1 Reviewer 1

In the manuscript "Influence of snow surface processes on soil moisture dynamics and streamflow generation in alpine catchments", the authors present a comprehensive modeling study using the model Alpine3D which was complemented with new descriptions for simulating soil moisture and streamflow. The distributed model was forced using meteorological station data at several points and validated by means of snow depth, soil moisture, and runoff measurements.

1.1 General Comments

The manuscript presents a modeling study using a detailed set of modules and methods to tackle the challenge of simulating the hydrology in a complex mountainous catchment with a fully distributed, spatially highly resolved model. The focus lies on the simulation of snow depth, soil moisture and the respective interplay of precipitation, snow melt, and runoff dynamics. The study gives valuable insights in the involved hydrological processes. The manuscript is well elaborated and written and is technically of very high quality. I recommend its publication after minor revisions. Generally, the presented analysis is a bit incomplete because of the lack of a groundwater description in the model. This is mentioned in the manuscript at the respective sections. But it should be emphasized even more that this is a major zhortcoming of the study and it should be addressed in future work with the model setup. Another criticism is the description of the presented streamflow model. It is not quite clear to me how it was coupled to the model and what the flux input at or from different depths mean (sections 3.2 and 4.3). As I understand it, the water fluxes from the soil model at three different depths (lateral flux or excess out of the respective soil layer?) were taken and "streamed" into an external streamflow model. This streamflow model is calibrated using the respective fluxes which produces the shown streamflow simulations for three different depths. This approach is quite unusual and definitely needs further explanation in the manuscript. Why is the flux taken separately from the depths and not combined? The runoff dynamics clearly reveal that a groundwater module is missing. But this missing groundwater module could be "replaced" by a calibrated low flow component of the water flux (baseflow) which seems to be totally missing (Fig. 7, underestimated low flow / baseflow in the winter months). All other presented findings regarding soil moisture, freezing, as well as event-based precipitation and melt are well elaborated and very interesting. Some more questions that need clarification are listed in the following specific comments.
We thank the reviewer for his positive remarks about the study and his constructive comments. We will take them into consideration when revising the manuscript. Regarding the ground water flow: here the issue is mainly that only the streamflow model treats groundwater flow, simulating the water storage dynamics of the deep soil compartment. However, there is no feedback to the Alpine3D model, such that a rising water table cannot be simulated in the Alpine3D model. One could envisage an approach where the level of the reservoirs in the streamflow model is coupled to the lower boundary of the SNOWPACK module in the Alpine3D model. However, it is not guaranteed that this approach will improve the soil moisture or streamflow simulations, as it also requires detailed information about soil properties and soil depths throughout the catchment. We will provide a more extensive discussion on ground water flow in the revised manuscript.

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.

1.2 Specific Comments

- P.1 L. 6: "in close proximity to" instead of "in close proximity of"
  Will be corrected, thank you.

- P. 1 L. 9-15: "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 including 30 cm of soil layers. Performance decreased when including 2 cm or 60 cm of soil layers. 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." The differences in NSE for three simulations are so small that I would not give this strong statement. It is also not at all an evidence for your second statement as you show no simulations without the new soil model, see comment below (P. 10 L. 18/19). It is for sure correct that soil moisture has to be taken into account but you show no real proof in this work.
  We agree with the Reviewer that the abstract was not accurately reflecting the results from our study at this point. Note that NSE coefficients are all very similar, as we recalibrated the streamflow model for each case individually. However, the conclusion about the importance of soil is not only drawn based on the NSE coefficients for discharge, but also for the relationship between initial soil moisture and runoff coefficients. We will rephrase this part of the abstract when revising the manuscript.

- P.1 L. 17: "which shows" instead of "and this shows"
  Will be corrected, thank you.

- P. 3 L. 7: Rephrase: "The measurement site Weissfluhjoch (WFJ), which is focused on snow-related

measurements, as well as several permanent meteorological stations are located in close proximity to the area." instead of "The measurement site Weissfluhjoch (WFJ), which is focussed on snow-related measurements, is located in close proximity of the area, as well as several permanent meteorological stations."
Will be rephrased, thank you.

- P. 3 L. 14: "of total precipitation" instead of "of all precipitation"
  Will be corrected, thank you.

- P. 4 L. 7: Better use "focused", not "focussed" (see also above P. 3 L. 7)
  Will be corrected, thank you.

- P. 5 L. 14: Lower computational costs compared to what other approach? Please add an example for clarification!
  It was meant here: the bucket scheme for snow has a lower computation cost than the full Richards equation and the bucket scheme is an appropriate choice when the main interest is for seasonal and daily time scales. We will improve the wording of the manuscript at this point.

- P. 5 L. 21: Remove brackets in citation!
  Will be corrected, thank you.

- P. 6 L. 13: Rephrase the first two sentences / the beginning of this section ("Two important components to initialise Alpine3D simulations are the digital elevation model (DEM) for the Davos area, provided by the Swiss Federal Office of Topography (swisstopo). Also the soil has to be initialised for each pixel, although limited information is available.") e.g.: "Two important components to initialise Alpine3D simulations are the digital elevation model (DEM) and distributed soil information. The DEM is provided..."
  Thank you for the suggestion, this part will be rephrased.

- P. 7 L. 6: Either remove "on a computer cluster from 2008." or preferably provide some more information about the HPC system (e.g. type and clock speed of nodes). I guess the 14 hours per year using 36 CPU cores are the necessary wall clock time (or CPUh?). Please add this information in the manuscript.
  We will revise the sentence as follows: "Using 36 CPU cores from a HPC system consisting of in total 32 compute nodes with two 6-core AMD Opteron 2439, 2.8 GHz processors per compute node, the computation took on average 14 *hours wall clock time for a single year, mainly depending on the snow height in the winter season."*

- P. 7 L. 11: Remove "also".
  Will be corrected, thank you.

- P. 7 L. 12: Why didn't you additionally inspect hourly values if you have the respective measurements? You could add at least some examples for showing the model performance on a smaller, hourly timescale, which would be very interesting to see.
  We agree with the reviewer that it is interesting to see the hourly behaviour of the soil moisture measurements and simulations. We therefore plan to amend the manuscript with an additional figure showing for one station an example of hourly soil moisture, during both the melt season as well as the summer season (see Fig. 1).

- P. 8 L. 6 ff and above and Figures 3–5: Consequently use one throughout the manuscript: either "snow depth" or "snow height" (personally, I prefer "depth").
  We will use the term "snow depth" throughout the manuscript and in the figures.

- P. 8 L. 12 ff and Fig. 3: Please try to remove the measurement errors in Fig. 3 (high frequency fluctuations, especially in the summer months)! In June / July 2012 and 2013, the model seems to miss the measured spring snow fall at stations (a) and (b). Why does this happen? Add a respective explanation in the manuscript.
These measurement sites showing the high frequency fluctuations measure over a meadow and the snow depth measurements are not only recording the grass growth, but are also receiving a noisy signal from the grass. A few times during the summer, the grass below the snow depth sensor is mowed by farmers, which is also visible in the signal. We did not explain this in the original manuscript, but, as also suggested by Reviewer 2, we plan to explain the measured signal in the revised manuscript. We do not want to filter the signal, as it is a typical signal for grass growth and thereby recognizable as such.

- P. 8 L. 15: To be consistent with the section title of 4.1 either remove "Measurements and Simulations" or add it in 4.1
Thank your for pointing out the inconsistency, we will shorten section title 4.2.

- P. 9 L. 20: "S1" instead of "S3"
Will be corrected, thank you.

- P. 9 L. 27: Are the r2 values calculated using the daily or hourly values? I guess daily, but please add this in the manuscript for clarification.
These concern hourly values. As the reviewer was expecting daily average values, we changed the graph accordingly (no significant change in results). We are sorry for causing confusion, but we will add this information in the manuscript.

- P. 10 L. 12: Remove "us".
Will be corrected, thank you.

- P. 10 L. 15: Please either explain your concept of the "virtual lysimeter" or use another notion! I think you are referring to the water fluxes at the three depths, but this is not clear here.
This indeed refers to the water fluxes at the three depths. We will rephrase this sentence and will replace the term "virtual lysimeter" with an explicit description.

- P. 10 L. 18/19: I am not sure if I understand this right, but the statement "The results suggests that the updated soil module of SNOWPACK is contributing to a better prediction of streamflow in the summer months." is misleading or drawn without any evidence. You show no Alpine3D runoff result without the new model, because – as I understand it – there was no soil moisture or runoff description in the model before. So a valid statement would be something like "The results show that the new soil module of SNOWPACK is enabling a simulation of streamflow."
We agree with the reviewer that the statement was misleading. There actually has been a very basic soil module in SNOWPACK for many years now, where water flow was described using a bucket-type approach. However, we did not want to aim for a comparison, as some very important physics is missing in the old module, for example water retention and water flow rates as a function of soil moisture. We think that a base-line soil model in a physics based model should at least apply Richards equation or something similar to describe water flow in soil. Nevertheless, taking soil water fluxes at 2 cm depth can be regarded as almost equivalent to directly routing snow melt and rainfall to the runoff routine (P7, L21-23), which we found to give a lower score than integrating 30 cm of soil layers. Our aim is to show that using a physics based description of soil processes improves the simulation of catchment discharge.

We will rephrase parts of the manuscript to better explain our reasoning, which we think is in line with the suggestion by the reviewer.

- P. 11 last paragraph of section 4.4: The conclusions here are of course valid but were somehow clear before your study and should be underlined with existing literature.
  We will refer to the appropriate literature in this section.

- Fig. 2, 3, 4, 5 and S1 – S5: Please add the year to the time-axis. This makes it much easier to look at when you write about single years in the text.
  This is a very good suggestion and the appropriate changes will be made.

- Fig. 7, caption: typo "tics"
  Will be corrected, thank you.

- Fig. 8, caption: I cannot see any data points plotted on the x-axis as stated in the caption. When you add them, please add the real value somehow because it is of interest how negative the NSE values are in these periods.
  Sorry for raising the confusion, but this remark referred to an earlier version of the plots, where NSE coefficients for summer 2012 were negative, due to, as was found later, a data processing error. This has been resolved. Now all NSE coefficients are positive and the manuscript will be updated accordingly.

References

Comola, F., B. Schaefli, A. Rinaldo, and M. Lehning (2015), Thermodynamics in the hydrologic response: Travel time formulation and application to Alpine catchments, *Water Resour. Res.*, *51*(3), 1671–1687, doi: 10.1002/2014WR016228.

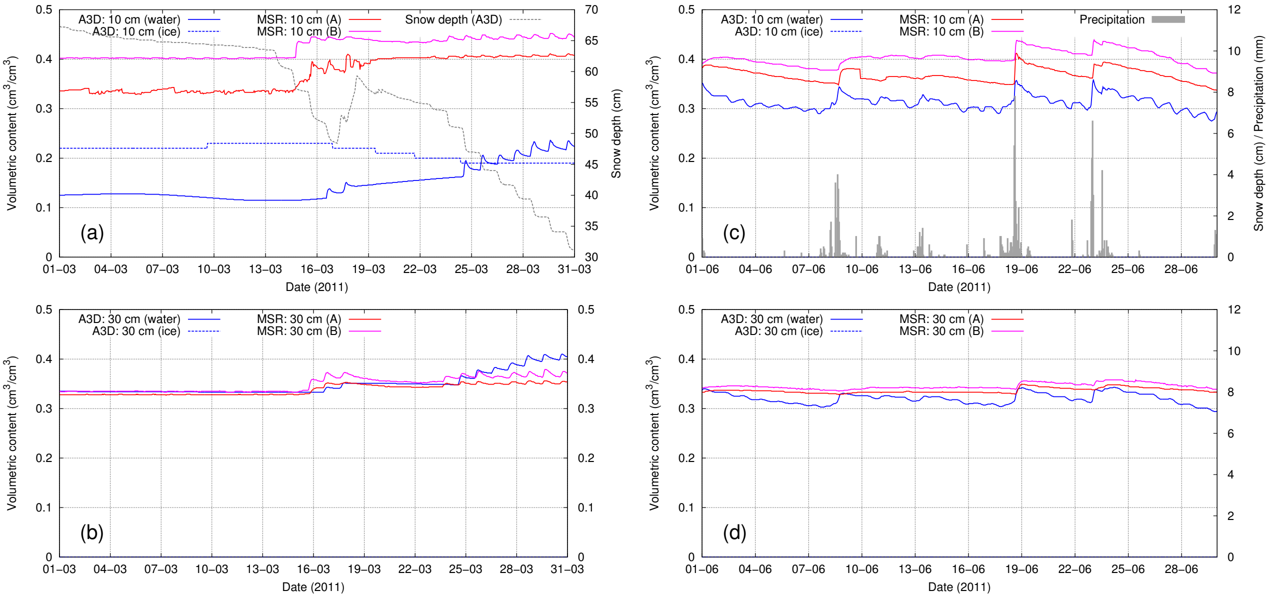

Figure 1: Measured and simulated soil moisture at the IRKIS station SLF2, for 10 cm depth (a, c) and 30 cm depth (b, d), during the snow melt season (a, b) and a snow-free summer month (c, d). In (a) simulated snow depth and in (c) precipitation is shown.