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Interactive comment on "Maximum power of saline and fresh water mixing in estuaries" *by* Zhilin Zhang and Hubert Savenije

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We would like to thank referee #1 for the discussion.

1. The fundamental principle underlying the new model ('freely evolving systems perform work and dissipate energy at maximum power, close to the Carnot limit') is only briefly introduced; a more extensive description of this concept, preferably illustrated with one or two examples would be helpful.

Reply: This manuscript is closely connected and a follow-up research of the previous paper by Zhang and Savenije (2018). The maximum power concept is well introduced in this paper. We shall summarize it in the revised version to facilitate the reader.

2. The estuarine geometry used in the model (Eq. 16, 17, 21). Why these expressions?

Do we know from earlier studies that these fit well with estuary geometries across the world? Reference?

Reply: The compilation of geometry using exponential equations is well documented by, such as in: Savenije (2005, 2012, 2015), Gisen (2015), and Zhang and Savenije (2018).

3. The geometric inflection point of an estuary (Section 3). How is this defined? Reference to literature?

Reply: The geometric inflection point is well defined and described by Savenije (2005, 2012, 2015). On the seaside of this point, the morphology of the estuary mouth is dominated by wave energy, beyond this point the morphology is dominated by the kinetic energy of the tide.

4. Based on the description of gravitational circulation and the definition sketch in Fig. 1, I would expect the horizontal length scale of the circulation to relate to the length of the salt wedge (= distance L in Fig. 1) rather than the tidal excursion E (which is the distance the salt wedge travels up and down the estuary between high tide and low tide). Please clarify. If so, does it affect the model formulations?

Reply: The tidal excursion is the distance that a water particle travels up and down the estuary during a tidal cycle. As a result, the tidal excursion is the length scale of the mixing process. The water particles do not travel the entire salt intrusion length during a tidal cycle, but circulate back and forth over the tidal excursion. All particles in the salt intrusion length L perform gravitational circulation within a distance E.

5. The model does not cater for a bed slope along the estuary. How would inclusion of such bed slope, even if minor, affect the gravitational circulation (order of magnitude analysis)? If of secondary importance, please state.

Reply: In alluvial estuaries, the bottom slope is small compared to the ratio of the increase of depth due to the salinity difference (Δh) to the salt intrusion length (L). More-over, it does not affect the residual water slope $\Delta h/L$, which results from the difference in hydraulic pressure, which is independent on the bottom slope. If, a downward slope were introduced in the picture, then we would have to include the horizontal component of the bottom pressure as well: the water pressure over the additional depth near the downstream boundary would then be balanced by the horizontal component of the sea water pressure near the bottom of the estuary mouth. This would make the sketch unnecessary complex.

6. From the presented results, it is not clear which estuary corresponds to the numbers listed in Figures 4 and 5.

Reply: Numbers are the labels of estuaries in Table 1. Two columns name the estuaries and their locations have been added in Table 1 in Page 25-26. We shall make this clear in the caption of the revised paper.

7. Why does the MP method calculate an (erroneous) strong decrease of salinity values seaward of the inflection point? If not realistic, isn't it better to leave this part of the model output out?

Reply: Near the estuarine mouth, the width is large and the convergence length is small, and the dispersion by gravitational circulation D_g is small according to Equation (15) in Page 4. In this case, D_g is by far not enough to describe the saline and fresh water mixing and, as a result, it bends down the salinity curve. We leave this strong decrease to show how the salinity would look like if there was no tidal mixing and all mixing would be density driven.

8. How much parameter fittings is needed to achieve the results presented here? Is it only the C3 value, or are other parameters modified as well? Were the geometry parameters varied as part of the calibration?

Reply: For the dispersion coefficient by gravitational circulation, D_g_0 (or C_3 using Equation (18) in Page 5) is the only parameter to be calibrated. Besides D_g_0, the

geometry is the determining factor but this is given for each estuary.

9. The estuaries labelled in red show larger deviations than the other ones. This becomes clear from Fig. 5 (not from Fig 4 yet – though indicated there as 'less reliable datasets'). What can be the physical explanation for this? In what sense are the red estuaries different from the other ones? Please clarify further on the explanation of model deviations.

Reply: Figure 4 has been edited; all labels are black now. In Figure 5, labels in red indicate the estuaries have relatively poor performance, as described in Lines 25-34, Page 6.

10. Calibrated and predicted values of Dg0 differ on a log-log scale. What is the implication of this in terms of deviations in calculated salinity profile? In other words, how sensitive is the model to offsets in C3.

Reply: In this log-log scale figure, it is easier to show the relationship between the calibrated and calculated values even in the small value range. In a linear plot, the lower values would plot close to the line of perfect agreement. In this research, we have not considered the sensitivity to C_3.

11.After having gone through this paper, the reader may wonder about the added value of this new model – as the existing Van der Burgh method generally gives better results (especially seaward of the infliction point). It would be good to clearly stipulate the benefits and added value of the new model in the paper, to avoid any possible confusion at this point.

Reply: First of all, this new model provides a physical explanation for the good performance of the Van der Burgh model in the region where gravitational circulation is the dominant mixing process. The Van der Burgh model, surprisingly enough, also works well in the part where tidal mixing is dominant. The very simple Van der Burgh model thus has a wider empirical applicability. The practical importance of the new model is, that it provides an additional constraint to the calibration of the Van der Burgh model. The Van der Burgh model has two degrees of freedom (the calibrated K and D_0). This new model, following the maximum power concept, has only one parameter to be determined. The fact that the dispersion by the gravitational circulation (of the maximum power model) should be smaller than the dispersion of all mixing mechanisms combined (of the Van der Burgh model) provides an additional constraint on the Van der Burgh method, which has two parameters to be calibrated (the Van der Burgh coefficient K and D_0), which may partly compensate each other. With this restriction, the Van der Burgh method is more accurate and more powerful.

Additional References: Savenije, H. H. G.: Prediction in ungauged estuaries: An integrated theory, Water Resour. Res., 51, 2464–2476, 2015.

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