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Interactive comment on "Uncertainty analysis of the estimation of stony debris flow rainfall threshold: the application to the Backward Dynamical Approach" *by* Marta Martinengo et al.

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We thank Velio Coviello for the comments provided that will be taken into account to improve the manuscript.

The paper by Martinengo et al. investigates the uncertainty in the determination of the debris-flow rainfall threshold based on the Back Dynamical Approach (BDA) proposed by Rosatti et al. (2019). The uncertainty analysis is performed through two Monte Carlo cascade simulations. The objectives of these simulations are (i) providing

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Discussion paper

a sensitivity analysis of the BDA parameters and (ii) quantifying the impact of the variability of the rainfall estimate on the threshold parameters. Results highlight that the variability in the rainfall condition estimate is strongly related to the debris flow characteristics and the to the hyetograph shape, while the threshold parameters are characterized by a low statistical scattering. The paper diligently presents the uncertainties of the BDA method. However, it neglects some theoretical limitations of this method that are, in my opinion, important uncertainties to discuss. Here following the main points I would recommend addressing to provide a complete, physically-based (i.e., based on both analytical framework and experimental observations) uncertainty analysis.

1. More details are needed about the dataset (e.g., location of debris flows and rain gauges, data source for the volumes, etc.), possibly as a supplementary material. One minor observation related to this point: "stony debris flow" is rarely used in the debris-flow community. If the authors are referring to debris flows characterized by coarse material, especially at the front, and to non-cohesive mixtures, I would suggest clarifying this point in the dataset description stating that they are analyzing "collisional-frictional debris flows".
We agree. More information on data used to perform the analysis will be inserted in the revised version of the manuscript. As correctly claimed by Velio Coviello, with the term "stony debris flow" we refer to a debris flow in which the presence of silt and/or clay in the mixture is negligible and the stress is dominated by the collision of the particles (e.g. Takahashi, 2009, Stancanelli et al., 2015, Bernard et al., 2019, Hürlimann et al., 2019). We will clarify this definition in the revised manuscript.

2. Direct observations collected in many Alpine basins (Bel et al., 2017; Coviello et al., 2020; Nikolopoulos et al., 2014) contradict the assumptions of uniform rainfall over the basin and of certain rainfall intensities associated with debris

flows. Rainfall data gathered in the Gadria basin, that is located in the study area of the paper, can be used to discuss the uncertainties descending from these assumptions (Coviello et al., 2020). At Gadria, two different rain gauges located in the headwaters (Malga Gadria and Spartiacque) can be used for defining a critical rainfall threshold and data show a significant variability of both measured intensity and duration (see figure below from Marchi et al., 2019). For instance, the debris flow of 10 July 2017 shows very different I-D values at the two rain gauges while a pure rainfall analysis does not explain the initiation of the debris flow of 26 July 2016 that is characterized by a very low rainfall intensity recorded by only one rain gauge.

As described in Rosatti et al., 2019, the rainfall data used in the analysis are radar rainfall data. Hence, the spatial variability of the rainfall over the basins has been considered and an overall hyetograph for each event has been computed. In the revised manuscript, we will clarify the data used in the analysis in a new specific section. However, as highlighted in the Introduction of the manuscript, the focus of this work is not on the uncertainty in rainfall estimation but the effect of some BDA inputs uncertainty (i.e. the average slope i_f, the basin area A_b, the deposited volume V_{dep} and the dynamical friction angle ψ) on the threshold calibration. We are aware of the importance of the rainfall uncertainty in the threshold calibration. Nevertheless, addressing this topic is not an objective of this work since a lot of literature already investigates this aspect (e.g. Peres et al. 2018, Marra 2019, Abraham et al 2020, Gariano et al., 2020).

3. “Since being greater than zero is the only constraint of the other parameters, for homogeneity this CV value is considered suitable for all parameters”. Field evidences and data show that a variation coefficient equal to 5% strongly under-estimates the real variability of both basin area and deposited volume. In many monitored basin worldwide, it has been observed that the actual area contributing to debris flow initiation is considerably smaller than the whole basin area (Berti

et al., 2020; Hürlimann et al., 2019). Debris-flow volume estimations significantly differ - up to 30% - when performed through a digital elevation model of difference analysis, compared to the time-integration of the debris-flow discharge estimates (Coviello et al., 2020).

We agree with Velio Coviello that the source of sediments area of a debris flow, i.e. the triggering zone, is not equivalent to the whole area of the basin affected by the event. The triggering area is only a portion of the basin and its size and location depend on the triggering condition of the debris flow (e.g. diffused erosion, erosions mainly along the main channel, failure of existing protection structures, landslides). However, the BDA method is not interested in where and how the debris flow is generated but in the amount of water that is needed to convey downstream and to deposit, in a given zone of the basin, the surveyed amount of sediments. This amount of water is linked to the hydrological discharge (i.e. to the rainfall) and since a considered debris flow has reached its deposition area, the whole basin upstream this area has to be considered as the source of the hydrological discharge, as described in Rosatti et. al., 2019.

As regards the deposited volume V_{dep}, the time-integration of the debris-flow discharge is the volume of the mixture V_{mix} and not V_{dep} (i.e. the saturated deposited volume surveyed after the event). Instead, the DEM of Difference (DoD) analysis provides an estimate of V_{dep}. V_{mix} is greater than V_{dep} since, at least, part of the water volume (and of the fine fraction of the sediments) flows away during the deposition (Coviello et al., 2019, Rosatti et al., 2019). For this reason, the volumes obtained performing the time-integration of the debris-flow discharge and the DoD differs (up to 30%) and their difference is consistent with the volume that flows away, as described in Coviello et al., 2019. This highlights that, in general, the large deviation between V_{mix} and V_{dep} is not primarily due to the uncertainty in the estimate of V_{dep} but it is mainly a consequence of the different definition of these two volumes.

Anyway, since the deposited volumes of the analysed events have been provided

by regional agencies, that do not use an univocal survey methodology, we were unable to accurately define the degree of uncertainty of this input. For this reason, we have assumed a constant value of the variation coefficient CV for each event, as also done for the other inputs.
For definition, the CV is the ratio between the standard deviation σ and the mean μ of the considered probability density function. Assuming an uniform distribution, to impose $CV = 5\%$ leads to set the lower and upper bounds of the input parameters and data distributions equal to $(1 - 5\%\sqrt{3})\mu \simeq (1 - 8.7\%)\mu$ and $(1 + 5\%\sqrt{3})\mu \simeq (1 + 8.7\%)\mu$ respectively (see table 1 of the manuscript in which μ is the reference value of the considered input parameter/data). The absolute range of variation between the lower and the upper bound is $\sim 17.4\%$. Lacking additional data on the uncertainty, we considered satisfactory this range of variability for all inputs.

4. A constant sediment concentration of 0.65 in the bed of all debris-flow channels is questionable. Field studies show that sediment concentration and rheo-physical properties of debris flows feature a significant variability also during a single event (see Hürlimann et al., 2019 and reference therein).
We are sorry but we didn't understand what was meant with this sentence. Perhaps there is a misunderstanding in the definition of the concentration of the sediment in the bed. In the BDA approach, the bed concentration c_b is the concentration of the sediments in the layer below the debris flow and therefore it is a characteristic that does not depend on the flow. On the other hand, it is true that during a debris flow event, the mixture concentration c changes in time and space, as described for example in Jacob and Hungr, 2005 and Takahashi, 2009. Instead, to the best of our knowledge, there are not experimental or field investigations asserting that also c_b changes significantly during a single event. Not even the mentioned paper of Hürlimann deals with this topic.

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