval and juvenile fish recruitment to estuarine nursery areas. In *American Fisheries Society Symposium* (Vol. 3, No. 5, pp. 1-67).

L37. Remove Pritchard (not on the GRE) and Losada citations. If you want to include some here, I suggest Álvarez et al. 2001 or Díez-Minguito et al., 2013.

Done, thank you

L39. Remove Reyes-Merlo et al. citation. The credit on this should go to Álvarez el al. 2001, I think.

Done, thank you.

L41. Remove citation. Citation here (Contreras and Polo, 2012) is on the influence of basin hydrology on the GRE. Please check out that statements throughout the manuscript are correctly cited.

Done, thank you.

L50. 'and decreasing saline intrusion.'

Done, thank you.

Figure1. Xo is the landward limit of the model. Does the boundary condition of salinity at Xo vary with time?

Yes, the salinity boundary condition at X0 (free transmission) varies over time at X0 (the first point in the model mesh). This behavior occurs because its value depends on the salinities of neighboring spatial points at the same time instant, making it a dynamic component of the model. We understand that the ability of the boundary condition to adjust to fluctuations in the system is crucial for capturing the complexity of estuarine processes and for providing more accurate simulations that better reflect the real environmental conditions.

L60. Bermudez et al. 2021 is on microplastic distribution in the GRE. I suggest to remove from here.

Done, thank you

L62. 'requires large amounts of freshwater' ?

Thanks, we have modified the sentence:

"However, it is also a source of economic and environmental conflict due to the coexistence of multiple activities (salt production, agriculture -especially rice, which requires large amounts of freshwater - fishing and navigation)."

L65. Notice that none of the citations in on degradation of the ecosystem. Moreover, Zarzuelo et al. 2017 is a study developed in Cadiz Bay.

We have modified it. Thank you

"The high anthropogenic pressure has caused changes in both the hydrodynamics and morphology of the system, favoring the constant degradation of the ecosystem (Mendiguchía et al., 2007; Ruiz et al., 2015: Siles-Ajamil et al. (2019); Sirviente et al., 2023)."

L79. And downstream, too. Seaward from Bonanza, salinity does not change so much either. Typically is modelled as a tanh(x) function. Nevertheless, it is possible that authors' model domain leaves out this part of the salinity distribution.

Thank you for your comment. The domain of our model extends up to Bonanza, thus this part of the salinity distribution is not included.

L86. -1 superscript.

Done, Thank you

L87. Climatic forcings

Thank you, done

L89. Salt/saline intrusion

Done, Thank you

L92. Notice also that hydrodynamic model by Siles-Ajamil et al. is linear. Authors' model is non-linear, which is quite an improvement.

Thank you; we have noted this in the text

Line 119: Using a linear analytical model, Siles-Ajamil et al. (2019)

L92. How does compare authors' model with that by Bouke et al. (2022)? (https://doi.org/10.1029/2022JC018669)

Thank you, we have included this reference as:

"Biemond et al. (2022) investigate the impact of freshwater pulses (brief periods of high river flow) on estuarine saline intrusion in GRE. They constructed an idealized nonlinear model based on the model of MacCready (2007), but not based on Pritchard equilibrium. The model is width-averaged, which means it doesn't resolve variations across the channel width, but fully captures variations in both the along-channel and vertical directions. The vertical structure is represented using multiple modes (between 5-15 depending on stratification) to capture the depth-dependent aspects of flow and salinity. The model features constant width and depth, as well as constant viscosity and diffusivity coefficients in space and time. The new model demonstrates that the intensity and duration of the pulse are the primary factors controlling the reduction of salt intrusion, with tidal force having a relatively minor influence. Additionally, the time required for saline intrusion to return to its initial position is found to be dependent on the river discharge following the pulse, rather than the distance the intrusion has traveled upstream."

Methodology

L121. Is really the focus of the manuscript the calibration and validation of the model? I think calibration and validation is necessary, but shouldn't be the solely objective of the study. I suggest to rephase the sentence.

Thank you for the suggestion, we have changed it:

"This manuscript presents an analysis of salinity behavior along the GRE. In this context, in situ observations collected from several short-duration oceanographic campaigns conducted during the dry seasons from 2021 to 2023 will be employed for the calibration and validation of the advection and dispersion module."

L123. Ok

L125. I suggest to mention or present these issues already in the introduction. It will help to motivate the object and give the proper context to the readers.

Thank you, following this comment and one suggestion of another reviewer, we have included some information about water withdrawals effect in saline intrusion in other estuaries. And mention this issue too.

After line 65:

"The detrimental effects of anthropogenic activities have been demonstrated in other estuaries around the world. Alcérreca-Huerta et al. (2019) show that the construction of a dam system in the estuary of the Grijalva River (Mexico) in 1959 altered the hydrological regime, reducing the seasonality of water discharge and decreasing the amount of available freshwater. This, together with changes in land use (more agricultural land, less mangrove cover and less vegetation), leads to variations in salinity concentration, with saline intrusion observed up to 46 km upstream, with salinity levels reaching 32.8 PSU. Studies such as Huang et al. (2024), based on numerical simulations using a 3D model, show that anthropogenic activities, in particular the regulation of freshwater flows by infrastructure projects, are drastically changing the dynamics of saline intrusion in the Changjiang River estuary (China). This study shows how an increase in freshwater flows (due to releases from the Three Gorges Reservoir) counteracts the advance of saline intrusion. However, water withdrawals in the city of Yangzhou as part of the implementation of the East Route of the South-to-North Water Transfer Project will inevitably lead to a reduction in inflow during the dry season, resulting in an increase in salinity intrusion in this system by approximately 6-7 km. This relationship between salinity and freshwater flow was previously observed by Webber et al. (2015), who assessed the effects of the Three Gorges Dam, the South-to-North Water Transfer Project, and local water withdrawals on the probability of intrusion in the Changjiang River estuary. They conclude that these projects will increase the probability of saline intrusion and suggest that water management should be adapted to mitigate the risk."

And after line 108:

This manuscript provides an analysis of the current state of saline intrusion in the GRE and evaluates the impact of anthropogenic pressures on the behavior of horizontal salinity gradient. This study represents the first attempt to analyze the impact of anthropogenic water volume withdrawals on estuary hydrodynamics and the associated increase of the horizontal salinity gradient.

L130. '…along the estuary.'

Table 1. Salinity measurements along the estuary are not simultaneous. They are out of phase from one point to another point within the estuary (salinity changes locally during floods, ebbs, etc.). Are the different phases somehow corrected to present 'simultaneous' salinity values along the estuary? (Also in L200)

Thank you.

Our hydrodynamic model accounts for the tidal phase lag between different points along the estuary. Similarly, the advection-dispersion model incorporates this phase lag, allowing us to simulate salinity more accurately. This means that we can calculate salt concentration at any point in the estuary, taking into account the specific tidal state at that location. In this way, local salinity variations are adequately represented based on the tidal phase at each point.

Line 185 (Revised manuscript version):

The observations corresponding to each vessel trip were taken at different points and time instances as the vessel ascended or descended along the GRE. Once the simulations corresponding to each campaign for validation are obtained, the same time instances as each observed data point are used. Additionally, model points are used as close as possible to the observed points, with small differences between them (Fig SM1). This ensures that the same points and time instances as the observed data are compared (tidal phase lag are contemplated in our simulations).

Where Fig SM1 corresponds to Fig R2 presented in this document.

After Equation (2) '.' not ','.

Thank you, done.

L148. Forces per unit mass.

Thank you, done.

L149. Units. Separate m from s

Thank you, done.

L150. Bottom friction or bottom drag coefficient?

K means bottom friction coefficient

L161. Why not include El Gergal and Brazo de la Torre too?

More tributaries were analyzed than those presented in the article, but only those considered to have a significant contribution were included. In the case of these two tributaries, their influence was minimal during the period analyzed. It was decided not to include contributions with very low contribution as they did not result in a significant change in the results obtained.

L170. Salt transport. Check out here and elsewhere: advection and dispersion transport (there exists advective and diffusive transport)

Thank you, done.

Equation (3). No sink terms in this equation? Could evaporation rates be comparable or may affect \delta estimates?

δ term is included in the hydrodynamic model. We understand that *delta* refers not only to anthropogenic activities but also to all processes that lead to a reduction in volume, including evaporation. However, we believe that processes such as evaporation are not the sole contributors to the high salinity concentrations observed. Anthropogenic effects play a crucial role and are fundamental in explaining these high salinity levels.

L197. Please, indicate determination coefficient of the fit and/or other performance scores of the calibration. (Or refer to Table 2)

A detailed description of the dispersion term (D) has been included in the new Section 3.1, along with a demonstration of the need to account for volume reductions in order to replicate the observed concentration. Also we have referred to Table 2.

Thanks to the reviewers' comments, we reviewed and adjusted the transport model to use a higher, more realistic constant diffusion coefficient without introducing instabilities into the model. In the revised version, based on Bowden (1983), we defined the most appropriate horizontal dispersion coefficient, taking into account the mean depth and tidal amplitude. This calculation was performed for all campaigns included in the analysis to ensure the use of a constant dispersion value appropriate for the system. The results indicate that the maximum constant dispersion based on velocity and depth is 150 m²/s (this has also been added and explained in detail in the revised version of the article). In addition, a sensitivity analysis was performed with different dispersion coefficients to optimize this parameter as much as possible. It was found that a dispersion value higher than 200 m²/s leads to numerical instabilities in the system.

Based on Bowden (1983), the effective horizontal dispersion coefficient can be calculated as $K_X=U^2H^2/30{*}K_Z$,, where *U* is the maximum tidal velocity, *H* is the mean channel depth, and *Kz* is the vertical eddy dispersion coefficient, assumed to be constant. In our case, we used *Kz*=0.01, as proposed by Bowden (1983).

Campaign	**U (ms^{-1})**	**K_x m^2s^{-1}**
MG1	0,85	143
MG2	0,88	154
MG3	0,88	153
MG4	0,80	127

This selection of a constant dispersion coefficient is based on the assumption that lateral dispersion is homogeneous and that strong tidal currents will induce vertical mixing, thereby rendering advection the dominant process in the behavior of the saline intrusion. The Peclet number (*Pe*), defined as *uL/D,* measures the relative contribution between the nonlinear advection and horizontal dispersion, where *u* is an averaged (in time and along the whole estuary) absolute value of the along-channel gradient of velocity, *L* is the estuary length, and *D* corresponds to the horizontal dispersion coefficient (Deng et al., 2024). Taking a value u= 0.5 ms^{-1}, extracted from realistic simulations performed with the hydrodynamic module and the values L= 107 km and D=150 m^2 s^{-1} yields a value Pe=356, clearly indicating a dominance of the advective transport rate over the diffusive one.

Results and Discussion

L110-115. I think this must be better justified here or elsewhere. Authors must be clear how they drew the conclusion that there must be water withdrawals (although certainly possible). 'Flow data by official sources?' Do you mean freshwater discharges? What were the tidal and riverflow conditions?

Thank you for this suggestion.

Yes, the official sources we are referring to (for instance, Guadalquivir Hydrologic Confederation) have provided freshwater discharges. On the other side, authors have not been able to find any official source that provided water withdrawals. In the current version of the manuscript we have added a new section (section 3.1) where the justification for including water withdrawals it is better addressed. In that section is analysed the effect of horizontal dispersion vs water withdrawals in the penetration of the saline front. Here reasonably high dispersion coefficient are allowed, following the formulation due to Bowden (1983). Regarding the phrase "flow data from official sources," we are actually referring to the simulation that only considered horizontal dispersion and freshwater discharge inputs. In other words, we were referring to the simulation where water volume reductions were not included. We have revised this to make the explanation much clearer and more detailed.

"During the model validation phase, it was found that the extension of the saline intrusion into the interior of the estuary coming from the data measurements was much greater than those simulated including only the freshwater flow data and horizontal dispersion. Hence, we became aware that significant undocumented water withdrawals were occurring during the different campaigns (as it has been described in section 3.1)."

New section has been included as:

"3.1. Effect of Horizontal Dispersion and Water Withdrawal on the Horizontal Salinity Gradient in the Estuary

First, the model is used to analyze the effect of horizontal dispersion on the development of the horizontal salinity gradient. To this end, experiments were conducted considering only the effect of horizontal dispersion, representing the natural behavior of the system without any additional intervention. Subsequently, experiments incorporating the presence of sinks were carried out, simulating a reduction in the water volume of the channel.

Figure 2 shows the observed horizontal salinity gradient during the MG3 campaign (upstream and downstream trips) along with simulations corresponding to a 13-day period. This figure compares the simulated horizontal gradients under different conditions: Figures 2a and 2b include only the effect of horizontal dispersion; Figures 2c and 2d include both horizontal dispersion and a uniform reduction in water volume (δ), constant in time and space; and finally, Figures 2e and 2f consider horizontal dispersion along with sinks (δ) that vary over time. It is important to emphasize that all the times shown in Figure 2 correspond to moments when the tidal behavior is identical to that observed at each point during the reference period. It should be noted that the simulations presented in this figure represent the simulated salinity concentration generated by the model at each time instance of the observations, corresponding to the nearest possible point to the sampling location of the vessel.

When analyzing the behavior of the horizontal salinity gradient along the estuary, considering only horizontal dispersion, it becomes clear that the system would not reproduce the observed salinity concentrations from the different campaigns. Even when the dispersion coefficient is increased to 190 $m^2 s^{-1}$ (Figures 2a and 2b) – the highest dispersion coefficient that can be used with this model without causing numerical instability – the observed concentrations are not matched.

Considering only the effect of horizontal dispersion, it can be observed that the system tends to slightly increase the salinity concentration over time in almost all sections of the river up to 45 km from the estuary. Beyond this point, the behavior becomes almost linear, with very low salinities close to 0 psu. These results show that if only the effect of horizontal dispersion is considered, the system is unable to reproduce the observed salinity range.

This highlights the need to include in the simulations those processes that could cause a significant increase in the horizontal salinity gradient. These processes may include those capable of reducing water volume. Considering only natural effects, such as evaporation or the small natural channels present in the estuary, would not generate a sufficient volume reduction to account for the high salinity range observed along the river during the different campaigns. It is therefore necessary to include anthropogenic processes such as water withdrawal for agricultural, industrial and urban activities, illegal wells, the creation of secondary channels and the reduction of marshes, among others. All these processes (both natural and anthropogenic) together lead to a reduction in water volume, which could be responsible for the high salinity concentrations observed in the inner part of the estuary.

The parameter δ is a key factor in quantifying the effect of extractions and minor contributions to water volume along the river. In other words, it represents all the natural and anthropogenic processes that can affect the volume of water, such as agricultural abstraction, industrial use, small side channels and evaporation. δ represents an average value between these two actions, and for our study it was positive, indicating that on average extractions exceed the contributions from smaller channels that drain into the main channel.

However, there is an inherent uncertainty in this parameter due to the complexity of accurately quantifying the amount of water extracted from the channel. The Guadalquivir system is heavily influenced by human activities (high levels of agriculture, industry, dense population in nearby areas, port activities, etc.), and it is also documented that numerous illegal extractions take place. This makes it difficult to obtain accurate data on abstraction within the estuary, as both the specific locations and volumes of water taken are unknown.

When a constant water volume reduction term is included in the channel ($\delta = 0.005$ mm), both in time and space (Figure 2c and d), meaning that the same volume of water is removed at all points in the estuary during the 13 days of simulation (dt = 1s and dx = 25m), it is observed that the system tends to reproduce higher salinity concentrations along the estuary over time, reaching the observed salinity ranges. This shows that it is essential to include this parameter in the numerical model in order to accurately simulate the high salinity concentrations observed along the GRE. The water volume removed in this experiment throughout the 13 days of simulation was 47.36 106 m3 which is not an excessive amount if it is compared with the water volume needed, for instance, to sow a rice field of 32000 hectares which requires 384.0 106 m3 of water consume.

Figures 2c and 2d show that a certain period of time is required for the sinks to effectively influence the system and produce salinity values close to those observed. Figures 2e and 2f show experiments where a stronger sink ($\delta = 0.01$ mm) is applied to all sections during the first 3 days of the simulation, after which it is relaxed, and a $\delta = 0.001$ mm is imposed for the remaining 10 days. It can be seen that the behavior reproduced at all time steps closely matches the observed horizontal salinity gradient, which allows us to conclude that in order to simulate realistic salinity concentrations with this model, it is also necessary to take into account the temporal effect of the sinks.

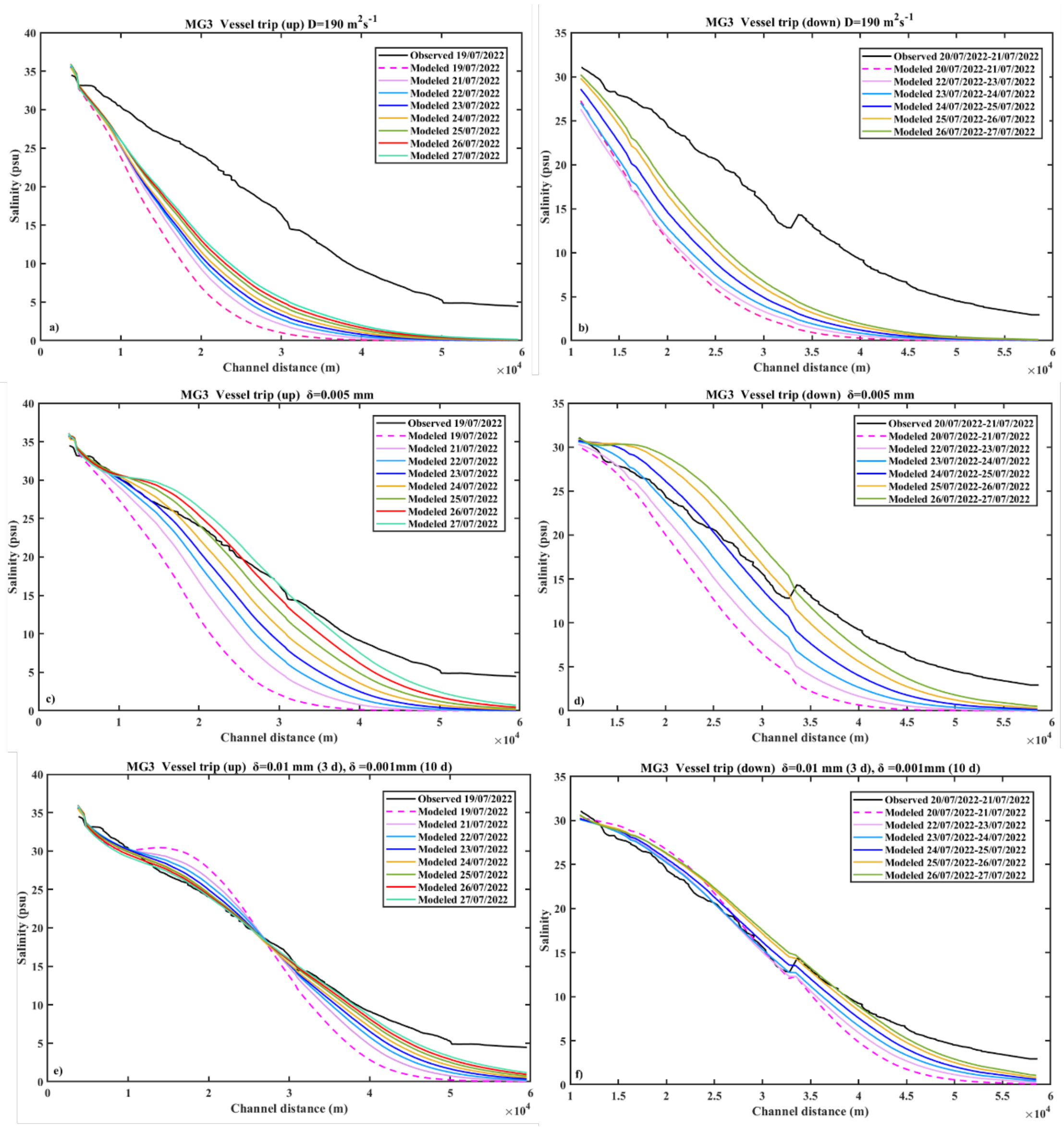

Figure 2: Comparison of simulated (temporal behavior of the simulation at the corresponding observation points) and observed salinity over the MG3 vessel trips: (a) and (b) show simulations including only the horizontal dispersion for the MG3 vessel trip upstream (a) and downstream (b), with the observations in black. (c) and (d) show simulations incorporating δ term (δ) for the entire simulation period as constant value, and (e) and (f) are the simulation including a time-varying δ, compared to the observations (in black) for the MG3 vessel trip upstream (c and e) and downstream (d and f).

These experiments highlight the necessity of including parameters in the simulations, as otherwise, the horizontal salinity gradient would never reach the observed values. As illustrated in the figure, a certain duration of sink activity is required for the simulated salinity concentrations to approach the range observed. Therefore, it is essential to define an initial condition that considers this progression, allowing the simulation to adequately capture the evolution of the water withdrawals and their impact on salinity over time. This is particularly justified by Figures 4e and 4f, where using a stronger δ during the first three days followed by a weaker δ reproduces the observed behavior.

To properly define this initial condition, it is necessary to consider that the observations recorded during the different oceanographic campaigns were made over different time periods (months and years). This implies that each simulation, corresponding to a specific time period, will have a slightly different initial condition due to the variations in the characteristics of the system over time. This approach emphasizes the importance of adjusting the initial conditions according to the temporal differences observed in the data, allowing for a more accurate representation of the system's behavior during each period considered.

It is important to emphasize that this numerical model, although simple, has been designed as a very useful tool for studying the hydrodynamic and physicochemical properties of the estuary. As a high-resolution 1D model, it is optimized to simulate relatively short time periods, ensuring high computational efficiency. The model is particularly effective at representing specific moments in time and extrapolating to a given time interval. Although it is designed to simulate shorter time periods, it can be used for longer simulations provided that similar conditions are maintained, such as low discharge regimes where the water column is well mixed and vertical gradients are homogeneous. However, in situations with significant stratification, alternative approaches would need to be considered as 1D simulations would not be suitable to accurately simulate the estuary."

F233. Please indicate if Figure 2 include the profiles with the sink correction. If not, it would be helpful to see also the uncorrected profiles.

Thank you done. Now this Figure corresponds to Figure 3 and is presented as follows:

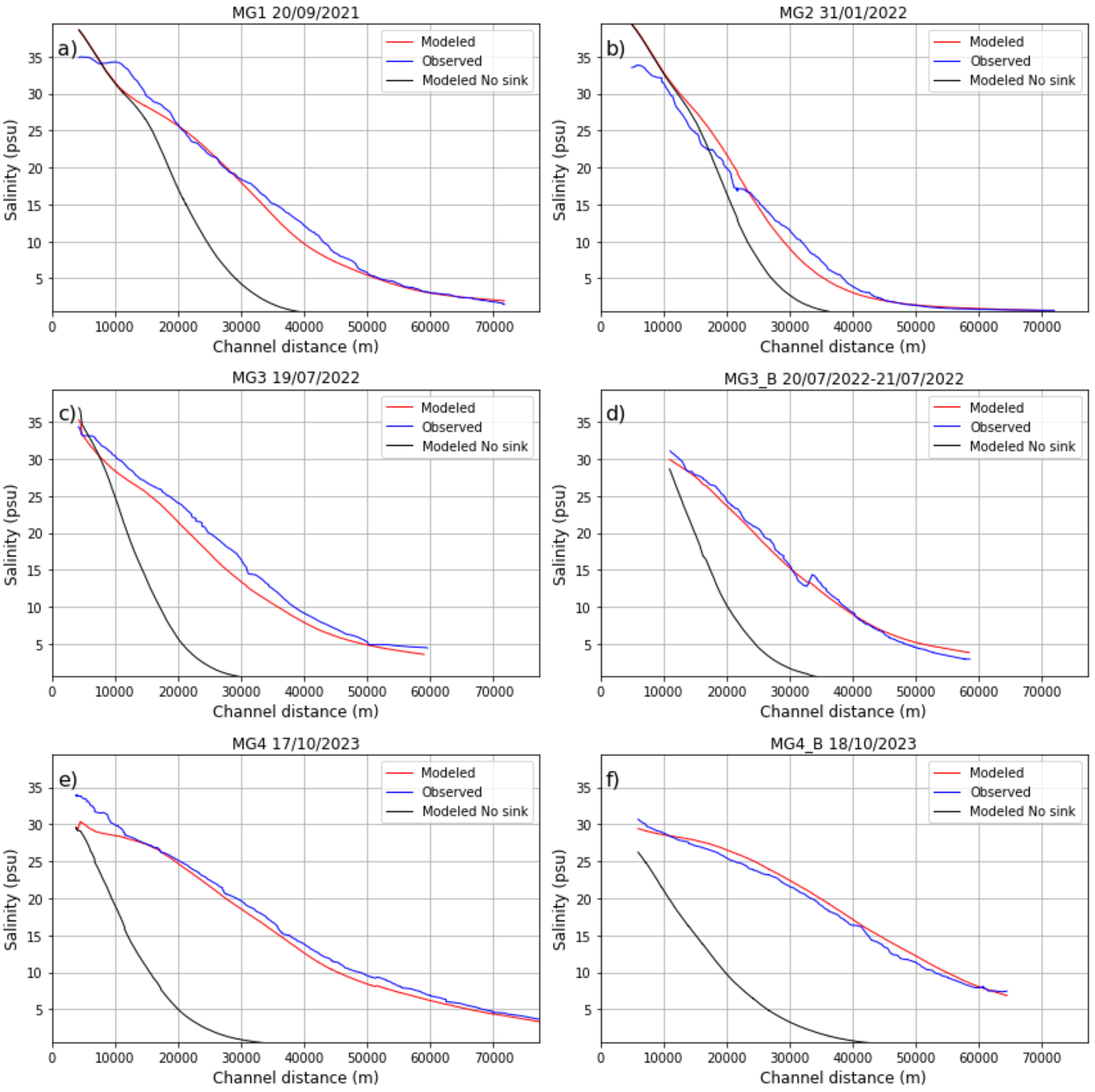

Figure 3: Comparison between the observations (blue line) and the simulation including sinks (red line) and simulations not including sinks (black lines) of the salinity (psu) for the hole channel for different campaigns (Table 1).

Figure 2. Name the panels a), b) etc. to link better to what it is described in the main text.

Thank you done, please see figure in previously comment.

L248-249. Please explain this according to the spatio-temporal variability of water extraction for agricultural activities.

This question cannot be answered with certainty. The lack of detailed knowledge about how the sinks operate prevents us from confidently addressing the spatio-temporal variability of water extractions. What we can affirm is that the discrepancies are observed in areas near crop fields, suggesting that these differences are likely linked to water extractions for agricultural purposes.

To clarify this point further, we have added the following explanation in Line 378:

"The discrepancies found between 30 km and 60 km may be attributed to the crop fields adjacent to the channel (this is the area where the largest concentration of crop fields is located on both sides of the GRE)."

L249. November 2023. Which panel?

This was a mistake, it is October.

L250. Could the authors provide a water volume to provide evidence for this? (Ok. Seen answer in L276)

Okey, thank you.

L276. I understand that these water outtakes for crops could be difficult to obtain. However, could be estimated with authors' model results.

We can provide a rough estimation; however, this comes with significant uncertainties due to our limited understanding of how the sinks operate—whether they are constant or variable, for example. We recognize that water extractions likely vary depending on the stage of the agricultural cycle (e.g., during periods when fields are intentionally flooded, water usage would be higher). However, we cannot confirm this with certainty, nor can we account for illegal extractions or situations where artificial channels may be opened for irrigation purposes.

For this reason, we have opted to treat water extractions as constant in our model to maintain methodological rigor. While we can approximate the total volume of water extracted during each campaign based on our results, extrapolating beyond this would not be reliable. Moreover, distinguishing between losses due to illegal extractions from fields, unauthorized well usage, secondary canal diversions, evaporation losses, and other factors remains beyond the scope of our current analysis.

To quantify these factors more accurately, in-situ data collection will be necessary. We plan to conduct this in the near future, which will allow us to investigate this issue in more detail. However, thanks to the results presented in this article, we can confidently state that quantifying these activities is crucial for a true understanding of the current system.

L276-L282. Again. Explain whether or not the timing of the salinity measurements along-estuary and model output yields discrepancies. Also in L291 Figure 3), please indicate whether or not the model output along-estuary is plotted at the same time? I presume that the results obtained from measurements are not, since they are measured as the vessel travelled upstream. Discrepancies up to 10psu could be observed, depending on the location and timing.

The data represented by the model, as previously mentioned, corresponds to the same time instances and virtually the same points as the observations. Regarding the comparison of the observations (vessel trips), the salinity gradient presented does not correspond to the same temporal moment at all points, since, as noted, the observations were taken as the vessel traveled upstream or downstream. On the other hand, the model data represented corresponds to the same temporal instances as the observations and to the same points, allowing us to validate the model both in time and space simultaneously.

Figure R3, shows the time series of current velocity for three different sections of the river (4 km, 30 km, and 60 km). The time points where the vessel trip data (up and down) were recorded during the MG4 campaign are marked in red. The purpose of this figure is to illustrate the behavior of current velocity at the times the data were collected. The three sections represent different locations in the river: one in the lower section, one in the middle section, and one in the upper section. This shows that the tidal moments vary depending on the specific section where the sample was taken, as phase shifts corresponding to each zone are included.

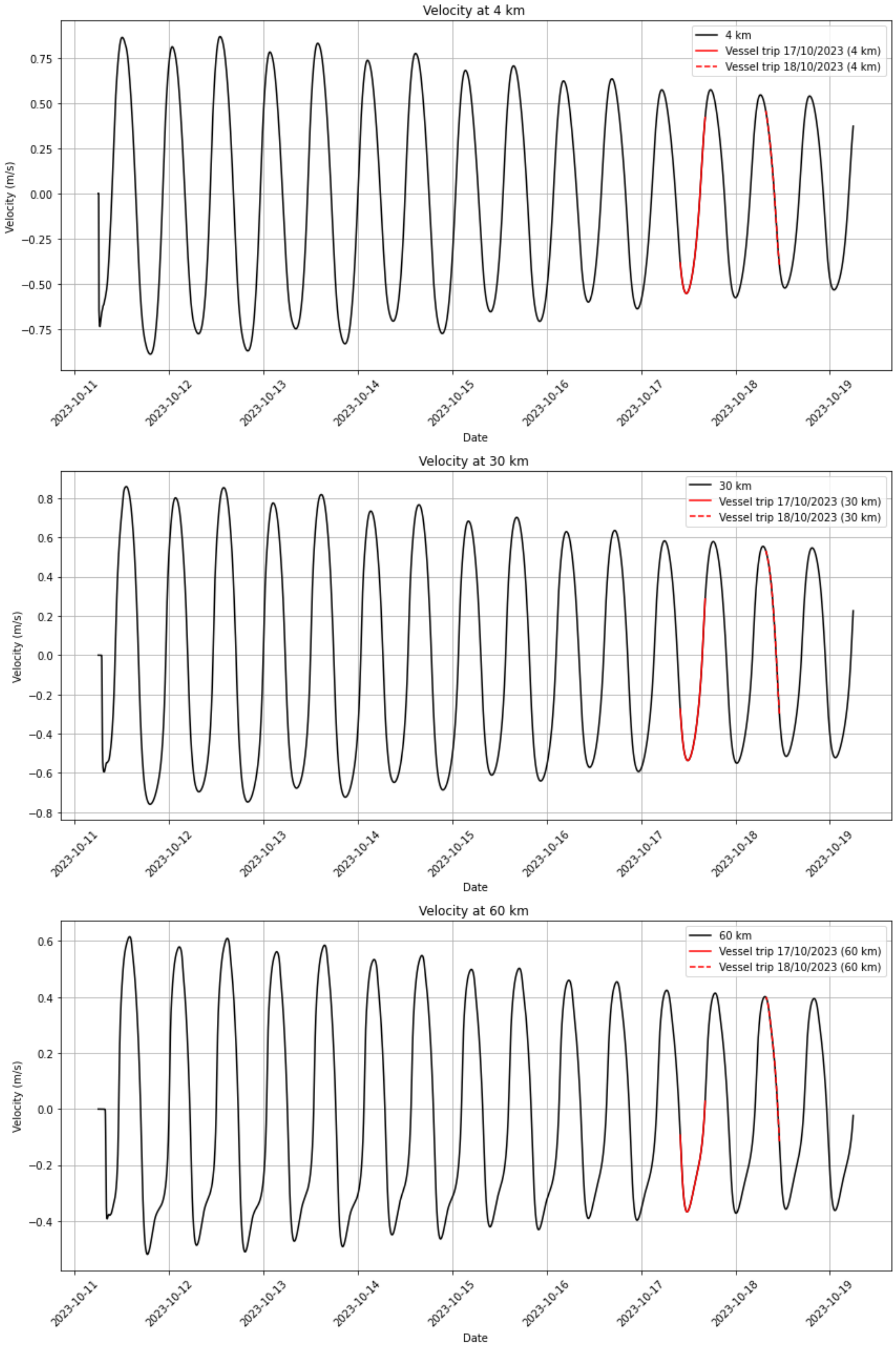

Figure R3. Evolution of velocity at three different distances (4 km, 30 km, and 60 km) over time. The observational data (red lines) corresponds to two vessel trips: on 17/10/2023 (solid line) and on 18/10/2023 (dashed line).

Figure 3. Label is wrong in panel (e) (it says (d))

Corrected thank you

L303. What would be the increase of freshwater discharges from the dam in that case?

We have not exactly quantified the required freshwater flow rate to maintain the salinity intrusion at a level that does not exceed 30 km. However, we know (due to our results) that it must be higher than 185 m^3/s in each campaign.

L315. Does the model need any spin up time?

Yes, the model requires a spin-up period of 3 days to stabilize the initial conditions and achieve realistic outputs. During this time, the model adjusts to a more stable state before the results can be considered reliable

L325. Theoretically, maximum (minimum) salinity values occur at high (low) water slacks, which occur at different times along the estuary.

Thank you, we have corrected this aspect along the hole manuscript.

As a example, line 325 (line 470 in new version):

"To account for water volume In Figure 5a, it can be observed that the maximum salinity levels occur near the high-water slack, while the minimum salinity levels are recorded around the low water slack."

Figure 4. Panels b) and c). Around km 17, along-channel salinity inversions are observed (larger salinity values upstream). Do have the authors any clue on this? Is due to tidal trapping in Brazo del Oeste?

Thank you for your comment. Looking at the plot, we do not see a clear indication of salinity inversions around km 17. The x-axis represents time, while the y-axis represents space, and if we examine the plot, we can see a general decrease in salinity as we move upstream in the estuary. Anyway the 'Brazo del Oeste' is not considered in the model geometry. In some preliminary tests this channel was included but it does not improve the experimental validation of the model. So, it was not considered in the final configuration of the model.

Furthermore, this figure has been modified (please see Figure 5 showed above)in the new version of the manuscript, where we used neap and spring tide moments to simplify the analysis and focus on more representative conditions. As for the specific salinity values around 17 km, we can confirm that the concentration at this location is higher than at 18 km, but lower than at 16 km.

L327. "the wedge demonstrates minimal intrusion". Rephrase

Done. We have modified the text of section 3.4, please see comment 3 on this document.

L338-340. As the authors mention, saline intrusion is important for water quality and residence times are relatively large in the estuary. Nevertheless, notice that author's model is cross-sectionally-averaged. This is ok, since mixing rates within the estuary are quite high. But should be recognized that the model does not resolve the vertical segregation of the flow, which could be important in the lower part of the estuary and enhance flushing times there.

Thank you.

The reviewer is right regarding the possible uncertainties in the flushing times arising from the cross-section average. Anyway, these comments about the transport to the continental shelf in estuary mouth are not considered in the current version of the manuscript.

L341. I don't see how this conclusion is drawn. Please explain why there is a positive mass balance at the mouth? Is this due to evaporation rates or outtakes for crops within the estuary? Does this volume compensate for freshwater losses within the estuary?

Thank you, we have removed this, with the new simulation the balance in the bonanza section is negative while it is positive in section at 11 km. To avoid confusion and the potential for erroneous hypotheses, it has been decided to remove this phrase.

Discussion of… (discussion in Section 3 and also in Section 4?)

I find this part the most interesting. Please consider to include it in Section 3.

L347-351. Perhaps the most recent estimates of salt intrusion trends in European estuaries are those by Lee et al. (2024) https://doi.org/10.1038/s43247-024-01225-w

Thank you, this reference has been included.

Line 488-490 (revised version of the manuscript)

"The natural flow regime of the Guadalquivir estuary has undergone significant changes due to different human activities in the basin (Bramato et al., 2010 Lee et al., 2024). Future projections indicate a reduction in freshwater flow for this estuary by the end of the 21st century (Lee et al., 2024)."

L374. Yearly-averaged value?

Yes, thank you.

L375-385. Maximum and minimum saline intrusion occur at slacks, not at maximum flood and ebb. I don't think this alters authors' point, but please amend here and elsewhere, and modify figures if needed.

Corrected, thank you. We have modified all text and figures.

L410-413 (here, before and after) I suggest to name the cases, including the reference one, and use the same notation in the Figures.

Corrected, thank you.

We named the experiment in section (4.1 now it is section 3.5.1) as : Experiment (i), Experiment (ii), Experiment (iii), Experiment (iv, Experiment (v), Experiment (vi).

And in section 4.2 (section 3.5.2 in new version) as: Experiment (i), Experiment (ii), Experiment (iii), Experiment (iv, Experiment (v), Experiment (vi).

"3.5.1. Changes in freshwater flows

The freshwater discharge observed in MG2 and MG3 are respectively Q = 12 m³ s^{-1} and Q = 8 m³ s^{-1}; these values were used as reference values. Five experiments were conducted under the following different freshwater flows:

(i) Original freshwater flow (Q_{MG2}=12 m^3 s^{-1}; Q_{MG3}=8 m^3 s^{-1})

(ii) Observed freshwater flow reduced by 50%. (Q_{MG2}=6 m^3 s^{-1}; Q_{MG3}=4 m^3 s^{-1})

(iii) Observed freshwater flow set to zero.

(iv) Observed freshwater flow increased by 50%. (Q_{MG2}=18 m^3 s^{-1}; Q_{MG3}=12 m^3 s^{-1})

(v) Observed freshwater flow increased up to Q=40 m^3 s^{-1}, established as the low-flow condition, following Díez-Minguito et al. (2012).

(vi) Yearly average freshwater flow of 185 m^3 s^{-1}, following Costa et al. (2009) and Morales et al. (2020). “

“3.5.2 Changes in the water volume sinks.

To evaluate the effect of decreasing or increasing water withdrawals from GRE, four experiments were conducted, taking the sinks established in the validation of the numerical model for MG2 and MG3 campaigns as a reference:

(i) Reference δ ($MG2_{0\text{-}22km}$=0.0005 mm, $MG2_{22\text{-}42km}$=0.0045 mm, $MG2_{42\text{-}85km}$=0.0005 mm, $MG3_{0\text{-}85km}$=0.00225 mm)

(ii) δ Decrease by 15%. ($MG2_{0\text{-}22km}$=0.000425 mm, $MG2_{22\text{-}42km}$=0.0038 mm, $MG2_{42\text{-}85km}$=0.000425 mm, $MG3_{0\text{-}85km}$=0.0019 mm)

(iii) δ Decrease by 50%. ($MG2_{0\text{-}22km}$=0.00025 mm, $MG2_{22\text{-}42km}$=0.00225 mm, $MG2_{42\text{-}85km}$=0.0005 mm, $MG3_{0\text{-}85km}$=0.0011 mm)

(iv) δ Increase by 15%. ($MG2_{0\text{-}22km}$=0.000525 mm, $MG2_{22\text{-}42km}$=0.0052 mm, $MG2_{42\text{-}85km}$=0.000575 mm, $MG3_{0\text{-}85km}$=0.0026 mm)

(v) δ Increase by 50%. ($MG2_{0\text{-}22km}$=0.00075 mm, $MG2_{22\text{-}42km}$=0.0067 mm, $MG2_{42\text{-}85km}$=0.00075 mm, $MG3_{0\text{-}85km}$=0.0034 mm)

(vi) δ Increase by 100%. ($MG2_{0\text{-}22km}$=0.001 mm, $MG2_{22\text{-}42km}$=0.009 mm, $MG2_{42\text{-}85km}$=0.001 mm, $MG3_{0\text{-}85km}$=0.0045 mm)”

L421. (here, before and after). What E and F stand for? I suggest to change the names or not saying that they correspond with the minimum or maximum intrusion.

Thank you, this has been corrected. Following your suggestion, we adjust the text indicating that maximum (minimum) intrusion correspond with high(low) water slacks moments.

Figure 6b and 6d. The estuary becomes ‘inverse’, with higher salinities than at the mouth.

In the revised version of the article, in which the model has been adapted as mentioned above, Figures 5 and 6 have been updated. This version presents a more realistic behavior and, by using a more accurate dispersion coefficient, the δ values are lower. Consequently, the increase observed in Figures 6b and 6d is smaller because the increase and decrease of the δ values used in the different experiments are smaller. However, the underlying concept and reasoning presented in the manuscript remain unchanged, although they have been adjusted to reflect these new results. In both figures, the time series of velocity and salinity are also included, overlaid for the Bonanza section (km 4), allowing the moments of maximum and minimum salinity concentration to be shown, as represented in Figures 5c-f and 6c-f.

New Figure 6 (Fig 5 in last manuscript version) and Figure 7 (Fig 6 in last manuscript version) of the manuscript are presented below:

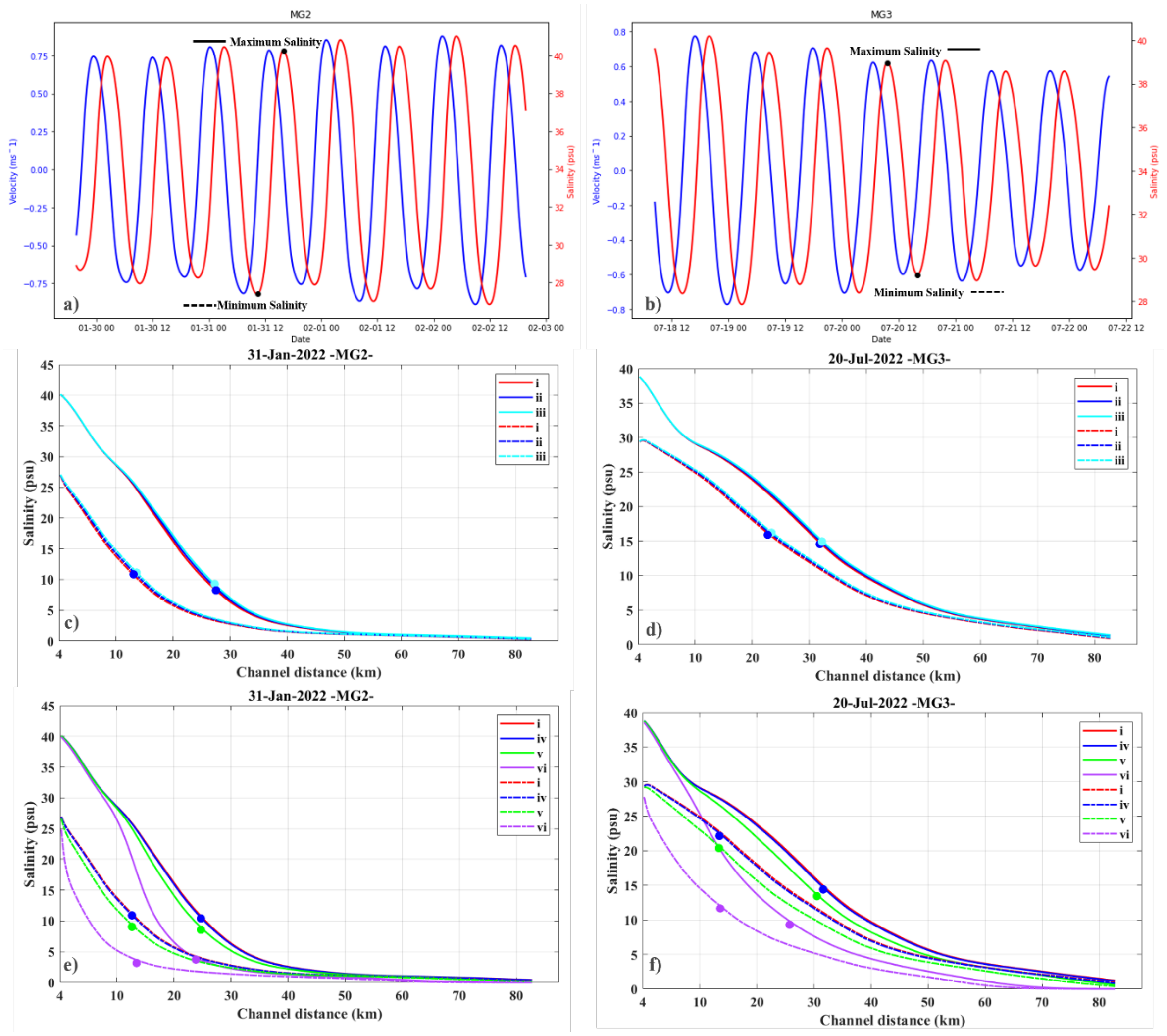

Figure. 6. Superposition of current velocity (ms^{-1}) time series and Salinity (psu) time serie at Bonanza station (4 km). black dots mean maximum and minimum salinity moments selected for MG2 (a) and MG3 (b) oceanographic campaigns**.** Series of salinity (psu) along the Guadalquivir estuary (km) between real flow and various reductions in freshwater flow for MG2 (c) and MG3 (d). In c and d, the red lines represent experiment (i), the blue lines correspond to experiment (ii) and the cyan lines are experiment (iii). (b) and (d) are the series of salinities using the real freshwater flow and greater freshwater flows for MG2 and MG3, respectively (Experiment (iv) is represented by the blue line, experiment (v) is green line and experiment vi is presented by pink lines). The solid lines represent the time of maximum salinity at Bonanza, and the dashed lines represent the time of minimum salinity at Bonanza. Color dots represent the km of maximum differences between each experiment with experiment (i).

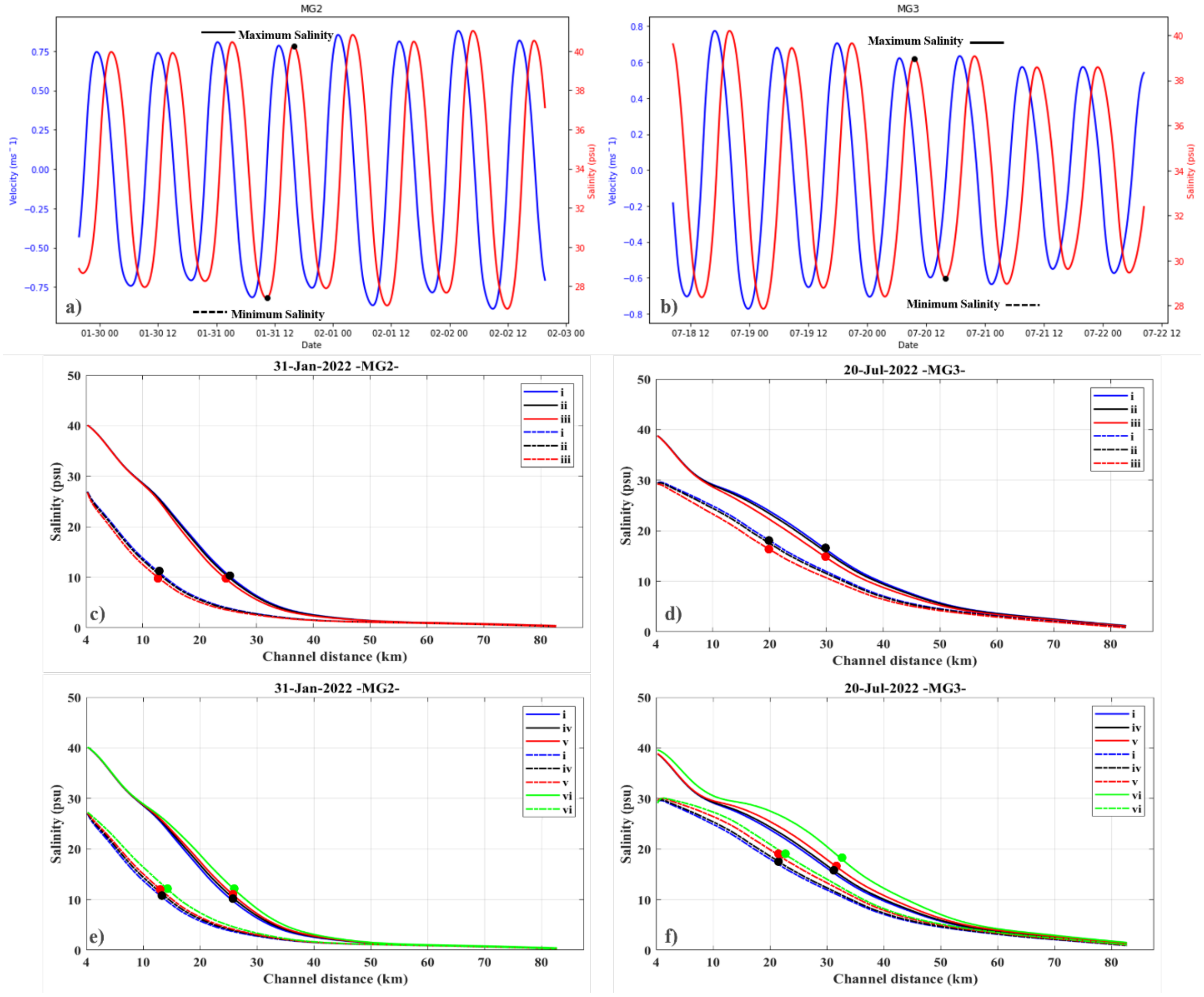

Figure 7*:* Superposition of current velocity (ms^{-1}) time series and Salinity (psu) time serie at Bonanza station (4 km). black dots mean maximum and minimum salinity moments selected for MG2 (a) and MG3 (b) oceanographic campaigns**.** Series of salinity (psu) along the Guadalquivir estuary (km) under a reduction of water withdrawals values are presented in (c) and (d) where original value are represented by blue lines (Experiment i), experiment (ii) corresponding to a smaller reduction is presented in black and a higher reduction of water withdrawal value is presented in red (Experiment (iii). (e) and (f) correspond to experiments increasing water withdrawal values. Original value is presented in blue (Experiment i), and different progressive increases are presented by black lines (Experiment iv), red lines (Experiment v) and green lines (experiment vi). The solid lines represent the time of maximum salinity at Bonanza, and the dashed lines represent the time of minimum salinity at Bonanza. Color dots represent the km of maximum differences between each experiment with experiment (i).

Conclusions

L452-455. I don’t think these (plausible) impacts are conclusions of the present work.

Thank you, we have removed these lines from this section and included them in Section 3.5.2.

L461-464. That depends on the discharge released from the dam during high riverflow conditions. Freshwater discharges of about 100-200m3/s move off the salt intrusion to the estuary mouth but tides are only significantly damped on the upper part of the estuary. Discharges of one order of magnitude higher damp significantly tides all along the estuary.

Thank you, we have included this.

Line 673 in revised version:

“Furthermore, the impact of anthropogenic activities extends beyond salinity. Upstream, various physicochemical and biological variables, such as nutrients, organic matter, and contaminants, may also accumulate. The removal of the salt intrusion from the estuary depends on the magnitude of freshwater discharge. Moderate discharges (100-200 m^3/s) typically shift the salt intrusion to the estuary mouth and reduce tidal currents in the upper estuary. In contrast, significantly higher discharges (approximately one order of magnitude greater) are required to dampen tidal currents throughout the entire estuary. Under such conditions, accumulated substances at the estuary mouth can be exported into the Gulf of Cadiz.”