

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 1

(1) Equation 1. The standard convention in the SW-GW interaction literature (i.e. those cited by the authors) is to use the z-axis to indicate depth, not elevation. Since the authors do not define it differently, the reader would assume that the z-axis is positive downward. Therefore, a positive value of velocity indicates downward flow, and a negative value indicates upward flow. This is opposite to the authors' interpretation of flow direction (P7, L19). This calls the validity of the results into question.

Answer: Thank you very much for the comments.

Our result didn't used the equation 1 directly. We used a solution for equation 1 that explicitly solved the thermal front velocity from consecutive pairs of temperature amplitude and phase shift data (Equation 2). In the equation 2, we only used ' Δz ', which is the spacing between measurement points (m). Thus, the depth doesn't influence the flow direction. The explanation has been added in the main text (Page 4, Line 11-15) to clarify the possible misunderstanding about z axis.

(2) P4, L27. Since the publication of Lautz (2012) and Rau et al. (2015), further advances have been made in analytical methods and tools for diurnal temperature signals. Without more rigorous efforts to quantify the Darcy flux, this manuscript stops short of meeting the standard expected for SW-GW interaction studies published in a referred journal. Since one of the two objectives of this study is to "test the validity of the heat tracing methods in permafrost hydrology" (P3, L3), it is critical that the authors use the best and the most current method for data analysis.

Answer:

The citing of the Lautz (2012) and Rau (2015) may be confusing. In fact, the calculation of Darcy flux is not complicated in our method. The equation of Darcy flux as flowing:

$$D = v \gamma$$

Where, D is Darcy flux, v is the thermal front velocity, γ is a constant (Equation 3 in the manuscript).

$$\gamma = \frac{n\rho_w c_w + (1-n)\rho_s c_s}{\rho_w c_w}$$

(Eq. 3)

Where, γ is the Darcy velocity index, n is porosity, ρ_w and c_w are the density (kg m^{-3}) and heat capacity ($\text{J kg}^{-1} \text{ }^\circ\text{C}^{-1}$) of water respectively; ρ_s and c_s are the density (kg m^{-3}) and heat capacity ($\text{J kg}^{-1} \text{ }^\circ\text{C}^{-1}$) of solid.

The direction of variation of the thermal front velocity is enough for reflecting on the change of interaction between SW-GW and we could also avoid the heterogeneity of the local thermal physical parameters. Thus, we only analysis the velocity on the result rather than the Darcy flux.

We revised the main text as flowing (Page 4, Line 27-28):

To avoid the heterogeneity of the local thermal physical parameters in constant γ , we only used the direction and variation of the thermal front velocity, which an reflect on the SW-GW interactions.

(3) P4, L31-P5, L1. I question the validity of this approach. The foundation of the analysis of diurnal fluctuations is Equation 2, which assumes harmonic temperature signals having a frequency of 24 hours. The peaks and troughs picked in the time domain are influenced by non-diurnal components of the temperature signal, which is not compatible with Equation 2. If the authors do not want to use the harmonic analysis, a proper approach would be to use a numerical model to solve the heat transfer equation and optimize the solution (e.g. Constantz 2008).

Answer:

Thanks for the question. To be clear, the approach is evidence to be validated, but the description of the method may be confused. The program selects not only the peak temperature, but also the corresponding time. If the time corresponding the max/min value was overflow a time boundary among a 24-hour period, the program would set the phase and time as null value.

It is true that some harmonic temperature signals have not a frequency of 24 hours due to the influence of the cold weather or other reasons. The Constantz's model was also a good numerical model. But we try to use the amplitude ratio and the phase shift directly, and tell the readers how much the permafrost environment influences the temperature signals. Thus, we don't use the harmonic analysis or numerical models, and some signals with non-diurnal components were set to null values. There are 6, 0, 8 and 13 days with non-diurnal signals set as null values in S1, S2, P1 and P2 respectively (we discusses this part in 4.2.2 Page 10, line24-30).

We have revised in the main text as flowing (Page 5, Line 5-8):

"The program selects the peak temperature and corresponding time in one temperature cycle based on diurnal fluctuations, followed by automatic selection of subsequent peaks and time across the remaining records. If the time corresponding the max/min value was overflow a time boundary among a 24-hour period, the program would set the phase and time as null value."

(4) P5, L30. Looking at Google Earth images of the study sites, I get a sense that this is a major river with a substantial channel width. How do the sensors located only one meter from the stream

bank represent the SW-GW interaction in the river? It will be useful to include the essential information about the river, such as discharge hydrograph, as well as depth, width, and velocity at measurement points.

Answer:

The S2, P1 and P2 were the tributaries of the upper Heihe River. The widths of the tributaries were only 2-3 meters in low flow period. For the S1, the discharge was very high and there were many rocks in the channels. It is very hard to fix the cable and loggers in the central channels. Between the site S1 and site S2, the river channel was showed as braided river, which I believed was the image you looked in Google Earth. The channels changed very frequently, and most braided channels have no water occurrence in the monsoon season.

(5) P6, L4-6. It has been widely shown in the literature that the contact between DTS cable and stream-bed sediment is critically important. I do not believe that the method described in these sentences ensures that the cable is actually measuring the stream bed temperature, not the temperature of water flowing just above the stream bed. Figure 5 seems to indicate that the cable is sensing the temperature of flowing water, not the temperature of pore water at the stream surface.

Answer:

The streambed temperature is influence by the vertical and horizontal heat transport (Constantz et al., 2013). The influence of the water flow on the streambed temperature due to the lateral heat transport is also a critical heat exchange in surface streambed (Ge et al., 2012).

However, the availability of DTS is not to detect the heat of pore water, 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 by DTS. Thus, we don't focus on the contact between DTS cable and the streambed sediment, but on the spatial distribution of the groundwater inflow points.

References:

- Constantz, J. (2008): Heat as a tracer to determine streambed water exchanges. *Water Resour. Res.* 44(10.1029/2008wr006996
- Constantz, J., Eddy-Miller, C. A., Wheeler, J. D., and Essaid, H. I. (2013): Streambed exchanges along tributary streams in humid watersheds. *Water Resour. Res.* 49(4), 2197-2204. 10.1002/wrcr.20194.
- Evans, S. G., Ge, S., and Liang, S. (2015): Analysis of groundwater flow in mountainous, headwater catchments with permafrost. *Water Resour. Res.* 51(12), 9564-9576. 10.1002/2015wr017732.
- Lauer, F., Frede, H.-G., and Breuer, L. (2013): Uncertainty assessment of quantifying spatially concentrated groundwater discharge to small streams by distributed temperature sensing. *Water Resour. Res.* 49(1), 400-407. 10.1029/2012wr012537.

(6) P7, L20. I am not sure if the authors' interpretation of the sign of velocity is correct (see my comment above). It is unusual to have a large river like this losing water at all the sites during the wet season.

Answer:

(1) Although the YNG basin is large, it is only a part of the upper reaches of Heihe Basin in the north edge of Tibetan Plateau (Figure R1).

(2) The interaction between groundwater and surface water is very complexed in permafrost area. All the sites that we observed are losing condition, but some reaches are still be in gaining condition, where located in between S1 and S2. We can see some temporary groundwater discharge in the braided reaches, which is dry up in the most time in wet season. Unfortunately, we cannot measure the streambed temperature due to the channel is changing in the braided reaches in the wet season. We have discussed with some professors in groundwater, and the future studies will be continued.

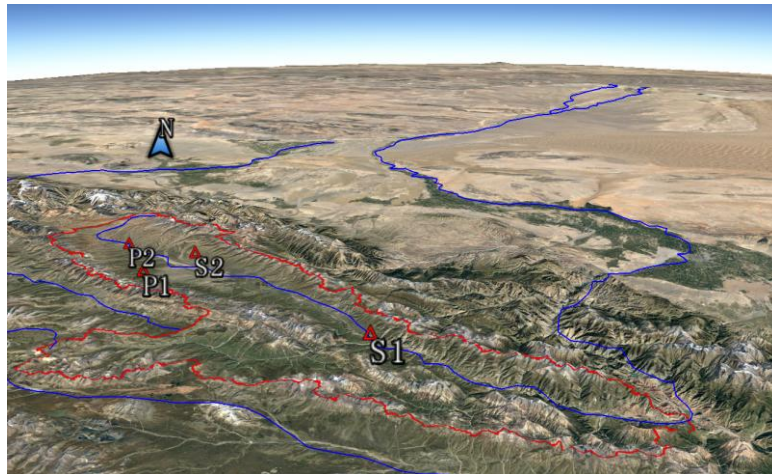


Figure R1 the location of Yeniuogou basin in northern Tibetan Plateau.

(7) P9, L24. I do not understand how the stream bed temperature exposed to flowing water can fall much below zero (-2 C in Fig. 2c) during summer months. Were the temperature sensors properly calibrated?

Answer:

We have calibrated all the sensor in lab before we installed them in the field. The average elevation in our study area is about 4200 m where it is common that the air temperature falls below zero. The following is the 30-min air temperature in Yeniuogou Basin by the air temperature sensor at a height of 2 m above the ground in summer time (Figure R2).

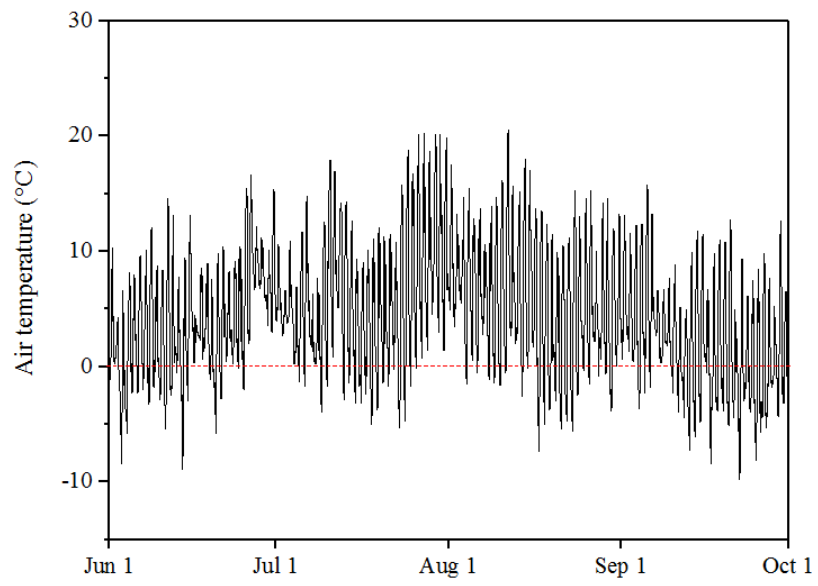


Figure R2 The 30-min air temperature at P2 in summer of 2015.