Nat. Hazards Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/nhess-2017-166-AC1, 2017

Natural Hazards and Earth System Sciences
Open Access
Discussions

Interactive comment on "Real-time prediction of rain-triggered lahars: incorporating seasonality and catchment recovery" *by* Robbie Jones et al.

Robbie Jones et al.

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Received and published: 29 August 2017

We would like to thank the reviewer for the comments and constructive suggestions relating to the underlying review of manuscript number nhess-2017-166. Please find below the reviewer's comment and authors' replies to these comments:

L. Capra (Referee) lcapra@geociencias.unam.mx Received and published: 16 June 2017

Comment: The paper represents an original contribution aimed to defined lahar occurrence, that represents a very useful tool to be implemented in volcanoes where lahar monitoring systems are not available, or to anticipate the occurrence of an event respect to an early warning system. The model is based on two years records of lahars

and their associated rainfalls of the Belham River Valley at Soufrière Hills Volcano, Montserrat. The 1-hour rainfall intensity is used to correlate lahar occurrence in dry and wet season, and lahar probability is defined considering also the 3-day antecedent rainfalls and the catchment evolution. The paper is well organized and nicely illustrated. I have identified some points that need to be better discussed:

Comment: A more detailed description of how lahars were grouped in these three different categories is needed (small, medium and large) at least indicating which the main differences are: i.e. duration, magnitude (i.e. maximum amplitude from the seismic record?); runout, flow-depth?

Reply: Increased information can be included in the manuscript regarding the magnitude categories assigned to the lahars. These categories were assessed using visual inspection of the degree of channel inundation and flow depth (where possible); in addition to the assessment of the duration and amplitude of seismic signals. Lahar signals show continuous readings in the 2-5 hz and peak at approximately 30 hz. The highest recorded amplitudes are associated with discharge and solid load in the lahar (based on observations). Lahar signals were cross referenced to visual observations and carefully excluded from signals associated with primary activity and other seismic noise (such as construction vehicles).

Comment: Can author also provide a simple description of these lahars, if they are debris flow or hyperconcentrated flow?

Reply: Detailed observations of lahars in the Belham River Valley have indicated that they are Newtonian and fully turbulent (Barclay et al., 2007; Susnik, 2009; Alexander et al., 2010; Froude et al., 2017) This interpretation is based on sampling of several small and large events and two detailed studies of flow deposits (2006-2009 and 2012-2015). Further details may be provided, however detailed observations of a flow and associated previous studies are fully referenced in Froude et al. (2017).

Comment: In addition will be useful to have a table with rainfall characteristics (total accumulated rain, peak intensity) for some selected lahar events, some examples for each lahar category (small, medium, large) in dry and wet season.

Reply: The authors agree and feel that a multi-part figure illustrating the timeline of several rainfall events and the associated lahar activity (size, timing and duration) and rainfall characteristics (timing, cumulative rainfall and peak intensity) could be added to the manuscript and would be of significant benefit to the research.

Comment: Why 1-hour rainfall intensity is here considered? Is a limitation due to the record? I don't know the weather conditions at Monserrat, but in other volcanoes (i.e. Merapi and Colima for example) especially for orographic rains (in the "dry" season), rainfall intensity is calculated over a 5 o 10 min. window, which is much more representative of these type of rains, of short duration (< 1 hours) and high intensity. Do shorter rainfalls (< 1 hrs) have triggered lahars at Montserrat? Is 1-hour peak intensity representative of different rainfall behaviors at Montserrat? Would you expect any difference in your model with a 10-min. peak rainfall intensity?

Reply: The reviewer is correct in identifying that 1-hour rainfall intensity was utilised in this study due to a limitation of the record (it was the maximum temporal resolution available). As noted by the reviewer, at other locations including Colima, Merapi and Tungurahua, 10-minute rainfall has been utilised and this has benefits in terms of assessing lahar triggering rainfall from short-duration high-intensity rainfall events which frequently occur in the tropics (e.g. Lavigne & Suwa, 2004; Capra et al. 2010; Jones et al. 2015). Short duration rainfall has resulted in lahars in the Belham Valley within the studied dataset and increased temporal rainfall data resolution would certainly be advantageous if available. However, the 1-hour approach has been demonstrated to be an effective basis for the methods developed in this study (Lavigne et al. 2000; Lavigne & Suwa, 2004; Jones et al. 2015). If incorporated alongside the current 1-hour peak rainfall intensity, 10-minute rainfall intensity could potentially be expected to further increase model performance by more appropriately capturing lahars triggered by short duration, high-intensity events. A discussion point relating to this concept could

be added to the manuscript.

Comment: Line 116. How the 1-hourPRIs threshold is defined?

Reply: In this study 1-hour peak rainfall intensity is defined as the maximum rainfall recorded in one hour during a single rainfall event. A single rainfall event is defined as a period of recorded rainfall in between two dry spells of six hours or longer. The 1-hour PRI thresholds referred to in the manuscript separate the dataset into those rainfall events which exceeded a given peak intensity threshold and those which did not, and examines the rate of lahar occurrence in each case. More detail regarding these definitions can be incorporated into the manuscript for clarity.

Comment: Line 124-129. From figure 2 at least two large lahars occurred in the dry seson2, with accumulated rainfall less than 20 mm for at least one of them. There are any evidences of hydrophobicity? Which type of vegetation grows at Soufriere Hills volcano?

Reply: Prior to the onset of eruptive activity 62% of the Belham Catchment was densely vegetated with Dry Forest (29%), Mesic Forest (48%) and Wet Forest (13%), with dry forest subsequently identified as the dominant species found on re-vegetating pyroclastic deposits (Froude 2015). Previous studies in the Belham Valley have not identified evidence of hydrophobicity, such as previously identified at Colima by Capra et al. (2010). In the Belham Valley increased vegetation damage has been identified as increasing lahar occurrence (Barclay et al, 2007; Alexander et al, 2010) and increased lahar activity late in the wet season attributed to increased deposit saturation and decreased infiltration rates (Barclay et al, 2007). Figure 2 displays hourly rainfall and whilst it is correct that neither of the two large lahars in dry season two were triggered by rainfall events featuring 1-hour PRI values of >20 mmhr-1, they were associated with rainfall events with significant total rainfall values of 39 mm (29/11/2011) and 22 mm (19/04/2012).

Comment: In addition, small lahars are more common in the wet season. For example during dry seasons 1 and 2 only medium (and 2 large) lahars were recorded and small events are only observed in the wet season. Please add some consideration about this behaviour in the discussion section, at line 215-218.

Reply: Small events are indeed more common in the wet season, a factor attributed to “flash flood” responses to rainfall during periods of increased antecedent rainfall. Small magnitude pulses of lahar activity did occur due to rainfall during dry seasons 1 and 2, however these often occurred during rainfall events which also triggered larger magnitude pulses and as such the small pulses are superseded in Figure 2.

Comment: Line 140-141. "This indicates that more intense rainfall is required to trigger lahars in the dry season than in the wet season." Can author please discuss this behaviour? Is this correlated with a higher permeability of the substratum in the dry season? How much rains accumulate during these high intensity events in the dry season?

Reply: The dataset indicated that lahars were statistically more likely to be triggered for a given peak rainfall intensity in the wet season compared to the dry season. This is thought to be a product of increased infiltration rates in the dry season associated with generally lower levels of antecedent rainfall. In terms of individual dry-season rainfall events that did not trigger lahars (of sufficient magnitude to be detected on the seismic records); 64 mm of rainfall was recorded on 4th/5th January 2011 and 73 mm on 4th/5th December 2011 without any recorded lahars. Recorded 3-Day antecedent rainfall was less than 3.1 mm at the onset of both rainfall events.

Comment: Line 165: 3-day antecedent rainfall values is a common time interval also used in previous works, such as at Colima volcano, please add some references.

Reply: Absolutely, additional references including Capra et al. (2010) to the prior use of 3-day antecedent rainfall will be added. Information and references will also be included regarding the previous use of other timescales (including 24-hour and 7-day antecedent rainfall) and how 3-day rainfall was chosen as the optimal timescale within

this study.

Comment: Line 166. Can authors be more specific about the definition of the term “total cumulative rainfall since significant eruptive activity”? In their model will be the total rain since Phase 5? And, how this term reflect the catchment evolution?

Reply: The reviewer is correct, the term “total cumulative rainfall since significant activity” reflects the total rainfall since the end of Phase 5. This parameter is used as a proxy for catchment evolution within the model under the assumption that in the absence of further eruptive activity hydrogeomorphic drainage basin recovery will occur following the catchment disturbance associated with phase 5 (Pierson & Major, 2014).

Comment: Line 215-218. This point needs a better discussion in light of Figure 2 (see previous comment at line 124-129).

Reply: As the reviewer identifies in their comment relating to line 124-129, large lahars are not exclusively triggered in the wet season and there are examples of large lahars in the dry season. However, the primary objective of the point in lines 215-218 is to emphasise that large lahars are frequently associated with the passage of large synoptic weather systems which produce large volumes of total rainfall. The increased frequency of rainfall events in the wet season (including such synoptic systems) results in an increase in the average antecedent rainfall, which is identified as contributing to the observed reduction in 1hr PRI based lahar initiation thresholds during the wet season.

Comment: Line 225-227. This is questionable based on data here presented; see previous comment about figure 2.

Reply: As identified by the reviewer, the term “absence of large lahars in the dry season” should be replaced with “the reduction in the frequency of large lahars in the dry season” as there are a couple of examples of such flows within the studied dataset. However, this reduction is still attributed to a combination of the occurrence of fewer sustained catchment-wide synoptic weather systems and a reduction in average antecedent rainfall and thus saturation level of pyroclastic deposits.

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