



EGUsphere, author comment AC2
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Reply on RC2

Pia Kolb et al.

Author comment on "Modelling the impact of anthropogenic measures on saltwater intrusion in the Weser estuary" by Pia Kolb et al., EGU Sphere,
<https://doi.org/10.5194/egusphere-2022-142-AC2>, 2022

Dear referee #2,

thank you for taking the time to read our manuscript, and for your detailed and helpful feedback. We highly appreciate your inputs and hope that all ambiguities are resolved now. Please find below our responses to your comments (in italics).

The authors conducted a series of numerical experiments to investigate impact of historic engineering on salt intrusion in the Weser estuary. Their methods are valid, figures and tables are clear, some findings are interesting and useful.

My major concern about their paper is that the authors assume estuarine circulation (or vertical exchange flow) is the only landward salt transport process about the salt transport processes. In addition to vertical shear dispersion, tidal pumping can act as an important salt transport mechanism in well mixed estuaries (Wei et al., 2016), weakly stratified estuaries (Wei et al 2021) and partially mixed estuaries (Uncles et al 1985). Uncles et al. (1985) also pointed out importance of transverse shear dispersion in wide sections. The Weser estuary is relatively long (>120 km) with a tidal range of 2.8-4.1 m, it is very likely that tidal pumping plays a significant role in salt transport here. Lateral shear dispersion may be also important in the wide Outer Weser.

These additional processes might help to explain the difference in the relationship between salt intrusion length and river discharge in the Weser with that in the Hudson estuary found by Ralston and Geyer (2019), where the vertical shear dispersion due to gravitational circulation was assumed to dominate the landward salt transport. I suggest the authors systematically explore the dominant processes of salt transport in all experiments and attribute changes in responses of salt intrusion (if any) to those processes. This should also help increase the impact of their study, for example, by making their findings applicable to other estuaries dominated by similar processes.

Reply: Thank you for pointing out the different mechanisms of salt transport. A general overview of these processes is given in our Introduction but their detailed analysis was not so much in the focus of our paper. Following your recommendation and that of reviewer #1 we conducted a decomposition of the salt flux components based on a method described by Becherer et al. (2016). We can confirm now the significant role of tidal

pumping which was previously not explicitly described in our paper.

Action: We described results of the salt flux decomposition in Section 4.6.1. In light of this additional analysis, we re-evaluated our results from the analysis of salt intrusion length vs. river discharge.

Other comments:

Figure 1: can you show the bathymetry map of the Weser with topography data of 2012?

Action: We included the topographical data in the map.

Line 140: how large are the horizontal mixing coefficients? Is it the same constant for all experiments?

Reply: The model is set-up with constant viscosity ($0.1 \text{ m}^2 \text{ s}^{-1}$) and diffusivity ($0.1 \text{ m}^2 \text{ s}^{-1}$) for all experiments.

Action: We added the information in the manuscript.

Line 140-145. "UnTRIM² was coupled with the sediment transport model SediMorph (BAW, 2002) to calculate bottom roughness. For simplicity, we neglected sediment transport in this study". These two sentences seem contradictory.

Reply: The model SediMorph was used for the calculation of bottom roughness (based on prescribed sediment data), but not for the calculation of the transport of sediments.

Action: We changed the phrasing: „UnTRIM² was coupled with the sediment transport model SediMorph (BAW, 2002), but only to calculate bottom roughness. Sediment transport was neglected in this study.“

Line 165: "the resolution of small-scale features such as bedforms in the different model topographies is not directly comparable." Can you show the bathymetry maps of different years as supplementary figures?

Reply: In order to illustrate the resolution of small-scale features we included sections of model topography 1972 and model topography 2012 in the manuscript (Fig. 2b and c). Maps covering a larger area would not allow to distinguish details of the resolution. Instead, we refer to the historical digital terrain model data, which we have added as an asset (linked to our paper on the EGU sphere website) and cited in our manuscript. The historical digital terrain model data can be found at <https://doi.org/10.48437/02.2020.K2.5200.0001>.

Action: To better demonstrate the effect of the different resolution of topographical data of different years, we included sections of model topography 1972 and model topography 2012 in the manuscript (Fig. 2b and c).

Line 255, "...with some variations among models." How different are the increased roughness in the lower Weser (landward side of Weser-km 55) across all experiments? How sensitive are salinity results to this increased roughness?

Reply: The additional roughness in Lower Weser is spatially varying. It ranges from up to 0.22 m (system state 2012) to up to 0.36 m (system state 1981).

Action: We added: "The additional roughness increases from Weser-km 55 towards Weser-km 26 and decreases afterwards again [...] the maximum additional roughness ranges from 0.22 m (system state 2012) to 0.36 m (system state 1981)". We also edited Table 3 to now show the average bed roughness along the navigation channel for all models.

Line 250-260. Can you show the estimated form roughness for each experiment? How large is the simulated form roughness compared to the additionally increased roughness?

Reply: While the estimated form roughness is in the range of 0.01 to 0.04 m, the maximum additional roughness ranges from 0.22 m (system state 2012) to 0.36 m (system state 1981).

Action: We added the information in the text in Section 3.6.

Figure 3: Model calibration with tidal range only, how about the tidal phase and tidal/residual currents? If exchange flow is the dominant salt transport process, it is essential to make sure the model reproduces the residual currents well. Right?

Reply: For each model, different roughness settings were determined by comparing model results with water level time series, if available (system state 2012), and the tidal range (all scenarios). Furthermore, a visual inspection of observed and modelled water levels was conducted concerning the phasing of tides. We agree that calibration with regard to residual tidal currents could have helped to further validate or improve our models. However, we think that a robust analysis concerning residual currents is difficult based on the data quality of tidal currents available.

Action: In our validation, we added: "The mean RMSE for the comparison of modelled and observed water levels in 2012 was 0.22 m, averaged over all measurement stations (see Figure 1) [...] A visual inspection of observed and modelled water levels suggested a correct phasing of tides, which is corroborated by the low RMSE."

Line 285: intertidal --> intratidal

Action: We changed it in the text.

Line 294-295. The fact that salt intrusion increases with increasing tidal range also suggests tidal pumping as an important landward salt transport agent.

Reply: Yes. Results indicate that salt flux in the Weser estuary is dominated by tidal

pumping contributions and advective flux. This also explains the result that saltwater intrusion is farther landward during spring tides compared to neap tides

Action: We analyze salt flux processes in Section 4.6.1 and discuss implications for the spring-neap variability in Section 5.

Figure 4. the ticks of the x-axis are not aligned with the labels.

Action: We corrected it.

Line 309: tide level --> tidal level

Action: We changed it in the text.

Line 319-321: salt intrusion length has already been defined on line 238-239.

Action: We deleted the repeated definition.

Line 322-335: this part is more suitable for the Methods section.

Action: We agree, we shifted it to the methods section.

Line 344-345: did salt transport mechanisms change from 1966 to 1981?

Reply: We think that the change in exponents is too small to support this interpretation.

Action: To make the text clearer, we deleted „pointing to a change in the system between 1966 and 1981“.

Line 353: “2012 – however, ...” --> 2012. However, ...

Action: We changed it in the text.

Line 373-374: Delete the content in the bracket as you have already defined brackish water zone.

Action: We deleted it.

Line 381: this sentence is misleading. You didn't include sediment transport or morphological evolution in the model, right?

Reply: We wanted to express that changes in roughness occur over time in the actual estuary, so roughness would be different for the scenarios which we represent with our models. This (along with other effects) would be visible in the calibration, when different roughness settings are determined for different scenarios.

Action: We edited the paragraph – hopefully, it is clear now.

Line 400: estuarine circulation is not the only important salt transport process for every estuary. See my major comment above.

Reply: Yes. See our comments and actions above.

Line 440-444: what about responses of salt intrusion length to tides? Did it change?

Reply: Topography changes can influence tides in the estuary, e. g. the tidal range may increase due to increasing depths. For the Weser estuary, this effect is confirmed in the simulations with identical forcing. Taking the tidal range at Weser-km 60 as an example it increases from 3.65 m in 1966, 3.67 m in 1972, 3.86 m in 1981, to 3.88 m in 2012.

Action: We included this aspect in Section 4.6.

The paper is lengthy with quite some information repeated. I suggest the authors to remove repetitive and unnecessary contents to make the paper more concise.

Reply: Thank you for your advice. Due to the additional explanations and the additional analysis added in the reviewing process, the paper did not become overall shorter in the end. We hope it is nevertheless more concise now.

Action: We removed repetitive sections (e.g. previous Section 4.6.3) and combined paragraphs to make the text more concise. In particular, we noticed that aspects related to roughness and calibration were discussed in several sections, which had caused repetitions. We now discuss reasons for the different roughness settings determined by calibration solely in Section 3.6. In Section 5, we discuss in which case individual calibration of each model is required and in which case it may not be required. To make the text shorter, we further deleted some unnecessary content, such as the analysis of the bottom and surface current velocity and the analysis of the depth variation.

References:

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Uncles, R. J., Elliott, R. C. A., & Weston, S. A. (1985). Dispersion of salt and suspended sediment in a partly mixed estuary. Estuaries, 8(3), 256-269.

Wei, X., Schramkowski, G. P., & Schuttelaars, H. M. (2016). Salt dynamics in well-mixed estuaries: Importance of advection by tides. *Journal of Physical Oceanography*, 46(5), 1457-1475.

Wei, X., Schuttelaars, H. M., Williams, M. E., Brown, J. M., Thorne, P. D., & Amoudry, L. O. (2021). Unraveling interactions between asymmetric tidal turbulence, residual circulation, and salinity dynamics in short, periodically weakly stratified estuaries. *Journal of Physical Oceanography*, 51(5), 1395-1416.