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Interactive comment on "Sub catchment Assessment of snowpack and snowmelt change by analyzing elevation bands and parameter sensitivity in the high Himalayas" *by* Vishal Singh et al.

Anonymous Referee #1

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Summary

This submission is a typical example of a modeling study that is using poor input data and large assumptions to make great inferences about the hydrological response of a watershed. The study is attempting to assess the role of elevation on snow accumulation and snowmelt contributions to streamflow in a data-poor river basin in the Himalayas. The authors provide very little information on how spatial units are discretized and how snow accumulation is estimated from CMIP-3 temperature and precipitation data for the 51,000 km2 basin that has one of the largest variability in elevation and

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relief found on this planet. The study describes how elevation bands are derived and mentions the use of meteorological station data to estimate the temperature lapse rate, however, the methods section does not contain any information on how many meteorological stations were included in the analysis nor where these stations are located. Similarly, the accuracy of the simulated snowfall is not validated with snow cover data or on-the-ground measurements making this input dataset highly questionable. The 'simulated' snowfall is then used as an input dataset to the SWAT model to predict the change in snowmelt runoff until 2030. The study does not even show a graph of the observed versus modeled streamflow to indicate the goodness of fit of the model (goodness of fit measures are only provided in the form of a table) thus it is highly questionable that the model is capturing runoff dynamics (e.g. peak flows, base flows) correctly. This study would have much more scientific value if the authors would attempt to improve uncertainty propagation of these huge uncertainties in the input data. Beyond these coarse assumptions, the study is also somewhat limited in scope in such that it only considers changes in snowmelt and largely ignores melt water contributions from glacier melt. As the authors clearly point out in their introduction, the Himalayas undergo drastic change in both snowmelt and glacier melt. Forward prediction of the snowmelt dynamics is therefore of limited value if the model does not include energy balance couplings to glacier melt. The authors therefore should clearly state up-front (e.g. in their abstract and study objectives) that the analysis has been done assuming that there is limited change in glacier melt over the time period considered or develop a glacier melt algorithm for the SWAT model.

Specific comments

Line 19: Suggest adding the size of the watershed considered in this study. This info is particularly of interest to assess how representative this study is for the entire Himalayan region.

Line 26: Delete "approach"

Line 25 ff.: It is not clear from the abstract what the SWAT model is used for? The abstract could be streamlined to clearly state what the objective of the study is and what the different datasets and tools (e.g. SWAT) are used for. Also it would be good to clarify what snowmelt module was used in SWAT.

Line 74: "timing snowmelt"? Timing of snowmelt? How is glacier melt considered in the SWAT model? How is the model calibrated to consider seasonal changes in glacier mass balance, which includes quite a bit of snow?

Line 76: Wording! "understanding modeling complexities, mainly snowmelt induced. . ."? Do you refer to snowmelt induced modeling complexities? Please revise!

Line 84: Delete "stream" in front of flows.

Line 85: What percentage of the entire Himalayan region does the Satluj river basin represent?

Line 89: What is the percentage of glacier cover in each of the 14 sub-catchments?

Line 110: What does SRES B2 stand for? This is not the most common way emission scenarios are referred to. Also it would be valuable to state what this scenario's main assumptions are.

Line 120: Can you clearly state how many meteorological stations and snow monitoring stations were included in this analysis and where these stations are located? Right now the manuscript suggests that the SWAT model uses only IPCC temperature and precipitation data, is then modeling the snowfall and snow accumulation and snowmelt. How much effort was spent to validate the quality and validity of the IPCC products in this river basin? There have been numerous studies concluding that snow accumulation in mountainous regions is highly variable. Without this uncertainty analysis in the input data the SUFI2 sensitivity analysis is worthless.

Line 126: How were historical scenarios of snowpack, snowmelt and other water bal-

ance components generated?

Line 131: The abstract states (line 21) that the basin was divided into 14 sub-catchment. Here you state 16. Which one is correct?

Line 134: A little bit more information on the HRU delineation is needed. How many HRUs were derived for each sub-catchment? What curve numbers were assumed for the different soil types (which are not clearly defined in Figure 1!)? How were the 10 elevation bands derived (e.g. natural break, equal interval, equal area)? Why not use local information on the lapse rate to define the elevation bands?

Line 140: More information on glacier cover in each sub-catchment is needed.

Line 181: The SUFI2 approach might be useful for a watershed where the modeler has high confidence in the input data. Given that this study is using FAO soil maps (1x1 degree), IPPC gridded temperature and precipitation data which aggregate rainfall and snowfall input over a large region that does not take any spatial difference due to topography into account, the approach use of the SUFI2 is useless in the uncertainty in the input data is not properly addressed. This study would have much more scientific value if the authors would attempt to improve uncertainty propagation of these huge uncertainties in the input data.

Line 216: It is not clear what stations were used to calculate the temperature difference and lapse rate for the elevation bands. The methods section does not contain any information on how many meteorological stations were included in the analysis.

Line 252: The authors state clearly that SWAT is not capable to simulate glacier melt. However, 5 lines further down they claim that glacier melt was integrated with the snowmelt. Glacier melt presents a streamflow contribution from a storage reservoir, which cannot or should not be captured by the snowmelt routine. Once the accumulated precipitation is exhausted no more runoff can be contributed by snowmelt, however, this is typically the time when glacier melt contributions dominate. The authors

state that there is a large number of glaciers in the basin (this should be clearly stated in the methods and basin description!) which can contribute glacier melt. Equation 7 is not capable to adequately capture glacier melt once the snow cover (snocov) is zero.

Line 302: “The Saltuj River drainage area is dominated by glacial hydrology, permanent ice sheets and seasonal well-packed snow.” This sentence captures nicely the variability in snow and ice cover in the basin and illustrates the spatial and temporal variability of snowmelt processes that prevail in the basin, which cannot be captured by a melt rate model. Well-packed snow has a much greater density that freshly fallen snow and melts differently that new snow, aged snow or glacier ice. Since the authors do not provide any information on the HRU discretization of each sub-watershed I assume these spatial differences in snow and melt patterns are not accurately captured by the model.

Line 394: The finding that low- to mid-latitude regions experience the most change from snowmelt to rainfall runoff is not surprising has been found in many other mountainous regions across the world (Foster et al. 2016, ERL; Klos et al. 2014 GRL).

Line 397: How would a change in elevation bands influence the results shown in Figure 7?

Figure 1: What do the black circles with the cross mean? Please ensure that each map shows a complete legend! The legend of the soil map is very uninformative. Could the different soils be grouped into know soil types or soil families? The 16 sub-catchments and their boundaries are hard to see. Please use a different line and text color for the catchment boundaries. Please add locations of glaciers within the basin. Also the locations of the three gauges mentioned in the methods cannot be found in any of the figures.

Figure 2: Please correct the spelling of “snowmelt” in each graph. Please define what you mean by snowpack and snowmelt. Is snowpack the depth of the snowpack and snowmelt the snow water equivalent?

Figure 4: The figure caption for this figure does not make sense. Graph (b) does not seem to show the cumulative variability in snowpack amount as stated in the caption.

Figure 6: This figure is somewhat awkward. The labels for each plot are too big and cover in some instances the map. I would suggest putting each map into a grid/frame that is then clearly labeled with both a-j and the thematic title of the map.

Fig. 7: Why are the bar graphs not sorted in increasing order from SB1-SB16 along the x-axis? SB5 is the last bar with the least change in snowpack but it is not clear what elevation band this sub-catchment belongs to.

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