Nat. Hazards Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/nhess-2020-37-AC2, 2020

Natural Hazards and Earth System Sciences
Open Access
Discussions

Interactive comment on "Sensitivity and identifiability of rheological parameters in debris flow modeling" *by* Gerardo Zegers et al.

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Received and published: 20 May 2020

We thank Dr. Hill for her time in reviewing our paper. We provide responses to each individual point below. For clarity, comments are given in italics, and our responses are given in plain blue text.

Being able to match data with model results will always be an important part of people believing model results. However, those of us who understand what goes into developing a model and its application know that a good match to data is just the first step of how models can help people understand the many processes that define the world upon which our lives depend. In this work, data and physical processes are modeled and explored. The results extend as far past just model fit as current technology

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Discussion paper

supports. The DELSA method is used to reveal a considerable amount about which parameters are important to four defined metrics, and summarizes in some detail how this changes over parameter paper space (fig. 3 and 4). The article also illustrates how new data can reduce parameter uncertainty and how this changes over likely parameter space (fig. 5). In both cases, the results provided by DELSA are a step towards being able to evaluate if the results suggest the model performs realistically – both because it fits the data reasonably well and because the parameters that are important and unimportant in different parts of parameter space make sense. I have two points I would like to make in this review

We thank the reviewer for her positive feedback and thoughtful comments. We use some of her wording in our revised manuscript.

First comment *One is to highlight a potential of DELSA not noted in the paper. In line 117, this paper refers only to the first-order sensitivity capabilities of DELSA. While Rakovec et al (2014) first demonstrated the DELSA approach using first-order sensitivity indices, they also note that the approach has considerable unexplored potential for evaluation of parameter interactions. This requires that the sensitivity matrix include the prior information used for first-order statistics, and also derivatives related to observations, as noted in Rakovec et al (2014, paragraphs 11, 20, 66 and 67, and Figure 12 and Appendix A), and Hill and Tiedeman (2007, Appendix B). The addition of observations in the sensitivity matrix allows calculation of statistics that address concerns such as those considered in Fig. 5 of this work. Commonly this is called a Value of Improved Information (VOII) analysis, and statistics such as OPR (Observation-PRediction) and PPR (Parameter-PRediction) could be used to explore the distribution of uncertainty measures throughout parameter space using the DELSA approach. OPR and PPR are described by Tiedeman et al. (2003, 2004), and Tonkin et al (2007). Parameter-value dependence of these or other statistics with similar goals has received little attention to my knowledge. I imagine that the analyses in this article and those suggested are a small beginning of a future that will see models of complex processes used in ways we* *early modelers can scarcely imagine. We are riding on horseback while in the future there will be progressively more insightful ways to regard models and integrate their insights into society. This is what I imagine. I am excited that I might live to see what will happen in a few coming decades.*

In response to the reviewer's comment, we plan to make the following changes to the main text:

1- Section 3.2 (Methods - Sensitivity analysis) we change the second paragraph:

"In this work, we apply the DELSA method (Rakovec et al., 2014), which is a frugal local-global hybrid technique, to identify the parameters that have the largest impact on simulated debris flow variables. Although our implementation only examines first-order sensitivities across the parameter space - as in Rakovec et al. (2014) - it should be noted that DELSA has considerable unexplored potential to characterize parameter interactions, which could be achieved by including additional terms in the prediction total variance, as suggested by Sobol' and Kucherenko (2010)".

2- Section 4.4 (Results and discussion: Parameter identifiability)

The main goal of this study was to characterize the sensitivity of model responses to variations in uncertain rheological parameters, using only independent information on parameter values (i.e., the situation comparable to Sobol', as proposed by Rakovec et al., 2014). Hence, the only verification dataset available (flood area and sediment volume from the March 2015 event) was used to examine the identifiability of model parameters. However, the relative importance of additional observations could be assessed through the Observation-Prediction (OPR) statistic (Tiedeman et al., 2004), and the potential new information provided by field data (e.g. sedimentological and morphological characteristics) for a specific parameter (e.g. alpha1, beta1) could be quantified with the Parameter-Prediction (PPR) statistic (Tonkin et al., 2007). It should be noted that, in both cases, the equation for the total local variance (Equation 7) would be different as additional information should be incorporated (see Appendix A in

Rakovec et al. 2014).

3- Section 5 (Summary and conclusions) we change the last paragraph:

"Future investigations should advocate for improving the structure of debris flow models to achieve better simulations of deposition/erosion processes, stopping phases, and changing rheologies. Further, the development of computationally frugal methods to improve understanding of parameter interactions in environmental models emerges as an attractive avenue for future research."

Second comment

My second comment is much shorter. In line 215 of the article we find the text "Although sediment concentration is one of the main parameters controlling debris flow rheology, model results are insensitive to Cvmax. This is explained by its small range of variation compared to the feasible range of beta-1, ..." I can see how a narrow parameter range can explain uniformity in parameter sensitivity, but fail to see how it can explain its insensitivity. Perhaps there is something not quite explained well here.

We thank the reviewer for this observation. Since the original sentence is not a proper explanation of Cvmax sensitivities, we have decided to reword the text as follows:

"The large sensitivities in model response to variations of beta-1 suggest that the viscous stress (second term in equation 3) is the main contributor to sensitivities in simulated frictional slope. On the other hand, DELSA sensitivity indices associated with yield stress (τ_y) and Manning's roughness coefficient - the other terms friction slope -, are of second-order importance. Interestingly, model results are insensitive to Manning's roughness coefficient."

I appreciate the opportunity to provide comments on this very fine paper. I hope my comments provoke a bit and are of some utility.

We deeply appreciate the reviewer's thoughtful comments that will help not only to improve our manuscript, but also bring new ideas on potential improvements and applications of sensitivity analysis methods.

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