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Natural Hazards and Earth System Sciences
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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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Response to RC2.

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.

Main issues As mentioned above, the rainfall simulations used in this work need to be clarified and care needs to be taken when analysing and drawing conclusions from the simulation results. In particular:

1. What are the assumptions of the SCS curve model and how may it affect results? The SCS approach is a simplified method for estimating rainfall runoff. Lower curve numbers result in less runoff for the same amount of rainfall. However, as stated on lines 229-231, this model simplifies the complex relationship between rainfall and overland flow into a single number. A weakness of this approach is that the curve number does not consider the effects of single storm properties (e.g. rainfall intensity) on infiltration.

R1: We agree with the reviewer that SCS-NC method does not consider the effect of the rainfall intensity on infiltration, a key point for the cases here analyzed. But it is worth mentioning that here the rainfall input for the FLO-2D simulation is given as a no-linear hydrograph curve where accumulated rainfall is discretized at each 10 minutes interval (as detected with the raingauge). Based also on the comment by L. Marchi (SC1), we tested the Green-Ampt (G-A) rainfall-infiltration method and we calibrated it with the images available for the Patricia event along the La Lumbre ravine, at least for the arrival time of the first slurry flow and for the main surges (this last correlation was already presented in fig.8). The parameters used for the Green-Ampt method were selected from FLO-2D reference tables according to the textural characteristics of the soil on the watershed (Table R1). The Ks (saturated hydraulic conductivity) of 20 mm/hr gives the best fit, and based on the equation proposed by Chong and Teng (1986) it corresponds to a CN of 75.5 in the range of the value used for the simulation performed with the SCS-NC method (see detailed explanation in the text below). It is worth to mention that the input parameters here used for the G-A model represent an average value for the entire watershed.

Figure R1 (see below) shows the comparison of the discharge curve obtained with the SCS and G-A methods and their comparison with selected images of the flow along the La Lumbre channel during the Patricia event. One first issue is the coincidence of the first water runoff along the channel observed in the image with the rise of the discharge in the curve modeled with G-A method, as the SCS-CN is not able to reproduce it. In fact, we performed additional simulation to try to reproduce the initial slurry flow with the SCS method but it was impossible. This can be explained considering that the model automatically assumes an initial abstraction (rainfall intercepted by vegetation) of 0.2S, where S is the potential retention included in the CN calculation (CN=2540/(S+25.4) (Mockus, 1972), value that it is too high for the studied area. In contrast, the value of initial abstraction can be controlled performing the simulations with the G-A method. However, the main peak discharges corresponding with the main lahar pulses are equally reproduced with both models. Under this evidence, we are able to affirm that the G-A method is much more reliable to detect the first streamflow, but the SCS method is also able to catch the main surges. One important point is that the simulations are here used to set up an early warning system to forecast the lag time of main lahar pulses at a specific site. The first water runoff along the channel was fundamental to calibrate the G-A simulation but it is not an essential data for the early warning system. In addition, input data for the G-A method are probably much more difficult to set, in contrast to the SCS method where only one parameter is needed. A new section has been added within the paragraph "2.4. Rainfall-runoff modeling" to show the comparison between the two infiltration methods based on which the SCS model was selected to be used in the early warning system. The SCS method has been largely used in rainfall-runoff estimations, and we consider that is a valuable method for the objective of the present work. This section was modified as follow:

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 to-

tal 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=3.579Ksˆ1.208 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, 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. 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.

2. How was rainfall applied over the simulation domain? The authors state that the rainfall 10 minute intervals were applied to the simulation (lines 249-50). However, there is no indication if this varied spatially. If a spatially homogeneous rainfall input was used, the authors need to indicate this and, in discussion, consider the effect of this assumption on results and implication for the migratory, long duration rainfall scenarios.

R2: The rainfall was applied to the entire watershed, no spatial variation was assumed. As stated before, the total amount of accumulated rainfall is discretized in 10 minutes interval, introduced in the code as a no-linear hydrograph. During tropical rainfalls rains are nearly stationary on top of the volcano. This can be observed by comparing rainfall data from different stations (fig R2). This figure will be added as extra panel in figure 3.

3. Related to point 1, in Fig. 8, simulated discharge shows better correlation to identified lahar pulses during Hurricanes Jova, Manuel and Patricia. In these events, rainfall intensity is much lower and cumulative rainfall is more linear than the 11 June event. This highlights a potential limitation of the runoff erosion model that needs to be identified and discussed.

R3: The 11 June 2013 event is presented to stress the fact that at the beginning of the rains season no-stationary, orographic events trigger lahars after few minutes of accumulated rainfall ($\sim$10 mm); in those cases, main pulses are clearly controlled by rainfall peak intensities, mainly because of a strong hydrophobic effect of the soils (see Capra et al., 2010). Therefore, the model here presented does not work for such type of events and can be only used during tropical rains associated to hurricanes, with low rainfall intensities and long durations. This concept is clearly stated in the discussion:

This model is strictly related to long-duration and large-scale rainfall events hitting tropical volcanoes such as the Volcán de Colima. In contrast, during mesoscale non-stationary rainfalls, typical at the beginning of the rainy season, lahars are usually triggered at low accumulated rainfall values and manly controlled by rainfall intensity due to the hydrophobic behavior of soils, and they usually consist of single-pulse events with one block-rich front that last less than one hour (i.e. Vázquez et al., 2016b). In perspective, the results presented here can be used to design an Early Warning System (EWS) for hurricane-induced lahars, i.e. event triggered by long-duration and large-scale rainfalls.

4. Although correlation between observed lahar pulses and simulated discharge indicate a level of agreement between simulation and reality, the models have not been calibrated to real world (i.e. measured discharge) data. In effect, the model can then only indicate differences in watershed response between the Montegrade and La Lumbre catchments. Based on these issues, elements of the discussion and conclusion may need modification:

R4. We totally agree. However, based on the calibration presented in the new section we consider that the model here used is reliable. Yes, Montegrande and La Lumbre have a different watershed response, which clearly controls the arrival time of the main lahar pulses that can be simulated with the rainfall-runoff modeling here proposed.

Line 338: pulses better match simulated watershed discharge. This is a crucial distinction, as without calibration we cannot estimate the potential error in the discharge

rate.

-Again, we think that this aspect is now better justified with the new information based on the comparison between G-A and SCS methods.

Line 338-340: "Nevertheless ...", in Fig. 8c, only one of the four observed pulses coincide with the simulated discharge - this correlation could be (in my opinion likely is) pure coincidence for this event - you need to account for this. I would recommend removing this sentence entirely, as it is largely repeated in lines 357-359.

-As stated into the test the 11 June 2013 event does not fit with the model here proposed, but apparently only the last largest pulse correspond with the simulated watershed discharge.

Line 368-371: "This is a well documented mechanism ..." it is hard to interpret what is being said here. What is the difference between discharge rate and watershed discharge? How does one control the other? Rainfall intensity and watershed shape seem to control the arrival of main pulses more than discharge.

-We agree we the reviewer and we simplified this section as follow.

Based on data presented here, formation of pulses within a lahar is mostly controlled by the watershed shape that regulates the timing of the arrival of main pulses, depending on the rainfall behavior. Nevertheless, the last pulse is always the largest in volume.

Overall, I suggest to the authors that the strength of this manuscript is in the correlations of multiple streams of data (rainfall intensity, cumulative rain, geophone records) to examine the relationship between rainfall and lahar pulses. Since the rainfall simulations are uncalibrated, they add some context to the discussion, but simulation results (in their current form) cannot be used to draw conclusions about the relationship. I believe the manuscript would be greatly improved by a rewording of the discussion, reducing the emphasis on rainfall simulations and instead focusing on the relationship between rainfall characteristics and lahar pulses.

-Base on the reviewers' comments and the comparison between the SC-NC and G-A infiltration models, we consider that at present our model is much more well justified. Simulations represent an important issue for the present work and, as proposed here, they can be used to perform an early warning system at least to determine the time arrivals of main lahars pulses.

Technical and minor issues Please see the attached .pdf for corrections to English style and grammar. All the suggestion to English style and grammar were taken into account.

Line 38, 160, 219: What is a 'stormwater'? This is unclear terminology This expression was changed to "theoretical rainfall distribution curve"

Line 58: Ruapehu is not in a tropical region. It was also observed by SC", so this example was removed

Line 161, 165, 170/Figure 1: "MgMS" do you mean MSMg? Yes, it is now corrected.

Line 163/Figure 1: "LMS" do you mean MSL? Yes, now corrected

Line 193/194: Change to "Volcán de Colima" Done

Line 202/203: "Sierra Madre Occidental high relieves" perhaps just Sierra Madre Occidntal range? Also based to the SC2 reviewer, the sentence was changes. The system began to develop on 18 October over the Pacific Ocean, strengthened into a hurricane shortly after 00:00 GMT on 22 October and early on 23 October it reached its maximum category of 5, before losing strength as it moved onto the Sierra Madre Occidental range.

Line 225: Reference is O'Brien et al. Done

Line 317-318 and 320: See above discussion, I think it is important to state the pulses match with peak simulated discharge. Also based on SR2, the text was clarified.

Line 322-324: Given model assumptions and disparities when compared to the other

events, there is a high chance this correlation is coincidental. If you want to note the correlation here, you should also highlight the disparity. We consider that as already stated into the text, the 11 june 2013 event is here reported only to show the different watershed response at the beginning of the rain season. The model here proposed will be not used to predict the arrival of main pulses for the events at the beginning of the rain season.

Line 333-335: Reword sentence to fix grammar... Seismic and visual data from events analysed here provide evidence to key factors... Also based on SC2 comment, the sentence was changes as follow: Based on the seismic and visual data gathered from the events analyzed here, it is possible to identify the key factors in controlling the arrival timing of main lahar fronts.

Line 338-380 and 357-359: See above, these two sentences are almost exactly the same. Recommend removing the first instance. We agree and 338-380 lines were deleted.

Line 398-399: "Based on the deigned storm obtained..." meaning is unclear, be specific on the requirements to anticipate start time and arrival of lahar pulses.

For the 2015 Hurricane Patricia event the weather forecast predicted an estimated value for the total rainfall, and also the approximate time of its landfall. Based on the deigned storm obtained with the rainfall/time distribution of the analyzed events, it would have been possible to anticipate when lahars started along the La Lumbre ravine, and the arrival time of main pulses. Then, this first prediction could be constrained using rainfall-runoff modeling based on real-time monitoring data, as simulations do not take more than 30 minutes to run.

Fig. 1 caption: "...locations of the monitoring stations are indicated by triangles" Done

Fig. 1: Is station MSMg_2015 identified in the manuscript? If not, remove. The station is now included into the text.

Fig. 3b/c: As a normalised plot, there is no need for the 'y' (norm) axis to be greater than one. Adjust to be between 0 and 1. Done

Fig. 5c is unnecessary, remove. Done

Fig. 8 needs to be improved, suggest the following: âĂć In the caption, rain intensity is a gray line, but in the figure it is gold/yellow. âĂć Fig. 8b - "Rain" and "Rain intensity" legend entries are switched âĂć Left axis (%norm) should only be between 0 and 1 (see above) âĂć Arrows in Fig. 8c do not seem to indicate anything - should "first stream flows" text be placed nearby? âĂć Color and line choice makes it hard to discriminate between rain intensity and discharge. Try adjust colors or line thicknesses.

Figure was improved as suggested (see next page)

Table 1: The manuscript suggested 'Jova' had seismic records for Montegrade ravine? Yes, corrected.

Please also note the supplement to this comment: https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-354/nhess-2017-354- RC2-supplement.pdf

All suggested changes were done

Additional References

Li Chen, Long Xiang, Michael H. Young, Jun Yin, Zhongbo Yu, Martinus Th. van Genuchten, 2015. Optimal parameters for the Green-Ampt infiltration model under rainfall conditions. J. Hydrol. Hydromech., 63, 2015, 2, 93–101

Chong, S. K., and Teng, T. M. (1986). "Relationship between the runoff curve number and hydrologic soil properties." J. Hydrol., 84(1–2), 1–7.

Mishra, S. K., and Singh, V. P. (2003). Soil conservation service curve number (SCS-CN) methodology, Kluwer Academic Publishers, Dordrecht, Netherlands.

Mockus, V. (1972). Estimation of direct runoff from storm rainfall national engineering

handbook, Soil Conservation Service, Washington, DC.

Ponce, V., and Hawkins, R. (1996). "Runoff curve number: Has it reached maturity?" J. Hydrol. Eng., 10.1061/(ASCE)1084-0699(1996)1:1(11), 11–19.

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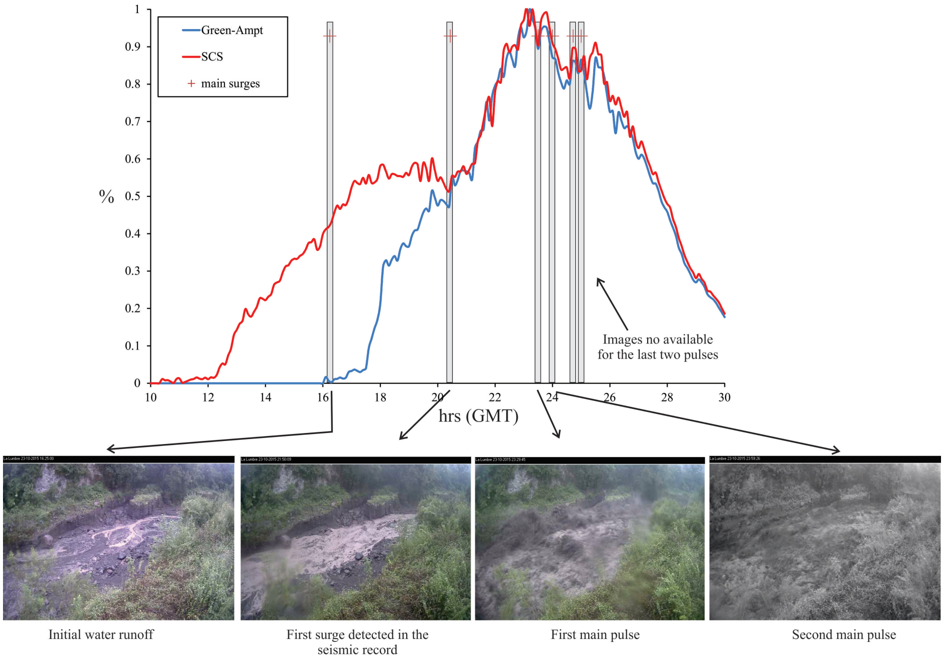

Figure R1. Comparison of simulated watershed discharge curves based on SCS-NC and G-A infiltration models. Qualitative calibration is here proposed based on the flow discharge as observed at the MSL site.

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

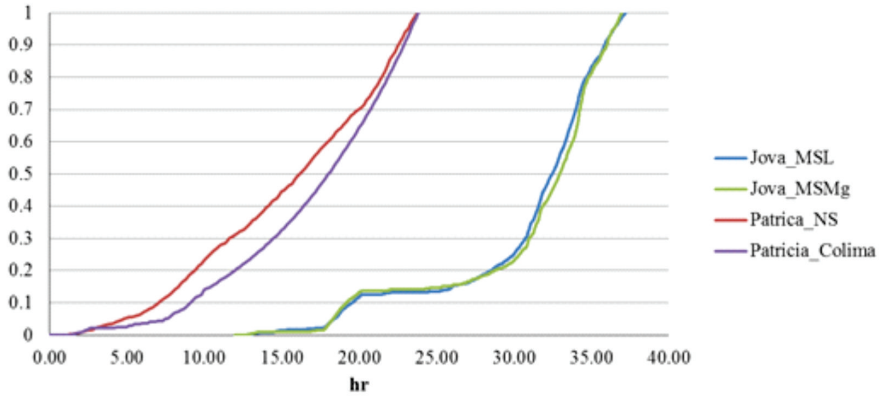

Fig. R2. Normalized rainfall of the Jova and Patricia event as gathered form different stations, pointing to a quasi-stationary rainfall behavior.

Fig. 3. Figure R2

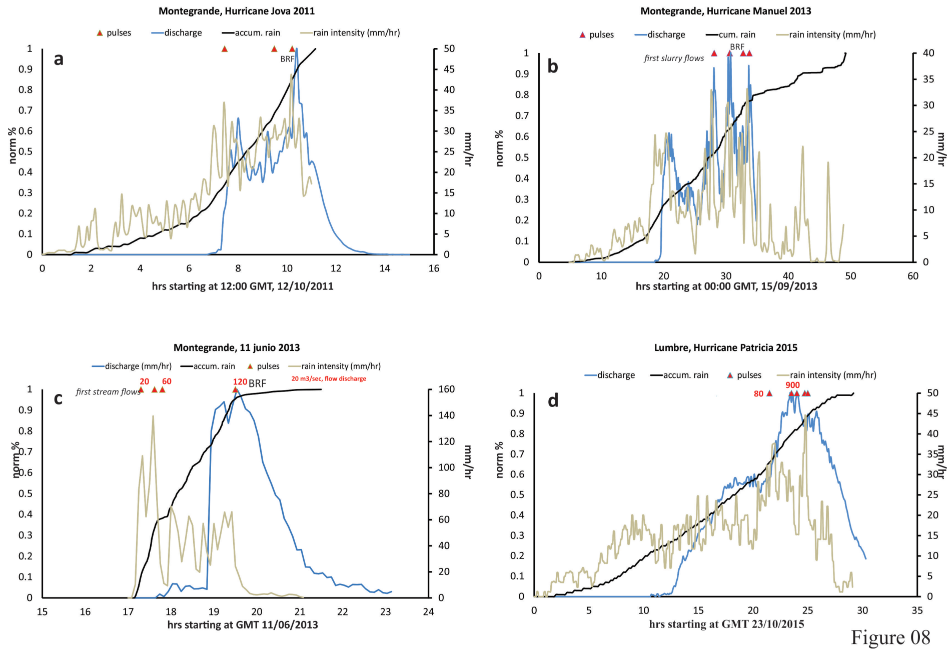

Fig. 4. Figure 8 modified