Anonymous Referee #2

This manuscript aims to develop a conceptual hydrological model for frozen ground. The topic is interesting for hydrological modeling in cold regions. I have some major comments:

Reply: We thank Referee #1's endorsement for the contribution of this manuscript. Please find our detailed responses in below.

1. Section 1.2 need to be improved to explain what are the gaps between our understanding and the real changes in frozen soil. For example, the author mentioned that most current models project a long-term drying of surface soil, dose this projection agree with the real changes? Can the conclusions of this manuscript or the model developed in this manuscript address or explain this problem? What is the contributions for the model developed for improving the prediction of the streamflow in permafrost regions?

Reply: We thank Referee's constructive suggestions. We will further improve the Introduction, to highlight the novelty and remove some less relevant narratives.

2. The method for this manuscript is not easy to follow. The model was developed base on the observations in the small Hulu basin, and then it is validated in the Hulu basin. I suggest to validate the model in other catchment in the upper Heihe basin, the whole upper Heihe basin and other basins in the Qinghai-Tibetan Plateau.

Reply: We will revise the methodology part, and clarify more details. This is the same question as Referee #1. And we paste our replies in below:

"For the applicability of this model to other cold regions, we believe that the model has great potential to be applied in other cold regions. There are mainly three reasons, which we shall mention in our revised paper.

Firstly, our study site, the Hulu catchment, although small (23 km^2), has a large elevation gradient (from 2968m to 4955m), diverse landscapes (hillslope vegetation, riparian area, alpine desert, and glaciers), snowfall and snowmelt, and both permafrost and seasonal frozen-soil. Our newly developed model explicitly considered all these spatial and temporal heterogeneities, and eventually achieved excellent performance. With such a comprehensive modeling toolkit, the model has potential to be upscaled or transfer to other cold regions.

Secondly, we obtained the perceptual model from not only the observations and our expert knowledge at the Hulu catchment itself, but also widely considered the impact of frozen-soil on hydrological processes in other catchments, including the Zhamashike and Qilian (two nested sub-catchments of the upper Heihe), the headwater of Yellow River,

and the Cape Bounty Arctic Watershed Observatory in Canada. Thus, we developed the model for the Hulu catchment in the context of larger scale observations.

Thirdly, the realism of the conceptual model was confirmed not only by streamflow measurement, but also by multi-source and multi-scale observations, particularly the freezing and thawing front in the soil, the lower limit of permafrost, and the trends in groundwater level variation.

Although our new model generally has great potential to be used in other cold regions, we should be cautious to arbitrarily use the model without any prior understanding of the modeling system. Since frozen-soil is merely one influential factor for cold region hydrology, there are other factors having notable impacts, which are intertwined with frozen-soil. This relates especially to the geology condition, which can have considerable impact on frozen-soil, but has large spatial heterogeneity, and where it is difficult to take measurements. Hence, before upscaling to other cold regions, we recommend to follow a vigorous modeling procedure, i.e expert-driven data analysis → qualitative perceptual model → quantitative conceptual model → testing of model realism."

Model validation in the upper Heihe basin and other basins in the Qinghai-Tibetan Plateau is an ambitious model transferability test, which is worthwhile to conduct for further studies, but seems outside the scope of this manuscript.

3. Figure 5, the discontinuous recession seems only evident in 2014. Why?

Reply: The discontinuous recession is probably more apparent in 2014, but definitely happened for other three years (2011, 2012, and 2013). What is even more interesting is the spikes during the thawing in Figure 5. This is another evidence for discontinuous recession, which is likely triggered by the sudden release of groundwater starting at lower elevations in the end of frozen seasons. Our model was capable to reproduce the spikes, which further confirmed our conceptual model of a sequence of thawing breakthroughs.

4. Figure 12, in 2 degree warming, the discontinuous recession seems not found, why?

Reply: We thank Referee #2 for this valuable question. The current discontinuous recession was caused by permafrost and seasonal frozen-soil. The first recession period was contributed by the groundwater discharge from both permafrost and seasonal frozen-soil areas, and the second recession period was only contributed by the seasonal frozen-soil area. Thus the recession was discontinuous. But two degree warming results in permafrost degradation, and permafrost is degraded to seasonal frozen-soil. Thus there will be only groundwater discharge from seasonal frozen-soil, and lead to continuous baseflow recession. We will add this discussion in the revised manuscript.

5. Section 4.2.2. There are some empirical parameters and settings, such as the 3 m threshold for the frozen depth and 10% for groundwater storage. I suggest to developed more robust equations to represent these processes.

Reply: These parameter values are based on our expert knowledge in the field and lab experiments (Romanovsky and Osterkamp, 2000). We agree with the value of further investigating these processes, and our paper is definitely not the end of our exploration in frozen-soil hydrology. In the revised paper we shall clarify this choice.

6. I suggest to show the distributions of HRUs in some figures.

Reply: The HRUs are shown in Figure 1 and 2 in current manuscript.

7. The storage simulated in conceptual models could not be considered as the real "groundwater storage", this should be noted.

Reply: Yes, they are different, but they have similar trend, which we believe is a strong model realism test. We will further clarify this in the revision.

References:

Romanovsky and Osterkamp. (2000) Effects of Unfrozen Water on Heat and Mass Transport Processes in the Active Layer and Permafrost. Permafrost Periglac. Process. 11: 219-239