

Response to reviewers' comments on the manuscript **The impact of suspended sediments on exchange flow in a macrotidal, hyperturbid estuary** #egosphere-2025-6311

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We would like to start by thanking the two reviewers of this manuscript for their thoughtful and constructive comments and suggestions. We believe that addressing these comments have led to an improved manuscript.

In the following, we address the reviewers' concerns and comments individually and indicate the corresponding edits to the manuscript based on their suggestions including the line number, which corresponds to the line numbers in the new version of the manuscript. The reviewer's comments are shown in blue and italics, whereas our responses are shown in black.

1 Response to Reviewer #1

Summary and General Assessment

This manuscript examines how including Suspended Sediment Concentration (SSC) in water density calculations affects the Total Exchange Flow (TEF). The authors employ a numerical model of the Gironde Estuary to compare an 'active' approach (where density depends on both salinity and SSC) with a 'passive' approach (where density depends solely on salinity). Their findings show that, although overall inflow differences between the two models are minor over seasonal periods (less than 4%), incorporating SSC can substantially modify TEF during spring tides and in the estuary's upper reaches—sometimes changing inflow estimates by up to 70%.

The study tackles an important issue in estuarine physics: how sediment dynamics interact with the TEF framework. The reported suppression of shear production and variations in stratification frequency are particularly noteworthy. I recommend a minor revision to ensure the robustness of the results. My comments below address aspects of the methodology and physical interpretation in the manuscript

Major Comments

Vertical resolution: *The model uses nine equidistant terrain-following layers. The authors then compute Ri , vertical shear, N^2 , and claim a ~ 30 km shift in mixing suppression. With 9 layers, shear and $\partial\rho/\partial z$ are very discretized, especially near-bed where SSC gradients are sharp. I would suggest at least adding a discussion of how layer count influences Ri exceedance frequency and the ~ 30 km claim (even if the authors can't rerun, they can sanity-check with vertical-gradient smoothing/finite-difference choices).*

We would like to thank the reviewer for their comment. We are aware of this model caveat. It was found that 9 vertical layers was a good compromise between accuracy and computational constraints, as the model is quite 'large' with hydrodynamic and sediment variables computed at 58,251 nodes over 10 months of physical time. To reduce the errors related to sediment and salinity stratification that could appear due to the low number of layers, we used a mesh transformation that allows a refinement near the bottom. This helps to decrease the error associated with sharp gradients that develop near the bed. With this configuration, the model can capture the sediment, salinity and current velocity distribution (as validated in Do et al., 2025). Further, previous numerical model studies in the Gironde have used a similar number of vertical layers (10 layers in Ross et al., 2017 and 9 in the case of Huybrechts et al., 2022). After considering this comment, we realized that the word 'equidistant' used to describe the model layers is incorrect and we have removed it from the text and explained the grid refinement near the bed. We have also added some information at the end of the discussion section to reflect the limitations of using a low number of vertical layers.

The main document has been modified in lines 113-115, reading as follows:

The model consists of nine terrain-following vertical layers that expand and contract following the tides. The number of layers was set to nine because of computational constraints. However, to increase the resolution of larger gradients near the bed, we incorporated a mesh transformation that allows a refinement near the bottom.

This information has also been added to the model caveats in lines 409-411, and now reads as follows:

Further, we only considered nine vertical layers in this model due to computational constraints. Although we use a mesh transformation that increases the resolution near the bed, future studies should consider incorporating more vertical layers if possible to ensure that fine scale sediment and salinity gradients near the bed are fully resolved.

Linear superposition of density components: *The authors calculate total density by linearly adding the effects of salinity (ρ_{sal}) and suspended sediments (ρ_{ssc}). While the authors acknowledge that non-linear effects exist and cite recent work on the subject, the manuscript would benefit from a more quantitative justification for this simplification within the specific context of the Gironde. Given the hyperturbid nature of the system, can the authors provide an estimate of the potential error magnitude introduced by neglecting non-linear equation of state interactions?*

For simplicity, the non-linear effects between salinity and suspended sediment concentration were not considered in this study. In Telemac, the water density mixture corresponds to the linear addition of both salinity and SSC effects as:

$$\begin{aligned}\rho_{all} &= \rho_{sal} + \rho_{ssc} \\ \rho_{all} &= \rho_{ref}(1 + \beta S) + SSC \times \left(\frac{\rho_s - \rho_{ref}}{\rho_s} \right) \\ (\rho_{ref} &= 999.972 \text{ kg/m}^3, \quad \rho_s = 2650 \text{ kg/m}^3)\end{aligned}\tag{1}$$

where β is the salinity contraction, S the salinity, and SSC the sediment concentration. Since there is no explicit multiplication between salinity and SSC, non-linear effects are not considered here. In the study by Zhou et al., (2025), the authors followed the formulation of Winterwerp (2001), in which water density considering both salinity and SSC was computed as:

$$\begin{aligned}\rho_{all} &= \rho_{sal} + \rho_{ssc} \\ \rho_{all} &= \rho_{ref}(1 + \beta S) + SSC \times \left(\frac{\rho_s - \rho_{Sal}}{\rho_s} \right)\end{aligned}\tag{2}$$

Since this equation uses ρ_{sal} inside of the parentheses, this formulation considers the non-linear effects between salinity and SSC. A comparison between the direct Telemac formulation and that from Zhou et al., (2025), shows larger density values in the case of the Zhou et al., formulation (see Figures 1 and 2). The differences were larger at the bottom than at the surface due to the larger sediment concentration near the bottom. However, the maximum difference between the formulations was found to be 0.3836 kg/m^3 , which occurred during spring tides near the ETM. As this value corresponds to less than 1% of the density of the water mixture, it justifies the use of the simplification.

This information has been clarified and summarized in the main document on lines 425-429 reading as follows:

A comparison between the water density calculated following Eqs. 1, 2 and 3, and the formulation of Zhou et al. (2025) showed maximum differences of 0.3836 kg m^{-3} (not shown). These differences were maximum near the ETM during spring tide with larger differences near the bottom than near the surface. The small magnitude of the non-linear effects, less than 1% in our case, justifies the use of the simplification where sediment and salinity effects can be added linearly. Nevertheless, although the magnitude of the non-linear effects is small, the importance of this variability and the magnitude of the effects caused by it require further research that is beyond the scope of this study.

Minor Comments

All the following minor comments have been corrected following the reviewer #1 comments. Thanks for pointing them out. Please check the document with track changes to see all changes:

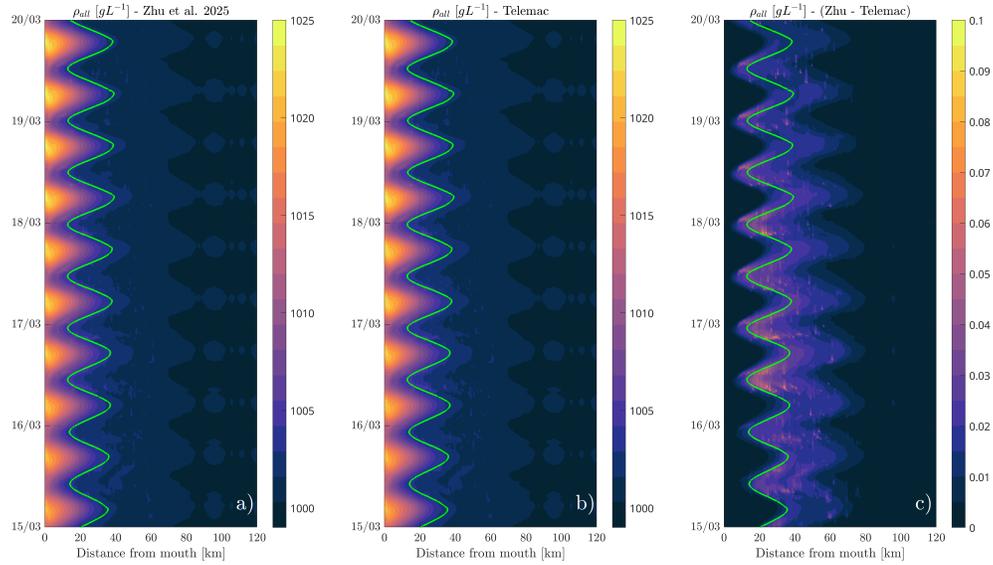


Figure R 1: Density calculations near the bottom. Left panel (a) shows the density calculated following Zhu et al., (2025), which includes non-linear effects between salinity and SSC. The middle panel (b) shows the density calculated following the Telemac formulation (without non-linear effects) that was considered in this work. Right panel (c) shows the difference between panels (a) and (b). The period shown corresponds to the same period as in Figure 2 in the main document.

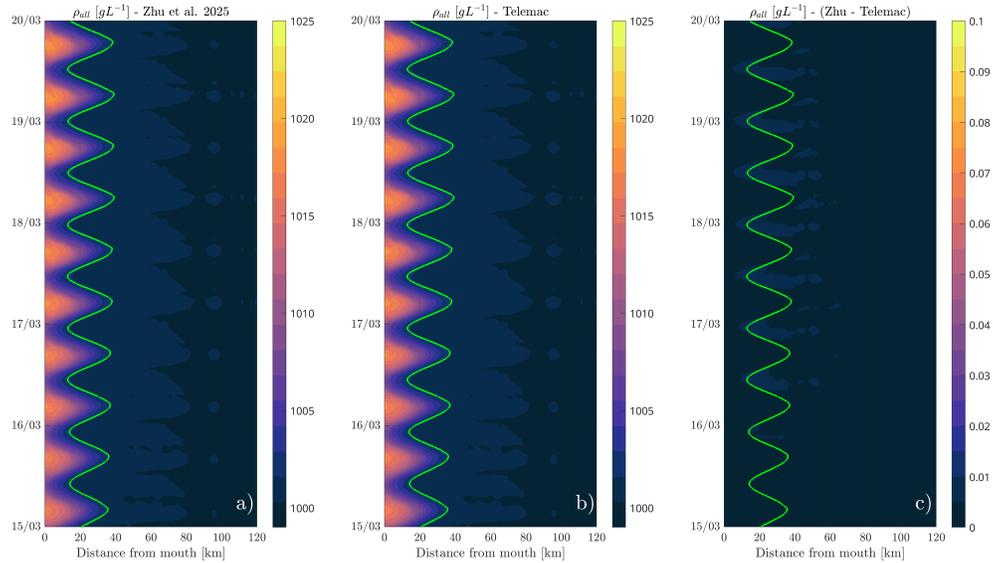


Figure R 2: As Figure R 1 but near the surface.

Page 1, Line 9: The ‘occur’ should be corrected to ‘occurs’.

Page 3, Line 59 (and other places): The unit ‘gL⁻¹’ should be corrected to ‘g L⁻¹’ (with a space).

Page 3, Line 85: The sentence ‘Is ~ 75 km funnel shape long...’ is grammatically incorrect. Please revise to ‘It is a ~ 75 km long, funnel-shaped estuary...’.

Page 5, Line 96: Add a space after ‘sediment transport dynamics’.

Page 6, Equation 1 and 2 (and other places): Please unify the case of ‘Sal’ in ρ_{sal} .

Page 8, Line 207: ‘it well reproduced’ should be corrected to ‘it was well reproduced’.

Page 9, caption of Figure 2: Add ‘dashed’ in ‘The horizontal red line’.

Page 12, caption of Table 1: ‘increase respect to’ should be corrected to ‘increase relative to’.

Page 12, Line 273: kg m^{-4} should be corrected to $\text{g kg}^{-1} \text{ m}^{-1}$.

Page 12, Line 275: ‘not-significant’ should be corrected to ‘not significant’.

Page 15, Figure 6: The units in Panel (b) should be corrected to kg m^{-3} .

Page 20, Line 431: The sentence ‘Is the first time a study analyze...’ should be corrected to ‘This is the first time a study analyzes...’ or ‘This is the first study to analyze...’.

Page 20, Line 440: The phrase ‘cause inhibit of mixing’ should be corrected to ‘inhibit mixing’ or ‘cause the inhibition of mixing’.

2 Response to Reviewer #2

This manuscript rigorously investigates how suspended sediment concentration (SSC) influences water density, stratification, and ultimately the total exchange flow (TEF) within a macrotidal, hyperturbid estuary resembling the Gironde.

The authors run two numerical models:

- *Active model, where density = salinity + SSC*
- *Passive model, where density = salinity only*

Using a 10-month, semi-realistic 3D Telemac–GAIA setup, they explore how SSC-induced density affects:

- *vertical density gradients*
- *longitudinal density gradients*
- *suppression of mixing ($Ri > 0.25$)*
- *TEF inflow during neap vs spring tides*
- *impacts upstream, at, and downstream of the ETM (estuarine turbidity maximum)*

Key findings include:

- *SSC strongly modifies stratification upstream and at the ETM, especially during spring tides.*
- *TEF inflows differ by $\leq 4\%$ over 5 months, but locally during spring tides differences reach 22% at the ETM and 70% upstream.*
- *SSC-induced stratification decreases the baroclinic pressure gradient and reduces TEF inflow by up to $2000 \text{ m}^3 \text{ s}^{-1}$.*

- *The interaction of salinity- and SSC-induced stratification produces dominant periodicities analogous to compound tides.*

Study concludes that neglecting SSC in density leads to systematic overestimation of estuarine exchange flows, especially in hyperturbid systems.

The Introduction is clearly written, well-referenced, and covers all key concepts required to understand the work, including SSC processes, ETM behaviour, and sediment–stratification interactions.

Thanks!

The Study Region section is also well presented, and the justification for selecting the Gironde estuary is sound. It would be helpful, however, to include information on suspended sediment and seabed sediment distributions within the Gironde

We have added some comments about this in line 97. Now, it reads as follows:

The channel bed is dominated by mud and the sediment accumulated in the estuary is predominantly from fluvial sources (van Maanen and Sottolichio, 2018).

Overall, the Methods are clearly explained, and the authors consistently apply robust analytical approaches such as wavelet analysis

Thanks!

The Methods section provides a clear description of the numerical model configuration. I was wondering whether the source code is available on GitHub and could be cited in the paper?

We have published the raw data on Zenodo and it is cited in the paper. The codes will be shared upon reasonable request as indicated in the Data Availability section at the end of the manuscript.

Only one sediment grain size is included in the model, which seems limited for an estuarine environment (page 5, line 120: “In the present study, however, only one class of fine sediment is considered”). Could you also specify the mean grain size of this class? Have different grain size distributions been tested?

While we understand the detriment of the use of a single sediment grain size in this work, we focused on the finer sediment (mud) since that is largely what composes the ETM in the Gironde and what has been used in other studies (see Van Maanen and Sottolichio, 2018 or Jalón-Rojas et al 2025). The diameter of the sediment has been added on lines 127-129, and it reads as follows:

The present model only considers a single cohesive sediment class (diameter of 0.00006 m), with a settling velocity computed dynamically through the Van Leussen flocculation parameterization (Do et al., 2025).

Regarding the vertical resolution, it would be useful to state whether a constant vertical spacing was

used, or whether the grid was adapted based on averaged density gradients. A brief discussion of sensitivity to vertical discretisation would strengthen the methodology.

A similar point was made by reviewer #1 and we welcome the reviewer to review our response above, but we have reiterated our methodology here. The model uses nine terrain-following vertical layers that expand and contract following the tides. We also incorporated a mesh transformation that refines the resolution near the bottom to help capture density gradients. This configuration was chosen to ensure that we accurately capture vertical density gradients, but also are within our computational limits. Further, the model configuration used for our study was presented and validated in the study by Do et al., (2025), where they verified the model capability of capturing the sediment, salinity, and current distribution. We realized that we were wrongly calling the grid equidistant, and we have corrected this mistake in the manuscript text.

For completeness we reiterate the modifications that were mentioned above in response to a similar comment by reviewer #1:

The main document has been modified in lines 113-115 reading as follows:

The model consists of nine terrain-following vertical layers that expand and contract following the tides. The number of layers was set to nine because of computational constraints. However, to increase the resolution of larger gradients near the bed, we use a mesh transformation that allows a refinement near the bottom.

This information has also been added to the model caveats in lines 409-411, and now reads as follows:

Further, in this model we only consider nine layers due to computational constraints. Although we use a mesh transformation that increases the resolution near the bed, future studies should use a larger number of layers if possible to correctly resolve larger gradients near the bed.

In addition, could you clarify whether alternative sediment densities were tested? A value of 2650 kg/m^3 may be high if flocculation processes reduce effective particle density.

The value for sediment density was chosen following the results of Do et al. (2025) who modeled the ETM distribution in the Gironde. We understand that this value is high, but with the flocculation formula used here (Van Leussen) this prescribed sediment density has proven effective in reproducing the position of the ETM. However, as the reviewer points out, this larger value for the sediment density produces realistic SSC during spring tides, but the values are too low during neap tides. We now mention this in the model caveats sections presented in lines 400 to 403:

The Van Leussen flocculation formulation has proven effective in reproducing the position of the ETM, with fairly realistic SSC during spring tides but values that are too low during neap tides. This implies that vertical gradients of sediments and the effect of near-bed SSC on stratification were thus underestimated during neaps.

The Results section is supported by well-chosen and relevant figures. The Conclusion provides a clear

and effective synthesis of the main findings

Thanks!

Typo

All the following typos have been corrected. Thanks for pointing them out. Please check the document with track changes to see all changes.

A few typos have been spotted:

- *Page 2, Line 42: “strength the estuarine exchange flow” \implies “strengthen”.*
- *Page 8, line 202: “For this, we considered the cross-sectional average density the mouth and the head of the estuary”. At missing after density?*
- *Page 8, Line 208: “it span \sim 70 km with” \implies “it spans \sim 70 km with”*
- *Page 8, line 207-208: “ it well reproduced by the model”: verb is missing. \implies ” it is well reproduced... ”*
- *Page 8, line 211 and 212: “reaching up to 3 gL⁻¹ , and”. You need an inseparable space between the value (3) and unit (g/L).*
- *Page 9 Line 223: “differences increases with the tidal range” \implies “differences increase”.*
- *caption figure 2: The horizontal red line. Maybe make this line solid, or long dash-dot (chain) line so that we do not think at first sight that it is similar to the dashed red lines of panel d?*
- *Page 20 Line 430: “Is the first time a study analyze the effects...” \implies “This is the first time a study analyzes the effects...”*