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Interactive comment on "Effects of mud supply on large-scale estuary morphology and development over centuries to millennia" *by* Lisanne Braat et al.

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This study investigates the effects of mud supply on morphodynamics and large-scale morphology of estuaries, and more specifically on the development of mudflats. The adopted approach consists in long-term (2000 years), 2D-horizontal simulations (using Delft3D modelling package) of the evolution of an idealized estuary broadly inspired from the Dyfi estuary in Wales (UK). The authors explore the sensitivity of mudflat development and estuary morphology to boundary conditions (tidal range, waves, fluvial discharge, marine and fluvial SPM concentrations) and sediment-related parameters (settling velocity, active layer thickness, cohesive behaviour of mixtures) through a significant number of simulations (23). Results of the more pertinent simulations are compared by the mean of planform views of the modelled estuaries, and through temporal and spatial analysis of an exhaustive list of morphological and

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Discussion paper

hydro-sedimentary parameters. The main finding of the study is that estuaries reach a dynamic equilibrium after self-confining, mainly attributed to mudflat formation on the side of the estuaries which reduce channels and bar dynamics. In contrast, pure sand estuaries tend to widen continuously in the absence of cohesion.

Compared to other studies based on morphodynamic modelling of real-world estuaries, this detailed sensitivity analysis on a simple synthetic case provides valuable insights into the role of cohesive sediments on estuarine morphodynamics, or at least into the functioning / behaviour of such morphodynamic numerical models.

General comments:

- Spatial pattern of mud flats in estuaries (section 1.1) is introduced through the example of two Dutch estuaries (Western Scheldt and Ems-Dollard), essentially using a compilation of bed samples analyzed in terms of percentage of mud content and hypsometric curves of mud-covered surfaces. The presentation of these examples is quite short, and somehow incomplete as very little information about the hydrodynamics are presented. In my opinion, a more thorough “state-of-the-art” review on the development of mudflats in estuaries, on the evolution of tidal asymetry during the estuary infilling, and on dynamic equilibrium is missing. Moreover, the authors make little use of these examples in the discussion, as comparison between the simulation results and the Dutch estuaries is mainly qualitative. Quantitative comparisons between simulation results and natural estuaries (in terms of estuarine morphology and hydrodynamcis) are based on datasets of estuaries in UK (Prandle et al., 2005) and around the world (Leuven et al., 2016). Are the Scheldt and Ems-Dollard examples really useful to the paper and discussion ?

- Mainy studies show that estuaries experience a global flood dominance during their earlier infilling history, which may shift to an ebb dominance with changes in hypsometry, in particular with the development of intertidal flats and deeper channels. Simulation results of this study clearly show the ebb-dominance of the equilibrium-state estuary after 2000 years (Fig. 4g,h). Information about the evolution of ebb-flood peak velocity ratios at different times in the estuary development and infilling would bring additionnal elements of discussion to the paper.

- Brown and Davies (2009, 2010) have performed hydro-sedimentary simulations of the Dyfi estuary using the Telemac modelling system, with both natural and idealized bathymetries. They show a clear ebb-dominance in the lower estuary, causing a net seaward sediment transport, which is consistent with the present study. However, they show that tidal flow is flood-dominated in the upper estuary, causing a net transport up-estuary. In the present study, no flood-dominance is observed in the upper estuary, even at low to null fluvial discharge. How do you explain these differences ? I think that the discussion could be improved if the present results are compared to other similar studies. In particular, the validation of the hydrodynamics of the model would strengthen your hypothesis that sediment cohesion is essential to reach a dynamic equilibrium, which can not be solely explained by tidal asymmetry. You could also include and discuss the work of Moore et al. (2009) on the Dee estuary.
[Moore et al. (2009) Morphological evolution of the Dee Estuary, Eastern Irish Sea, UK: A tidal asymmetry approach. Geomorphology 103, 588-596].

Specific comments:

- Section 1.1 (p. 2): Presentation of the Western Scheldt and Ems-Dollard estuaries. Some information on hydrodynamics would be useful. What is the tidal range at the estuary mouth ? Tidal excursion ? Tidal current peak velocities ? Global wave climate

?
See for example data presented in Dyer et al. (2000) - An Investigation into Processes Influencing the Morphodynamics of an Intertidal Mudflat, the Dollard Estuary, The Netherlands: I. Hydrodynamics and Suspended Sediment.

- Figure 1. (p. 3) A small location map of the two estuaries would be useful. Please specify the elevation datum used (Amsterdam Ordnance Datum ?)

- Table 1. (p. 6): Please specify in the caption which “sensitive parameters” will be varied (mud settling velocity ?). Please provide the settling velocity of sand, as well as the critical shear stress for erosion of sand.
I do not understand the value given for the critical bed shear stress for sedimentation of mud (1000 N/m^2). Generally, the critical shear stress value for deposition is smaller than the one for erosion.
Why are specific densities of mud and sand equal ? 1600 kg/m^3 is a typical value for pure sand. However, dry bed density of mud is generally lower than for sand, well below 1000 kg/m^3. See for example the data from Wadden Sea sediments from Flemming and Delafontaine (2000), Fig. 2B, where dry bulk density is plotted as a function of mud content. Dry bulk density falls down to 400 kg/m^3 for 100% mud content. Other data for different estuaries are presented in Dyer et al. (2000).
[Flemming Delafontaine (2000) Mass physical properties of muddy intertidal sediments: some applications, misapplications and non-applications. Continental Shelf Research, 20, 1179-1197]

Dyer, Christie, Wright (2000) The classification of intertidal mudflats. Continental Shelf Research, 20, 1039-1060

2. Methods – p.5 l. 10: “(Guo et al., 2016)”. See also the work of Moore et al. (2009)

on the Dee estuary (UK).
[Moore et al. (2009) Morphological evolution of the Dee Estuary, Eastern Irish Sea, UK: A tidal asymmetry approach. Geomorphology 103, 588-596]

2.2 Model schematization

- p. 10 l. 2-4. It is not clear how the fluvial discharge is partitioned. Is the sinusoidal partitioning performed between the upstream grid cells of the 300m-wide channel ?

- p. 10 l. 13. How is defined / calculated the flow capacity ? Is it somehow related to the Rouse profile ?

3.1 General development, Figure 3 (p. 13)
- Please change the colour of (a), (b), (c) and (d) labels to white on the bathymetry sub-plots, as the black letters on the purple background is not visible on the printed version.

- In the caption, it is mentioned that bathymetry and mud fraction are shown for simulation times of 50, 150 and 2000 years. However, there are four sub-figures displayed. Please correct the caption. It would also be useful to display the simulation times directly on the upper-right corner of each sub-figure, both for bathymetry and mud fraction.

- This is a very personal preference, but I would prefer [$\times 10^6 m^3$] instead of [hm^3] in sub-figures (e) and (j).

- It is not clear how are defined the absolute and net bed level changes. Please

provide more details. I am also not convinced by the term “bed level change” as the data correspond to sediment volumes.

- What does the vertical blue dotted lines in sub-figures (e) and (j) represent ? There is not mention of these markers in the manuscript text, nor in the caption, although I suppose these correspond to different phases of adaptation of the model.

- The link to the YouTube video does not work. Please consider submitting the video as supplementary material.

3.2 Hydrodynamics and sediment transport

- p. 14 l. 33: The two formulas defining the tidal prism are “dropped” at the end of the paragraph. I am not sure these are essential. Maybe the tidal prism should be defined simply in a sentence within the paragraph.

- Figure 4, caption: Please specify that negative distances (for instance -10 km) refer to “open sea”.

- Figure 4d : The bedload and suspended river curves, supposed to be dashed, appear almost continuous. Please increase space between the dashes.

- Figure 4g,h : Ebb-Flood velocity ratio is positive in sub-figure (g), and negative in sub-figure (h). Ratio values should be consistent between the two plots.

3.3 – “Effects of mud flat formation”. I suggest to change this sub-section title by

“Effect of mud supply”.

p. 16 l. 4: “Locally, mud accretes on bars that are rather stable (e.g. Fig. 3b, on the ebb delta).” Figure 3b shows delta elevation, not mud fraction, and no ebb delta is visible on this image. Please check that Fig. 3b is the figure that should be referred to.

p. 19 Figure 7: Do the data presented in these sub-figures (in particular BI, W, A and Ux) correspond to the final stage of the simulations (i.e. 2000 yr) ? If so, please specify in the figure caption.

p. 19 Figure 7a-d: Please specify somewhere in the caption that the two black dotted lines for initial bed level correspond to the initial bed level of the floodplain (line above zero) and to the intimal bed level of the estuary (line below zero). Figure 7e-h: The braiding index should be defined somewhere in the manuscript, as several definitions exist (Brice 1964, Rust 1978, Howard et al. 1970, Friend Sinha 1993,...), or an appropriate reference should be cited.

p. 20 Figure 8 : Once again, a personal preference, please change [hm^2] to [$\times 10^4 m^2$] and [hm^3] to [$\times 10^6 m^3$].

p. 24 Figure 9 : Please suppress the variable units in the caption, as it is already specified in the sub-plot axis labels. “a more aggressive masking technique in which high mud flats are masked”: what is a high mudflat ? What are the threshold altitudes for the two methods ?

p. 25 l. 13: “[. . .] while typically settling velocities of marine mud are significantly

higher." Due to flocculation ? Any reference to support this assumption ?

p. 26 Figure 11: "Lines indicate estimations of estuarine length by Prandle et al. (2005) of 5, 10 and 20 km" add "from left to right".

Throughout the manuscript and in the figures and figure captions, when presenting simulation results, it would be useful to refer directly to run (lab) numbers listed in Table 3.

Technical corrections:

- p. 2, l. 7: "large-scale planform that develop over centuries" should read "large-scale planforms that develop over centuries".
- p. 2 l. 11: "Eems-Dollard estuary" should read "Ems-Dollard estuary" (or keep Eems if this is the right spelling, and correct Ems in the rest of the manuscript)
- p. 2 l. 13-14: "so we only look at general patterns and properties" of what ?
- p. 2 l. 14: "measures for mud in the bed" should read "measures of mud in the bed" or "measures of mud content in surficial sediment".
- p. 2 l. 21: "found in areas on the sides and bars shielded from [. . .] tidal flow" should read "found in areas on the sides of bars shielded from [. . .] tidal flow" ?
- p. 3 l.1 (caption): "Eems-Dollard" should read "Ems-Dollard".

p. 4 l. 16: "less active channels and less channel migration" - redundant ?
p. 4 l. 20-21: "showed that channel-bar patterns form that are similar to those in nature" should read "showed channel-bar patterns that are similar to those in nature"
p. 5 l. 6: "to vary the [. . .] boundary conditions for the main question." Please specify "the main question".
p. 5 l. 21: "(Fischer, 1972, as defined by)" should read "(as defined by Fischer, 1972)"

p. 6 l. 6: “implementation of van Ledden (2001); Jacobs et al. (2011)” should read “implementation of van Ledden (2001) and Jacobs et al. (2011)”
p. 6 l. 9: “it’s” should read “its”
p. 6 l. 16: “,but” should read “, but” (add space)
p. 7 l. 19: “0.25 mm/s” change to “0.25 mm s^{-1}”
p. 7 l. 21 “0.1 - - 0.4 mm s^{-1}” should read “0.1 - 0.4 mm s^{-1}”
p. 7 l. 24-25 : “similar to Le Hir et al. (2011); Sanford (2008).” should read “similar to Le Hir et al. (2011) and Sanford (2008).”
p. 8 l. 21: “bedslope” should read “bed slope”
p. 9 l. 3: “between de” should read “between the”
p. 9 l. 15: “The sea has an depth” should read “The sea has a depth”
p. 9 l. 15: “van der Wegen” should read “Van der Wegen”
p. 10 l. 2: “$100m^{-3}s^{-1}$” should read “$100m^{3}s^{-1}$”
p. 10 l. 17: “20 d” change to “20 days”
p. 11 Table 3, header of column 5 and 8: “$s-1$” should read “s^{-1}” (superscript)
p. 11 l. 14: “bedslope” should read “bed slope”
p. 12 l. 8: “of20 mgL^{-1}” should read “of 20 mgL^{-1}” (add space)
p. 13 l. 18: “the an initial bar pattern” should read “an initial bar pattern”
p. 14 l. 3-4: “At the mouth the water level rapidly progresses from low to high water and slowly progresses from high to low water.” Replace by “At the mouth the water level rapidly increases from low to high water and slowly decreases from high to low water.”
p. 14 l. 10: “around7.5 km” should read ’around 7.5 km” (add space)
p. 14 l. 20: SPM acronym has not been defined before (Suspended Particulate Matter)
p. 14 l. 20: “45 mg/l” should read “45 mg L^{-1}”
p. 16 l. 6: “mud- dominated” should read “mud-dominated” (delete extra space)
p. 16 l. 6-7: Please rephrase sentence. Proposition : “As a consequence, the critical shear stress for sand erosion equals the entrainment threshold of mud (Eq. 6). The mud-dominated mixed sediment thus becomes more difficult to erode and more rapid

aggradation is likely to occur".
p. 16 l. 29-31: Too many "furthermore" and "therefore"
p. 18 caption: "at below this elevation" should read "below this elevation"
p. 22 l. 22-23: "higher flood velocities near the mouth, especially flood velocities" should read "higher flow velocities near the mouth, especially flood velocities" ?
p. 22 l. 23-24: Please rephrase the end of the sentence.
p. 22 l. 26: "The sensitivity [. . .] was assessed by" should read "The sensitivity [. . .] assessed by"
p. 22 l. 33-34: Please rephrase the sentence (difficult to read and understand)
p. 24 caption l. 2: "mouth with" should read "mouth width"
p. 25 l. 6: "McLaren dataset" should read "McLaren (year) dataset"
p. 27 l. 4: "absence or river influence" should read "absence of river influence"
p. 27 l. 12: "mud flat with at the mouth" should read "mud flat width at the mouth"
p. 28 l. 29: "a range of tidal amplitudes and river discharge" should read "a range of tidal amplitudes and river discharges"
p. 33 caption: "m^3s-1" should read "m^3s^{-1}" (superscript)
p. 34 caption: "m^3s-1" should read "m^3s^{-1}" (superscript)
p. 35 caption: "m^3s-1" should read "m^3s^{-1}" (superscript)
p. 43 l. 3-4: Please check the reference. "Team, C." is "CCCR Team". This reference is a conference poster. Please provide the conference details: BSRG 2008, December 14th-17th, Liverpool.
p. 43 l. 31: "Journal of fluid mechanics" should read "Journal of Fluid Mechanics"
p. 46 l. 28: "betweenvegetation" should read "between vegetation" (missing space)

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