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Interactive comment on "sedFlow – an efficient tool for simulating bedload transport, bed roughness, and longitudinal profile evolution in mountain streams" *by* F. U. M. Heimann et al.

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We are grateful to the three referees for their detailed and constructive comments. Below we respond to each of the referees' main points using the same order as in the individual reviews.

1 Answer to comments of Anonymous Referee #1

1.1 Structure in form of two companion manuscripts

The referee states that "*interesting issues are introduced whose demonstration and discussion are in the companion paper ... leading for each of them to an uncompleted discussion ... with a lack of synthesis*". This formulation implicitly suggests to combine the two companion articles into one manuscript.

The authors have chosen the structure in form of two companion manuscripts as an effective way of adressing the two different target audiences. The first manuscript documents the methods implemented in sedFlow and describes the main assumptions and key concepts that underpin the technical development of the model. The second manuscript shows how the model can be applied, outlines the advantages and limitations of the model and demonstrates in a proof-of-concept study that sedFlow can be used to recalculate bedload transport observations. The first manuscript is targeted to an audience interested in the technical details of sedFlow, such as, for example, model developers considering to modify the model code or to use some of the concepts for their own model. In contrast, the second manuscript is targeted to an audience that is mainly interested in the applicability of sedFlow, such as, for example, practitioners planning to use the model in some of their projects. Before submission, this approach of audience targeting via two companion manuscripts has been discussed with the managing editor. The authors would like to keep the structure of two companion manuscripts, as a combined text would be extremely long at the expense of readability. This is even more true as the referees of the two manuscripts are interested in further details and request different additions to the texts.

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1.2 Schematic cases

The referee "*misses the presentation of schematic cases in order to assess the efficiency and the robustness of the choices that were made*". Testing the efficiency and robustness of a numeric model can be done either based on schematic i.e. artificial and simplified case studies or based on real world case studies. If the model simulates a system of non-linear processes like sedFlow does, the test based on artificial and simplified case studies requires a global sensitivity analysis that systematically covers the complete parameter space (Saltelli et al., 2006). Such a study is beyond the scope of the present manuscript. Therefore, the authors have decided to demonstrate the efficiency and robustness of the model implementation based on real world case studies. As stated in the abstract, introduction, and conclusion, these case studies are provided in the companion manuscript of Heimann et al. (2014). Furthermore, there, the real world case studies are used as a basis for simple sensitivity studies, which are already beyond the usual extent of the presentation of a new numerical model in the geomorphology community.

1.3 Spatial scale

The referee asks to "*give some indications of the typical space interval that is currently envisaged*". We agree that it is important to delineate the spatial scale of the intended application of the model sedFlow. We will more clearly elaborate on this topic and refer to it in the contexts suggested by the referee.

1.4 Role of bed roughness

In our manuscript we point out bed roughness as a major issue in modeling sediment transport in mountain streams, and describe different options to consider bed roughness that can be used in sedFlow. The referee suggests to skip these points as a "*sensitivity analysis, and the assessment for the difficulty for calibration would be a paper in itself*". We do agree that a sensitivity analysis and an in-depth assessment of calibration problems in the context of bed roughness would be beyond the scope of this manuscript. However, the main aim of this manuscript is to present the main components that are used in sedFlow to estimate local bedload transport rates. Therefore, bed roughness, and the way in which it is considered in sedFlow, are important parts of the manuscript and the authors would prefer to keep them.

1.5 Model consistency

The referee states that the "*consistency (p.745, l.10) of the simultaneous use of a hiding function, a correction factor γ for the critical shear, and the possibility for a variable thickness of the active layer, as a function of its grain composition (p.747, l.22) is highly questionable*". The elements listed by the referee influence different parts of the simulated system. A hiding function accounts for hiding and exposure effects and adjusts the threshold for the initiation of motion for the individual grain size fractions as a function of relative grain diameter. The correction factor γ ensures a consistent use of shear stress and threshold for the initiation of motion, if the effects of macro-roughness and shear stress partitioning are considered. The thickness of the active layer determines the degree of inertia of the evolution of the local bed surface grain size distribution. The authors are not aware of any in-depth assessment of the effects of different thicknesses of the active layer in interaction with other model components. However, it is well established that the use of a hiding function improves the results of fractional bedload transport estimation (e.g. Parker, 2008), and amongst others Nitsche et al. (2011) have stressed the importance of a shear stress partitioning and a consistent use of shear stress and threshold for initial grain movement.

1.6 Active layer

The referee suggests that "*different options for the interactions between the active layer and the underlying subsurface alluvium could be simplified because the second and the third approaches are only simplifications from the first method*". We do agree that the second approach can be described as an extreme case of the first one and that the third approach is a variation of the second one. Both points are stated in the manuscript (p.748, l.10 and l.19). However, for the sake of clarity, we do not think that the text should be shortened in this section. The interaction between the active layer and the subsurface alluvium is not a trivial process, which does not allow for further simplification in its description.

The authors agree that the active layer is an important component in the numerical representation of fluvial morphodynamics. We will therefore include the suggested reference of Belleudy and SOGREAH (2000).

1.7 Channel geometry

The referee raises the point that "*Fig.3 is not very demonstrative in itself*". The mentioned figure (especially its panels *(a)* and *(b)*) clearly shows that the variation of accumulated bedload transport estimates due to different channel representations is negligible compared to the overall uncertainties of the numeric estimates, which is demonstrated by the difference between the estimates and observed data. In this way, the argumentation of the manuscript text is illustrated and supported by Figure 3. The figure uses test cases based on real world data, which in contrast to artificial set ups ensure a high degree of representativity.

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1.8 Grain size distribution dynamics

Further on the referee requests to illustrate "*the statement that 'grain size distribution will dynamically adjust' (p.750, l.3)*". As stated in the abstract as well as in the introduction and conclusion of the manuscript, illustrating test cases are provided in the companion manuscript of Heimann et al. (2014). There Figures 6 and 7 show that at the beginning of a simulation the along-channel spatial distribution of grain sizes can be described by a step function. Throughout the simulations, the local grain size distributions dynamically adjust, resulting in a final along-channel spatial distribution of grain sizes that differs from the initial step function. As discussed in the text, the final grain sizes can be interpreted as a function of bed slope (coarse grains in steep sections), channel width (coarse grains in narrow sections), and channel network (coarse grains at confluences with steep tributaries).

1.9 Structure of the manuscript

The referee notes that in the discussion the "*comparison with existing tools is rather disorderly*". The sections of the discussion are ordered by decreasing relevance for the applicability of the model.

The referee states that the "*estimation of the energy slope for bedload transport is misplaced in section 2.1.1, flow routing*" and suggests that it "*should be moved to section 2.2, Bedload transport calculation*". We do agree that the effects of the energy slope are closely related to the bedload transport calculation. However, the estimation of the energy slope is embedded in the context of flow routing. By definition the energy slope cannot be negative. If kinematic wave routing is used, the channel bed slope serves as proxy for the friction slope and is therefore assured to be positive. In this case, the channel bed slope can be directly used as proxy for the energy slope. The implemented uniform discharge approach allows negative channel bed slopes, but ensures positive

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gradients of hydraulic head, which in this case can be used as proxy for the energy slope. As shown, the method for the estimation of the energy slope directly depends on the selected flow routing. Therefore, we present the estimation of the energy slope in the context of flow routing.

1.10 Titles

To improve the manuscript title, the referee suggests that “*the mentions ‘efficient’ and ‘bed roughness’ could be dropped*”. We have changed the title to “*sedFlow – a tool for simulating fractional bedload transport and longitudinal profile evolution in mountain streams*”.

It is further suggested that the title of section 2.2.2 “*should mention that the updating concerns also the channel elevation or geometry*”. To include the elevation, we have changed the section title to “Evolution of channel bed elevation and slope”. As documented on page 746 in lines 8 to 15, the code structure of sedFlow is prepared for the implementation of complex and dynamically adjusting channel geometries. However, at the moment, infinitely deep rectangles are used as the shape of cross sectional profiles. This means that, at the moment, updating does *not* concern channel geometry.

1.11 Used symbols

We agree with the referee and will use ∂ instead of δ for partial derivatives.

2 Answer to comments of Jeff Warburton

2.1 Adverse slopes and pondages

Jeff Warburton raises the point that the "*whole idea of adverse slopes and pondages is not very clearly explained. These terms are somewhat ambiguous.*" The authors agree that the term "pondages" is normally used in civil engineering for water storage behind a weir. Therefore, we will replace it by the term "ponding" and explain that it refers to water ponding behind sediment obstructions. We will more clearly define "adverse slopes" as uphill slopes in downstream direction. From this definition, it clearly follows that a slope of zero represents "*the critical value at which a slope becomes adverse*", which Jeff Warburton had asked for.

2.2 Computational stages

As suggested by the referee we will include "*a diagram that shows the overall structure of sedFlow with the various options indicated and key governing equations signposted*".

Jeff Warburton correctly states "*that the model has 'options' that are selected to fit the application*". We fully agree that this should be highlighted at the beginning of the manuscript and we will adjust the text correspondingly.

2.3 Channel geometry

In the manuscript Figure 3 is used to demonstrate that the variation of accumulated bedload transport estimates due to different channel representations is negligible compared to the overall uncertainties of the numeric estimates, which is demonstrated by the difference between the estimates and observed data. Jeff Warburton suggests to include a "*simple table summarising % over / under prediction in relationship to the observed*". We do agree and will include a table summarising the relative deviation of the simulations among each other as well as from observation.

As suggested, we will more clearly state that Tom^{Sed} is a one-dimensional model that allows for the definition of cross sections with laterally varying bed elevations.

2.4 Active layer dynamics

The referee correctly states that there are "*three methods used to characterise the active layer dynamics ... but no real guidance is given to indicate the 'best' selection for a particular setting*". To the authors' knowledge there are unfortunately no in-depth studies that assess the influence of different active layer dynamics representations on the simulation results. Therefore, at the moment, no recommendations can be made concerning which algorithm is most appropriate for a particular setting. As sedFlow contains three different formulations for active layer dynamics in the same modelling tool, it provides the base for a future study on the effects of different active layer algorithms. However, such a study would be quite extensive and is therefore beyond the scope of the current manuscript.

In addition Jeff Warburton suggests to summarise Figs 4,5,6 in a single diagram and simplify it. The interaction of the active layer and the subsurface alluvium is a complex process. Therefore the figures cannot be further simplified without losing information about the implemented algorithms and concepts. The combination of the three figures into one single diagram would create a very large and therefore less manageable or clear figure. The authors agree that at the moment the three figures are very prominent in the manuscript and will move these figures to the appendix or supplementary material.

2.5 Inter-model comparison

In the manuscript, sedFlow is compared with three models (Topkapi ETH, Tom^{Sed} and SEDROUT). This is done qualitatively through description and discussion. Jeff Warburton suggests to quantitatively compare simulation results of the four models. We fully agree that such a quantitative comparison would be interesting. However, such a comparison is a study of its own and therefore beyond the scope of the present manuscript. Already in its current state, the manuscript covers the usual extent of the presentation of a numerical model in the geomorphology community. For example, the presentation of CAESAR (Coulthard et al., 2002) also just includes qualitative comparisons and the presentation of Tom^{Sed} (Chiari et al., 2010) does not even contain a qualitative comparison with other models. An in-depth, quantitative comparison and review of existing bedload transport models as suggested by Jeff Warburton represents an interesting option that the authors prefer to save for future research papers.

2.6 Discussion

As suggested by Jeff Warburton, we have stressed more clearly the advantages of the sedFlow approach in the discussion.

Jeff Warburton "*also expected to see greater discussion of river bed / sediment transport interactions as it is not made particularly clear how feedback from grain-size changes and/ bedload transport updates in the model and equates with changing macroroughness (bed roughness) of the channel.*" The authors agree and will further elaborate on the interaction mechanisms in sedFlow between the sediment transport and the river bed.

Jeff Warburton expects "*to see a recommendation of how sedFlow can be most effectively implemented to deal with such applications*". The authors would love to provide straightforward guidelines for using sedFlow most effectively in different catchments and settings. Unfortunately, fluvial bedload transport is characterised by a complicated network of feedbacks and interactions. This complexity does not allow for simple and straightforward recommendations. The best we could do was to provide an efficient tool, which allows researchers to easily test different options in a certain setting within short time.

In addition Jeff Warburton recommends to "*define the limits to the proposed modelling approach*". The authors agree and will further elaborate on how the process implementations used in sedFlow limit its range of applicability.

2.7 "Efficient tool" concept

As Jeff Warburton suggested, we have more clearly defined our use of the term "efficient tool".

We will include the following definition: 'By "efficient tool" we mean a model that combines straightforward pre- and postprocessing of simulation data with fast calculation speeds.'

2.8 Definition of mountain streams

As Jeff Warburton suggested, we have more clearly defined our use of the term "mountain streams" as those kind of streams in that the effects of macro-roughness and shear stress partitioning play an important role in the sediment transport system.

2.9 Minor Issues

Jeff Warburton suggests to drop Table 1. It is one of the objectives of the current manuscript to clearly outline the differences between sedFlow and similar models. The

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direct comparison of the models in the clear structure of a table is an efficient way to communicate these differences. For the sake of clarity, we would like to keep Table 1 in the manuscript.

Except this point, the authors agree with all minor comments and will implement them in the final manuscript.

3 Answer to comments of Anonymous Referee #3

3.1 Sensitivity study

The referee suggests "*to expand the sensitivity analysis of the companion paper and include it here*". The authors agree with the referee on the importance of sensitivity analyses for a good understanding of the model's dynamics. Therefore we have included the presented sensitivity analyses in the companion manuscript of Heimann et al. (2014). For the sake of readability, we have restricted the analyses to the parameters that have the largest influence on the simulation results. As mentioned in the companion manuscript on page 797 in the lines 16 to 19, the selected simple structure of a one-at-a-time sensitivity study exhibits limitations for the analysis of non-linear processes (Saltelli et al., 2006). However, an adequate global sensitivity analysis, in which the complete parameter space is covered, would go beyond the scope of the manuscripts. Furthermore, the presented sensitivity analyses are beyond the usual extent of the presentation of a new numerical model in the geomorphology community. For example the presentations of Topkapi ETH (Konz et al., 2011), Tom^{Sed} (Chiari et al., 2010), SEDROUT (Hoey and Ferguson, 1994), or the model of Mouri et al. (2011) do not contain any sensitivity analysis at all. Therefore, the authors prefer to save a more extensive in-depth sensitivity analysis for future research papers.

For the sake of representativity, it is important for the authors to provide sensitivity

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analyses that are based on real world data. Therefore we have included the presented analyses in the companion manuscript of Heimann et al. (2014), where two test cases from the field are comprehensively documented and can be used as a basis for the sensitivity analyses we have performed.

3.2 Structure in form of two companion manuscripts

The referee introduces the option "*to combine both companion papers into one large manuscript*". The authors have already argued for their choice of the structure in form of two companion manuscripts as an effective way of adressing two different target audiences. Please see section 1.1 for further details.

3.3 Discussion in comparison to existing models

The referee states that in "*the discussion, the sedFlow model is contrasted against three other existing models (Topkapi ETH, SEDROUT, and TomSed) and some additional studies, in terms of handling grainsize distributions (section 3.1), adverse slopes (section 3.2), and simulation speeds (section 3.3). However, in each of these three discussions one of the three of the other models is ignored: section 3.1 does not refer to TomSed, while sections 3.2 and 3.3 do not include SEDROUT.*". In section 3.1, the model Tom^{Sed} is discussed on page 750 in lines 8 to 10. The observation that SEDROUT is not included in the discussion of simulation speeds and the treatment of adverse slopes is correct. Unfortunately, the available documentation of SEDROUT does not provide the information that would be necessary for the discussion of the model in the mentioned contexts.

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