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Discussions

Interactive comment on "Hydrological control of large hurricane-induced lahars: evidences from rainfall, seismic and video monitoring" *by* Lucia Capra et al.

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Responses to L. Marchi. We would like to thank the reviewer for the comments and constructive suggestions made to improve the present work. Please find below the reviewer's comment and authors' replies to these comments.

The paper of Lucia Capra and her colleagues provides a valuable contribution to the analysis of the relationships between flood runoff formation and lahar occurrence during hurricanes. Lahar monitoring and characterization of hydraulic properties of soils in a difficult environment deserve to be stressed. The aim of this note is to propose some comments on specific aspects of the analysis. The core of the study is the as-

sessment of the runoff response to hurricanes and the comparison of simulated flood hydrographs with the monitored lahars. Since no measurements of water discharge are available in the studied catchments, rainfall-runoff modeling (this term should be preferred to "rainfall simulation") remains essentially uncalibrated. It is well-known that a careful selection of model parameters does not ensure a satisfactory correspondence between simulated and real hydrographs. The lack of rainfall-runoff model calibration and the impossibility of performing it in the studied catchments should be acknowledged and discussed. More could be said, moreover, about the propagation of rainfall excess computed by means of the SCS Curve Number method: this part of runoff simulation is of utmost importance for the timing of flood response. A sensitivity analysis on rainfall-runoff model parameters, although does not surrogate model calibration, could help coping with the uncertainties in the assessment of flood response. The impossibility of calibrating rainfall-runoff models is the reason why simulated water flood hydrographs have seldom been compared with observed debris flow hydrographs in catchments instrumented for debris flow monitoring. A possible, even if only partial, check of model results with the observed runoff response could consist in the comparison of the time of the first rise of the simulated hydrograph with video images showing the onset of the water flood at the monitoring stations. According to figure 8, this comparison could be possible for Hurricane Manuel at Montegrande (Fig. 8b) and Hurricane Patricia at La Lumbre (Fig. 8d), whereas the early occurrence of lahars prevents it in the other two cases (Figs. 8a and 8c).

-We perfectly agree with the reviewer. As pointed out, no measurements of water discharge are available at both La Lumbre and Montegrande watershed, so a model calibration is not possible. We followed the suggestion by L. Marchi and we calibrated the simulated watershed discharge using the information gathered from video images acquired by the monitoring station of La Lumbre ravine during the Patricia event. For Montegrande ravine a calibration would be possible only for the 11 June 2013 event, but considering the strong effect of soil hydrophobicity at the beginning of the rainy season it is difficult to set up a comparison. For the new version of the manuscript, a rainfall-runoff modeling was performed with both SCS-CN and Green-Ampt (G-A) methods. We decided to also run the simulations with the G-A infiltration method to discuss the limitation of the SCS-CN that does not consider the rainfall intensity (for more detail see response to RC2). The simulated watershed discharge obtained with the G-A method best fits with the initial shallow-water flow observed in the video images, however, main peaks discharges corresponding with the main lahars pulses are equally reproduced with both infiltration models (see new figure R1 at the end of this document). Based on this result, and considering the limited number of parameters needed to apply the SCS-CN method, we focused on the latter method that would be more suitable to adopt in an early warning system devoted to forecast the lag time of main lahar pulses at a specific site. We improved and modified the section “2.4. Rainfall-runoff modelling” as follows (see also response to RC2). Other authors already performed a sensitive analysis of the G-A method, showing that the saturated hydraulic conductivity Ks is a key factor in the estimation of inïňĄltration rates and exerts a notable inïňĆuence on runoff calculations (i.e. Chen et al., 2015). With respect to the SCS-CN model, the only input parameter is the Curve Number, thus we present a simple comparison for Patricia event at La Lumbre ravine. Results obtained with the 80/75 CN values for channel and vegetated area respectively are compared with two other simulations performed using global values of 75 and 80 (see table R2). This exercise shows that the uncertainty in simulated maximum peak discharge is in the range of 0.1 hr, pointing that a global CN value could be also used for the Volcán de Colima. Here below the new section for the paper.

-2.4. Rainfall-runoff modelling

To better understand the lahar behavior and duration during extreme hydrometeorological events at Volcán de Colima, rainfall-runoff simulations were performed with Flo-2D code (O′Brian et al., 1993). The Flo-2D code routes the overland flow as discretized shallow sheet flow using the Green-Ampt or the SCS Curve number (or combined) infiltration models. For the present work, the SCS Curve Number (SCS-CN, i.e. Mishra

and Singh, 2003) was selected but a comparison between both infiltration models is presented below. The rainfall is applied to the entire watershed, without spatial variability as we are dealing with large-scale, long-duration hurricane-induced rainfall. This rainfall is discretized as a cumulative percent of the total precipitation each 10 minutes. With the SCS-CN model, the volume of water runoff produced by the simulated precipitation is estimated through the use of a single parameter, i.e. the Curve Number (CN). This parameter summarizes the influence of both the superficial and deep soil features, including the saturated hydraulic conductivity, type of land use, and humidity before the precipitation event (for an accurate description of the origin of the method see Rallison, 1980; Ponce and Hawkins, 1996). A similar approach was previously used for modeling debris flow initiation mechanisms (i.e. Gentile et al., 2006; Llanes et al., 2015). To apply the SCS-CN model, it is necessary to classify the soil in one of four groups, each identifying a different potential runoff generation (A, B, C, D; USDA-NRCS 2007). La Lumbre and Montegrande watersheds were subdivided into two main zones: 1) the unvegetated upper cone and the main channel, that consists of unconsolidated pyroclastic material with large boulders embedded in a sandy to silty matrix, and 2) the vegetated lateral terraces, composed by old pyroclastic sequences with incipient soils and are vegetated with pine trees and sparse bushes. Based on these observations, soils were classified between group A and B (Bartolini and Borselli, 2009). CN for the vegetated terraces and for the nude soils is estimated at 75 and 80 respectively (in wet season, Hawkins et al., 1985; Ferrer-Julia et al. 2003). To perform a simulation with the FLO-2D code, two polygons were traced to delimit the un-vegetated portion of the cone from the vegetated area of the watershed, and at each polygon the relative CN value was assigned. At the apex of each watershed a barrier of outflow points were defined to obtain the values of the simulated watershed discharge computed at each 0.1 hr. The simulation was performed with a 20-m digital elevation model. One of the limitations of the SCS-CN model is that it does not consider the effect of the rainfall intensity on the infiltration. In addition, since no measurements of water discharge are available at both La Lumbre and Montegrande basins, it is difficult to calibrate the simulations here presented. To investigate the SCS-CN model uncertainties in the assessment of flood response, the Green-Ampt (1911) model (G-A), sensitive to the rainfall intensity, was also applied and results were compared with the outcome of SCS-CN model. For the G-A method, the main input parameters are the saturated hydraulic conductivity (Ks), the soil suction and the volumetric moisture deficiency. Ks is the key factor in the estimation of inïňĄltration rates and exerts a notable inïňĆuence on runoff calculations, therefore it requires great care in its measurement (Grimaldi et al., 2013). These values can be extrapolated from reference tables or directly measured with field experiments. Based on the textural characteristics of soils at Volcán de Colima as well as type of vegetation, input parameters were selected from the FLO-2D reference manual. In particular, with a value of Ks of 20 mm/hr the simulated watershed discharge best fits with the precursory shallow-water flow observed in the video images, as it will be showed below (Figure R1). The Ks value of 20 mm/hr is equivalent to the CN value used for the SCS-NC simulation. In fact an empirical relation between Ks and CN has been proposed be Chong and Teng (1986): S=3.579(Ks1)ˆ1.208 where S is the potential retention and it is related to the CN as follow (Mockus, 1972): CN=2540/(S+25.4) Based on these equations, a value of Ks equal to 20 mm/hr corresponds to a CN of 75.5 in the range of values here used for the SCS-NC infiltration model.

The G-A infiltration model was tested at La Lumbre ravine, using the Patricia rainfall and comparing the simulated watershed discharge curve with the available video images. Figure R1 shows the discharge curve that best fits with the data gathered from the images (Table #), based on which the two method were qualitative calibrated. The G-A infiltration model nicely reproduce the initial scouring of a muddy water and it corresponds with the first increase in the simulated watershed discharge. The SCS-CN infiltration model is not able to reproduce this first water runoff. This can be explained considering that the initial abstraction due to the interception, inïňĄltration and surface storage, is automatically computed in the SCS-NC model as 0.2S, being probably too high for the studied area. In contrast, with the G-A method, the initial abstraction can be modified and best results were obtained with a value of 6 mm that corresponds to

a surface typical of a vegetated mountain region (Table #). However, both infiltration models give similar results for the main peaks of the simulated maximum watershed discharge that correspond with the arrival of the main lahar pulses as observed from the image (Figure R1). These results show that the G-A model is much more reliable to detect precursory slurry flows, while both models are equally able to catch the main surges of a lahar. One important point is that the simulations are here used to set up an early warning system to forecast the lag time of the main lahar surges. The first slurry flows were here important to calibrate the G-A simulation but they do not represent an essential data for the early warning system. In addition, input data for the G-A method often are difficult to set, requiring great care in its measurement; in contrast, the output of the SCS-CN method only depends on the CN value. The SCS-CN method has been largely used in rainfall-runoff modeling, and we consider that is a valuable method for the objective of the present work, as we are not seeking for a quantitative estimation of the watershed discharge but on the arrival time of the main lahar pulses.

Additional references

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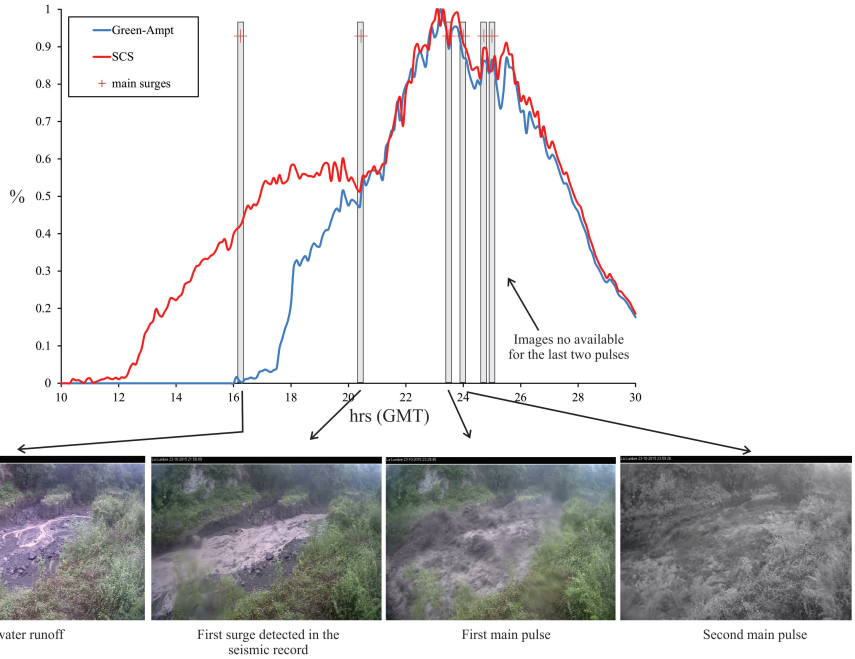

Figure R1. Comparison of simulated watershed discharge curves based on SCS-NC and G-A infiltration models. Qualitative calibration is here proposed based on the flow discharge as observed at the MSL site.

Fig. 1. Figure R1

Table R1

Parameter used in the G-A simulations	
Abstraction	6 (mm)
Ks	20 (mm/hr)
soil-suction	100 (mm)
initial saturation	0.35
final saturation	0.7

Table R2. SCS-CN simulations with different CNs

Surges observed in the images	**peak III (23.5 hr)**	**peak IV (24 hr)**
CN	*time in the simulated watershed discharge curve*	
75 global	*23.4*	***24.1***
80/75 (channel/vegetated)	***23.5***	***24.1***
80 global	***23.5***	*24.2*

Fig. 2. Table R1 and R2