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Interactive comment on "Landslide displacement prediction using the GA-LSSVM model and time series analysis: a case study of Three Gorges Reservoir, China" *by* Tao Wen et al.

Tao Wen et al.

tanghm@cug.edu.cn

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The authors would like to thank the reviewer for the careful reading and constructive comments that have helped sharpen this manuscript. In this revision, all the comments of the reviewers have been carefully addressed. Specific responses to the review comments are listed below. The line numbers refer to those in the revised manuscript.

Anonymous Referee #2

1. Introduction P1_29, "…external factors, such as geological conditions…"ïijN geological conditions should be internal factors.

Response: Thank you for the careful reading. Indeed, geological conditions are considered as an internal factor in the manuscript. We have revised the manuscript accordingly. Please see Introduction: Pg 1_lines 35-36 in this revision.

2. Introduction P1_36,"in recently years" should be " in recent years".

Response: Thank you for the careful reading. We have revised the text accordingly. Please see Introduction: Pg 1_lines 40 in this revision.

3. Introduction P2_23-26, Here, the studies, which also used GA-LSSVM model to predict landslide displacement, are suggested to be mentioned. For example, Cai Z, Xu W, Meng Y, et al. Prediction of landslide displacement based on GA-LSSVM with multiple factors. Bulletin of Engineering Geology & the Environment, 2016, 75(2):637-646.

Response: Thank you for the constructive comments. We have revised the text accordingly. Please see Introduction: Pg 2_line 34 in this revision.

4. Methodology P3_24, "By searching or a function. . ."ïijNhere "or" I guess is a spelling mistake.

Response: Thank you for the careful reading. That is really a spelling mistake. We are very sorry for that our mistake in spelling words. We have revised the text accordingly. Please see Methodology: Pg 3_line 34 in this revision.

5. Methodology P4_17-18, I suggest the authors to supplement an equation contains both C and σ to express the model.

Response: Thank you for the careful reading and constructive comments. We have revised the text accordingly. Please see Methodology: Pg 5_line 1-2 in this revision.

It can be seen from this paper that C is a penalty factor representing the penalty degree of the training samples, and is a parameter of the kernel function. The parameter of the model C and the parameter of the kernel function significantly influence the prediction performance. The parameter C represents the error tolerance. The more accurate the parameter is, the higher the prediction performance is, but this can lead to overtraining. The parameter implicitly determines the spatial distribution of data mapping in the new feature space. In this paper, the radial kernel function is selected as the kernel function in the LSSVM model, so the determination of the parameters C and σ is very significant for the great prediction performance. However, the equation between C and σ expressed jointly the Eq. (5) $\sim$ (10) is extremely complicated, which is inconvenient to be expressed by a certain formula. In the machine learning of LSSVM, the parameters C and σ are hyper parameters that set the values before the beginning of the learning process, rather than the parameter data obtained by training. In general, it is necessary to optimize the hyper parameters and select a set of optimal hyper parameters for the machine learning of LSSVM to improve the performance and effective of learning. In this paper, the GA is selected as the method of parameter optimization in the LSSVM due to its advantages in determining the unknown parameters that are consistent between the predicted data and the measured data. By introducing the GA, the parameters C and σ can be derived automatically. In the process of calculation, the best parameter C is first obtained by searching the optimum. Then based on the best parameter C, the best parameter σ is obtained by training.

6. Methodology P4_22-P5_2, These could be mentioned in introduction or put forward in a discussion section.

Response: Thank you for the careful reading and kind comment. We have revised the text accordingly. Please see Introduction: Pg 2_line 24-31 in this revision.

7. Methodology P5_23-24, “The sampling…sampling data.” This sentence is confusing. Why the data is independent.

Response: Thank you for the careful reading and constructive comment. We have revised the text accordingly. Indeed, the sampling data used for landslide displacement prediction are continuous and mutually dependent landslide data which are applicable or feasible to the specific method. We are very sorry for that our mistake in this sentence. Please see Introduction: Pg 3_line 1-6 and Methodology: Pg 5_line 25 in this revision.

It is well known that the evolution process of landslide is a complex non-linear process that is caused by the complex interaction of different factors, e.g. the complicated geological settings, varying hydrological conditions. Displacement time series are generally appreciated as the direct representation of the complex and non-linear dynamical behaviour of landslide. However, the landslide displacement induced by the exteral factors is approximately periodic. Therefore, a landslide displacement sequence is an instability time series with a periodic episodic movement characteristic. Because the integrity of the data collected at monitoring points has an effect on the displacement prediction, the monitoring data from July 2003 to October 2013 are selected to explore landslide deformation.

8. Methodology P5_26, It is not strict to conclude GA-LSSVM model has higher accuracy than other models due to the consideration of the trigger factors. Some other models also consider the trigger factors.

Response: Thank you for the careful reading and constructive comment. We have revised the text accordingly. Please see Methodology: Pg 5_line 27-28 in this revision.

9. Methodology P6, Fig 2, The technical route of left part is not clear. The methodology section is too long, authors are suggested to focus the introduction on what is new and what is developed by the authors to use the methodology to predict landslide displacement.

Response: Thank you for the careful reading and constructive comment. We have revised the text accordingly. Please see Methodology: Pg 6_Fig. 6 in this revision. In addition, Methodology P4_22-P5_2 of original manuscript, these are mentioned in Introduction: Pg 2_line 24-31 in this revision.

10 Case study P6_7,P6_17,P6_20-21,P6_25,P6_27-28, language should be improved.

Response: Thank you for the careful reading and constructive comments. We have revised the text accordingly. Please see Case study P6_8, P6_17-20, P6_26 in this revision.

11. Case study P7, Fig.4,& P8, Fig.5,the numbers in the legend needs to be explained.

Response: Thank you for the careful reading and constructive comments. About Fig. 4 and Fig.5, we have added the key for legend information accordingly. Please see Case Study: Pg 7_Fig.4 & Pg8_Fig.5 in this revision for details.

12. Case study P8_9-10, "in frontal area were relatively low" and "in the middle-rear areas were very high" are not consist with the monitoring data.

Response: Thank you for the careful reading. That is really a mistake in writing. We are very sorry for that our mistake. We have revised the text accordingly. Please see Case Study: Pg 8_line 12 and line 14 in this revision for details.

13. Case study P9_5, The location of the local road in fig.7 is suggested to be marked on the map.

Response: Thank you for the careful reading and constructive comment. We have revised the text accordingly. Please see Case study: Pg 10_Fig. 7 in this revision.

14. Case study P9_17-21, There is no groundwater monitoring method or data mention Here.

Response: Thank you for the careful reading and constructive comment. We have revised the text accordingly. Please see Case study: Pg 9_line 17-18 and Fig. 6 in this revision.

15. Landslide displacement prediction P11_5-6, "The model. . .regarding. . .", language should be improved.

Response: Thank you for the careful reading and constructive comment. That is really a spelling mistake. We are very sorry for that our mistake in spelling words. We have revised the text accordingly. Please see Landslide displacement prediction: Pg 11_line 5-6 in this revision.

16. Landslide displacement prediction P11_17-19, R2 are calculated according to the total data or to the predictive part of the data? Fig.9 is suggested to mark the R2, calculated according to the predictive part of the data, on the curves.

Response: Thank you for the careful reading and constructive comments. We agreed with the reviewer about the suggestion. We have revised the text accordingly. Please see Landslide displacement prediction: Pg 11_line 16-21 in this revision.

17. Landslide displacement prediction P12_11-16, “ slight lag” is not described clearly.

Response: Thank you for the careful reading. In this submission, we have revised the text accordingly. Please see Landslide displacement prediction: Pg 12_line 15-19 and Pg 12_line 22-24 in this revision. Specific responses to the review comments are listed below.

From April 2007, it began to deform gently, giving rise (at station ZG86) to a maximum displacement of 184 mm over the 4-month period in May, June, July and August. Then from September, the periodic displacement of the landslide started to fall. During February and June 2007, the reservoir level decreased 10 m, while the rainfall was 297.7 mm during the subsequent 2 months, which should have been enough to trigger landslide deformation. Hence, the decrease of the reservoir water level continued to have an effect on displacement and there was also a lag effect, which means the displacement did not occur as soon as the reservoir water level decreased, but was delayed. As time passed, the effect of rainfall on the displacement diminished. From June to September 2007, the reservoir level remained stable, but displacement was still 115 mm, which demonstrated the lag effect of the influence of reservoir water level. When the reservoir water level and the groundwater depth are decreasing at different speeds, the groundwater will respond with a lag in relation to the variations of the reservoir water level. Because of this, falls between the levels increase in magnitude, which will make the hydrodynamic pressure in the landslide grow continuously and induce the most significant deformation of the year. This means that every decline in reservoir water level results in a rise in the curve of cumulative displacement of the landslide. Seen in terms of the spatial evolution of the landslide deformation, the surface cracks of the Shuping landslide develop during April and August every year and have mainly been located on the road at the middle-frontal areas of the landslide. There is also substantial consistency between cumulative displacement and the development of cracks: the greater the deformation, the more seriously the cracks developed.

18. Landslide displacement prediction P12 Fig.10, P13 Fig.11, why the authors choose the current month and past two month as two time periods for the indexes of variation of reservoir water level and rainfall? Is this choice reasonable? Because the influence period should be determined by detailed analyzing on the respond relationship between landslide displacement and influence factors.

Response: Thank you for the constructive comment. In this submission, we have revised the text accordingly. Please see Landslide displacement prediction: Pg 14_ line 2-3 and line 6-8 in this revision. Specific responses to the review comments are listed below.

In the Three Gorges Reservoir area, the external factors, including the reservoir water level, the rainfall and the groundwater, are the most significant transient forces that act upon landslides (Chen et al. 2005). In addition, as the identification of the landslide stability states may also be approached through the history of slope movements (Crozier 1986), the prophase displacement of landslides is also an essential item in the prediction of movement. Based on research on the relationship between landslide and reservoir water level (Please see Landslide displacement prediction-The predicted periodic component displacement: Pg 11_line 25 and Pg 12_line 1-19 in this revision), the variation of the reservoir water level 1 and 2 months before failure has a strong influence on landslide deformation rates. As shown in Fig. 10, over the previous 1 and 2 months, there are close relationships between variation of reservoir water level and the velocity of displacement. Change of reservoir level during the last month to reflect the influence of the rapidity of reservoir water level regulation: the analysis assumed that the water level was increased/decreased at constant velocity during 1 month. Based on research on the relationship between landslide and rainfall (Please see Landslide displacement prediction-The predicted periodic component displacement: Pg 11_line 25 and Pg 12_line 1-19 in this revision), the rainfall 1 and 2 months before failure has a strong influence on landslide deformation rates (Keefer et al. 1987; Zhang 2006; Du et al. 2013; Cao et al. 2015). As shown in Fig. 11, over the previous 1 and 2 months, there are also close relationships between cumulative rainfall and the velocity of displacement. Therefore, by detailed analyzing on the respond relationship between landslide displacement and influence factors, we choose the current month and past two month as two time periods for the indexes of variation of reservoir water level and rainfall.

References: Chen, J., Yang, Z.F., Li, X.: (2005) Relationship between landslide probability and rainfall in Three Gorges Reservoir area, Chin J Rock Mech Eng, 17, 7, 2005. Crozier, M.J.: Landslides: causes, consequences and environment, Croom Helm, London, 1986. Keefer, D.K., Wilson, R.C., Mark, R.K., Brabb, E.E., Brown, W.M., Ellen, S.D., Harp, E.L., Wieczorek, G.F., Alger, C.S., Zatkin, R.S.: Real-time landslide warning during heavy rainfall, Science, 238, 921–925, 1987. Zhang, G.R.: Spatial prediction and real-time warning of landslides and it's risk management based on WEBGIS, China University of Geosciences, Wuhan, 2006. Cao, Y., Yin, K., Alexander, D. E., and Zhou, C.: Using an extreme learning machine to predict the displacement of step-like landslides in relation to controlling factors, Landslides, 4, 725-736, 10.1007/s10346-015-0596-z, 2016. Du, J., Yin, K., and Lacasse, S.: Displacement prediction in colluvial landslides, Three Gorges Reservoir, China, Landslides, 10, 203-218, 10.1007/s10346-012-0326-8, 2013.

19. Landslide displacement prediction P13_16-18," the cumulative rainfall in the current month, the cumulative rainfall in the past two months, the reservoir water level, the variation in the reservoir water level in the current month, the variation in the reservoir water level in the past two months, and groundwater depth are selected as input variables", these variables have strong correlation, for instance, the reservoir water level and groundwater depth. Will this kind of dependent relationship between the variables influence the accuracy of prediction? How the authors think about it?

Response: Thank you for the constructive comment. We have revised the text accordingly. Please see Landslide displacement prediction: Pg 14_line 11-18 in this revision. Specific responses to the review comments are listed below.

Based on the analysis of monitoring data and deformation characteristics, rainfall and reservoir water level are the main factors that influence the landslide displacement. The reason is that the infiltration of rainfall and reservoir water level changes the dynamic characteristics of groundwater in landslide, which reflects the change of groundwater level. On the one hand, the change of groundwater level makes sliding mass or sliding zone in a dry and wet circulation state, which leads to changes in the physical and mechanical properties of the sliding mass or sliding zone. On the other hand, due to the change of groundwater level, the seepage force and the uplift pressure of groundwater acting on the landslide change dynamically. Due to differences in permeability of different landslides or the different parts of the landslide, the responses of groundwater level to rainfall and reservoir water level are not the same. In addition, the change in groundwater level exhibits considerable agreement with rainfall and reservoir water level fluctuations, with a slight lag. The relationships between the periodic displacement and the groundwater and the reservoir water level are illustrated in Fig. 10 and 11. For instance, in the rising phase of reservoir water level, the groundwater level gradually increases, with a slight lag behind the increase in the reservoir water level. The groundwater remains high enough for ongoing movement to continue. Conversely, the groundwater level decreases in the declining phase of the reservoir water level.

Therefore, groundwater influences displacement. Hence, considering the influences of rainfall and reservoir water level on landslide displacement, and in order to make prediction performance more accurate, it is necessary to select groundwater level as input variable for landslide prediction.

20. Landslide displacement prediction P14_9-10,"Notably,. . .water level." However, Fig.12 (b) did not match well.

Response: Thank you for the careful reading and constructive comment. We have revised the text accordingly. Please see Landslide displacement prediction: Pg 14_line 32-35 in this revision.

21. Landslide displacement prediction P14-16 Table 3, Table 4, Table 5, the measured cumulative displacement data are not from small to large in time. For example, ZG85ïijN2012/11/1, 3442.907mm is smaller than 2012/10/1, 3460.208mm. Please explain why the cumulative displacement decreased?

Response: Thank you for the careful reading and constructive comment. To avoid the potential confusion, essential discussion was added in this revision.

It was noted that there are three situations like this. For example, in Table 3, 2012/11/1, 3442.907 mm is smaller than 2012/10/1, 3460.208 mm, and 2013/3/1, 3460.208 mm is smaller than 2013/2/1, 3477.509 mm. In Table 4, 2013/9/1, 4602.076 mm and 2013/10/1, 4602.076 mm are all smaller than 2013/8/1, 4619.377 mm. However, in Table 5, the measured cumulative displacement data are from small to large in time. To address the comments by the reviewer, the following explanations are made in this submission. Due to the rapid deformation rate of Shuping landslide in the present, Shuping landslide may deform and even fail. Hence, in order to prevent the deformation and failure of the landslide during the recession period of reservoir water level or heavy rainfall, it is necessary to take measurements to reduce the landslide displacement rate and improve the stability of the landslide. It is noted that from August 2012 to December 2012, Hubei Province geological environment Terminus had completed

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Discussion paper

the investigation and emergency control design of Shuping landslide. The overall plan for emergency control engineering of Shuping landslide is to cut slope in middle-rear areas, press foot in frontal areas below 175 m of the reservoir water level and layout the drain ditch in the surface near the landslide boundary. After starting the emergency control project in 2013, by comparing the deformation characteristics of the landslide before and after the implementation of the project, the displacement rate decreased and the abrupt change of landslide disappeared gradually during the recession period of reservoir water level, which indicated that the emergency control project has achieved good performances. In addition, in the rising phase of the reservoir water level, the anti-sliding sections of the landslide are constantly submerged, and the anti-sliding force decreases while the sliding force decreases continuously at a faster rate. Moreover, due to the reverse seepage function of reservoir water level, it is beneficial to the stability of the landslide with characterizing of unobvious deformation of the landslide. Conversely, in the declining phase of the reservoir water level, the sliding force increases under the action of the hydrodynamic pressure in the anti-sliding sections of the landslide, which results in the large deformation of the landslide and the decline of the stability. In terms of this kind of landslide, there is basically no sign of deformation in the rising phase of the reservoir water level. But it is very sensitive to the decline of reservoir water level. For instance, in October 2012, the reservoir water level rose close to higher value (172.7 m) than that (166.5 m) in November 2012. In this month, the deformation velocity of the front edge (ZG85) decreased to 0.56 mm/day. Hence, for ZG85, the cumulative displacement on 2012/11/1 is smaller than that on 2012/10/1. During the subsequent water level decreasing stage in July 2013, the water level decreased to the lowest value (145 m). The deformation velocity of the front edge increased to 3.58 mm/day. In conclusion, the rising phase and the declining phase of the reservoir water level will make landslide displacement vibration. That means that the trend of displacement growth of some landslides is not obvious, with characterizing of jagged cumulative displacement curve related to the rising phase and the declining phase of the reservoir water level. Therefore, the measured cumulative displacement data are not necessarily from small to large in time. Such is the displacement of Sangshuping landslide, which is also located in Shazhenxi town, Zigui country, Hubei province, China, near the tributary of Yangtze River, Qinggan River and approximately 6 km into the Yangtze River. Moreover, according to the reference (Huang et al. 2016), the cumulative displacement of the Baijiabao landslide monitored by GPS are fluctuation within a narrow range and is not monotonically increasing with time, such as in August 2007 and June 2009.

References: Huang, F. M., Yin, K. L., Zhang G. R., Gui, L., Yang, B. B., Liu, L.: (2016) Landslide displacement prediction using discrete wavelet transform and extreme learning machine based on chaos theory, Environmental Earth Sciences, 75, 20, 1376.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-87/nhess-2017-87-AC3-supplement.pdf

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