General comments

This ms tried to improve the WEP-COR model by adding two parameters (gravel and snow cover), and model the water cycle on the QTP. This improved model seems reasonable and the observed results fit well with the modelled data. However, some important discussions were not fully addressed. Especially, the scientific gaps you proposed in the abstract were not presented in the discussion. In addition, the scientific hypothesis seems inappropriate. Thus, I think it is not suitable for publication in the current version. I suggest rewritten it carefully before it can be published.

Dear reviewer:

We appreciate the detailed and valuable comments, which will substantially improve the quality of our manuscript. We will rewrite the manuscript carefully following the comments and suggestions provided by the three reviewers in the revised version. Our responses to the comments are provided below.

Abstract

I don't think that the dominant lithology of the whole QTP is thick gravel layers. The Quaternary deposit is prevalent on the QTP. Thus, you should define the thickness of the gravel layer and the depth. If the gravel layer occurred at depth as deep as 50m or more, how can it affect the hydrological processes? Importantly, the hydrological and water cycles on the QTP differed due to the remarkable spatial heterogeneity of precipitation, the topography, and the atmospheric circulation, even in a small watershed. For example, maybe the shallow gravel layers generally occurred in the river valley and at the foot of valley, however, it may be buried in deep layer on the mountain slope.

Accordingly, how can you determine the mechanism of water cycle on the entire QTP by only modelling one site? In addition, due to the occurrence of permafrost, although the high permeability of the gravel, the sub-permafrost water is hard to involve the surface water cycle.

Line 18: If I can understand, you tried to study the water cycle mechanism of the Qinghai–Tibet Plateau via a local study in the southeast QTP, I don't think it is a good idea. As you mentioned, the geological and climatic characteristics varied on the QTP, including the distribution of cryosphere, the precipitation regimes, as well as the lithology, so how did you achieve your goal via the investigation at only one site?

non-freeze–thaw period: please define it, did you mean the absolutely freeze period?

Or completely thaw period? freeze–thaw period: the same question. How did you define it?

Reply: Thanks for the insightful comments. Sorry for being not clear enough in the previous version of the ms on the aspects pointed out by the reviewer, which will be clarified here as well as in the revised version of the manuscript. As the reviewer said, the Quaternary deposit is prevalent on the QTP. The focus of this study was the hydrothermal migration process in the Quaternary deposits (including the deposits in the upper layer that have developed into soil and the mixture of sand and gravel, and soils in the lower layer that have not yet been fully developed), rock layer below the Quaternary sediments was not within the scope of this study.

Affected by topography and atmospheric circulation, although there are regional differences in the water cycle process of the QTP, there also share certain similarities. During the continuous uplift of the QTP, a series of ascending areas (denuded areas) and descending areas (deposited areas) have been formed in this area. Quaternary deposits are generally thinner in denuded areas and thicker in deposited areas (valleys, plain). The thickness of Quaternary deposits varies greatly at the transition between the denuded areas and the deposited areas controlled by the fault zone. The soil forming process of Quaternary deposits on the QTP is intermittently affected by surface uplift. In addition, under strong freeze-thaw conditions in the cold plateau region, the humus accumulation of herbaceous plants is slow and the decomposition of minerals is weak, resulting in slow soil development and thin soil layers. This phenomenon is prevalent in the QTP (Sun, 1996; Yang et al., 2009; Chen et al., 2015). Moreover, we also confirmed this phenomenon in the present study through field campaigns in the study area (field investigation, sampling, laboratory analysis, etc.). In view of this phenomenon, most of the previous studies have improved the accuracy of hydrothermal simulation by adjusting the parameterization scheme. However, because the soil was generalized into a homogeneous structure, it was difficult to reflect the influence of this region's obvious upper and lower layered geological structure on hydrothermal migration and on watershed hydrological cycle only through parameter adjustment.

Based on this geological feature of the QTP, in this study, we took the aquifer and unsaturated zone above the impervious boundary as the research object (this part contains both soil layer and gravel layer, with a strong freeze-thaw effect and close interaction with surface hydrological process, which is the key link affecting the hydrological cycle in this area). Through field experiments in the Niyang River Basin, the simulation object of hydrothermal coupling was generalized as the binary medium of soil and gravel. Considering the characteristics of hydrothermal migration in different periods, the simulation of hydrothermal transport was carried out by dividing the freeze-thaw period and the non-freeze-thaw period. On this basis, the influence of the ubiquitous geological structure of the QTP on the hydrological cycle of the basin was analyzed.

The lithosphere is basically below the Quaternary deposits or deeper below the permafrost. Affected by the impermeability of rock and permafrost, the interaction between this part and the hydrological process is weak, which was not considered in this study.

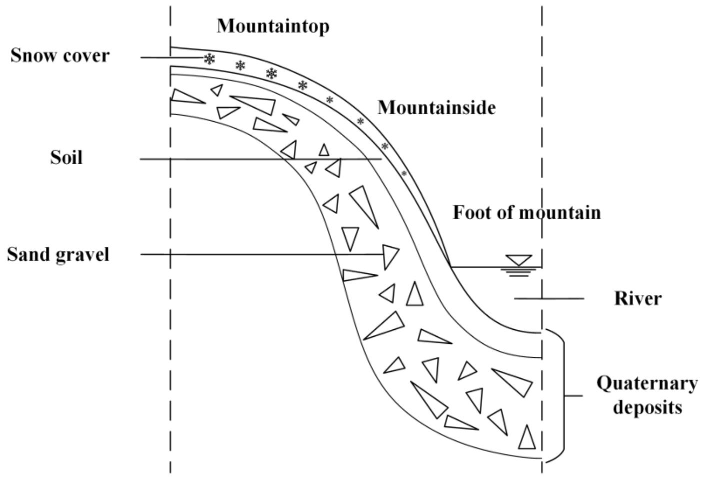
For other differences such as glacier distribution, precipitation and climate characteristics, in this study, we fully considered the effect of these differences on hydrological simulations through glacier remote sensing and spatial interpolation of precipitation and temperature in the Niyang River Basin. The spatial differences of these hydrological elements on a larger scale in the QTP need to be further studied by combining remote sensing and spatial downscaling.

The non-freeze-thaw period defined in this model was the complete thawing period. We will also make it clearer that in this study, the division between the freeze–thaw and non-freeze–thaw periods was determined according to the soil and gravel temperatures in each calculation unit. Non-freeze–thaw period is defined as when all the soil/gravel layer temperatures were greater than 0 °C, and all of the water was a liquid. As long as a layer of soil or gravel had temperature below 0 °C, it is considered as freeze–thaw period.

Introduction

1. ***I suggest that the authors should reconsider the hypothesis: the lithology on the QTP differed significantly, not what you said, the gravel layer only occurred in some special conditions, e.g. the low river valley or some fluvial alluvial landform. The Quaternary deposits is important. Especially when you investigate the water cycle.***

Reply: Thanks for the comments. For more details please refer to our reply to the comments on Abstract above. The soil and gravel structures are common in this area. The gravel layer does not occur only in some special conditions. The structure above the impervious boundary has been summarized in the figure below:



The object of this study was the hydrothermal migration process in the Quaternary deposits (including the deposits in the upper layer that have developed into soil and the mixture of sand, gravel, and soils in the lower layer that have not yet been fully developed), rock layer below the Quaternary sediments was not within the scope of this study. We will redefine this concept in the Introduction.

2. ***From the title, I suggest that the first section should be focused on the importance of water cycle on the QTP. And the influence of lithology is discussed to propose the knowledge gap. Thus, the introduction section should be rewritten.***

Reply: Our writing ideas and the reviewer's suggestions are the same, sorry that we failed to express it clear enough in the original version. In the revised version we will make it clearer that Paragraph 1 introduces the importance of the QTP to water resources in China and Southeast Asia. Paragraph 2 illustrates the effect of frozen soil on the water cycle in the region. The rest paragraphs highlight the knowledge gap by comparing with the frozen soil hydrology research that has been carried out in the QTP, state the research objectives and implications. We will supplement the relevant information and revise the Introduction in the revised manuscript.

Study area

Lack of the geological data and the lithology characteristics in this basin.

Reply: Thank you for pointing out this deficiency. The Yarlung Zangbo sediments consist of greywacke and litharenitewith low-moderate maturities of textures and minerals (Huyan et al., 2022). In the Niyang River Basin, where the study was carried out, we measured the basic geological conditions in the basin by field campaigns. We will supplement this information in Section 2.1.1 in the revised version.

Results and discussion

The contents in this section did't fit with what you have presented in the abstract and the title.

Reply: Thanks for the insightful comment. In the Abstract, we will reformulate the purpose of the study (Lines 17-20) as follows:

In order to deeply study the influence mechanism of the underlying surface structure on the hydrothermal migration and water circulation process in the Qinghai－Tibet Plateau, we performed comprehensive study combining field experiments of the water and heat transfer processes and development of a Water and Energy transfer Processes model in the Qinghai–Tibet Plateau (WEP-QTP), based on the original Water and Energy transfer Processes model in Cold Regions (WEP-COR). The Niyang River Basin located on the Qinghai–Tibet Plateau was selected as the study area to evaluate the agreement between theoretical hypothesis, observation and modeling results.

In addition, we have also revised the title as "Application of a new distributed hydrological model based on soil–gravel structure in the Niyang River Basin, Qinghai–Tibet Plateau" to better reflect our research content.

1. ***As you mentioned, the ice in the embedded in the soil pore is important, so I think the ice conditions should be considered.***

Reply: Thanks for the comment. In this study, the effect of ice in soil pores on the water cycle was manifested as the effect on soil saturated hydraulic conductivity (Equation 27). When the temperature of the soil or gravel layer is lower than 0°C, the water in the pores freezes, blocking the pores and affecting the soil saturated hydraulic conductivity. Considering the difference in the hydrodynamic properties of the soil and gravel layer, different values of K_0 were used in the soil and gravel layer.

2. ***I do not see the discussions of the influence of gravel content on the model, as well as on the water cycle.***

Reply: The effect of gravel content on the hydraulic properties of the gravel layer was shown in Equation 3. Through field sampling in the Niyang River Basin, we found that the gravel content in the gravel layer in the basin is 50%–65% (Line140), and the gravel content in the model was determined and adjusted according to the measured value.

3. ***The discussion section is insufficient. The authors only presented the applications of model in the flow process, the moisture, etc. However, it was absolutely lack of some important things. I suggest discuss the influences of gravel***

layer and snow cover on the water cycle, which you aimed to address in the abstract. I think what you presented in the result section was just the model result. How you determined the water cycle using your improved model on the QTP is important.

Reply: Thanks for the comment. In the revised version, in addition to the comparative analysis of the simulation results in Sections 3.1 and 3.2, we will enhance the discussion on the effects of gravel layers and snow cover on the water cycle in Section 3.3. Snow and gravel alter the water cycle process by affecting the temporal and spatial changes in frozen soil. In terms of water transfer, the large pores of the lower gravel layer increase the regulation and storage effect of groundwater of the flow processes. For heat transfer, snow and gravel block heat conduction, slow down the freezing and thawing rates of aquifers, and thus change the water circulation flux process (Fig.12). In the revised manuscript, we will also further discuss the similarities and differences between our study and the previous hydrological model studies in the QTP.

Special suggestions

Page 2 line 42: change "permanent" to "permafrost"

We have made the necessary revisions throughout the ms.

Page 3 line 66-67: the geological structure of the Qinghai–Tibet Plateau is special, with a thick gravel layer under the thin soil layer. How did you draw this conclusion? As I suggested, I don't think the gravel layer is thick over the whole QTP.

Reply: Thanks for the comment. Referring to our detailed response to the comments on Abstract, we have improved the description of this important part by combining our field experiments results of the soil texture and the common consensus in literature (Sun, 1996; Yang et al., 2009; Chen et al., 2015). This phenomenon is prevalent in the QTP.

Page 7 line 179: how did you set the thickness of the soil layer at different depth?

Reply: Thanks for professional questions, and sorry for being *unclear*. Similar comment has also been raised by Reviewer #1. The division of soil layer thickness was mainly based on the convenience of accurately simulating the hydrothermal migration process. As the surface soil is more sensitive to changes in atmospheric temperature, the thicknesses of the first and second layers were set to 10 cm each, and the third through eleventh layers were divided evenly, each with a thickness of 20 cm.

Page 8 How deep did you model?

Reply: The depth from the surface to the impermeable layer was an adjustable parameter in the model that can be adjusted based on the actual basin conditions. Considering the activity range of seasonal frozen soil, the depth of the hydrothermal numerical simulation in the model was 2 m. When the groundwater depth was greater than 2 m, the excess comprised the twelfth layer (transition layer). We have redrawn Figure 4 to ensure that the readers can better understand our model structure.

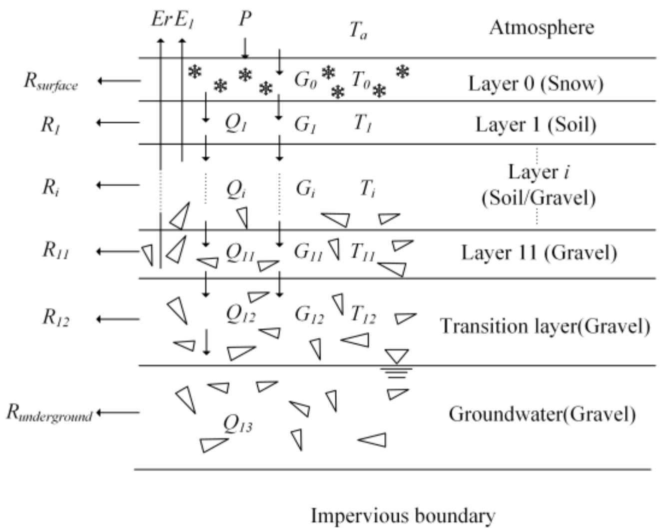


Figure 4. Layered structure of the dualistic "soil–gravel" structure

Page 19 415-416, how did you obtained the snow cover period in this area?

Reply: The model constructed includes snow accumulation and melting process, and the thickness of the simulated snow at the experimental point was calibrated with the measured value (Fig.7). The snow cover period was decided according to the snow thickness simulated by the model. When the snow thickness was > 5 cm, it was the snow cover period.

Page 21 the differences between the modelled moisture by using two different models are big, how did you explain it?

Reply: The WEP-COR model ignores stratified geological features and the simulation object was homogeneous soil. Therefore, the simulated moisture changes gradually in the vertical direction, and there was a large difference from the measured value below the 40 cm layer (the soil layer thickness at the experimental point is 40 cm, and the gravel layer (mixed layer of gravel and soil) appears below 40 cm.). The WEP-QTP model took this geological feature into account. The existence of gravel increases the hydraulic conductivity of the gravel layer and reduces its water retention capacity, which is manifested in the simulated difference of the water content. The results of the improved WEP-QTP model were closer to the measured values. A detailed description of this difference can be found in lines 452–459 of the current manuscript.

Please check the grammars and expressions by inviting a native English speaker.
Page 23 line 476: I can not understand the expression" …the WEP-QTP model can recharged groundwater more quickly during heavy rains….". May be "…the groundwater recharged more quickly in the WEP-QTP model…"
Page 24 line 479; the same question, the expression is hard to follow, please improve the ms by inviting a native English speaker.
Reply: Sorry for the grammar error, before the revised version is submitted, we will invite native English speakers to polish the language.

Page 24 line 485: what do you mean the area of WEP-COR? I think the area of frozen soil in the WEP-COR model is correct.
Reply: Thanks, we will correct it and other potential errors native English speakers in the revised version.

References
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[2] Yang K, Chen Y Y, Qin J. Some practical notes on the land surface modeling in the Tibetan Plateau[J]. Hydrology and Earth System Sciences, 2009, 13(5): 687-701.
[3] Chen H, Nan Z, Zhao L, et al. Noah modelling of the permafrost distribution and characteristics in the West Kunlun area, Qinghai-Tibet Plateau, China[J]. Permafrost and Periglacial Processes, 2015, 26(2): 160-174.
[4] Huyan Y, Yao W, Xie X, et al. Provenance, source weathering, and tectonics of the Yarlung Zangbo River overbank sediments in Tibetan Plateau, China, using major, trace, and rare earth elements[J]. Geological Journal, 2022, 57(1): 37-51.