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# *Interactive comment on* "Prediction of rainfall induced landslide movements by artificial neural networks" *by* Janko Logar et al.

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The comments of the referee are welcome and will be useful for the improvement of the paper. The response to each specific comment is given below.

The purpose of the article is to test the ability of artificial neural networks to develop reliable short-term predictions based on data that is normally available. The paper is of interest for the journal by treating an extremely fascinating subject and, according to many authors, full of prospects. In particular, authors face two cases of slope instability, on which data sequences are available. Specifically, in the first case, the Macesnik landslide, they processed data regarding the displacement of geodetic points, in the second, the well-known landslide of Ventnor, the data was derived from measurements



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Discussion paper

on a crackmeter. In this respect it should be noted that the historical series used are limited and, since neural networks are very powerful nonlinear interpolators, they need long historical series to "learn" the phenomenon, otherwise they tend to over-adapt to the few data available. This could lose the ability to generalize predictions. This problem has not been commented by the authors. On the basis of the above, the following points are highlighted which, in my opinion, should be improved or rewritten.

**Answer**: We are glad that the referee agrees that the use of ANNs has potential in the field of prediction of landslide movements based on long-term monitoring data. However, based on our experience with performed analyses (many more analyses were performed than are presented in the paper) we are convinced that it may be a drawback to use a very long series of observation data in ANN training and predictions. This can be very clearly seen from the Macesnik case history where the ANN ceases to give suitable predictions when drainage works started. Even without human activities, during sliding, changes occur within the landslide body and especially conditions for water inflow and changes in drainage conditions. Therefore, using too long time series for ANN training may not give the short term predictions of landslide movements, which would correspond to the **present** landslide condition. Authors believe that the appropriate time series for each single landslide has to be found by trial and error procedure.

1. The introduction is particularly long and addresses aspects not directly related to the subject. Many of the papers are cited without a specific purpose (15-20).

**Answer**: Since all the referees share the same opinion we will shorten the introduction in the final paper by reducing the extent of literature review.

2. In the same introduction, as in the following, the authors refer to landslide and earthflows (5) (25): the reason for this is not clear being earthflows themselves landslides.

**Answer**: Comment accepted. We wanted to emphasize that landslides can be of different types.

3. In relation to the data, and as far as the Macesnik landslide is concerned, the meaning of the highest intensity of earthflow movements should be clarified. In addition, earthflows show, especially when particularly extensive, complex movements that may involve differentiated sectors over the time. In this regard, papers such as Guerriero, et al (2014). Influence of slip-surface geometry on earth-flow deformation, Montaguto earth flow, southern Italy. Geomorphology, 219, for example, should be referred as examples of kinematism over time.

**Answer**: By the term "highest intensity of earthflow movements" we wanted to explain that only movements of one geodetic point of the measuring profile that consisted of several geodetic points was used in the analysis and is shown in figures for the Macesnik landslide. Only the geodetic point with largest observed movements (highest intensity of movements) in specific profile was used in the analysis.

The referee's observation on the earthflow movement is correct. Also Macesnik earthflow shows the type of behaviour as described e.g. by Guerriero et al (2014). This can be deduced from the data presented in our paper. Since the focus of our paper is on the predictions of landslide movements by ANN we didn't want to describe both case histories in too much detail.

4. Even for the Ventnor landslide, the meaning of the measures should be clarified in the kinematic characteristics and evolution of the movement in order to understand its overall significance.

**Answer**: Comment accepted. We will improve the description and add suitable reference. Undercliff landslide in Ventnor is well documented case history and details of its kinematism may be found elsewhere.

5. As a result, it would be opportune to describe the landslide phenomena through maps and models that could permit to understand the meaning of the data.

**Answer**: The scope of the paper was not to describe landslide phenomena but to

show that movements of two very different landslides (whose movements are believed to be governed mainly by rainfall) can be predicted by ANN if a long enough history of measured displacements and rainfall as a triggering factor is available. Trained ANN can then be used as a decision support tool for authorities such as civil protection.

Another scope of the paper is to encourage the research community in the field of application of artificial intelligence to the landslide phenomena, not to focus only on the selection of new and better ANN algorithms but also to organize the input data for training and testing ANNs in different ways.

6. Clarifications should also be made on the choice of cumulative displacement output. This parameter defines the history of the movement itself. This facilitates the prediction, while it would appear more appropriate to use the displacement velocity. The chosen model seems to give the illusion of very accurate predictions.

**Answer**: For Macesnik earthflow we have shown both, velocities and displacements. We agree that by showing displacements instead of velocities the results seem to be in better agreement with observations. However, taking into consideration the aim of the paper which is to propose the use of ANNs as a decision support tool for civil protection officer, we believe that expected movements within short-term future of expected heavy rain is exactly what the end user will need in order to decide e.g. whether to close the road or evacuate the house(s).

7. Explanations should be given regarding the use of neural networks. In particular, it is not clear how the training data, on which the network is built, the validation data, and the test data were shared. This also to prove what the real capacity of the network generation.

**Answer**: We have tried to explain in detail the procedures used to obtain the results which are shown in the paper. We simulated the probable real data flow when dealing with particular landslide. First the ANN is trained on the basis of long enough data series of available measurements. Then, using rainfall data for next time period (in real

case that would be weather forecast rainfall), the expected displacement was predicted. This prediction was compared with actually measured displacements. In the following step, the ANN was trained with extended data base that included rainfall and displacement data from this last time period. Such step-by-step procedure was then used for the remaining time steps. We will consider to add a flow chart of the procedure.

At the very beginning, the suitable ANN architecture was selected among many different trial ANNs by validation procedure using the initial data set (the same as for the prediction for the first time period). The ANN architecture with best performance was selected and used afterwards.

8. The so-called neural network kernel functions are not easily understandable.

**Answer**: The simple feed-forward ANN with sigmoid activation function was used. The mechanism of the ANN kernel can be seen from Fig. 2.

9. Forecast reliability is demonstrated only graphically, without providing performance index values, which are normally calculated on the training set. This in order to demonstrate the effective capacity of the network to predict with data different from those used for the construction of the same. It would be advisable to define statistics or performance indices.

**Answer**: Comment accepted.

10. Selected networks are quite complex (with many neurons) and, at least in the first case, layered. Given the limitations of the data analyzed, this could be a problem, because the complexity of the architecture of neural networks should be linked to the available data.

**Answer**: We have used two very different ANN architectures for two case histories. They were selected separately for each case history (considering available data) among many trial ANN architectures.

11. Knowing superficially the two case studies, it would be appropriate to reinforce the

reasons why we use a neural network, which is a nonlinear modeling technique.

**Answer**: For modelling nonlinear and complex landslide movements as a function of one or more influencing parameters we need a nonlinear model.

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