Cover Letter

Dear Editor,

Thanks for providing detailed reviews of our manuscript ***Interaction of soil water and groundwater during the freezing-thawing cycle: field observations and numerical modeling***. Following the suggestions of the two reviewers, we have revised the manuscript.

A detailed response is attached in this file. If there is any problem with the revision, please let me know.

Thank you for your consideration.

Best regards,

Xiao-Wei Jiang

Professor of Hydrology

E-mail: jxw@cugb.edu.cn

Responses to the Reviewers

Reviewer #1

It's my pleasure to review hess-2020-657 "Interaction of soil water and groundwater during the freezing thawing cycle: field observations and numerical modeling" by Xie et al. The authors have appropriately addressed my previous comments, and the paper can be accepted after addressing following minor comments.

Minor Comments:

1. The language can be further improved, and I note that many long sentences are often used, which can be divided into several short sentences.

Response: Thanks for your suggestion. We have divided many long sentences into short sentences. The language of the manuscript has also been improved.

2. For the description of implication, can the authors mention which parts of the world need to well demonstrate the freezing induced water table fluctuations?

Response: Seasonally frozen soils underlie approximately 24% of the Northern Hemisphere exposed land surface, the distribution of which is shown in Figure R1. As shown in Figure R2, regions with water table depth shallower than 2.5 m occur widely in the Northern Hemisphere. We found winter-time water table recession has been reported in such countries as Canada, China, Russia, Sweden and the USA. Although the number of field observations is still limited, we believe that the phenomenon could occur widely.

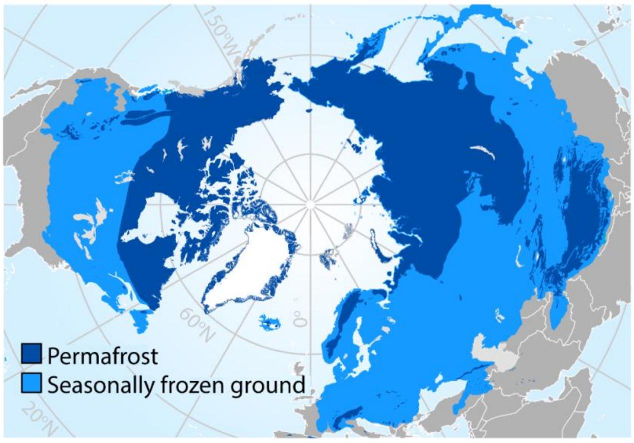

Figure R1 The distribution of permafrost and seasonally frozen ground in the Northern Hemisphere (Evans and Ge, 2017).

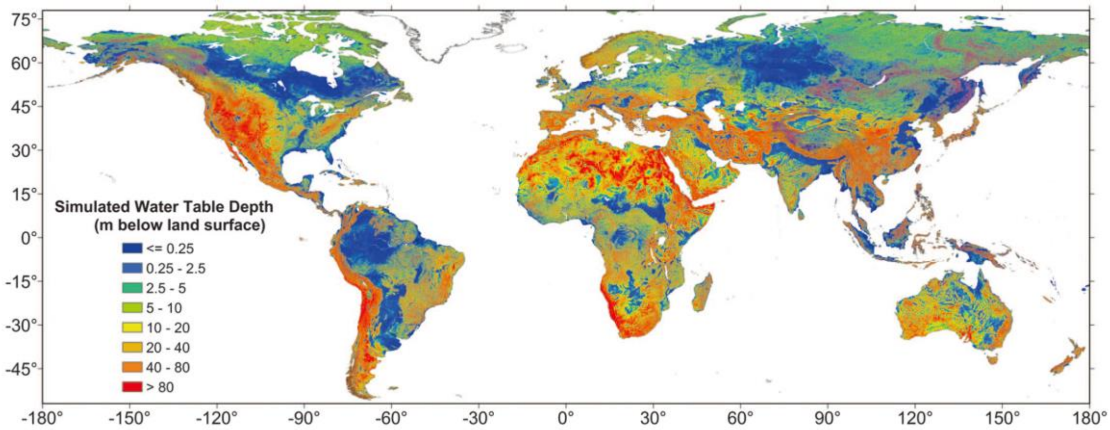

Figure R2 The distribution of global water table depth (Fan et al., 2013).

We have added the following sentences in the revision "Fan et al. (2013) reported that regions with water table depth shallower than 2 m account for around 31% of the global land area while Zhang et al. (2003) reported that seasonally frozen soils underlie approximately 24% of the Northern Hemisphere exposed land surface. Moreover, winter-time water table recession has been reported in such countries as Canada (van der Kamp et al., 2003;Ireson et al., 2013), China (Wu et al., 2016;Zhang et al., 2019), Russia (Vinnikov et al., 1996), Sweden (Stähli et al., 1999) and the USA (Drescher, 1955;Schneider, 1961;Daniel and Staricka, 2000), implying that the involvement of groundwater in freezing-induced water redistribution could be widespread."

3. Since the Otak station is 35 km away from the study site, I think the authors need to mention the potential impact of meteorological input uncertainties (e.g. spatial mismatch) on the simulations.

Response: Thank you for pointing out this problem. First of all, we want to emphasize that snowfall in the whole Ordos Plateau is limited and quite uniform. For example, in the winter from 2015 to 2016, the cumulative snowfalls in Otok and in Dongsheng are 11.3 mm and 10.7 mm, respectively. Note that the Dongsheng station is around 170 km away from the Otok station. Figure R3 shows the correlation between snowfall in Otok and snowfall in Dongsheng during 2013 and 2018. Therefore, we believe the uncertainty caused by snowfall is limited.

In our observation site, we installed a meteorological station in 2017. Figure R4 shows air temperature, relative humidity and wind speed from 1 NOV 2017 to 1 APR 2018 measured at the two meteorological stations. As shown in Figure R4 a, b and c, the maximum and minimum daily temperatures, and relative humidity at the two stations are close enough. The freezing index, i.e., the cumulative negative temperature, equals -885.8 ℃-days at the Otok meteorological station, and equals -897.4 ℃-days at our monitoring site. We believe that such a small difference in freezing index has limited impact on frost depth and freezing-induced groundwater migration.

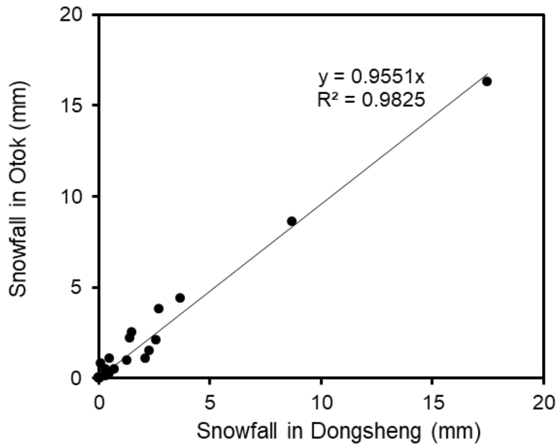

Figure R3 A comparison between snowfalls in the Otok and Dongsheng meteorological stations from NOV 1 2013 to DEC 31 2018.

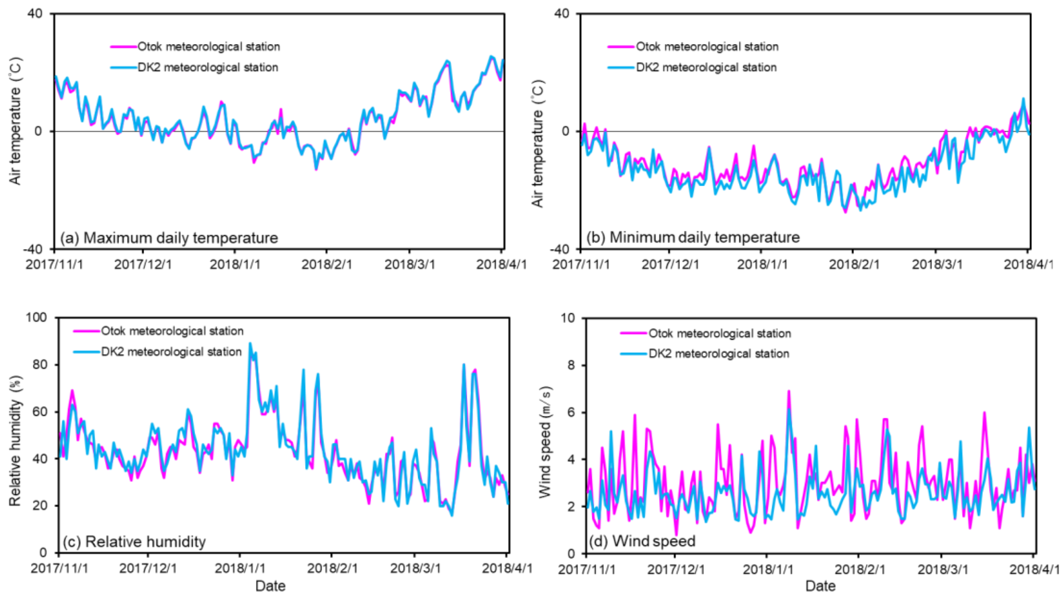

Figure R4 The comparison between the Otok meteorological station and DK2 meteorological station on (a) Maximum daily air temperature; (b) Minimum daily air temperature; (c) Relative humidity; (d) wind speed from 1 NOV 2017 to 1 APR 2018.

Figure R4d shows the wind speeds at the two stations are quite different due to the control of local topography. To investigate the sensitivity of freezing-induced water redistribution to wind speed, we show the total water content and water table fluctuations induced by freezing under two different wind speeds when all other climatic conditions are the same (Figure R5). Although the total water content in the shallow part of the frozen zone is impacted by the wind speed, the total water content in the deep of the frozen zone and in the unfrozen zone, and the water table fluctuations are seldom impacted by wind speed. Therefore, we believe that the uncertainty of wind speed does not undermine our conclusion on freezing-induced groundwater redistribution.

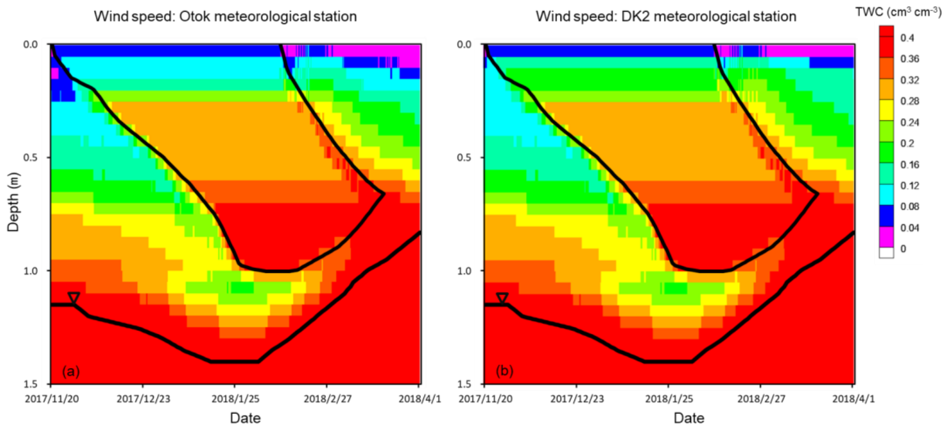

Figure R5 The evolution of simulated total water content from 20 NOV 2017 to 1 APR 1 2018 based on the wind speeds of the Otok meteorological station (a) and the DK2 meteorological station (b). Note that all other climatic conditions (air temperature, relative humidity, solar radiation and snowfall) are based on the Otok meteorological station.

4. Zheng et al. (JHM, 2015, 2017) have also reported the accuracy of 5TM sensors especially in measuring unfrozen liquid water content.

Zheng, D., R. van der Velde, Z. Su, J. Wen, X. Wang, and K. Yang (2017), Evaluation of Noah Frozen Soil Parameterization for Application to a Tibetan Meadow Ecosystem, Journal of Hydrometeorology, 18(6), 1749-1763.

Zheng, D., R. van der Velde, Z. Su, X. Wang, J. Wen, M. J. Booij, A. Y. Hoekstra, and Y. Chen (2015), Augmentations to the Noah model physics for application to the Yellow River source area. Part I: Soil water flow, Journal of Hydrometeorology, 16(6), 2659-2676.

Response: Thanks for your recommendations. Zheng et al. (2015) used the 5TM sensors to measure the soil water content in the unfrozen condition, and Zheng et al. (2017) used the 5TM sensors to measure the liquid water content in the frozen soil. In Zheng et al. (2017), it was also pointed out that the accuracy of 5TM sensors is 0.02 cm^3/cm^3. Therefore, we cited Zheng et al. (2015) and Zheng et al. (2017) in our revision.

Reviewer #2

I would like to thank the authors for their substantial modifications, which address most of my concerns. I would suggest a minor revision before its publication. Please find below my specific comments for consideration.

1. bottom boundary conditions

Thank the authors for the explanations why using flux boundary conditions, not constant head/specific head for the bottom boundary condition. My concern here is why using no-flux boundary conditions. I am not sure about the amount/magnitude of the vertical flux exchange at the bottom boundary.

Response: In a completely closed system, water table would decline when groundwater is migrated toward the freezing front. In a 1D model, a no-flux lower boundary condition is the most suitable boundary condition to characterize the freezing-induced water table decline in a closed system, which had already been employed in the pioneering study of Harlan (1973).

In our monitoring site, the water table recession is alleviated by the vertically upward component of regional groundwater inflow, the magnitude of which is controlled by the regional-scale water table undulation. Theoretically, this upward component of groundwater flow can be characterized by a specified-flux lower boundary condition. In the 1D SHAW model, such a boundary condition can be realized by combining a no-flux lower boundary condition and a specified rate of lateral groundwater inflow near the bottom. In this way, the response of water table to freezing and regional groundwater inflow is well characterized.

2. Line 39-41: "…, water from the unfrozen zone would migrate to the freezing front" suggest to be "…, water fluxes migrate from the unfrozen zone to the freezing front" or something similar.

Response: Thanks for the suggestion. We have changed the sentence into "As a result of cryosuction generated by soil freezing, (Williams and Smith, 1989;Hohmann, 1997;Yu et al., 2018), water migrates from the unfrozen zone to the freezing front."

3. Line 121: "…, we performed site-specific calibration by comparing the liquid water content measured by the 5TM sensors and by the gravimetric method." Feel awkward, please rephrase.

Response: We have changed the sentence into "we performed site-specific calibration by establishing the relationship between the liquid water content measured by the 5TM sensors and that measured by the gravimetric method."

4. Table 1 and Table 2 should better be merged into one table.

Response: Thanks for your suggestion. We have merged the two tables.

5. Figure 8: It is better to add the scenario name with different subplots, according to Table 3.

Response: Thanks for your suggestion. We have added the scenario names on the subplots.

6. This work can benefit from the English edits.

Response: Thanks for your suggestion. The language of the manuscript has been improved.

References:

Daniel, J. A., and Staricka, J. A.: Frozen Soil Impact on Grounf Water‐Surface Water Interaction, JAWRA Journal of the American Water Resources Association, 36, 151-160, 10.1111/j.1752-1688.2000.tb04256.x, 2000.

Drescher, W. J.: Some effects of preciptiation on ground water in Wisconsin, Wisconsin Geological Survey, 1955.

Evans, S. G., and Ge, S.: Contrasting hydrogeologic responses to warming in permafrost and seasonally frozen ground hillslopes, Geophysical Research Letters, 44, 1803-1813, 10.1002/2016gl072009, 2017.

Fan, Y., Li, H., and Miguez-Macho, G.: Global patterns of groundwater table depth, Science, 339, 940-943, 10.1126/science.1229881, 2013.

Harlan, R.: Analysis of coupled heat‐fluid transport in partially frozen soil, Water Resources Research, 9, 1314-1323, 10.1029/WR009i005p01314, 1973.

Hohmann, M.: Soil freezing — the concept of soil water potential. State of the art, Cold Regions Science & Technology, 25, 101-110, 10.1016/S0165-232X(96)00019-5, 1997.

Ireson, A. M., van der Kamp, G., Ferguson, G., Nachshon, U., and Wheater, H. S.: Hydrogeological processes in seasonally frozen northern latitudes: understanding, gaps and challenges, Hydrogeology Journal, 21, 53-66, 10.1007/s10040-012-0916-5, 2013.

Schneider, R.: Correlation of ground-water levels and air temperatures in the winter and spring in Minnesota: US Geol, Survey Water-Supply Paper, 1962, 1961.

Stähli, M., Jansson, P.-E., and Lundin, L.-C.: Soil moisture redistribution and infiltration in frozen sandy soils, Water Resources Research, 35, 95-103, 10.1029/1998wr900045, 1999.

van der Kamp, G., Hayashi, M., and Gallén, D.: Comparing the hydrology of grassed and cultivated catchments in the semi-arid Canadian prairies, Hydrological Processes, 17, 559-575, 10.1002/hyp.1157, 2003.

Vinnikov, K. Y., Robock, A., Speranskaya, N. A., and Schlosser, C. A.: Scales of temporal and spatial variability of midlatitude soil moisture, Journal of Geophysical Research: Atmospheres, 101, 7163-7174, 10.1029/95JD02753, 1996.

Williams, P., and Smith, M.: The frozen earth: fundamentals of geocryology, Cambridge University Press, 1989.

Wu, M., Huang, J., Wu, J., Tan, X., and Jansson, P.-E.: Experimental study on evaporation from seasonally frozen soils under various water, solute and groundwater conditions in Inner Mongolia, China, Journal of Hydrology, 535, 46-53, 10.1016/j.jhydrol.2016.01.050, 2016.

Yu, L., Zeng, Y., Wen, J., and Su, Z.: Liquid‐Vapor‐Air Flow in the Frozen Soil, Journal of Geophysical Research: Atmospheres, 123, 7393-7415, info:doi/10.1029/2018JD028502, 2018.

Zhang, T., Barry, R., Knowles, K., Ling, F., and Armstrong, R.: Distribution of seasonally and perennially frozen ground in the Northern Hemisphere, Proceedings of the 8th International Conference on Permafrost, 2003, 1289-1294,

Zhang, Z., Wang, W., Gong, C., Wang, Z., Duan, L., Yeh, T. c. J., and Yu, P.: Evaporation from seasonally frozen bare and vegetated ground at various groundwater table depths in the Ordos Basin, Northwest China, Hydrological Processes, 10.1002/hyp.13404, 2019.

Zheng, D., Velde, R., Su, Z., Wang, X., and Chen, Y.: Augmentations to the Noah Model Physics for Application to the Yellow River Source Area. Part I: Soil Water Flow, Journal of Hydrometeorology, 16, 2659–2676, 10.1175/JHM-D-14-0198.1, 2015.

Zheng, D., Rogier, V., Su, Z., Wen, J., Wang, X., and Yang, K.: Evaluation of Noah Frozen Soil Parameterization for Application to a Tibetan Meadow Ecosystem, Journal of Hydrometeorology, 18, 1749-1763, 10.1175/JHM-D-16-0199.1, 2017.