Anonymous Referee #1

General comments

The paper deals with debris-flow occurrence thresholds in terms of rainfall intensity-duration by using radar data in an earthquake-affected area (Sichuan, China). The paper addresses technical questions within the scope of NHESS and is conform to international standards; scientific methods are clearly outlined. Authors try to address the definition of the rainfall-field by the use of radar to better evaluate the relation between rainfall and debris-flow. But, as described in the technical comments, to overcome some objective limitations of the methodology used, further investigations would be needed to properly take into account the susceptibility of the territory. The title is clear; the abstract is pertinent, easy to understand and resumes well the contents of the paper. Mathematical formulas, symbols and abbreviations are correctly defined. Technical language is precise and understandable.

An I-D threshold curve is proposed on the basis of six rain events that caused 512 debris-flows between 2012 and 2014. Based on rain data estimates obtained from 2 radars, the authors use various techniques for estimating rainfall from reflectivity, by also considering the rainfall detected by rain gauges for comparative analysis and correction of the bias. As shown, the use of radar data provides a better estimate of the precipitations responsible of landslides triggering. In one case (cf. Table 2), the amount of rain measured by radar is 10 times greater than that detected by the rain gauge network (Event # 3). Before evaluating the I-D threshold, the authors describe some techniques to detect the best estimate of radar precipitation, identifying the Kalman's filtering application as the best tool to reduce radar-rain gauge bias. Using the frequentist approach, the authors compute the relation $I = \alpha D^{-\beta}$ which binds intensity and duration of precipitation for three estimates of rainfall fields. Scatter plots are shown in fig. 8

Response: We thank the reviewer for giving so helpful suggestions. In this paper we try to evaluate the feasibility and limitation for radar-based regional I-D thresholds over earthquake affected area in China. The information on hydrology, lithology, land use, geomorphology over study area could enhance the understanding of debris flow initiation. Some information on underlying surface are provided in the following paragraph describing the response. However doing an in-depth delving into those topics is beyond the scope of this paper.

Technical Comments

The article is of interest as it performs a radar application on I-D threshold models, historically developed using only rain gauges. Although, I-D thresholds generally suffer from limitations that can affect practical applications. In fact, in case of convective rainfall events (responsible of most debris-flow and shallow-landslide events), the area affected by ground effects is usually small (normally few km2) and tends to reproduce a low I-D curve when only rain gauges are used. On the other hand, landslides occur in correspondence of highest rainfall intensities. Aiming at evaluating the precipitation field, authors try to solve the problem by also using radar data, and considering possible estimation errors. Another intrinsic lack of the method lies in the determination of the duration of the event, and the simplification of the average intensity or accumulated precipitation for the whole interval. Analyses of uniform rainfall distribution inside the intervals excludes soil characteristics that heavily affect the development of gravitational movements. In the case of stratiform rain events, with uniform intensity, landslides are more frequent in permeable areas; in case of convective rainfalls, landslides are more easily triggered in areas with low permeability. An additional limit of the model is the absence of discriminant analysis of susceptibility to shallow landslides in the study area. The adopted method for determining the threshold I-D, in fact, ignores lithology, geomorphology (e.g. slope), land use, and soil coverage. Consequently, it tends to lower the threshold as is results mostly controlled by the most fragile portions of the territory. Looking at the threshold I-D of Figure 8 for the same duration of precipitation, the corresponding rain intensity that triggers debris-flow varies with one order of magnitude. The paper, assessing thresholds I-D using radar rainfall field, contributes to improve the model by reducing limitations due to the use of only rain gauges, especially in the case of convective phenomena. Among possible improvements to the method, multiple thresholds (e.g. for class of slope, lithology, etc.) could be considered in addition to accurate rainfall radarestimation.

Response: We thank the reviewer for the valuable and constructive comment. We totally agree with the reviewer that the detailed spatial information on the hydrological, lithological, morphological, and soil characteristics could help us better understand the physical initiation of shallow landslides. In the revision, we have added the information about lithology, land use and morphology. In addition, potential debris flow watersheds are retrieved. We have updated the manuscript to include these points (P.3 L.6). However, we want to note that it is challenging to get the high resolution high quality data continuously for this area, such as soil water status and soil drainage. Therefore, the empirical model is adopted in this study. We have clarified this in the revision. The manuscript was supplemented with the following contents:

“The geological structure of the study area show a northeast to southwest orientation. The rocks over this region are mainly comprised of volcanic rocks, mixed sedimentary rocks, siliciclastic sedimentary rocks, carbonate sedimentary rocks, acid plutonic rocks, intermediate colcanic rocks, intermediate plutonic rocks, unconsolidated sediments, metamorphic rocks, basic Plutonic Rocks, and pyroclastic rocks. Figure 1a shows the lithological map. Quaternary deposits were distributed in the form of river terraces and alluvial fans. Owing to frequent tectonic activities, most of the gully are steeply sloped over this area. The main land use types in this region are mixed forest, cropland, and grassland, as shown in Figure 1b.”(P.3 L.6)

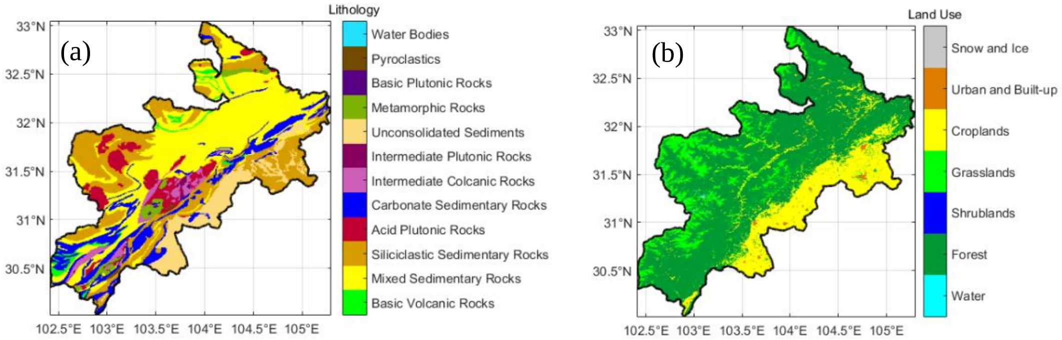

Figure 1. Lithology map (a) and land use map (b) for the study area

“Potential DF watersheds over study area is extracted from morphological variables, using the logistic regression method. Berenguer et al.(2015) simplified the geomorphological variables, as the watersheds maximum height(h_{max}), mean slope(s_{mean}), mean aspect(θ_{mean}) and melton ratio(MR) are the variables with the smallest overlapping areas for assessing the susceptibility of the watersheds. The h_{max}, s_{mean}, θ_{mean} and MR were retrieved from DEM data. Combined with the DF occurrence over this area in the three years, the potential susceptibility map was calculated with logarithm regression method as shown in the figure 2c. “(P.4,L.3)

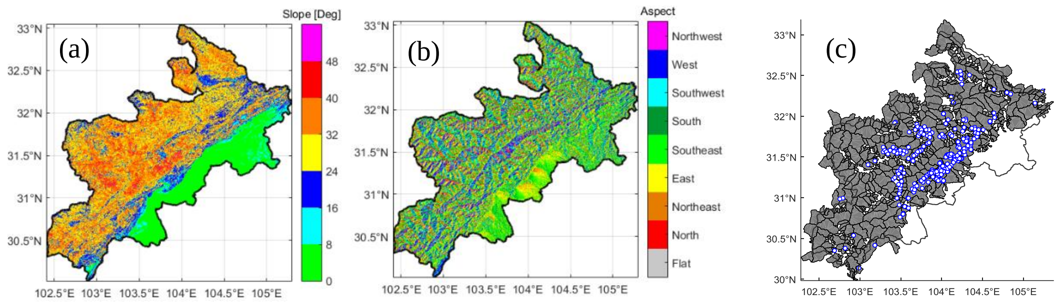

Figure 2. Morphology and potential DF watersheds map over study area.(a) slope, (b) aspect, (c) potential DF watersheds(gray polygon) with DF observation(blue circle)

"The identification results show that there are 673 potential debris flow watersheds in this region. 519 debris flows triggered by six rainfall events (point data) are shown in Figure 2c. In total, 98.6 % of the identified DF watersheds are located in the potential DF watersheds. "(P.4,L8)

Concerning the empirical relation of rainfall and debris flow, we adopted the widely used model described in (Guzzetti et al., 2007) , as D here is the duration from the beginning of the rainfall to the occurrence of the debris flow (h), and I is the mean rainfall intensity in the period of D (mm h^{-1}). The duration and intensity are determined by an interval of at least 24 hours, rain rates of less than 0.1 mm h^{-1}, or correspondingly radar reflectivity of less than 10 dBz to separate two consecutive rainfall events. We also note that there are various definition of rainfall thresholds for the initiation of debris flow in lots of literatures. Based on reviewer's constructive comment, we also would like go further to apply those definitions and investigate its performance in the following study by using the radar data.

Reference:

Guzzetti, F., Peruccacci, S., Rossi, M., and Stark, C. P.: Rainfall thresholds for the initiation of landslides in central and southern Europe, Meteorology and atmospheric physics, 98, 239-267, 2007.

M. Berenguer, D. Sempere-Torres, and M. Hürlimann.: Debris-flow forecasting at regional scale by combining susceptibility mapping and radar rainfall.Nat. Hazards Earth Syst. Sci., 15, 587–602,2015.