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Interactive comment on "Evaluating critical rainfall conditions for large-scale landslides by detecting event times from seismic records" *by* Hsien-Li Kuo et al.

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RC #1: Kuo et al., present a landslide catalogue in Taiwan, obtained by remote sensing, from which they extract 62 large landslides that can be accurately timed thanks to seismic detection, and Compared to local rainfall gaging data. Then they assess which type of rainfall threshold could be derived for this dataset, including a threshold guided by physical considerations, and compare it to a dataset of smaller landslides in Taiwan. The paper ends with a rather unconvincing or unclear discussion on potential variability of the thresholds and on issues sith seismic detection. Overall, the authors present an interesting, novel dataset (although relatively modest) and do a series of classic

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Discussion paper

(rainfall threshold) and less classic (physically based threshold) analysis that can be worth publishing, but the discussion and some of the analysis need to be improved before that.

R: The authors very much appreciate the constructive feedback of the reviewer – it has certainly helped the authors improve this manuscript.

*Figure and Line by line reply have been provided with the supplementary file. Please see the attached material.

Major comment

1. Timing is an issue but rainfall estimation as well. Notably because rain gage may be far from the landslides and not experiencing similar rainfall especially due to orographic effects. The author explain they only associate landslide with rainfall measured within 100km2. I think this is a good start but in the analysis it would be good to indicate (by a color coding ?) the horizontal distance from the landslide, as well as to discuss difference in elevation between station and landslide median elevation for example. This would allow the authors to discuss uncertainty and the degree of reliability of rainfall estimates for the landslides.

R: The authors appreciate the reviewer's constructive suggestion. The spatial information (distance and elevation) of each used rain gauge station will be added to supplementary materials as Table S1. The effect of rain gauge distribution over the accuracy of rainfall has been assessed using gauge observation in a 35 km $\times$ 50 km region of south Taiwan (Fig. S1). The amounts of daily rainfall during 2009 Typhoon Morakot (8/6-8/11) recorded at 19 rain gauge stations were selected to validate the accuracy of rainfall. At first, the amounts of daily rainfall were interpolated to 01V040 station using IDW methods. The errors between measurements and interpolated data were smaller than 15 %. It indicates IDW method can be used to interpolate rainfall to a selected location in our study area. Secondly, the amounts of daily rainfall at the central point of the 35 km $\times$ 50 km region were estimated. The errors of daily rainfall between the central point and the nearest rain gauge station (01V040) were smaller than 10 % (0.5%-10% at different date). Besides, the correlation coefficients would keep at 90% as a distance between the central point and rain gauge stations less than 20 km, and even keep at 98% as a distance less than 10 km (Fig. S2). Therefore, in the study, an upper limit of basin area smaller than 100 km2 (10 km $\times$ 10 km was adopted to avoid a significant decrease of the accuracy of rainfall. The influence of topography on rainfall variability has been analyzed in the same 35 $\times$ 50 km region of south Taiwan. The highest station elevation is 1792 m a.s.l. at C1V270, and the lowest station elevation is 105 m a.s.l. at C10830. The standard deviation of station elevation is 561 m. The values of standard deviation of daily rainfall at the 19 stations were calculated, and less than 13% except for a high standard deviation, 45%, on sixth August (average daily rainfall less than 2 mm). The results demonstrated that high and even extreme rainfall are less influenced by elevation, while low and medium rainfall events are significantly influenced by elevation variation, with most of the rainfall appearing on high elevations. Similar results have also been reported by some previous studies (Sanchez-Moreno et al., 2014; Ge et al., 2017). Because the study only considered the rainfall events with total cumulated rainfall greater than 500 m, the elevation effect was ignored as selecting rain station.

2. I think the attempt of the authors to define a threshold based on physical considerations is worth, but insufficient in the present form: the assumption and limit of the model lack validation/discussion, and the practical utility/validity of the model compared to pure empirical ones is poorly demonstrated. I give detailed proposition to test and refine the model, but in any case a more quantitative comparison of the validity of the different threshold seems important if the author want to underline the physical model has a path forward. I think also this part may benefit from being put in perspective compared to other work on physically based threshold. For example: Salciarini and Tamagni 2013, Physically based rainfall thresholds for shallow landslide initiation at regional scales Papa et al., 2013, Derivation of critical rainfall thresholds for shallow landslides as a tool for debris flow early warning systems Alvioli et al., 2014, scaling

properties of rainfall induced landslides predicted by a physically based model

R: The authors appreciate the reviewer's suggestions and agree that the comparison of physically-based and statistically-based thresholds is needed. The study focused on rainfall conditions for triggering landslides in a wide (national scale) study area, a purely physical model may be not suitable. We would like to call it a mixed physically- and statistically-based model. The rainfall threshold using a mixed physically- and statistically-based model in the study will be compared with others using physically-based models. The relative discussion will be added to the text as below. "In general, physically-based models are easy to understand and have high predictive capabilities. However, they depend on the spatial distribution of various geotechnical data (cohesion, friction coefficient, permeability coefficient, etc.) which are very difficult to obtain. Statistically-based methods can include conditioning factors that influence slope stability which is unsuitable for physically based models. Statistically-based models rely on good landslide inventories and rainfall information. In the study, the Qc threshold for large landslides is estimated based on mixing physically- and statistically-based methods. Comparing to other physically-based I-D thresholds which were constructed based on artificial rainfall information for shallow landslides (Table S3), the Qc threshold proposed by the study seemed to be higher and more suitable for large landslides (Fig. 6).

In order to verify the application of the rainfall early warning model, we chose the typhoon Soudelor for demonstrating the forecasting performance. Typhoon Soudelor was one of the strongest storms in the world during 2015. It generated 1400 mm of rainfall in northeastern Taiwan and almost 1000 mm of rainfall in the southern mountainous area of Taiwan (Wei, 2017; Su et al., 2016). After completed the seismic signal analytical procedure, we obtained the occurrence time, 2015/8/8 18:59:50 (UTC), of a large landslide events located in southern Taiwan (Fig.7). This event was also detected by Chao et al. (2017) using a seismicity-based method. This event could be interpreted by six BATS stations and the location error was less than 6 km. We chose the C1V190 rain station which situated in the same watershed and was 14.6 km away from the large landslide event. The typhoon Soudelor landfall in Taiwan on August 7, 2015, and dropped a cumulated rainfall and a maximum rainfall intensity of 546 mm and 39 mm/h on August 8 at the rain gauge station C1V190 (Fig. 8). The rainfall event began at 22:00 August 7 and last 26 hours while the landslide initiate at the 22th hour. Regarding this event, the average rainfall intensities exceeded the threshold were considered to be unstable, while those lower than the threshold were stable. According to the records, the landslide warning could be issued at 5:00 which was 4 hours earlier than the landslide initiated (Fig. 8). Then, comparing to the application of the I-D threshold which would issue the warning alert 12 hours before the landslide occurred, the Qc method seemed to be more suitable for large landslide early warning model.

3. I think the discussion needs to be revised significantly. The authors seek to discuss effects on critical threshold that cannot really be assessed with the data they have, while several points are not really discussed: For example 1/ uncertainty on rainfall parameters, 2/ the added value of seismic dating of landslide and its limit (size of landslide distance from stations (currently section 5.3 needs significant clarification) , 3/ The value of the critical rainfall volume : how better compare with other, how to determine or constrain I0 etc

R: The authors appreciate the reviewer's constructive comment. The section of discussion has been revised significantly. The revision includes: 1) The authors agree that uncertainty on rainfall parameters will influence the distribution of statistically-based rainfall data. In order to constrain the indeterminate variation of rainfall threshold analyses, a consistent process of calculating rainfall data with a standard of station selection has to be constructed. In the study, we tested the accuracy of rainfall data and used a consistent calculation method for rainfall parameters carefully. Therefore, the variation of rainfall parameters (I, D, and Rt) could be under control. The further discussion will be added to text. 2) The statement of detection limitation will be modified to make the point clear. 3) The quantity of critical water volume (Qc) was estimated using the physically-based model proposed by Keefer. Subsequently, the threshold equation, (I-I0)*D=Qc, was adopted to fixed the lower boundary of rainfall data in the I-D plot. The value of I0 was estimated using the same statistically-based method with I-Rt threshold. The value of 1.5 was obtained as the exceeding probability of 5%. We would like to call it a mixed physically- and statistically-based model. The mixed model could recover the limitation while we just used a purely physically-based model or a purely statistically-based model. The modified illustration will be added to the test.

4. Last, I strongly suggest the authors to define variable names for antecedent rainfall (e.g. Ra), cumulated rainfall (e.g. Rc) to later compare with Rt (Rt = Rc + Ra) and to be consistent in text and figure when they talk about rainfall amount.

R: Thanks for the suggestion. The variable names have been modified according to the suggestions.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-126/nhess-2018-126-AC1-supplement.pdf

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