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Natural Hazards and Earth System Sciences
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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Many thanks to 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 comments and the authors' replies to these comments:

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Comment: Attempts to use rainfall intensity/duration thresholds to effectively predict debris-flow occurrence in non-volcanic terrains and lahar occurrence in volcanic landscapes have been ongoing for decades. This paper, utilizing a rich data set from Montserrat and innovative statistical treatments of the data, makes an important contribution to the discussion. The paper is clearly and concisely written and the figures



are quite good. Overall, I would like to see a bit more clarification of the methods used, more explanation (in plain English) of what the statistical treatments are attempting to show, and a broader discussion of the significance of the results in the context of other research. What makes this paper an important contribution is the authors' consideration of (1) catchment stability (measured as total cumulative rainfall since the last significant eruptive activity); and (2) the "false positives problem", i.e., when the occurrence of rainfall intensities above a threshold can, in some cases, trigger lahars but which in other cases do not. While the conclusions reached on both of these topics are a valuable contribution, more discussion of the significance of these findings in the context of previous studies would be extremely helpful.

There are several places in the paper where more attention is needed to clarify the research itself and its significance:

1) It would be helpful if there were a Methods section that summarized all of the approaches and assumptions used in the study. Explanations of these are currently scattered throughout the paper.

Reply: The authors agree that a restructure of the manuscript to include a consolidated methods section would be beneficial to the manuscript.

2) The sentence in lines 52–56 is overly complex and confusing. In fact, a word seems to be missing.

Reply: Amendments to this sentence are required and would help to clarify this section. E.g. "Despite this geographic coincidence and the importance of climatic rainfall regimes on storm intensities, durations and antecedent conditions (all significant factors in lahar initiation: Pierson and Major (2014)), the impact of seasonal rainfall on rain-triggered lahar initiation has not previously been explicitly considered within the development of rain-triggered lahar hazard assessment tools."

3) In line 64 it would be good to say a bit more about what is meant by "temporal

catchment development."

Reply: Absolutely, this is a key theme later in the manuscript and it would be beneficial to further develop the introduction to this topic at this point in the manuscript. Studies including but not limited to Major et al. (2000), Major & Yamakoshi (2005), Gran & Montgomery (2005) and Pierson & Major (2014) extensively cover this topic and could be used to provide key references when developing this concept within the manuscript.

4) In lines 81 and 84 there is inconsistent capitalization of "Vulcanian."

Reply: This inconsistency will be rectified.

5) At the beginning of section 4, please explain why data sets from different rain gauges are used for different time intervals. Different catch efficiencies can bias results between gauges, and local convective rainstorms can deliver different RF amounts to different gauges.

Reply: The different rain gauges were used for different time periods out of necessity, and it would indeed be advantageous to have both enhanced continuity of rain gauge location and increased spatial distribution of rainfall gauges across the catchment. As highlighted by the reviewer, the spatial variability in recorded rainfall from local convective rainstorms is certainly a consideration in the Belham Valley. However, the methods presented in this manuscript using the different rain gauges are shown to effectively forecast lahars, and this effectiveness could potentially be further enhanced at locations where networks of permanent gauges are present. Equipment failure is a common issue in monitoring volcanic environments and it of potential benefit that the method here is robust against this.

6) More explanation is needed for how the peak rainfall intensity (PRI) of 1 hour was chosen for the analyses, and some discussion of PRIs used by other researchers is warranted.

Reply: One hour peak rainfall intensity was the highest temporal resolution available



and as such was the selected resolution. Other studies have shown one-hour peak rainfall intensity to be an effective parameter in lahar initiation threshold assessment (e.g. Jones et al. 2015), although if higher temporal resolutions were available these would have the potential to enhance the performance of lahar forecasting tools, particularly with respect to more accurately capturing the intensities of local convective rainfall events. Previous studies have shown 10-minute rainfall (Arguden & Rodolfo, 1990; Tungol & Regalado, 1996; Lavigne et al. 2000; Lavigne & Suwa, 2004; Okano et al. 2012, Jones et al. 2015), 30-minute rainfall (Lavigne et al. 2000; Tungol & Regalado, 1996; Jones et al. 2015) and 1 hour rainfall (Lavigne et al. 2000; Lavigne & Suwa, 2004; Jones et al. 2015) to be useful parameters in the assessment of lahar hazard.

7) What are the time lags between the PRIs and lahar initiations?

Reply: The authors agree that highlighting the lag time between recorded rainfall and lahar detection is important in portraying the potential benefits of the methods discussed in this manuscript. Examples of lag times will be displayed in a new figure displaying the timelines of individual lahar events and recorded rainfall data.

8) Decline in lahar frequency and magnitude following catchment disturbance is a commonly reported phenomenon. Discussion is needed on how the results of this study specifically compare to the results of other studies.

Reply: A decline in lahar frequency following catchment disturbance is indeed a commonly reported phenomenon, although direct comparison of the results of this study to previous research is difficult due to the contrasting methods used. However, general comparisons of the conclusions of studies including Van Westen & Daag (2005), which identify increasing lahar initiation thresholds with time, would be beneficial to the manuscript.

9) Sentence in lines 187–189 is unclear. Is there a word missing?

Reply: The authors agree that this sentence could be amended to improve its clarity.

E.g. “ROC analysis plots the true positive rate against the false positive rate as a threshold (estimated lahar probability in this instance) is varied in order to assess how effectively the parameter discriminates between lahar and non-lahar producing rainfall events.”

10) In lines 193–194, the AUC produced by Eq. 2 is given for the analysis of all RF events. What is it for Eq. 3?

Reply: The AUC produced by Eq. 3 is 0.89 when all rainfall events are analysed, indicating that the AUC increases by a similar magnitude to that of Eq. 2 when all rainfall events (regardless of magnitude) are considered. This detail can be added to the manuscript.

11) Discussion is needed for why the antecedent moisture index of 3-day previous rainfall was chosen. What indices have been used by other researchers?

Reply: A key point also raised by another reviewer, the discussion of the use of antecedent rainfall by other researchers will be expanded and specific mention will be given as to why 3-day rainfall was selected alongside other timescales for testing as an antecedent moisture index. When tested within this study, 3-day antecedent was the optimal timescale, as also utilised by Capra et al. (2010) at Colima, where the lower rainfall and higher evaporation rates made this shorter timescale more relevant than the 7-day timescale used in previous studies in Indonesia (Lavigne et al. 2000; Lavigne & Suwa 2004). As well as being heavily influenced by local climate (Capra et al. 2010), the optimal antecedent rainfall timescale is also influenced by the grain size of pyroclastic material in lahar source regions (Rodolfo & Arguden, 1991). 24-hour (Okano et al. 2012; Jones et al. 2015), 3-day (Capra et al. 2010; Jones et al. 2015) and 7-day (Lavigne et al. 2000; Lavigne & Suwa, 2004) antecedent rainfall have been used in previous research as a lahar initiation threshold assessment parameter.

12) In lines 225–226, it would seem that the longer durations of the synoptic rainstorms are critical for providing the antecedent moisture during the wet season. It would be



good to emphasize that here for the main reason that lahars are harder to trigger in the dry season.

Reply: An excellent point and a topic that needs to be further emphasised in the manuscript. The total volume of rainfall applied during the wet season during synoptic events is key to decreasing lahar initiation thresholds.

13) In line 227, a reference for inefficient bulking in dry channels is in order.

Reply: The authors agree, references to this process will be added to the manuscript, including Fagents & Baloga (2006), Doyle et al. (2011) and others.

14) Toward the end of the discussion section, a better explanation of the meaning and significance of the ROC analysis is needed. From what you have written, I assume (not being familiar with this analysis) that (1) AUC = 0.5 means the number of true positives equals the number of false positives, and that (2) AUC = 1.0 means the number of true positives is 100%. Is this the case?

Reply: This understanding of ROC analysis is correct, however further explanation of ROC analysis would be beneficial to the manuscript and could be implemented within the proposed updated methods section.

15) How far above the PRI thresholds are the false-positive rainfall intensities? For example, if you set a PRI threshold of 25 mm/hr, how large a PRI can occur that does not trigger a lahar?

Reply: Taking the reviewer’s example, if a strict threshold of 25 mm/hr was selected there would be 18 rainfall events in the study period above this threshold that would be expected to trigger lahars. Of these 18 rainfall events, there would be three false positives, with peak rainfall intensities of 26, 28 and 34 mm/hr respectively. All rainfall events exceeding 34 mm/hr that were analysed in this study triggered lahars. Consideration of this topic could be added to the manuscript as a discussion point.

16) Figure 2 caption: Please explain the vertical dashed lines.

Reply: These dashed lines are periods where equipment failure occurred and resulted in a gap in the record. Further detail will be added to the caption to make this clearer.

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