Response to report # 1

This manuscript describes the effect of different model variants on model performance and simulated flow components. They perform various model tests using the physically-based DHSVM model. Especially the evaluation of flow components is a novel aspect.
The authors of the manuscript thank the referee for his positive evaluation of the manuscript and for his comments, which helped improving the manuscript.

However, I am afraid that I have a list of rather major concerns as described in detail below. Major revisions, including new computations, are needed to bring this manuscript to its full potential.
Detailed responses to all components are given below (blue).

- *Flow component definition*

Defining and simulating flow components is not trivial and it is interesting that the authors here test different definitions. However, this discussion would be even more valuable if the authors could relate their definitions to those suggested by Weiler et al.(2018) (this reference is included, but not put in relation to the definitions used here).
The section 3.2.5 "Quantification of the flow components" has been modified in order to present the different types of contributions of the flow components as defined in Weiler et al. (2018) :

"Quantifying the relative contributions of ice melt, snow melt and rainfall in the river discharge at different time scales is a difficult task because hydrological models usually do not track the origin of water particles during transfer within the catchment (Weiler et al., 2018).
There are also different ways of defining the origins of the streamflow. Weiler et al. (2018) lists three types of contributions: 1) contributions from the source areas i.e. from each class of landcover , 2) contributions from the runoff generation (overland flow, subsurface flow, and groundwater flow), and 3) input contributions (icemelt, snowmelt, and rain).

In this study, two different definitions were used to estimate the hydrological contributions.
First, we estimate the input contributions to the total production of runoff (definition 1) according to the following equations […].

In order to evaluate the seasonal components of the outflow at the catchment's outlet, we also define the hydrological contributions as fractions of the outflow coming from the different contributive areas (definition 2) : […].

The definition 2 combines contributions from source areas (glacierized and non-glacierized areas) and contributions from runoff generation (direct runoff, englacial contribution, and soil contribution)."

Depending on the definition of flow components it can be required to track the different types of water through the model. For instance, glacier melt which is added to the groundwater (or 'soil', see below) might there mix with water coming from rain or snow melt. I am not fully sure, whether and, if yes, how this is done in DHSVM. Please clarify!
In DHSVM-GDM the amounts of icemelt, snowmelt and net rainfall are first estimated independently for each grid cell. Then, the three volumes are added up before estimating infiltration, runoff and losses by evapotranspiration. This means that the contributions corresponding to definition 2 are all a mix of icemelt, snowmelt and rainfall.
The following sentence was added to the section 3.2.5 "Quantification of the flow components" in order to clarify this point: "These contributions (definition2) are based on the simulated volume of water reaching the soil surface. This volume is a mix of icemelt, snowmelt and rainfall and can either infiltrate in the soil or produce runoff."

- *Model evaluation*

I am missing a comparison of daily observed and simulated flows using a measure like the NSE. Why are these results not shown?

NSE and KGE values were added to Figure 12. Furthermore, Table 3 with all calculated NSE and KGE values for the daily discharges for each model configuration was added to section 4.1.3 "Simulated Outflow and flow components".

	V0	V1	V2	V3
NSE	0.87	0.53	0.74	0.91
KGE	0.83	0.50	0.65	0.88

Table 3: NSE and KGE values calculated on the daily discharges on the period 2012-2015 for each model configuration.

Table 3 shows that configuration v0 leads to good simulated daily discharges with NSE and KGE values equal to 0.87 and 0.83. Although the implementation of the new parameterization of the snow albedo in configuration v1 improves the simulation of the SCA (Figure 8), it does not improve the simulation of the discharges since the values for NSE and KGE are reduced to 0.53 and 0.5. The implementation of the avalanche module in configuration v2 contributes to an improvement of the simulation of the daily discharges because the NSE and KGE values increase to 0.74 and 0.65. However, an improvement of the simulation with respect to the NSE and KGE values for the daily discharges is only reached with configuration v3 after the implementation of the new snow albedo parameterization, the avalanche module, and the reduction coefficient for the melt of debris covered glaciers leading to values of 0.91 and 0.88.

Given the uncertainties in observed snow cover and mass balances: are the differences in model performances really significant? Overall, I am missing a quantification of uncertainties (please see Pappenberger and Beven (2006)

In this study we do not have conducted a complete analysis of uncertainties of our simulations such that presented in Pappenberger and Beven (2006). The quantification of uncertainties is an analysis that would have required substantial work. Using a distributed model in such a task does demand very significant computational resources. Furthermore the existing DHSVM-GDM framework was not designed to support general uncertainty analysis.

We analysed the dependency in models factors (point 9.5) by using a multi-signal (snow, glacier and discharge) and a multiple evaluation criteria approach (NSE and KGE) to evaluate the quality of our results.

Our work could be considered as a contribution to the point 9.2 (Taking account of uncertainty in model choice), by giving a better documentation on the model development as proposed by Pappenberger and Beven (2006).

This study also analyses a large variety of sources of uncertainty by comparing results obtained with (i) different representations of the processes in the model (configurations v0, v1, v2, and v3), (ii) different parametrizations (melt coefficient for debris covered glaciers ranging from 0.3 to 0.5, soil depth under glaciers ranging between 1 and 5 m), (iii) different descriptions of the glacierized areas (Racoviteanu et al, 2013, GAMDAM and ICIMOD glacier inventories).

A second paper on the uncertainties associated to the precipitation forcing data (point 9.3) will be submitted soon (Mimeau et al., 2018). Overall, a large number of simulations were realized to analyze the uncertainties and the synthesis these simulations (presented in a thesis manuscript which will soon be published as well) shows that the main uncertainty is related to the precipitation forcing data.

- *Model parameterization*

I am not convinced about the choice of the parameter values. Can one really use standard values for the parameters for this application in a high-mountain environment?

The model DHSVM-GDM was developed to be used in high mountain environments and a lot of published results showed than these parameters were well adapted (Naz et al., 2014 ; Frans et al., 2015).

There is very little information about soil and vegetation properties in high-mountain environments. Since the vegetation in the study area is very limited and the soils are rather thin due to the steep topography, we selected standard values for the simulations. Moreover, data to validate subsurface and groundwater flows do not exist making it very difficult to adapt the parameter values to the study area. Obviously, the model parameters could have been calibrated based on the discharge measurements, but this method may have only compensated errors in other processes that are not well represented in the model (see below).

The authors also state: “As a results, soil depth outside glacierized areas ranges between 0.5 and 1 m. Under the glaciers, the soil depth was set to 2 m.” Why should we expect deeper soils under a glacier than elsewhere?!? This seems more like a trick to ensure a delayed response rather than a physically-based representation. As there is no description of groundwater, I assume that groundwater *is not represented explicitly. The unrealistic soil depths are probably needed to compensate for the missing groundwater.*

We agree with the referee that the 2 m soil depth under glaciers does not represent the real soil depth under glaciers. The selection of this value allowed a delay in the response for glacierized areas because in the glacier module icemelt is immediately transferred to the soil under the glaciers neglecting retention and storage of liquid water in the firn and ice..

The sentence in section 3.2.4 "Glaciers parametrization" referring to the soil depth under glaciers is modified to:

"In the original DHSVM-GDM version, glacier melt is instantaneously transferred to the soil, which is parameterized as bedrock under glaciers (Naz et al., 2014). This significantly underestimates the transfer time through glaciers. In this study we modified the soil parameterization for glacierized areas by increasing the soil depth to 2 m. This modification of the soil depth under glaciers compensates the absence of the representation of the retention and storage of liquid water in the firn and ice of the glaciers."

For the more sensitive parameters: how would changes in reasonable ranges affect results?

The soil parameterization does not impact the annual outflow and the annual contributions from glacierized and non-glacierized areas. However, it may impact the simulated seasonal discharges and the partitioning between direct and delayed contributions (soil water and englacial water contributions). We tested the sensitivity to the soil depth under glaciers (1, 2, and 5 m) with the configuration v3 (see supplementary information below). The increase of the soil depth leads to a slight delay of the outflow with very little impact on the NSE and KGE values. The soil depth under glaciers mainly impacts the estimation of the delayed contributions from glacierized area which ranges from 35 to 47 % of the total annual outflow when the soil depth varies between 1 and 5 m. A new section was added to the manuscript to present the sensitivity of the hydrological modelling to the soil depth under glaciers.

Please also address the devil's advocate question: the tested model variants might just compensate differently for other model errors and if the rest of the model would be 'more correct' results would be different.

Indeed, further modifications of the model will lead to different model results. It is also not excluded that different model errors are compensating each other. For example, our study demonstrated that the original model version leads to a correct simulation of the river discharges because the non-representation of the insulation effect for debris covered glaciers on the ice melt was compensated by the incorrect representation of the snow albedo decrease. Due to the complexity of the model and the resented processes, no guarantee can be given that similar compensating effects still occur in the model. Therefore, we extended the validation of the model output beyond the annual river discharge to discharges at different time scales, the snow cover area, and glacier mass balances in order to validate the simulations of the snow cover, glacier melt and discharges separately. The results demonstrate that the new version of the model performs well for all three signals. Moreover, the new parametrizations of the snow albedo and ice melt under debris were based on observed data (MODIS and in situ albedo measurements, and coefficient for ice melt under debris from Vincent et al. 2016) and do not result from a calibration in order to avoid compensation effects. Therefore, we are confident that the new implementation improved the quality of the represented processes and go well beyond a simple compensation of further modeling errors.

- *Avalanche routine*

I have several concerns with this routine. First of all, while I agree with the authors on the need to consider snow redistribution, the way it is described it largely ignores other ways of snow redistribution than avalanches (see Freudiger et al, 2017, for a recent review on snow redistribution in hydrological models).

Secondly, the routine and its parameterization seem rather ad hoc and not fully motivated. Can the parameters be motivated? What is the effect of varying them?

Furthermore, as far as I understand the text, only cardinal directions are considered. Isn't that an unrealistic assumption?

Also, from my understanding, I would assume that the avalanche routine would result in unrealistic line patterns of snow accumulation.

The glaciers located in the Pheriche catchment are known for being partially fed by avalanches, especially the West Changri Nup glacier whose mass balances are used in this study for validation (Sherpa et al, 2017). Ragettli et al, 2015 also showed the significant impact of avalanches on the river discharges in the Langtang region. In order to consider these processes in the model we implemented

a simplified avalanche module in the model and tested the sensitivity of the routine for the simulated water balance (snow cover, glacier mass balance and river discharge). The implementation of the avalanche routine led to an improvement on the simulated snow cover area and glacier mass balances compared to the versions with no representation of the snow redistribution and showed the importance of considering snow redistribution in glacio-hydrological models. Apparently, further potential improvements are possible: 1) considering 8 directions for the snow redistribution would indeed be more realistic and will necessitate the implementation of a more complex routine (in this study the avalanche routine is based on the overland flow routing algorithm of DHSVM-GDM which only considers 4 directions), 2) considering the redistribution of snow by wind. However, such modifications are beyond the scope of this study since they require more detailed data on the snow distribution based on in-situ observations for the study area. A sentence was added in the limitation section in order to present these potential model developments:
"The avalanche routine implemented in this study is simplified and only considers 4 directions for the snow redistribution. A perspective of this study is to improve the representation of the avalanches in DHSVM-GDM by considering 8 directions for the snow redistribution and considering other parameters such as the age of the snow cover, the snow density and the type of land-cover as it was proposed in Frey and Holzmann (2015)."

Finally, the avalanche routine is based on Wortmann et al. (2016). This, however, is a reference to a manuscript which had been in review (HESS-D) but then has never been published in HESS. I do not think we should refer to rejected manuscripts. This means a much better description (and motivation) of the routine is needed in this manuscript.
The avalanche module presented in Wortmann et al. (2016) (based on slope and snow height thresholds) seems realistic and the referees comments do not address this module, which is why we decided to cite this study even if it has not been published.

- *Structure and language*

Please do not mix results and discussion. This makes reading the manuscript much more difficult. I strongly suggest separating these two sections.
There are a number of typos and places were grammar or words could be improved
The structure of the manuscript was modified to separate the results and discussion sections.

Quantification of different flow components in a high-altitude glacierized catchment (Dudh Koshi, Nepalese Himalaya). Supplementary information

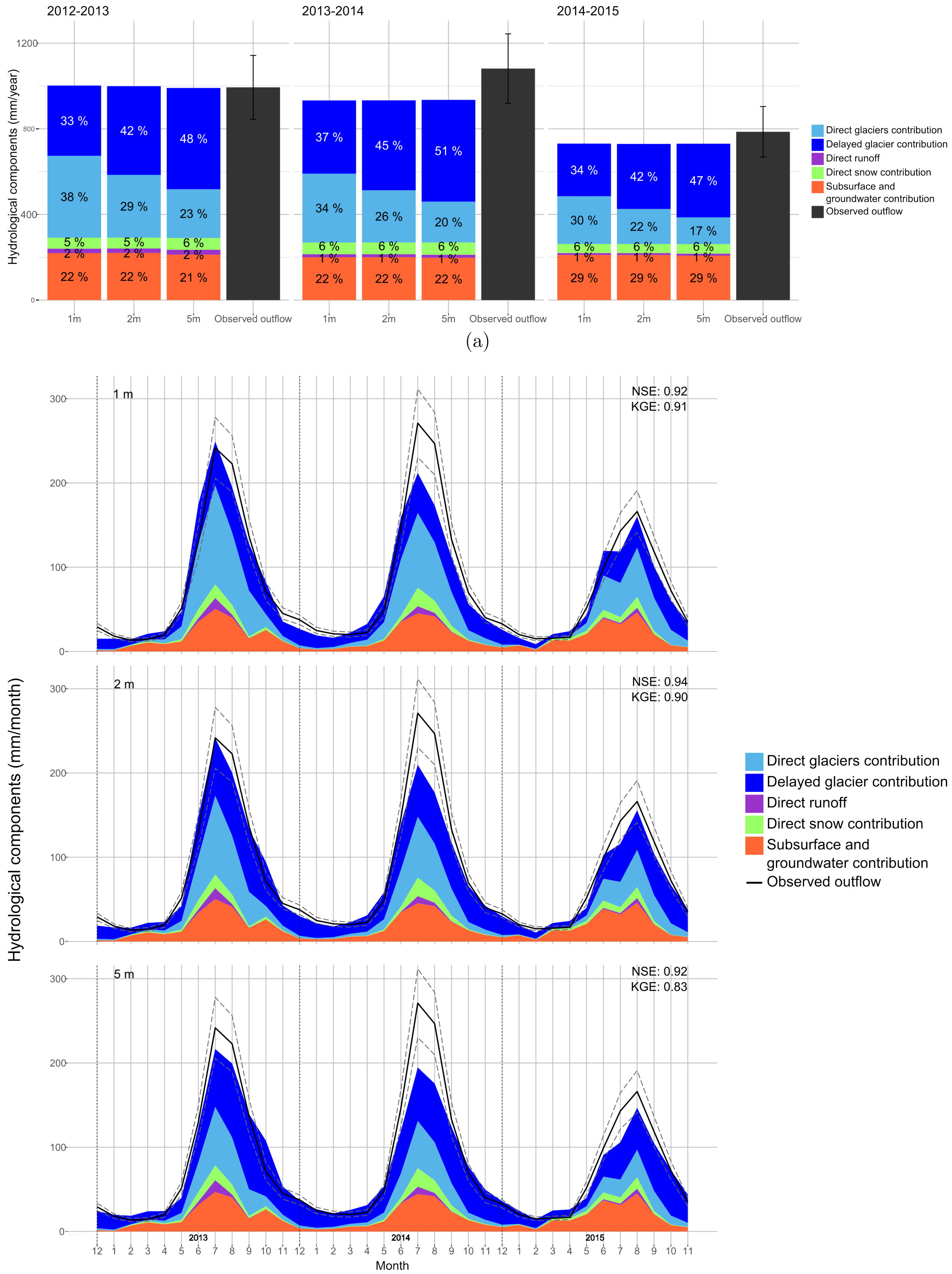
May 16, 2018

1 Sensitivity of the soil depth under glaciers on the simulated discharges

Three different values of soil depth under glaciers were tested in order to assess the sensitivity of the soil depth under glaciers on the simulated discharges. Figure 1 shows the simulated discharges and flow components simulated with configuration v3 for a soil depth under glaciers equals to 1 m, 2 m and 5 m.

Figure 1a shows that the soil depth under glaciers does not impact the simulated annual outflow and the total annual contributions from glacierized and non-glacierized areas. The soil depth under glaciers only impacts the partitioning between direct and delayed contributions (soil water and englacial water contributions): when the soil depth under glaciers ranges between 1 m and 5 m, the direct glaciers contribution ranges from 34 to 20 %, and the delayed glacier contribution ranges from 35 to 47 %.

An increasing of the soil depth under glaciers leads to a delay of the outflow as there is more infiltration simulated during the pre-monsoon and monsoon seasons, but this has a limited impact on the NSE and KGE values (see Figure 1b).



(a)

(b)

Figure 1: a) Annual and (b) monthly discharges and flow components (definition 2) simulated with configuration v3 with three different soil depths under glaciers (1 m, 2 m et 5 m). Observed monthly discharges are represented with an interval of uncertainty of 15 % (dashed back lines).