Visualization of Distributed Temperature Sensing shows fine-scale water temperature dynamics in a subarctic stream over melt season

Danny Croghan[1], Kieran Khamis[2], David Hannah[2], Ilkka Martinkauppi[3], Pertti Ala-Aho[1], and Hannu Marttila[1]

[1]Oulun yliopisto
[2]University of Birmingham
[3]Geologian tutkimuskeskus

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Abstract

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Danny Croghan[1], Kieran Khamis[2], David M. Hannah[2], Ilkka Martinkauppi[3], Pertti Ala-Aho[1], and Hannu Marttila[1]

(1) University of Oulu, Oulu, Finland

(2) University of Birmingham, Birmingham, United Kingdom

(3) Geological Survey of Finland (GTK), Finland

Description:

Rising global air temperatures are altering thermal regimes of streams with major implications for physical, chemical and biological processes (Hannah & Garner, 2015; Michel et al., 2022; Van Vliet & Zwolsman, 2008) Stream water temperature increases in high latitude regions are more pronounced and rapid than anywhere else in the world (Post et al., 2019), hence thermal regimes in polar streams are currently undergoing rapid perturbations that require urgent study (Blaen et al., 2013; Docherty et al., 2019; Park et al., 2017).

Technological advances in high-resolution monitoring offer tools to improve processes understanding, feed hydrological-thermal models and guide more targeted management strategies (Ouellet et al., 2020). The development of Distributed Temperature Sensing (DTS) allows high-resolution spatial (centimeter to meter scale) and temporal (minutes to hours) continuous measurement of water temperature to enable identification of patterns and processes at finer-scales than possible previously (Matheswaran et al., 2014; Mohamed et al., 2021). However, the use of DTS to explore in-stream temperature dynamics in high-latitude regions over seasonal scales has been poorly documented to date. Ploum et al. (2018) visualized DTS data in a boreal stream, where the stream thermal regime was heavily influenced by an upstream lake. In this article, for the first time, we visualize spatially resolved DTS measurements of water temperature changes across the melt season in a subarctic stream.

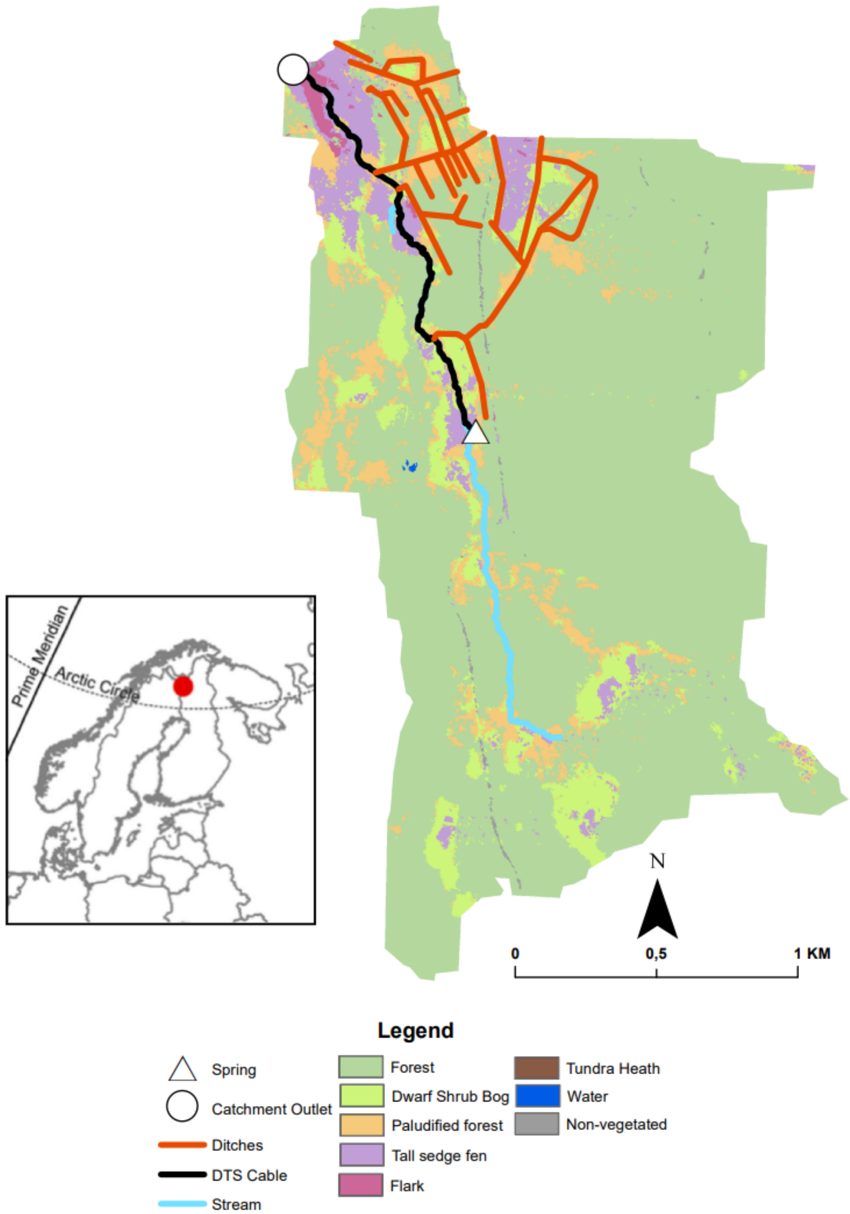

Figure 1 *– Map of Pallas catchment and location in Finland. The location of the DTS cable, stream, and ditch systems are shown. Classification of vegetation in the catchment is derived from Räsänen et al. (2021).*

The video (Video S1) shows daily mean water temperature at a 10m resolution for a 2 km reach in a headwater subarctic stream in Pallas, Northern Finland (68°02'N, 24deg16'W; Figure 1). For context, moving graphs of precipitation, air temperature, and snow depth are also shown. A Halo DTS system (Sensornet, UK) was installed into the stream and made double-ended measurements. The DTS measured water temperature at 2 m spatial resolution and at a 30-minute temporal resolution from 01 May 2021 to 16 Sep 2021. The data collection captured the onset of snowmelt period and continued to early autumn which comprises the period where the stream shows the strongest connectivity with the wider catchment in Pallas (Marttila et al., 2021). DTS temperature records were calibrated against a reference HOBO Pendant water temperature logger (Onset, MA, USA) located in an upstream spring. The DTS data were then cleaned, with areas the cable that were exposed to air temperature due to dewatering filtered out using cross-correlation analysis, and 10 m averages calculated (n = 5). To facilitate assessment of spatial and seasonal dynamics daily mean water temperature records are presented. All data processing and visualization was completed using R version 4.04 (R Core Team, 2022). Graphs were created using the "*ggplot* " package and "*gganimate* " was used to generate moving images.

Our visualization shows snowmelt to be a dominant control on the thermal regime of the whole Lompolonjanganoja stream system. Throughout the snowmelt period, water temperature remains relatively low and constant at all locations along the cable, likely because of cold meltwater runoff from the catchment dominates temperature dynamics at all points during this period. Thus, length of snowmelt season is highlighted as a crucial control on stream temperature dynamics (Slemmons et al., 2013). After snowmelt, localized fluctuations in water temperature regime become apparent. The 500-650 m segment of the stream had consistently above average stream temperature during the summer period. Thus, it may be inferred that localized inputs of warm surface water occur here, creating a "hotspot" of potential increased biogeochemical activity (Marruedo Arricibita et al., 2018). GIS investigation revealed drainage ditches may be a possible source of these warm water inputs, a prominent feature in Nordic peatlands due to historical drainage practices (Hasselquist et al., 2018; Nieminen et al., 2018).

The cable terminates in a large natural spring (located at the 1900-2000 m portion of the cable), which is seen as a very constant temperature in the spring throughout the study period. Interestingly, while DTS has previously been used to identify groundwater inputs into streams (Marruedo Arricibita et al., 2018; Matheswaran et al., 2014), and despite numerous other springs visible in the channel, the impact of springs on stream temperature appears minimal during the summer period. Only one area of the cable (~800m) appeared consistently cooler than the rest of the stream during the warmest period of early July. While cold water refugia have previously been found to be important refugia from high temperatures in other systems (Fullerton et al., 2018), the low impact visible for this subarctic stream suggests that the downstream influence of springs provides minimal mitigation to high temperature events. By autumn (September), water temperature across the cable once again became relatively spatially homogenous despite air temperatures remaining elevated. This indicates the hydrological connectivity providing localized 'hotspots' in water temperature become disconnected from the main channel by early Autumn. Thus, it is notable the most dynamic period of water temperature response to catchment behavior appears constrained to the post-melt summer months.

Our dataset has potential to investigate dominant controlling processes for water temperature at high spatial resolution in logistically challenging high latitude environments. Identification of patterns in the resolved spatial and temporal data become apparent through animation and the great potential of DTS to assess seasonal drivers of water temperature can be observed.

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