Hydrol. Earth Syst. Sci. Discuss.,
doi:10.5194/hess-2016-143-AC2, 2016

Hydrology and Earth System Sciences
Open Access
Discussions

Interactive comment on "iCRESTRIGRS: A coupled modeling system for cascading flood-landslide disaster forecasting" *by* K. Zhang et al.

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Received and published: 10 July 2016

1. *"I read with interest this research paper which describes a coupled system for prediction of landslide occurrences triggered by intense precipitation. The system is based on the use, in a cascade manner, of the models CREST and TRIGRS. Finally, the authors describe the results of an interesting case study. In the Introduction, the issues of flood and landslide disasters are well described in the context of natural hazards, which characterize the study area. The general objects of the work are clear and well stated, the proposed methodology is of good scientific interest, and also the presentation quality is satisfactory. However, I have some doubts on the efficiency of the created system and I argue the use of the terms 'early warning system' and*

'flood'."

Response:

We thank the reviewer for his/her positive and constructive comments. We agree with the reviewer that our study is of good scientific interest and have a good quality. In terms of the naming of this system, we agree that the system we developed is a modeling system rather than an early warning system. However, we only called the system as an "early warning system" once in the manuscript. We will change the statement and correct the wording in the revised manuscript. Regarding the word "flood" used in this study, please see Item 2 of Responses to Reviewer 2 (i.e. the following item).

2. *"I am not sure if using the term 'flood' is here appropriate. If I understood correctly, CREST model predict the discharge at outlet and the spatially distributed surface runoff. I did not see here any flood disaster forecasting analysis (as claimed by the authors), which normally expects identification of floodplains, critical discharges, etc.. Does the model include a propagation module? Also, note that in flash flood events, the evapotraspiration is almost negligible, whereas the spatially distributed component of CREST model mainly derives, if I understood correctly, from the use of LAI and vegetation cover, from which evapotraspiration and interception processes are estimated."*

Response:

We respectively insist that the term 'flood' used in our modeling system is appropriate. It is widely known in our field that hydrological models, either lumped models or distributed models, are used to simulate streamflow (discharges) at the outlet or any grid cell. These simulated streamflow values can be used to detect the risks and occurrences of floods based on flood frequency analysis of retrospective model simulations. Based on this idea, several well-known global or regional flood forecasting/monitoring systems have been established (please refer to http://www.gdacs.org/flooddetection/, http://flash.ou.edu, http://flood.umd.edu, and http://eos.ou.edu). In addition, the

CREST model is able to simulate discharges at any stream cell and surface flow at any grid cell. We didn't represent much flood analysis simply because we didn't run the model long enough to generate enough samples for this type of analysis. The CREST model doesn't have a propagation module but it does have a routing module. In terms of evapotranspiration, it is trivial for the simulation of a flash flood event. However, it impacts the long-term water balance, which can impact the accurate simulation of hydrograph in turn.

3. *"Similarly, an early warning system is a more complex system which includes the definition of a 'chain of different communication systems working together and aimed at the detection, analysis and mitigation of potentially hazardous events'. For example, they normally includes a monitoring network for real-time analysis and the definition of thresholds for launching alert/waning signals. I would simply say that the developed system could be potentially used within an early warning system' (P1L23)"*
Response:
We agree that "an early warming system" is more complicated than a modeling system. Like we mentioned in Item 1 of Responses to Reviewer 2, we only called the system as an "early warning system" once in the manuscript. We will change the statement and correct the wording in the revised manuscript to make it more accurate.

4. *"Authors state that 'studies on dynamically coupling hydrological processes predicted by distributed hydrological models with soil physics and mechanics determining slope stability are still in a very early stage' (see discussion at P3L16-25). Actually I do not agree with authors analysis. Literature provides many examples of spatial distributed and coupled hydrological-stability models, which have been successfully utilized. Besides the ones cited by the authors (Simoni et al., 2008 and Lanni et al., 2012), authors can refer, for example, to Burton and Bathurts (1998), Claessens et al. (2007), Arnone et al. (2011), Lepore et al. (2013), Tao and Barros (2014) (these last two are also cited and described by Bogard and Greco (2014) as 'good examples' of coupled physically based hydrological and slope stability modeling at catchment*

scale). Also, you may more deeply discuss the sentence 'due to lack of knowledge of interactions between these processes and differences in the spatiotemporal scales of the flood and landslide events'."
Response:
We mean that there is still large room for studies on the coupling of distributed hydrological model with the landslide model. We will relax corresponding statements and discussions, and cite additional appropriate references in the revised manuscript.

5. *"If I understood correctly, CREST model does use only precipitation, LAI and vegetation cover as distributed in input variables (as said above). Other model parameters I guess are homogenous across the watershed. How about the soil parameters that influence the infiltration processes, and slope stability, such as porosity, hydraulic conductivity, retention curve parameters? Please specify whether these are distributed or homogeneous."*
Response:
Most of model parameters for the CREST model in this study are distributed, including the soil parameters that influence the infiltration processes, and slope stability. These parameter values at each grid cell were determined by its soil class through a look-up table (Table 1). We described how we determined these parameters in Section 2.2.3. We can provide further details on how these distributed parameter values are determined if necessary.

6. *"There is no mention on how FS is computing and which are the parameters affecting stability. I would like to see the FS equation, explain whether is based on classical Mohr-Coulomb or Bishop failure criterion (for unsaturated conditions) and if it is computed ad a fixed soil thickness of different soil depths. Indeed, FS varies significantly with depths, at given parameters (see other comments below)."*
Response:
We followed the way that TRIGRS computes FS and the depth of slope initiation. FS

is calculated as the ratio of resisting basal Coulomb friction to gravitationally induced down-slope basal driving stress (Baum et al. 2010, JGR, doi:10.1029/2009JF001321). FS is calculated for transient pressure heads at multiple depths, Z . Failure is predicted when FS < 1 and stability holds where FS >= 1. Thus, the depth Z where FS first drops below 1 will be the depth of landslide initiation (see Baum et al. 2010, JGR, doi:10.1029/2009JF001321).

In the unsaturated zone, a simple approximation for Bishop's (1959) effective stress parameter (χ) is used in computing the factor of safety. To compute the factor of safety above the water table, the matric suction in the FS computation equation is multiplied by χ. More details can be found in Baum et al. 2010, JGR.

7. *"The integration between the two models is not very clear to me. TRIGRS model has its own infiltration module which is based on an analytical solution of the Richards equation for vertical infiltration. As input, it requires rainfall intensity; based on the hydraulic properties, which vary in space, it computes the infiltration rate and thus the pore-pressure (or soil moisture), which are used to compute the FS. My question is, how this framework interfaces with CREST model? My impression is that the two models are simply used in 'cascade' and therefore they are run separately, to evaluate first the runoff, and then the FS, which use a different infiltration scheme. This is not a really 'coupled model' , as compared to others existing (same references as before, i.e., Burton and Bathurst, 1998, Claessens et al. 2007, Simoni et al., 2008, Arnone et al., 2011, Lepore et al., 2013, Tao and Barros, 2014). The 'initial condition' (P5L9) are updated at each time? These means that, in TRIGS, each time step is 'independent' from the previous. Honestly, I don't see the efficiency of such a system when many other models exists that do the same in a continuous way. Actually, I would directly substitute the TRIGRS infiltration model within CREST an then implement the FS equation as a function of the moisture and water table. (they are both written in fortran language); it is more complex but more efficient and functional."*
Response:

We coupled the CREST model with TRIGRS model through a one-way coupling approach. The CREST model provides all hydrologic storages and fluxes, including interception by vegetation, infiltration, runoff generation, water routing, and re-infiltration of excess surface runoff from upstream cells to downstream cells, and provides the initial conditions, e.g. soil wetness and depth of water table. Therefore, the CREST model provides the infiltration for the TRIGRS model. The initial condition of the TRIGRS model is not necessarily updated at each time step. Instead, the coupled model can automatically determine the beginning of each storm. During the course of the storm, all of time steps share the same initial condition.

8. *"Are all the input data listed in fig.1 fed to both the models?"*
Response:
No. We will revise the figure to show the accurate data flow in the revised manuscript.

9. *"Working spatial resolution is 90m (P7L18). How this size is compared to the landslide average size? Since you build up a confusion matrix, you need to convert the inventory map into raster structure. Some studies (e.g. Claessens et al., 2005 and Tarolli and Tarboton, 2006) have demonstrated the model performances also depend on the comparison of the landslide size and resolution cell (the impact on model results is mainly caused by the effects of landform parameters, i.e. slope, aspect, curvature). I believe that a description of landslide types and characteristics (size, depths) should be given in Section 2.2.1. Also, It should be reminded somewhere that such models fit well for shallow landslide."*
Response:
The reviewer is right that model performance also depends on the landslide size and the resolution of grid cells. We don't have the size information for all landslides. When we compared the model simulations with the observations, we think that the model correctly captures the landslide event if one or more 90-m grid cells within a radius of 250 m (3 grid cells) around the center of the recorded landslide have FS<1. The radius is roughly based on the average landslide size. We can provide more information on

the landslide sizes and types.

SPECIFICS CONCERNS:

10. *"P6L30. This sentence is misleading. It's true that the 'minimum forcing data' are precipitation and evapotraspiration, but it requires various parameters and input maps. Note that, other models, needs only the precipitation forcing."*

Response:

We respectively argue that the parameters and input maps are static input data not the forcing data. The "minimum forcing data" for this model indeed just include the precipitation and evapotranspiration. In addition, we don't comment the other models here.

11. *"P7L34. It is not clear to me whether the soil properties are spatialized in CREST. How the soil texture classes are involved in the model?"*

Response:

As we mentioned in Item 5 of Responses to Reviewer 2, the soil properties are distributed and derived from the SSURGO dataset (please refer to Section 2.2.3 and Fig. 2c). We built a look-up table to assign specific parameter values to each soil class (Table 1) based on valued provide in the literature. We then used the soil class of each grid cell to determine the parameter values of the same grid cell.

12. *"P8L14. USDA textural soil classification does not provide the mechanical properties (i.e. friction angle and cohesion). How did you estimated these? FS is obviously extremely sensitive to these parameters?"*

Response:

The friction angle and cohesion values of the USDA textural soil classes were derived as the means of the ranges determined from Das (2008), Hough (1969), Terzaghi et al. (1996) and (Dysli, 2000) (please refer to Table 1).

13. *"P9L27 – Are you able to explain the shift between modeled and observed peak*

discharges?"

Response:

There are a couple of possible reasons causing this shift. It could be due to the uncertainty in the routing scheme of this model. It could be caused by the uncertainty in the spatial distribution of rainfall data. We can add discussion on the possible causes in the revised manuscript.

14. *"P9L29 – Which is the depth of failure? Please specify. This is crucial."*

Response:

Depth of failure calculated by the CRESTRIGRS and TRIGRS models vary spatially and temporally.

15. *"P9L30 – In both Fig.5a and 5b, the second basin from the left (Tuckasegee River basin?) is the one in which landslide are overpredicted. I guess because it's the basin with most the steepest areas. Moreover, I would like to see the corresponding pore-pressure map (TRIGRS and iCRESTRIGRS)"*

Response:

We can provide the additional information in the revised manuscript.

16. *"P9L35 – radius 500 m means 78.5 ha that means 96 computation grid cells. This means that 'your model success' when 1 over 96 cells success. Again, in such analyses the landslide size should be taken into account."*

Response:

There is one mistake here. We mean a radius of 250 m (a perimeter of 500m). We will provide more information on the landslide size and further consider its impact in the revised manuscript.

17. *"P10L15 – Please, report the corresponding AUC values in the figure."*
Response:
We can add the AUC values in the figure in the revised manuscript.

18. *"P12L2 – you could also work on FS equation and mechanical properties (a better soil characterization?). Also, as said before, model performances are very sensitive to the landslide size and characteristics, which here are not taken into account in no way."*
Response:
We agree that these are good points to be mentioned in the discussion section.

19. *"MINOR P7L30 – it should be Fig.2a. P7L33 – please specify Fig.2c (map of soil) and Fig.2d (land cover map)"*
Response:
Thanks for pointing this out. We will correct it and specify Figs. 2c,d in the revised manuscript.

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