1 Reviewer 2

The manuscript mainly presents a comprehensive, multi-objective model validation study of an extension of the complex, physics-based Alpine 3D model. The model's performance to represent streamflow, snow depth, soil moisture and soil temperature/freezing is analyzed for 3 years in a Swiss mountain catchment and its surrounding. This evaluation is a framed by the context of the importance of soil moisture as a pre-disposition for floods. This framing – for my taste – is a bit wanted, and the title is somehow misleading. However, the quality of the model validation study is of a high standard and certainly of high importance. Especially the parallel evaluation of snow, soil and streamflow representation is cool. Although the overall impression of the article is very good, I do have some moderate remarks. The manuscript is certainly within the scope of HESS, it my knowledge of original content and can be a valuable article after my concerns are addressed.
We thank the reviewer for the constructive comments and positive remarks about our study. We will take them into consideration when revising the manuscript. As we will discuss below, we agree that the title may be considered confusing and we propose a modification of the title. However, we would like to keep the framing of the study of soil moisture as a predisposition for flooding. This notion is introduced in the introduction section, with, in our opinion, appropriate citations. Furthermore, we do find evidence that our model framework is able to reproduce the relationship between soil saturation at the onset of large rainfall or snowmelt events and the discharge behaviour in the Dischma catchment.

1.1 General comments:

- As mentioned before, I find the title a bit misleading, as it reads as the influence of snow processes on soil moisture and streamflow is analyzed. Instead, the focus is clearly on the model validation to reproduce the linkage between snow, soil and streamflow. I would recommend a rephrasing of the title.
  We agree that the title is somewhat misleading, so we suggest to add the word "Simulating" in the beginning of the title, so we propose now: "Simulating the influence of snow surface processes on soil moisture dynamics and streamflow generation in alpine catchments".

- Alike reviewer 1 (I haven't read his comments until I finished my review), I do not understand the usage of the soil water fluxes for streamflow generation. As reviewer 1 wrote to the point, why should one just take one of the fluxes (-2cm indicating surface runoff, -30 cm indicating interflow, -60 cm indicating baseflow). I also had a look in the cited publication, yet I find the entire concept very unusual and irritating. Because of this (I guess), the interpretation of the influence of soil moisture (Page 10, lines 14 ff) on streamflow is a bit simple. E.g. "neglecting the soil layers almost completely, by routing the 2 cm flux to the runoff model, is reducing the model efficiency". – This is logical as you neglect interflow and baseflow in summer months and interflow widely considered to be the dominant process in alpine catchments. Hence, the concept of this streamflow generation needs to be clarified and its strong limitation in terms of dynamic runoff generation should be discussed. Furthermore, effects of this simplified approach on the interpretation should be discussed.
  This comment is similar to the general comment of Reviewer 2 and for simplicity, we give the same response here: As both reviewers raise similar concerns, it is clear that we need to pay particular attention to describe the coupling between the Alpine3D and streamflow model in more detail and with more clarity when revising the manuscript. The streamflow model is a spatially explicit hydrologic response model at sub-catchment scale. Each sub-catchment is identified based on geomorphological analysis of the watershed. The model simulates the water storage dynamics in two soil compartments, namely an upper and lower one, of each sub-catchment using a travel time distribution approach. Outflow from the

upper compartment represents interflow, while that from the lower component represents baseflow. We would like to point out that our model is reproducing baseflow, albeit too low at the end of the winter. If one would be particularly interested in correctly representing baseflow, a recalibration of the streamflow model with a focus on the statistics for the winter period would allow to have a more accurate representation of baseflow. But we do not agree with both reviewers that the baseflow is absent. Furthermore, the streamflow model needs a surface scheme, to provide the influx into the system. For this, we use the Alpine3D model. However, it is somehow arbitrary where to draw the boundary between the surface scheme and the streamflow model. For this, we tested 3 scenarios: a soil flux at 2, 30 and 60 cm depth. So we do not use the fluxes combined, but we used the three fluxes as three different scenarios. Although it would be similar as running 3 separate simulations, with either 2, 30 or 60 cm of soil, this approach would have the disadvantage that specifying the lower boundary condition for the Alpine3D model becomes tricky. For example, at 3 m depth, one can assign a constant geothermal heat flux and a water table and this would hardly influence the snowpack dynamics. On the other hand, at 2 cm below the surface, a constant geothermal heat flux would provide a too strong heating of the snowpack, as the soil buffer is not represented. Therefore, we choose the approach of doing a single simulation, and extracting soil water fluxes at three depths in order to test how to achieve an optimal coupling between the surface scheme Alpine3D and the streamflow model. This is illustrated in Fig. 3 in Comola et al. (2015). We will rewrite the Methods section discussing the model coupling thoroughly, in order to better explain our approach.

Please find our response to other issues raised by the reviewer below.

- The description of the different soil layers is unclear: You introduced increasing soil layer magnitudes (from 2cm to 40 cm) up to a soils depth of 300 cm in the model. However, you take water fluxes from 2, 30 and 60 cm. Moreover you compare these to soil moisture measured at 10, 30, 50, 80, and 120 cm depth. And finally, you take the average of the upper 40 cm (page 10, line 25) as the soil moisture state within the catchment. As these number do not match at a first glance, a clarification is advisable. Maybe a sketch would help.
  We think this is a very good suggestion and we will add a descriptive illustration in the revised manuscript. Please find the new figure below as Fig. 2. Note that the layer spacing was erroneously reported as ranging from 2 cm to 40 cm, where it should have been from 2 cm to 25 cm. This will be corrected in the revised manuscript.

- In the manuscript, the SNOWPACK and Alpine3D are described as two separate models (e.g. in the model description and partly in the introduction). But as written in the Conclusion, SNOWPACK is a module of Alpine3D and as I understand an integrated part of Alpine3D. This should be clarified throughout the text, especially in the beginning (Aims section)
  The reviewer is correct, the SNOWPACK model serves as the snow and soil module for the distributed Alpine3D model. When revising the manuscript, we will pay attention that this is correctly formulated throughout the manuscript.

- As the Dischma catchment is an alpine catchment I assume that skeleton fraction is a major issue, both for measuring the "correct" soil moisture as well as for simulating the soil moist dynamics. Please, clarify how and if the skeleton fraction was considered in the pedo-transfer-function and how it was considered in the selection of the measuring location (and how representative the selection in terms of skeleton fraction is). Moreover, please discuss if the found biases in the soil moisture and soil temperature simulations can be explained by skeleton fraction. Finally (I hope I did not miss it), how do the soil types of all measuring stations represent the soil types in the Dischma catchment.

- We agree that the skeleton fraction in alpine catchment is an important factor to take into account. For example, the study by Rössler and Löffler (2010) demonstrates in a sensitivity study that changing the skeleton fraction has an impact on streamflow and soil moisture simulations. They particularly describe the effect of an increase in porosity, and associated changes in hydraulic parameters. However, the study by Rössler and Löffler (2010) also points out that spatial variability of the skeleton fraction is largely unknown. In the current version of the SNOWPACK model, which provides the surface scheme for the Alpine3D model, the skeleton fraction is not taken into account, as the SNOWPACK uses prescribed soil types. We actually found that for some sites we get an adequate soil moisture simulation without considering the skeleton fraction, whereas for other sites the simulations are showing less agreement with measurements. But these contrasting results indicate that with the current information, only ad-hoc modifications of the skeleton fraction are possible, as we cannot separate well enough between the soil moisture sites based on available information (land use and soil permeability). For further development of the SNOWPACK and Alpine3D model, this certainly is an area of attention. As discussed by Brakensiek and Rawls (1994), neglecting rock fragments in soil may overestimate hydraulic conductivity. Thus, the bias in soil moisture we found can be explained by an overestimation of hydraulic conductivity in the model, which would bring down liquid water faster. As wetter soils need more energy to freeze, the underestimation of soil moisture in the top layer may also result from this bias. The above mentioned points will be discussed in the revised manuscript.

- The representativeness of the soil moisture measurement sites is given by that the Grossalp and Pischa stations were located in the "alpine meadow" class, which is 21.1% of the land use coverage (see Table 4 in the original manuscript). The Uf den Chaiseren, Dorfji and Stillberg stations are located in the "mixed forest", "bush" and "bare soil" class, respectively, which is found in 12.9%, 7.3% and 6.0% of the Dischma catchment, respectively. The SLF2 and Golf Course stations would officially fall into the category of "settlement", but one would describe the area as "alpine meadow". We will add this information to the manuscript.

- The description of the meteorological data is quite long and very detailed. I would suggest to just briefly describe the table 2.
  When revising the manuscript, we will put effort in shortening this section.

1.2 Specific comments:

- Page 1, line 11, and 12: Please clarify the word "including", as you do not combine the three layers.
  As our description of the coupling to the streamflow model was clearly confusing in the original manuscript, we plan to revise this part of the abstract as: "Streamflow simulations performed with a spatially-explicit hydrological model using a travel time distribution approach coupled to Alpine3D provided a closer agreement with observed streamflow at the outlet of the Dischma catchment when driving the streamflow model with soil water fluxes at 30 cm depth. Performance decreased when using the 2 cm soil water flux, thereby mostly ignoring soil processes. This demonstrates that the role of soil moisture is important to take into account when understanding the relationship between both snowpack runoff and rainfall and catchment discharge in high alpine terrain. However, using the soil water flux at 60 cm depth to drive the streamflow model also decreased its performance, indicating that an optimal soil depth to include in the simulations exists."

- Page 2, line 29: "small scale surface processes". Please, specify the scale. *This refers to 10-100m scale, on which wind drifts form, and for which local topography strongly influences the energy balance via the slope aspect, angle and local shading. We will amend the manuscript at this point.*

- Page 3 ,line 5: Please, specify the catchment size.
We will report that the catchment size that is represented by the gauging station is 43.3 km^2*, as reported by the Swiss Federal Office of the Environment (Federal Office for the Environment (FOEN), 2017).*

- Page 3, line 13 ff & Figure 2: How did you separated snow from rain here.
In the manuscript, we did all separations of precipitation in rain and snowfall based on an air temperature threshold of 1.2 °C for half-hourly measurements. We will specify this in the manuscript where necessary.

- Page 3, and Table 1: A comparison to the long term norm period would be interesting
We agree with this suggestion. We now add the 10-year averages to the table, which corresponds to the period for which the streamflow simulations were performed. Note that we came across an inconsistency. The data shown was not based on the same meteorological dataset as used for the Alpine3D simulations. Particularly an undercatch correction was not taken into account when constructing Table 1 and Fig. 2 in . This will be corrected.

- Page 4 and Figure 1: "Golfplatz" in the Figure versus "Golf course" in the text. "SLF2" site is named "SLF" in the map. How were the boarders of the Dischma catchment defined (topography based from the model?). I would recommend some light, partly transparent background color for the names, to improve readability. I have to admit, I am not a fan of topographic maps as background, especially if the legend is missing. Any chance to replace it with a more generalized map?
Thank you for pointing out these inconsistencies in labelling; they have been resolved. Furthermore, we added a white, slightly transparent box behind the labels. Unfortunately, an illustrative map that is not a topographic map is not available. However, in order to increase readability, we switched to a less detailed map. See the new map below in Fig. 1 in this document. The Dischma catchment border is provided by the Swiss Federal Office of the Environment (FOEN). We plan to amend the manuscript at this point, and explain that model grid points with the center point inside the (sub-)catchment border polygon are considered being part of the (sub-)catchment.

- Page 6, line 5 ff: Are the interpolations done for each time step?
Yes, as with the other parameters, the interpolation for precipitation is also done at every Alpine3D time step of 1 hour with the help of the MeteoIO library. This will be made clear in the revised manuscript.

- Page 6, line 14: I do not think that "initialization" is the correct term. Is it not parameterization?
This sentence will be revised based on a suggestion by Reviewer 1. We now term it "soil properties".

- Page 7, line 21. "sub-catchments" – so is this approach some kind of HRU approach?
Although it sounds similar to a HRU approach, a major difference is that the surface processes at every grid point inside a sub-catchment are explicitly resolved by the Alpine3D model, for example by taking into account variations in altitude, incoming solar radiation as a function of aspect and slope angle. It is only determined here which grid cell is draining to which sub-catchment and the residence time within the sub-catchment, based on terrain analysis only (and not soil properties, land use, etc.). We will revise the description of the coupling of Alpine3D to the streamflow model, hopefully adequately avoiding confusion with the HRU approach.

- Page 7, line 33: Again, the soil moisture is calculated for the first 40 cm. Can you clarify its relation to the 30 cm stated before and after.
  We will add Fig. 2 to the revised manuscript (see below), indicating the soil layering in the simulations, as well as the soil moisture measurement depths. The choice for 40 cm is motivated by the fact that the upper soil moisture measurements taken at 10 cm and 30 cm will more or less represent the upper 40 cm of the soil. The dielectric sensor 10HS for soil moisture used in this study measures approximately a volume of 1.32 l, as specified by the manufacturer. We will amend the manuscript at this point.

- The definition of a rainfall event is a bit broad. Do you used mowing 12 h sum? What if a rainfall event is ended by falling below the 3mm thresholds criteria, but followed by a >10mm event again. Why do you choose a time window of 12 mm. Did you do any concentration time analysis?
  Yes, a 12 h moving sum was used, we will specify this in the manuscript. In the case mentioned by the reviewer (rainfall falling below 3mm, but followed by a >10mm event), two events will be taken into the analysis. The time window of 12 hours was arbitrarily chosen, motivated by the fact that we aimed to select rather intense events. In total 168 rainfall events and 301 snowpack runoff events were selected (i.e, on average 16.8 and 30.1 events per year, respectively). The average duration of an event was 21.8 hrs (rainfall) and 20.9 hrs (snowpack runoff). On average, there are 6.8 days in between rainfall events, excluding the winter season. There are 1.3 days in between snowpack runoff events, excluding the summer season. We will add this information to the revised manuscript.

- Page 8, line 14, and Figure 3. A comment on the vegetation growth (?) during summer would be nice.
  Thank you for this suggestion, we will discuss this in the revised manuscript.

- Page 9, line 27 ff. In my opinion, the r2 is not the appropriate statistical measure here, as it does not consider any systematic offsets/biases. The application of the RMSE or similar would be more fair. Furthermore, can you set your results in light of other models of soil moistures in alpine terrains? Also to show that your results are pretty good.
  We are actually interested in to what extend the simulations are able to reproduce the variability in soil moisture. As the comparison of the two measured soil moisture sensors at a single station and single depth shows, often a bias is already present between both measurements. This suggests a bias in the sensors which could be resolved by recalibration of the sensors. We therefore do not necessarily want to express the existing bias in the statistical measure and we prefer to keep the results for r^2. Note that the existence of a bias can be clearly identified by readers by the soil moisture figures we show. We will clearly discuss the existence of a bias in the revised manuscript. Regarding the comment about citation of existing literature, the studies we are aware of that both simulate and measure soil moisture in alpine terrain are the studies by Gurtz et al. (2003); Rössler and Löffler (2010); Kumar et al. (2013); Pasolli et al. (2013); Brocca et al. (2013); Pellet et al. (2016). We will discuss our results in light with the results published in these studies.

- Page, line 10: "however, ..." Isn't this finding clear and logical as you only consider "deeper" water fluxes
  This is true, and we will rephrase this sentence.

- I am looking forward to the revised manuscript.
  Thank you.

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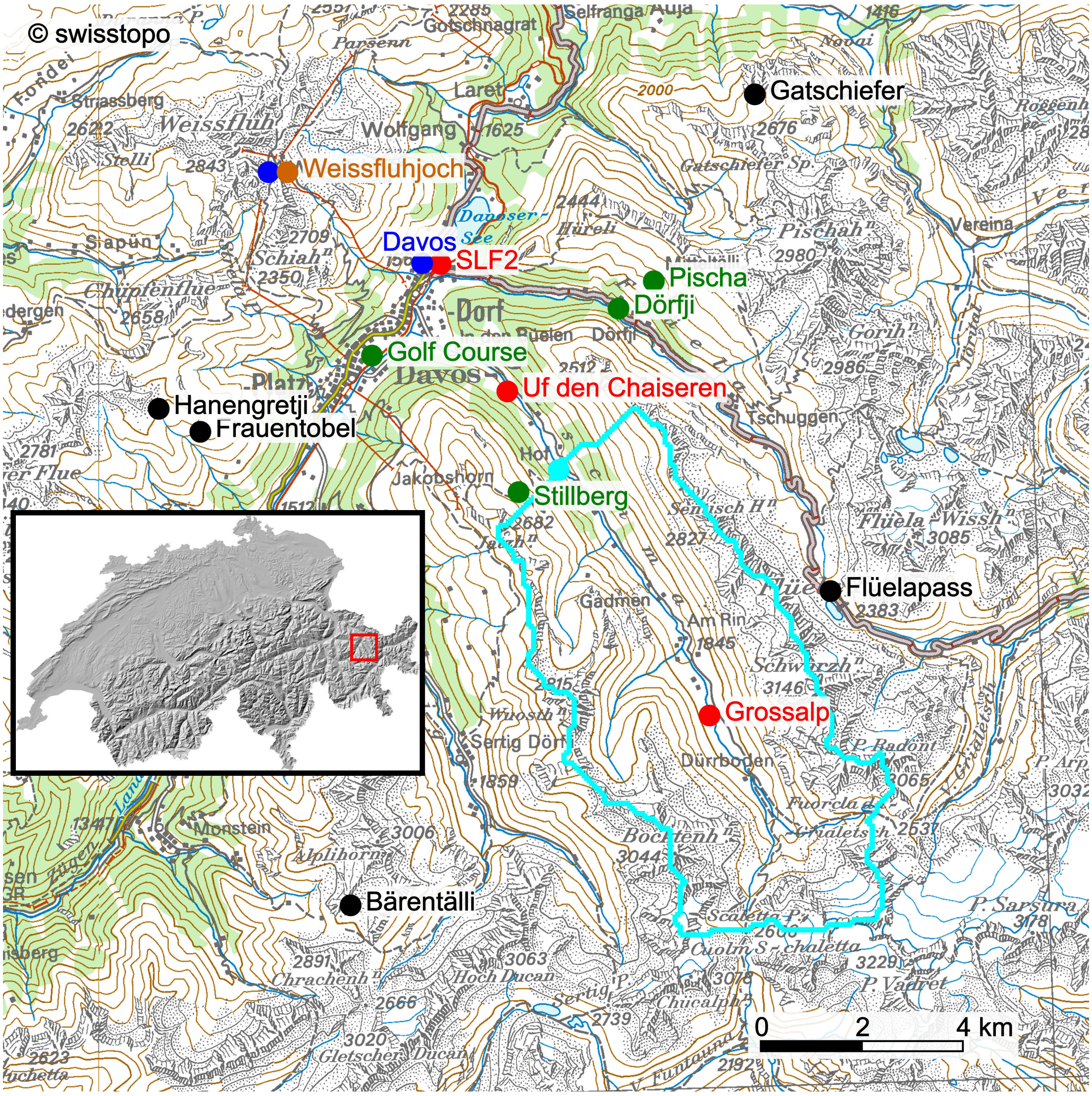

Figure 1: Topographical map of the simulated domain, showing the locations of the stations. IMIS stations are shown in black, IRKIS stations in red, SensorScope stations in green, SwissMetNet stations in blue and Weissfluhjoch in brown. The Dischma catchment and the gauging station measuring streamflow in the Dischmabach at the outlet of the Dischma catchment are shown in cyan. The inset shows the location of the simulation domain (red square) in Switzerland. Maps reproduced by permission of swisstopo (JA100118).

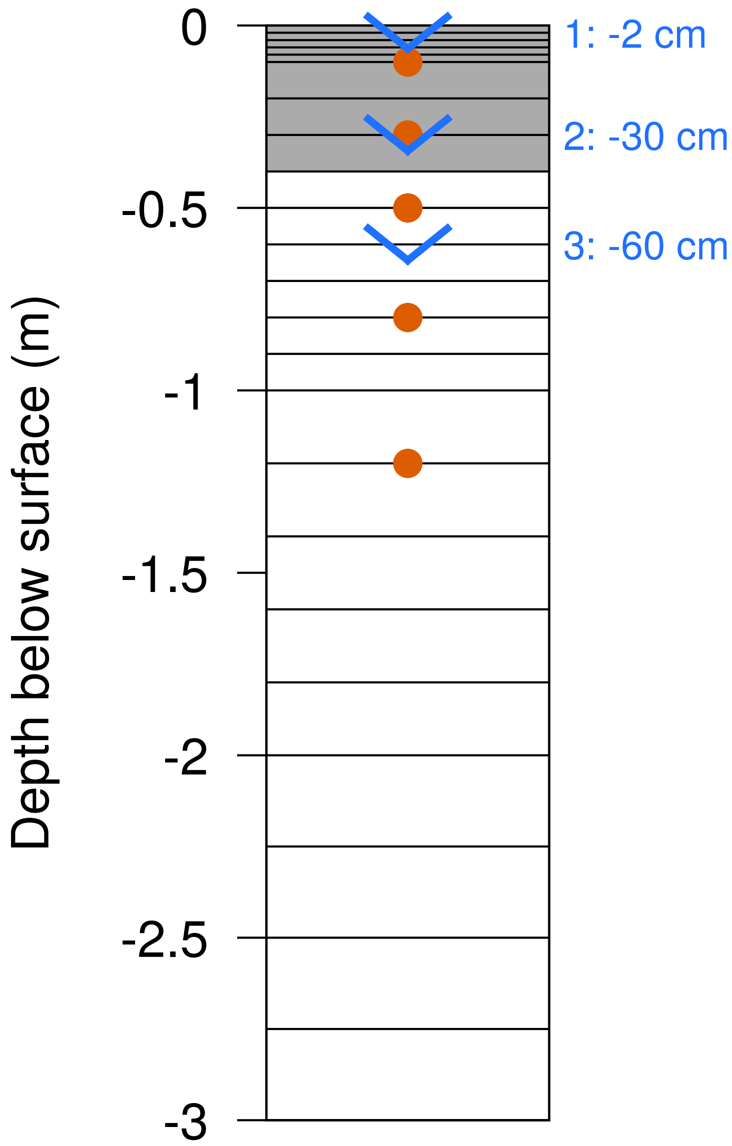

Figure 2: Soil layering as used in the Alpine3D model. The three water fluxes used to drive the streamflow model are shown in blue arrows. The soil moisture measurements are indicated by brown circles.