Dear Anonymous Referee #1:

First of all, we would like to express our sincere appreciation of your very constructive comments and suggestion.

Next, in a sequence, we would like to respond to comments in a point to point manner so that hopefully all the questions can be answered or clarified. All the answers and responses are in red.

The paper presents a new data-driven methodology, based on a multi-attribute entropy analysis of deformation states which are obtained through joint clustering method combining K-means and cloud model. This method aims at identifying, at site-specific scale different state of activity of a landslide, in particular moment of acceleration or reduction of the displacement. The model was applied at different landslide test-case and it obtained consistent results respect to the real deformation patterns of the analyzed phenomena. The paper presents in details all the methodological approach and the achieved results. It represents an interesting model which could allow to improve the comprehension of the state of activity of slope instability, also in relation to an early warning application.

Thanks for your encouraging words.

Instead, some aspects of the results presentation are incomplete, requiring clarifications and further explanations. Thus, several revisions are recommended to improve the overall quality of the work. Suggested revisions follow:

General comments

1) In Introduction section, it is important to describe better the other methodologies indicated in the text (Saito's method, FEM, LEM), in particular their fundamental principles, the main advantages and limitations and their range of application. This can be reinforced further with references of significant works presented case studies of these applications.

   A more detailed introduction of other methodologies (Saito's method, FEM, LEM) has been added, including their fundamental principles, advantages and limitations.

   Saito's method is an empirical forecast model and is suitable for the prediction of sliding tendency and then the failure time. Based on homogeneous soil creep theory and displacement curve, it divides displacement creep curves into three stages: deceleration creep, stable creep and accelerating creep, and establishes a differential equation for accelerating creep. The physical basis of Saito's method helped it to successfully forecast a landslide that occurred in Japan in December 1960, but also makes it strongly dependent on field observations. LEM is a kind of calculation method to evaluate landslide stability based on mechanical balance principle. By assuming a potential sliding surface and slicing the sliding body on the potential sliding surface firstly, LEM calculates the shear resistance and the shear force of each slice along the potential sliding surface and defines their ratio as the safety factor to describe landslide stability. LEM is simple and can directly analyse landslide stability under limit condition without geotechnical constitutive analysis. However, this neglect of geotechnical constitutive characteristic also restricts it to a static mechanics evaluation model that is incapable to evaluate the changing regularities of landslide stability. In the meanwhile, LEM involves too many physical parameters such as cohesive strength and friction angle, which

makes it greatly limited in landslide forecast and early warning. As a typical numerical simulation method, FEM subdivides a large problem into smaller, simpler parts that are called finite elements. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. FEM then uses variational methods from the calculus of variations to approximate a solution by minimizing an associated error function. In landslide stability analysis, FEM can not only satisfy the static equilibrium condition and the geotechnical constitutive characteristic, but also adapt to the discontinuity and heterogeneity of the rock mass. However, FEM is quite sensitive to various involved parameters and the computation will increase greatly to get more accurate results. If parameters and boundaries are precisely determined, LEM and FEM can provide results with high reliability. [Has been added in "Introduction"]

2) In Introduction section, please indicate some works when displacement thresholds were defined and the values of these thresholds, in relation to the type of phenomenon and the geological context.

This paragraph has been rephrased and three references have been added.

Macciotta et al. (2016) suggested that velocity threshold be used as a criterion for early warning system and the annual horizontal displacement threshold for Ripley Landslide (GPS 1) can be 90 mm and that between May and September can be 25 mm. Based on the analysis of a large number of displacement monitoring data, Xu and Zeng (2009) proposed that deformation acceleration be used as an indicator of landslide warning, and the acceleration threshold of Jimingsi landslide was regarded as 0.45 mm/d2 and that of another landslide in Daye Iron Mine as 0.2 mm/d2. Federico et al. (2012) presented a systematic introduction to the prediction of landslide failure time according to the displacement data. [Has been added in "Introduction"]

3) The developed methodology is a data-driven model, which is based on displacement data. For a better definition of the k-clusters, it could be necessary developing the method using real data where inactive, active, reactivated, and, also, failure states occurred during the considered measurement periods, as demonstrated in the analyzed case studies. Please, discuss about this aspect, in particular in relation to the potential ability of the methodology to identify the failure times of a landslide even if it has not been occurred yet.

To verify the effectiveness of the state fusion entropy method, five landslides in the Three Gorges Reservoir area in China were selected as examples for stability changing regularities analysis. Among them, Xintan landslide is a reactive landslide triggered by rainfall and has failed. Baishuihe landslide, Bazimen landslide and Shuping landslide are reactive landslides mainly triggered by reservoir water level and rainfall. Pajiayan landslide is a new-born landslide. [Has been added in "Case study"]

For now, the state fusion entropy is designed without the function of forecasting but it still offers helps for landslide stability analysis and further the early warning. Cumulative state fusion entropy reflects the overall instability of landslide and its changing forms (fluctuation around zero type and fluctuant increasing type) also do help to judge landslide evolutionary stages and deformation tendency. Besides, the historical maximum index indicates the renewal of the most dangerous state of the landslide and may server as a new clue for landslide early warning. But this new clue should not be exaggerated to such an extent that other clues can all be replaced. Once historical maximum is renewed frequently, other clues such as macro cracks should also be taken into account to fully determine landslide early warning level. [Has been

added in “Discussion and conclusion”]

4) Could this method be applicable also at higher time resolution of displacement data (e.g. daily, hourly)? This could improve the prediction for early warning applications. Please, insert a discussion about the aspect.

   While defining deformation states, deformation velocity and acceleration are selected because they are considered to represent the landslide deformation characteristics well on the assumption that displacement is monitored monthly. At this time scale, the monitoring error of GPS can be ignored compared to landslide actual deformation. However, as the time resolution of displacement monitoring data increases, the impact of monitoring errors will be greater. In this case, landslide deformation features may not be deformation velocity and acceleration but determined by some feature extraction methods. Neglecting the consideration of monitoring error, the method is capable to monitoring data with higher time resolution and corresponding feature extraction methods are under study.

5) Please indicate if there are several references, in previous works, which highlight that the historical maxima identified by the model for each studied landslide are correspondent to acceleration/reactivation periods or failure moments.

   More macroscopic phenomenon has been added as the evidence to validate the effectiveness of this method.

   The macroscopic behaviors of Xintan landslide near historical maxima was investigated according to previous studies (Wang, 1996). In June 1982, some trees in the top area of Jiangjiapo were dumped. A small amount of north-west tensile cracks appeared on the steeper section of the east. Around August 1982, the front edge of Jiangjiapo went through a small collapse. In June 1983, the colluvial deposits between Guangjiaya and Jiangjiapo showed signs of resurrection. At the end of 1984, the trailing edge of the landslide showed an "armchair" shape and the leading edge was bulged out. Some collapse pits were found on the upper side while several new tensile cracks in the middle. Meanwhile, some small collapses which seem irrelevant to rainfall occurred. In May 1985, old cracks widened and new cracks appeared, forming a ladder-shaped landing ridge. Moreover, Jiangjiapo presented a clear trend of the overall slippage. These proofs suggest that the historical maximum index is highly consistent with landslide macroscopic deformation behaviors. [Has been added in “Introduction”]

Specific comments

1) Page. 2 line 11: The sentence is unclear. Please, clarify its concept, introducing other references, if it is necessary.

   The sentence has been rephrased.

2) Please, substitute all the abbreviations in the text (e.g. ’s, can’t) with the corresponding entire terms.

   Abbreviations like “it’s” and “can’t” has been substituted. Saito’s method is reserved because it is the name of one method.

3) Page. 2 line 19: are there any previous works about entropy concepts application to landslides state of stability analysis? If yes, please refer to them and summarize their main achieved results.

   At present, studies about entropy concepts application to landslides state of stability analysis are quite rare. Nevertheless, we detailed one literature and summarized its results and

disadvantages.

Shi and Jin (2009) proposed a generalized information entropy approach (GIE) to evaluate the "energy" of multi-triggers of landslide and found that the GIE index showed a mutation before landslide failure in a case study. But this GIE method is aimed at landslide triggering factors and thus cannot directly indicate landslide stability because of the ignorance of energy transfer efficiency between triggering factors and landslide. [Has been added in "Introduction"]

4) In Methodology section: how many landslide deformation state can be identified by k-means/cloud analysis? This could have effects also on the definition of changing in landslide activity, e.g. a reactivation phase following a stable one.

Theoretically, the k-means clustering method is based on the data distribution of input data. The cluster number K only determines the division roughness of clusters and has little impact on the distribution of clusters which is the basis of the state fusion entropy approach. Therefore, the cluster number was empirically set to 3 in the case study. Now some strategies have been proposed to determine cluster number totally and automatically according to input data. And this can also be used as an improvement of the method.

5) Please, divide the description of the selected case studies from the results. Thus, it could be added a section ("Study area" or "Materials") before "Results" section.

Thanks for your suggestion. This paper mainly analyses the landslide stability changing regularities from the perspective of landslide system entropy. Five landslides in the Three Gorges Reservoir area are selected in which Xintan landslide is selected as a detailed case study and other four landslides as brief ones. If divide the description of the selected case studies from the results, a detailed description of the background information (including geological and geomorphological features, triggers, etc.) of all these five landslide will be required, which may take too much space. Meanwhile, the part of the deformation states definition may be too thin after this division. Thanks for your kind suggestion, and we may choose "Case Study" for the section.

6) It could be useful highlighting more geological and geomorphological features of both the study area and the test sites and also the triggering factors of the studied landslides.

Explained in the former comment.

7) "Discussion" and "Conclusion" section present several repetitions of the same concepts. It could be better merged these sections in another one ("Discussion and conclusion"), adding also references supporting the presented concepts.

Thanks for your constructive suggestion. We have merged and rephrased the "Discussion" and "Conclusion". The revised "Discussion and conclusion" section is as follows.

Under the guidance of dynamic state system and based on the relationship of displacement monitoring data, deformation state and landslide stability, a state fusion entropy approach is proposed to conduct a real-time and site-specific analysis of landslide stability changing regularities. A joint clustering method combining K-means and cloud model is firstly proposed to investigate landslide deformation states, and then a multi-attribute entropy analysis follows to estimate landslide instability. Furthermore, a historical maximum index is introduced for landslide early warning. To verify the effectiveness of this approach, Xintan landslide is selected as a detailed case and four other landslides in the Three Gorges Reservoir area as brief cases. Taking Xintan landslide as an example, cumulative state fusion entropy mainly fluctuated around zero in the initial deformation stage and uniform deformation stage, but an

obvious fluctuant increasing tendency appeared after Xintan landslide entered accelerative deformation stage. In the meanwhile, a thorough collection of the macroscopic proofs also suggested that historical maxima are highly consistent with landslide macroscopic deformation behaviors.

Compared with traditional safety factor, state fusion entropy evaluates the landslide instability, and is capable to indicate its extent and changing regularities. Compared with simulation methods for landslide stability analysis, this approach takes displacement monitoring data as the basis of landslide stability analysis, and thus is prone to real-time stability analysis. Compared with direct judgment from deformation velocity and acceleration, this approach analyse landslide deformation states by a data-driven model, avoiding the disunity of individual engineering geology experience, ensuring its applicability to the geological conditions of different landslides.

However, several issues also need to be clarified. The landslide stability changing regularities are obtained by comparing current stability with the past stability and thus it is meaningless to compare the state fusion entropy of different landslides. In addition, if displacement monitoring data only covers one evolutionary stage, cumulative state fusion entropy may not present the fluctuant increasing trend but a relatively simple curve with only a few historical maxima. For now, the state fusion entropy is designed without the function of forecasting but it still offers helps for landslide stability analysis and further the early warning. Cumulative state fusion entropy reflects the overall instability of landslide and its changing forms (fluctuation around zero type and fluctuant increasing type) also do help to judge landslide evolutionary stages and deformation tendency. Besides, the historical maximum index indicates the renewal of the most dangerous state of the landslide and may server as a new clue for landslide early warning. But this new clue should not be exaggerated to such an extent that other clues can all be replaced. Once historical maximum is renewed frequently, other clues such as macro cracks should also be taken into account to fully determine landslide early warning level.

Technical corrections

1. pag. 1 line 13: the evolutionary stages of the phenomenon Modified
2. pag. 1 line 15: for assessing landslide stability Modified
3. pag. 1 line 18: damages of properties every year Modified
4. pag. 1 line: at site specific scale Modified
5. pag. 2 line 5: it becomes of interest to find Modified
6. pag. 2 line 9: Due to its easy acquisition Modified
7. pag. 2 line 16: Previous works have introduced Modified
8. pag. 3 line 8: the individuation of different deformations states Modified
9. pag. 3 line 9: to investigate deformation states Modified
10. pag. 7 line 18: As time goes on Modified
11. pag. 8 line 4: with a length of 2000 m Modified
12. pag. 8 line 17: monthly indexes for Xintan landslide Modified
13. pag. 13 line 8: entering accelerative deformation stage highlighted in previous works (please insert references about this) Modified