Dec10, 2017

Dear editor and reviewers,

The manuscript: *Estimating interaction between surface water and groundwater in a permafrost region using heat tracing methods* **by Gao TG et al.**

The manuscript number: tc-2017-176

We greatly appreciate the reviewers' constructive comments to improve the paper. We have revised our manuscript according to these comments (blue color in the main text), and hope the revised manuscript is suitable for publication in The Cryosphere.

The "point to point" response to comments are listed as below.

Sincerely yours,
Tanguang Gao and Tingjun Zhang

Response to Review 2

Mainly viewpoints

1. In introduction part, the author haven't reviewed if the method have been used in the permafrost area? If yes, what are the difficulties in using this method and what's about the feasibility?

Answer: Thank very much for the constructive comments. We truly learned and tried our best to revise in the main text.

So far, there is not such method applied in the permafrost area according to our literature researches. Even through, some modelling studies of increases in baseflow and sub-permafrost flow are based on hypothetical scenarios (Ge ta l., 2011; Bense et al., 2012). Thus, the difficulties of using this method and the feasibility have been discussed in the section 4.2 *limitations and uncertainties in permafrost region*. We have also modified section 4.2 to strength the difficulties in using this method in the permafrost area".

References:

Ge, S., McKenzie, J., Voss, C., and Wu, Q.: Exchange of groundwater and surface-water mediated by permafrost response to seasonal and long term air temperature variation, Geophys. Res. Lett., 38, 2011.

Bense, V. F., Kooi, H., Ferguson, G., and Read, T.: Permafrost degradation as a control on hydrogeological regime shifts in a warming climate, Journal of Geophysical Research-Earth Surface, 117, 18, 2012.

2. The author pointed out the temperature at the depth of 0 cm is representative of streambed temperature. How about the river water? Have you measured groundwater temperature from the wells?

Answer:

(1) Within the streambed, heat is transferred into and through sediments as a result of four heat-transfer mechanisms, i.e. radiation, conduction, convection, and advection. These four mechanisms may act simultaneously to create dynamic spatial and temporal streambed-temperature patterns (Figure R1) (Constantz, 2008; Constantz et al., 2013). The influence of the river flow on streambed temperature due to the lateral/convective heat transport is a critical heat exchange in streambed. However, the availability of DTS does not aim to detect the heat of pore water or the groundwater, but the low diurnal variation associated with temperature of groundwater inflows entering the stream system because of stable temperature condition prevalent in subsurface stratum (Constantz, 2008). According to an artificial point source experiment by Lauer et al. (2013), even small groundwater inflow fraction down to approximately 2% of upstream discharge could be detected with the DTS. Thus, we don't focus on the influence of river water or pore water, but the spatial distribution of the groundwater inflow points.

(2) We have drilled three boreholes in permafrost area in 2011 to measure the groundwater temperature. However, all of them can't be measured, because they are got frozen even in the thawing season. The other boreholes have been filled with -35# diesel oil in case to be freezing, and data could only use to be the permafrost temperature.

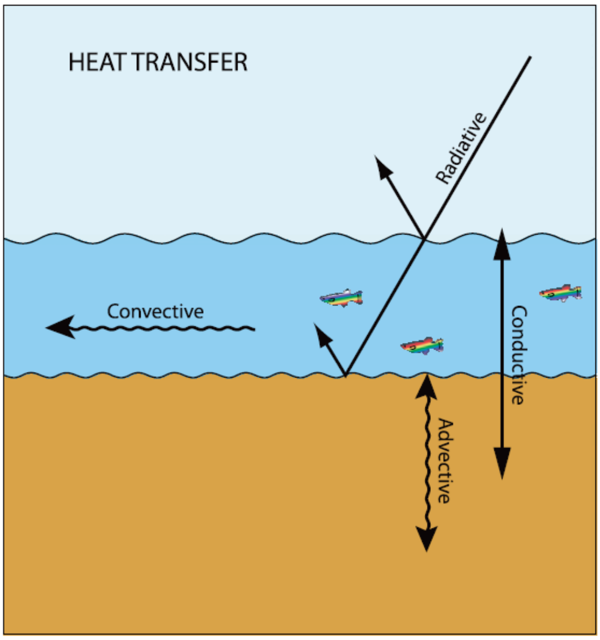

Figure R1 Longitudinal view of a stream and streambed with the four significant heat transfer mechanisms depicted passing over or through the streambed.

Reference:

Constantz, J.: Heat as a tracer to determine streambed water exchanges, Water Resour. Res., 44, 2008.

Constantz, J., Eddy-Miller, C. A., Wheeler, J. D., and Essaid, H. I.: Streambed exchanges along tributary streams in humid watersheds, Water Resour. Res., 49, 2197-2204, 2013.

Lauer, F., Frede, H.-G., and Breuer, L.: Uncertainty assessment of quantifying spatially

concentrated groundwater discharge to small streams by distributed temperature sensing, Water Resour. Res., 49, 400-407, 2013.

3. Line 7 at page 5: I don't understand how the streambed temperature is related to the thick permafrost. As I understand, the talik should occur below the river channel.

Answer:

Thanks for pointing out this mistake. The streambed temperature is not related to the thickness of permafrost. It is should be "colder permafrost" rather than "thick permafrost".

4. The results and discussion section are mixed together and many conclusions are speculative. The more data and evidence are required to further support them. For example, the authors concluded that " As expected, the 5 streambed temperature at P2 was lower than those at S2 and P1, because of its higher elevation and the thick permafrost; In the streambed at P2, the mean temperature at 0 cm was higher than that at S2 and P1, likely because of the shallower depth of the stream and the lower discharge". These conclusions are too arbitrary.

Answer:

We have revised the result of discussion sections. In the revised result section, we have deleted some speculative sentence and move some discussion part to discussion section. As for the discussion section, we have revised this part.

5. Line 20 at Page7: please provide related parameters used to calculate the velocity. What is the depth of the velocity plotted in the figure? Averaged? How to validate these values? Are there any numerical models in there?

Answer:

Figure R2 (Hatch et al., 2006) shows the key parameters to calculate the thermal velocity, including Δz (the spacing between measurement points (m)), Ar (the amplitude ratio (/)), and $\Delta\Phi$ (the phase shift of temperature maxima (d)).

We have added the information in section 2.2.1 as flowing (Page 4-5, Line 29-30 and Line 1-2): *"The principle of this method is that daily temperature fluctuations within a SW body due to solar radiation lead to a temperature response in the streambed at the SW-GW interface due to conduction and convection (Rau et al., 2014). In this paper the convention used is that v is positive for gaining conditions (i.e., when the SW body gains water), and negative for losing conditions (i.e., when the SW body loses water)."*

In Figure 4 of the main text, the velocity means the heat transferred from depth of 0.2 m to 0.5 m. It is calculated by equation 2 (1-D HTE) (Line 16, page 4). In fact, the 1-D HTE (one-dimensional heat transport equation) is a heat transport model to calculate the velocities by the temperature.

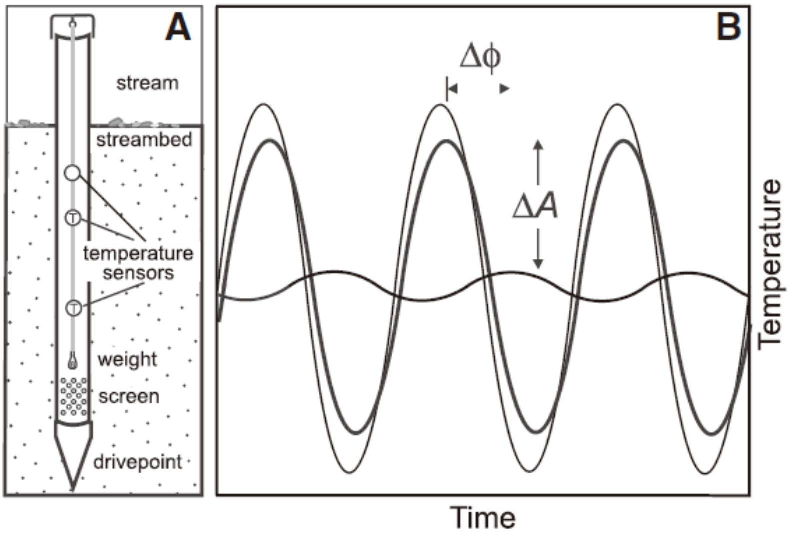

Figure R2 (A) Example of a field installation measuring temperatures at multiple depths. (B) Illustration of temperature amplitude ratio (Δ A) and phase shifting (Δ φ) with depth of measurement (Hatch et al., 2006).

Reference:

Hatch, C. E., Fisher, A. T., Revenaugh, J. S., Constantz, J., and Ruehl, C.: Quantifying surface water-groundwater interactions using time series analysis of streambed thermal records: Method development, Water Resour. Res., 42, 2006.

Rau, G. C., Andersen, M. S., McCallum, A. M., Roshan, H., and Acworth, R. I.: Heat as a tracer to quantify water flow in near-surface sediments, Earth Sci. Rev., 129, 40-58, 2014.

6. It seems that the authors only measured the temperature during July to September in 2015 which are within the thawing season. For investigating the GW-SW interaction in permafrost area, it is hard to use these data to analyze the impact of the permafrost on GW-SW interaction.

Answer:

In our study area, all the reaches in areas with permafrost have been completely frozen with no interaction with groundwater. Thus, we can only analyze the data in thawing season. The following is the (a) 30-min air temperature at P2 in Yeniugou Basin by the air temperature sensor at a height of 2 m above the ground in 2015, and the (b) picture of the reaches near P2 taken in Jan 9, 2016 (Figure R3).

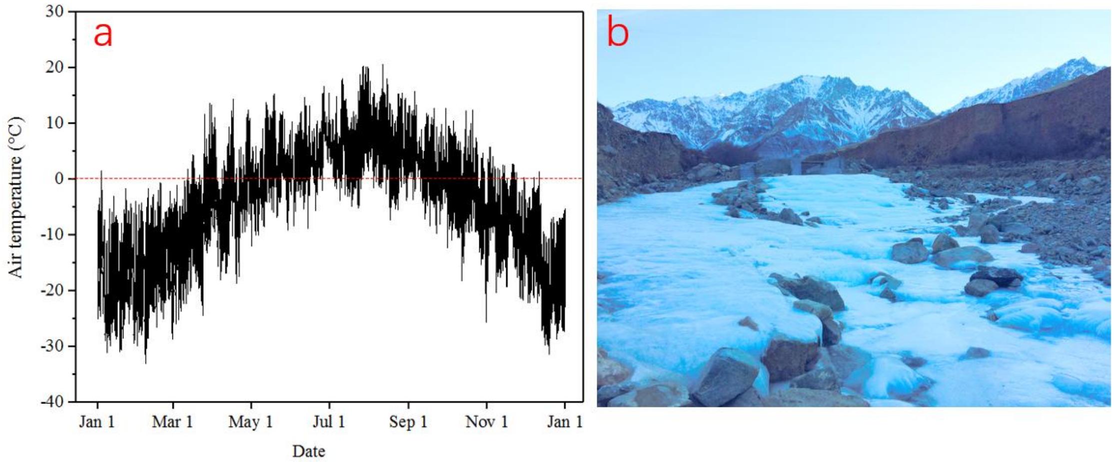

Figure R3 (a) The 30-min air temperature at P2 in 2015; (b) the picture of the reaches near P2 taken in Jan 9, 2016.

7. Line 15 at Page 8: how did you get this conclusion “The losing condition at all the observation sites and the less temperature anomalies demonstrated the low connectivity between the stream and the underlying aquifer”?

Answer:

Constantz (2008) summarized four conditions in streambeds under the influence of streamflow based on the heat tracer method (Figure R4). The losing condition according to 1-D ETH means that the ground water table is deeper beneath the SW body. Meanwhile the less temperature anomalies according to FO-DTS means no groundwater inflow to the SW body. In summary, it demonstrated the low connectivity between the stream and underlying aquifer.

We have revised the sentence as following (Page 9, Line 4-6)：

“*The losing condition according to 1-D ETH means that the ground water table is deeper beneath the SW body. While the less temperature anomalies according to FO-DTS means no groundwater inflow to the SW body. In summary, it demonstrated the low connectivity between the stream and underlying aquifer.*”

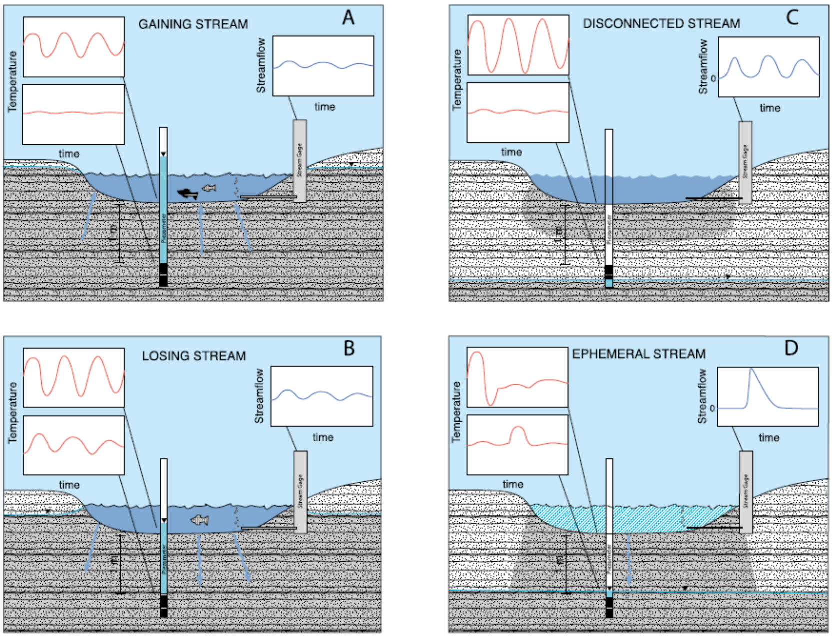

Figure R4 Thermal and hydraulic conditions in streambeds under the influence of streamflow for (a) gaining, (b) losing, (c) disconnected, and (d) ephemeral stream settings (Constantz, 2008).

8. For section 4.1 "Implications of SW-GW interaction in permafrost region": the discussion should be based on the results obtained from this study and the condition that related to the study site. Many discussions are the common knowledge or existed understandings.

Answer:

We have revised the results and discussion section.

9-1 From discussion part, I can't see how the permafrost affect the GW-SW interaction based on the analysis from the measured data. Also, I can't see any differences of SW-GW interaction processes between permafrost and permafrost-free area.

Answer:

There are two differences or the influences of permafrost of SW-GW interaction in this paper, and we have addressed in the manuscript.

(1) the SW body trends to lose more water to GW in permafrost area over time associated with the deepening of active layer, while the intensity of SW-GW interaction in permafrost-free area is fluctuated but exhibits no such trend.

(2) permafrost area may become more disconnected between the SW body and groundwater with the thawing active layer due to the ground water table is deeper with the thickening active layer.

Section 4.2.1: the limitations talked about here are not really the limitations of the application of the heat tracer in permafrost area.

(1) Line 26-29 at Page 9: One could encounter this kind of situation at other places which are not specific in permafrost area.

Answer:

We have revised the sentence as following (Page 9, line 28-31)

“The permafrost region is characterized by the intensification occurrence of the freeze-thawing and frost heavy actions. We installed FO-DTS at seven observation sites for temperature-depth variations in the study area, three of which failed because of frost heaving damage. Even in the available observation sites (e.g. S1), the sensor cannot exactly catch the signals giving rise abnormal data influenced by the freeze-thawing cycle (green rectangles in Fig. 7).”

(2) Lines 30-31 at Page 9 and lines 1-4 at Page 10: these are not really the difficulties since the measurements are simple.

Answer:

The extreme climate condition is one of the big challenges for our measurement. It is almost impossible to measure the thermal properties in all 500-m distance. That is the reason why we don’t use the Darcy velocity but the thermal front velocity as the tracer of SW-GW interaction. But we agreed this is not one of the difficulties. We have moved this part to the *4.2.2 Uncertainties*.

(3) Lines 6-11 at Page 9: These statements are unrelated to the study topic “GW-SW interaction”.

Answer:

We have deleted this part in the manuscript. In addition, we have tried or best to revise this section.