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Interactive comment on "Fluvial response to changes in the magnitude and frequency of sediment supply in a 1D model" *by* Tobias Müller and Marwan Hassan

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We thank the Referee for the helpful comments provided. Following the comments, we intend to change the manuscript in the following way:

1) Structure and readability of the manuscript require improvement. Reviewer 2 provides a list of suggestions. I was especially troubled by the later part of the manuscript

- We will follow the suggestions of Reviewer 2 and improve the structure of the manuscript.

2) the model result (BESMo_SupplementVid_OF.mp4) seems to be nonuniform (concave) at times at which, the reviewer thinks, the result should be uniform or spatially invariant;

- We do not agree that the model result should be uniform. The model has 12 nodes that respond to the applied shear velocity with selective entrainment and deposition of material in different grain size classes on the surface of each node. Furthermore, sediment feed is only introduced in the first upstream node, which then must cause a spatially non-uniform sediment transport, especially if we deal with non-constant sediment supply.

3) there seems to be a problem with the modelling of the substrate grain size (it is varying during the run); is sediment mass properly conserved?

- Yes, the sediment mass is conserved in our model. That the substrate grain size varies is correct and follows from the chosen subsurface implementation. The perceived problem might stem from the condition that we have a dynamically changing active layer depth (parallel to the bed surface) and a fixed, regular subsurface layering that is parallel to the bottom of the model domain. It is possible that a volumetrically small first subsurface layer is either growing (from material in the active layer) or shrinking (with its material going into the active layer) and thus represent very fine or very coarse transient conditions in contrast to the surrounding layers.

4) in run BESMo_SupplementVid_OF.mp4 the water surface elevation shows unphysical wiggles;

- This was a problem at the outflow boundary condition and was fixed in a model version that was not used to create this video. We will update the video with the fixed model version output. The results presented in the paper are not affected.

5) the numerical model consists of only 13 cells: this seems to be a small value given the focus of the manuscript on the spatial propagation of disturbances induced by sediment pulses. I suspect that the simulations would crash for a smaller grid size given the boundary condition of the sediment supply?

- While we are interested in the spatial effects of the sediment pulses within a channel reach, we do not explicitly study the spatial pulse propagation. We rather focus on the temporal evolution of averaged armouring and slope conditions within a channel reach. The model does not necessarily crash with tighter node spacing if we reduce the time steps accordingly. Our backwater implementation following Cui et al. (2006) does not predict the location of a hydraulic jump on a finer scale though (within less than one channel width, which is 1m). We also did not see enough added value of finer gridding in comparison to the computational costs.

6) the model is applied to transcritical conditions, which implies that bed level change and the flow need to be solved in a mathematically coupled manner (Lyn and Altinakar, 2002);

- While a more sophisticated simulation of the conditions in the flume would be very insightful, we chose to use a simpler approach to model sediment transport that is applicable to many different temporal and spatial scales. Our approach is successfully applied in other studies (e.g. Cui Parker 2005, Cui et al., 2006)

7) The strategy used for parameter calibration needs to be clarified. What parameters are considered to be calibration parameters? Why? How is the calibration conducted?

- We will describe the calibration of the model in the revised manuscript.

8. Now slope at the end of the experimental and model runs seem to be equal. Is this the result of the current method of calibration?

- Yes, we calibrated the model to visually match the slope, Dg, D90 and the average transport rate.

9. Friction parameter(s) can be calibrated separately from parameters in the sediment transport relation. This simplifies the calibration procedure and improves its result.

- Yes, we present the successful calibration in the manuscript. We supply other model calibrations in the Supplement in form of a sensitivity analysis, showing the variation of model results with the active layer thickness parameter n_a and the active layer exchange ratio alpha.

10. It would be good to use part of the laboratory experiments for model calibration and the remaining part for model validation. It may be a good idea to use the 'simpler' experimental runs (equilibrium runs?) for parameter calibration.

- It would be valueable to do a more expansive model calibration and validation. Yet we see our model calibration as sufficient for the scope of our study, as we present our main findings as relative to other simulations with the same numerical model. We will change our manuscript to reflect that we do not validate, but only calibrate the model with the flume experiments.

Other main comments

11. P5 Eq. 2b. It is unclear to the reviewer whether and why the equation for the normal flow depth would hold under transcritical and supercritical conditions. Please explain.

- Cui Parker (1997) show that the quasi-normal flow assumption is a good approximation for conditions with high Froude numbers. This method is then used in other studies (e.g. Cui et al., 2006, Ferrer-Boix et al., 2014, Ferrer-Boix et al., 2016).

12. P5 Fig 1. Unnecessarily complex figure. Also, why is slope included in the 'hydraulic part'? Should it not be part of the 'sediment part', right after 'elevation change'?

- Slope was moved to the Hydraulic Part only because it is calculated after the temporal step and is first used in the hydraulic part of the model. We will review the figure and simplify parts.

13. P3 ln 20. What is a "quasi-grey box system"?

- We will remove 'quasi'.

14. Definitions of 'equilibrium', 'quasi-equilibrium', and 'dynamic equilibrium' would be more suited in the introduction section.

- We will move the description of equilibrium to the introduction.

15. After providing these definitions I think the authors need to describe the controls of the equilibrium state of a channel. Also, please explain which parameters are governed by these controls. Also, Blom et al (2017) describe how it is the mean sediment supply (and its grain size distribution) that sets the mean channel slope and bed surface texture in the normal flow zone. It may be nice to test this finding in the current manuscript. Problem here would be that it is not straightforward to create a normal flow zone in a laboratory flume (see next comment). In any case I think it would be useful to relate the current findings to the Blom et al (2017) findings. P2 ln 19-21 "in contrast to". This statement may be fine-tuned by addressing the findings of Blom et al (2017).

- We will follow this advice and add a discussion of our finding in relation to Blom et al. (2017).

16. Authors' laboratory experiments are, over their entire length, governed by a "hydrograph boundary layer" (e.g. Parker, 2004; Wong and Parker, 2006) and, at the same time, a backwater segment (e.g. Nittrouer et al., 2012; Lamb et al., 2012). The reviewer thinks that this fact, as well as the associated implications, need to be well explained to the reader.

- A hydrograph boundary layer can only develop under changing discharge, while constant discharge was used in the flume experiments. We assume the referee refers to a sedimentograph boundary layer, which is a similar phenomenon caused by changing sediment feed (An et al., 2017). We agree that we should discuss our result in relation to the sedimentograph boundary layer. We communicated with Gary Parker and Chenge An about the occurrence of a boundary layer in the flume experiments and both agreed that the experiment time was too short to develop this layer. Zhang et al. (2018) provide a timescale for the development of a sedimentograph boundary layer, which applied to our case is longer than the 40 hours per pulse phase in the experiment. The calculation also shows that the length scale of this layer would be about half of the flume length with 7.5m. This finding supports the choice of our node spacing, as this phenomenon would be captured within multiple nodes. The time scale is $T_m \approx S_b L^2/q_{af}$, with the length of the layer $\delta \approx L(T/T_m)^{1/2}$ (Zhang et al., 2018; pers. comm. Gary Parker). We will add this finding in the revised manuscript.

17. Please note that a dynamic equilibrium will only be reached if the sedigraph is repeated for a sufficiently long time.

- After running the equilibrium experiments for 20,000 simulated hours we did not observe any difference between slope, grain size and transport rate from pulse to pulse. We see this as proof of reaching the dynamic equilibrium to the forcing parameters.

18. P2 ln 33-35. I think a connection should be made to the above-mentioned hydrograph boundary layer. P3 ln 3 “temporal sensitivity”. It seems that here the authors are actually talking about the hydrograph boundary layer? P3 ln 1. “may never achieve equilibrium”. The fluctuations of bed elevation and surface texture in the hydrograph boundary later do not imply that equilibrium is not achieved.

- As stated in response 16, the flume experiment was too short to achieve a dynamic equilibrium with the changing supply conditions.

19. P3 ln 8. “This reaction is not instantaneous, but delayed by a reaction time in which no adjustment takes place.” Why would there be a phase of NO adjustment? I do not understand the physics underlying the “reaction time”.

- We agree that a reaction time is not relevant in a physics based model. We will remove the reference from the manuscript.

21. P2 ln 2 “substantial body of research”. Please specify references. I am not certain that, regarding the impact of sediment pulses, lowland have received more attention than mountain streams.

- We will review this statement and add references.

22. P5 Eq 10. I would call this equation the Hirano (1971) equation (describing conservation of the mass of sediment of the ith class within the active layer) and not the modified Exner equation.

- We will add this to our manuscript

23. P7 ln 9-10. “fixed bed elevation at the outlet”. Does this mean a hydrodynamic downstream boundary condition in which the normal flow depth is imposed at the downstream end? If so, please explain this to the reader.

- We will add a more detailed description of the flow boundary conditions.

24. P7 ln 13-17. These lines do not fit in this section on model setup.

- We will move this paragraph to the experimental setup description.

25. Section 2.1. How are the model equations solved? What numerical schemes have been used for the time and space discretization?

- We will add a description of the numerical schemes used to the manuscript. We used an upwind scheme.

26. Given the fact that the laboratory experiments, over the entire length, are governed by a hydrograph boundary layer, the results of the numerical model are expected to depend on the spatial grid size. Please address this issue.

- As stated in response 16, we assume that our node spacing is sufficient to capture the forming of the sedimentograph boundary layer.

27. P7 ln 31 “Photos were used..” what method was applied here? What parameters were measured using this method?

- We will add a more detailed description of methods to this sentence

28. I do not well understand Tables 1 and 2. I see codes R1-R7 and OF-cFtM. How do these codes relate to each other? Are you certain you want to use the complex codes OF-cFtM? Table 2 lists the total mass fed, but what is the duration of each experiment? In other words, what is the mean sediment supply rate? In table 2 why are the values either 1500 kg or 2100 kg and not all 1500 kg? What about the grain size distribution of the supplied sediment? I do not well understand the feed rate, duration, and pulse period values of Table 1. Please explain or reconsider the presentation of the values.

- The mass differences stem for the method how we translate the flume based pulse phases (R1-R7) to the representations in the model (OF-cFtM), as we add constant feed phases in some cases. We will rework both tables and make the link clearer.

29. P12 ln 2-3 “For example a transport rate equilibrium might be reached before an equilibrium in slope.” I am not certain I agree with this statement.

- We will remove this statement as it is unsubstantiated.

30. P12 ln 14 “In the flume Dg and D90 were measured in a 2 m wide middle section, while slope, Dg, and D90 in the simulation are averaged 15 over the full 12 m length.” This mismatch seems unnecessary. For the simulation data the modeller can chose any averaging length, so also the one that matches with the laboratory experiment.

- In the simulation we averaged over the full length of the flume as we assume the average condition is the best representation of the state of the system. In the flume experiment the central 2m section of the flume was assumed to best represent the state of the experiment to avoid a bias of bed surface measurements due to the outflow and inflow conditions. Note that both transport rate measurements and the slope measurements represented the state of the full length of the flume.

31. P12 ln 16. “. We achieved the best match (shown in Fig. 3) with a grain size distribution of width σ = 1.6”. This I do not understand. The grain size distribution of the sediment does not need to be calibrated, right? The sediment specifications seem to be known from the laboratory tests?

- In the simulations we used a normally distributed approximation of the flume grain size distribution (GSD) with a sigma of 1.6 to allow for systematic alteration of this

distribution in the equilibrium experiments. This distribution and the original flume GSD are statistically the same in D_g and D_{90} is within the error of measurement of the flume experiments.

32. P13 ln 3. “which shows that the main factor determining the long-term slope is the total volume of sediment fed”. This seems to confirm the findings by Blom et al (2017)? What is the role of the GSD of the supplied sediment?

- We will add a reference to the findings of Blom et al. (2017) and a more detailed discussion of the role of the supplied sediment grain size, which is a modulation by potentially promoting bed surface armouring.

33. The conclusion section seems to be a summary rather than a conclusion section. I would reconsider and shorten this section.

- We will follow this advice and rework the conclusion section.

Specific or detailed comments

We accept all of the detailed comments 34-49 and will rework the manuscript following the suggestions.

References

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