Specific comment:

#1

It is stated that the STARWARS model considers unsaturated transient flow in vertical direction due to gravitation (page 11047, line 18), assuming freely drainable water (page 11045, lines14-15). This implies that capillary forces are neglected in the calculation, and soil saturation cannot go below field capacity. If that is the case, the fact should be added to the description of the model, together with a short description which state variables and governing flow equations are used in the calculations, and how retention is handled (e.g., in Fig. 3(b) a "soil water retention curve" shape factor is displayed).

Please, see the answer for the general comment.

The hydrological components of STARWARS model describes the transient saturated and unsaturated flow as a function of gravitational potential only, neglecting the matrix potential for the flow in the unsaturated zone. As a consequence, percolation is limited to gravitational vertical flow only. Of course, lateral exchange between fissures and matrix is taking place under certain conditions as described in the general comments.

The soil moisture can fall below field capacity, but when it happens, the relative unsaturated hydraulic conductivity (Equation 2) quickly becomes very small.

#2

It appears that in the "connected fissures" scenario, the toe of the hillslope is always saturated (Fig. 5) due to groundwater accumulation from uphill. The fissures are also discussed to act as lateral drains, resulting not in an accumulation but merely faster flow of water. The latter I would also have expected for the "connected fissures" scenario if the fissures extend over the model boundary. What kind of boundary condition was specified for the sides and the hillslope toe?

Connected fissures act as a natural lateral drainage network that allow for faster lateral flow of water. This is what we observe in the results of "connected fissure" scenario: the majority of the infiltrated water is accumulated in the lower part of the landslide while the upper part of the landslide is relatively dry.
However, the results of the 'connected fissures' scenario are also clearly affected by pre-defined bedrock topography (no-flow boundary) and converging water flow paths. The outflow from the landslide area is only possible in form of surface runoff at the toe of the landslide. Therefore, faster drainage through the connected fissure network propagates water relatively rapidly downward and downslope with converging flow paths resulting in an accumulation of water in the lower part of the landslide. The saturation of matrix is then the result of fissure matrix exchange ($\Gamma_{Unsat,\ FM}$,).

We will improve our description of the bedrock boundary condition of the modelled landslide with the above clarification.

 # 3

Is it correct that the number and aperture of fissures are only used to determine the mean distance for calculation of the gradient? Would the aperture not also be useful for assessing the hydraulic conductivity of open fractures?

Please, see the general comment reply.

In the model we have assumed that fissures are filled with reworked material. Therefore they retain their porosity and soil moisture. We adopt the same equations to describe the unsaturated hydraulic conductivity of the fissure network (please refer to Equations 1 and 2 above). Alternatively, and not explored here, the model also allows fissures to be represented as clean conduits that only transport and hold water when fully saturated. We welcome the suggestion of the reviewer to base the saturated hydraulic conductivity of the fissure network on the basis of the aperture but at the same time realize that this would complicate the representation of fissures holding reworked material.

4

It is stated that the infiltration capacity of the fissures is potentially unlimited (page 11048, lines 1-2). Would not the storage capacity or the conductivity of the fissure filling mark an upper limit to infiltration?

We agree with the Reviewer that storage capacity in the fissures is limited by their volume and porosity. Saying that infiltration of the fissure is potentially unlimited we wanted to stress what the model represents and how it is implemented: the infiltration to the fissures is not limited a priori in order to allow for sufficient flow of water through them towards the matrix. Only when after infiltration and lateral exchange the storage in the fissures exceeds their capacity it is returned to the surface.

 # 5

What impact has the filling of the fissure? Apparently, there is a filling considered for all fissures; otherwise the hydraulic conductivity of fissures with apertures between 5 and 20 cm would be much higher.

Please, see the reply to the general comments.

#6

What is Ffis;max (page 11051, line 24)? Is the fissure fraction varying over the model run, or why is an initial fissure fraction to be chosen for the "dynamic" scenario (page 11052, line 2)?

For all scenarios where fissures were implemented (scenarios 2, 3 and 4) equal fissures distribution is assumed over whole landslide and an average fissure fraction was set to be equal 0.30, 0.20 and 0.05 for each of the soil layer respectively. There is no such a term as $F_{fis,\ max}$.

The correct sentence (page 11051, line 24) is "An average fissure fraction was set to be equal 0.30, 0.20 and 0.05 for each of the soil layers respectively". The sentence from (page 11052, line 2) "For scenario 4 (dynamic connectivity scenario) the initial F_{fis} is equal $F_{fis,max}$" will be deleted.

#7

How is the vertical connectivity between the different soil layers handled in the model? From Fig. 2 it appears as if there are fissures that extend from top to bottom, while others terminate in the first layer.

Please, see the answer for the general comment.

 # 8

Page 11049, line 5-8: Eq. (4): As fissures and matrix may maintain different water levels, the calculation of resulting pore pressure for one cell needs more explanation. The calculation of the weight of fissure and matrix fraction should also be explained; were these based on moist, saturated and buoyant bulk densities as described in Van Beek [2002]? Perhaps the values used can be given as a table or mentioned in the text.

Please, see the answer for the general comment.

The total head in each cell is composed of the gravitational potential, the elevation of the bottom of the soil column, and the average of the water level in the fissure network and the matrix, weighed by the respective surface areas.
The weights of matrix and fissure fraction for the stability assessment are calculated separately based on soil moisture content, water level height and buoyant bulk densities (see also van Beek, 2002).

 # 9

Does the outflow include overland flow? It would be interesting to know if there was more overland flow in the scenarios without fissures compared to the scenarios with fissures.

The outflow is basically overland flow that occurs at the toe of the landslide. See also our answer to #2.
Will we elaborate this in the revised version and show the differences in the appearance of overland flow across the landslide area for the scenarios with and without introduced fissures.

10

Are the gaps in the water balance (calculated from Table 1 as: initial storage + rain – final storage – outflow - evaporation), which are also a little different between the scenarios, due to numerical accuracy or some modelled processes that are not included in the table?

The gaps in the water balance (Table 1) are very small and in range of 8-11m^3 and they are due to numerical accuracy only.

11

The amount of evaporation (two-third of total rainfall) appears to be rather high for a mountainous area at a first glance. As vegetation is not mentioned in the manuscript, this would be soil evaporation only, or were there any open water surfaces in the model? Based on the described geometry of the hillslope, the rainfall would be between 990 and 1200 mm, the evaporation thus around 660 – 800 mm. It would be helpful to have rainfall input and evaporation in mm, and information about the climate that was considered.

In order to focus on the effect of fissures on the landslide hydrology, the model has no vegetation cover and no open water sources. Calculated evaporation is soil evaporation only. The meteorological input data are taken from the meteo-station located at 1725 m.a.s.l located in the Barcelonnette Basin (French Alps). The Barcelonnette basin has a dry and mountainous Mediterranean climate (Maquaire et al., 2003).
However, high evaporation volume can be explained by the relatively high soil moisture content of the landslide.

 # 12 Discussions

The major part of the "Results and Discussion" section is presenting results; the discussion part is rather narrow. It would be helpful for the reader if the authors could come up with a critical discussion that evaluates the results obtained in the light of the underlying assumptions of the model. Furthermore, they should compare their approach to the "simplistic" representation of fissure flow already implemented in STARWARS, and discuss in which aspects their treatment of fissure flow within a zone of higher conductivity is beneficial or more realistic. It would be excellent if they would also discuss their findings in comparison to the more general literature on preferential flow modelling in hillslope hydrology and modelling using dual-permeability approaches.

We restructured our paper in line with the reviewer's suggestion.

 # 13-1 References

A comprehensive discussion on "double-porosity" vs. "dual-permeability" approaches is, of course, beyond the scope of the paper. But as it this issue is raised in the introduction (page 11041, lines 16-22), and it is not so clear from the literature, how the terms are exactly defined, appropriate citations should be inserted to

clearly point out which definitions are referred to [e.g., Gerke, 2006; Jarvis, 2007; Simunek et al., 2003]. The theoretical considerations of Barenblatt et al. are not necessarily limited to flow in fissures, they also derive the equations for both fissures and porous blocks [Barenblatt et al., 1960]. I think the important point to make is that two overlapping continua are considered, which requires the formulation of an exchange term. As an additional suggestion, consider skipping the entire part from page 11041, line 9: "This creates : : :", to line 22: ": : : both domains (matrix and fissures).", and move it into an introductory section on "Preferential flow modelling" (see comments on section 1.3 below).

We wanted to make it clear, in the introduction, what we mean by "dual – permeability" approach and how we implement it. The Reviewer made a valid point that we should make it clear that the two continua (matrix and fissures) are overlapping and that there is flow exchange between them. The reviewer is right that cited article (Barenblatt et al., 1960) refers to basic "double – porosity" theory and that there are more appropriate citation that can help to clarify used definitions. The reviewer's reference suggestions will be included.

 # 13-2 References

Page 11049, line 9: The cited reference (EGU abstract) seems not appropriate as a general reference for the infinite slope model. Besides the original work [Skempton and DeLory, 1957], many better references from recent applications can be found in the published literature.

The reviewer is right the EGU abstract reference should be replaced by more appropriate references to this work and look at the reference suggested by the reviewer.

 # 14 Structures

We will take into account the suggestion of the Reviewer and improve the structure of the manuscript in order to make it more clear and easy for the reader. (see also #12)

 # 15 General writing style

The revised manuscript will be proof read by a native English speaker.

***# 16* Technical comments/questions**

We will carefully address all technical questions of the Reviewer.

Let us answer here to the most important, in our opinion, technical comments of the Reviewer concerning presented equation 1-3.

The Reviewer is right that presented equations 1-3 are not harmonized with the description of the fissure presented in the paper.

The equations in the form presented in the paper were used in the older version of our code where the F_{fis} was defined in different way. By carelessness, it remains unchanged in one place in the new version of the code - when calculating the number of fissure. This then influenced the calculation of gradients for fissure – matrix interaction within the soil column and transitivity of groundwater flux between the cells. In all other calculation (e.g: storage capacity, partitioning of the precipitation, percolation, etc) the term F_{fis} was correctly applied.

The correct equation are:

Equation 1: (please not that we have fissure in both directions (x and y) within one cell)

$$N_{fis,x} = N_{fis,y} = (1 - \sqrt{1 - F_{fis}})\frac{\Delta x}{a_{fis}}$$

where $N_{fis,x}$ is the number of fissure in x directions.

Equation 2:

$$L_{mat} = \sqrt{1 - F_{fis}}\frac{\Delta x}{N_{fis,x} + 1}$$

And Equation 3

$$\overline{L_{mat-fis}} = \frac{1}{2}(L_{mat} + a_{fis})$$

We performed additional model runs with corrected equations. The influence of our mistake has relatively limited impact on overall model outcomes. The absolute values are changed but the trends and overall conclusions remain the same. We will correct the calculation result and adapt the description.