Geophysical Research Abstracts
Vol. 19, EGU2017-15405, 2017
EGU General Assembly 2017

Gravel bar thermal variability and its potential consequences for CO_2 evasion from Alpine coldwater streams

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Gravel bars (GB) are ubiquitous in-stream structures with relatively large exposed surfaces, capable of absorbing heat and possibly acting as a heat source to the underlying hyporheic zone (HZ). The distinctive mixing of groundwater and surface water within their HZ largely determines its characteristic physical and biogeochemical properties, including temperature distribution. To study thermal variability within GBs and its possible consequences for CO_2 evasion fluxes we analysed high frequency spatio-temporal data for a range of stream and atmospheric physical parameters including the vertical GB temperature, in an Alpine cold water stream (Oberer Seebach, Austria) over the course of a year. We found the vertical temperature profiles within the GB to vary seasonally and with discharge. We extended our study to 13 other gravel bars of varying physical characteristics within the surrounding Ybbs and Erlauf catchments, conducting diurnal spot samplings in summer 2016. Temperatures within the observed permanently wetted hyporheic zone (-56 to -100cm depth below GB surface) of the OSB, were warmer than both end members, surface water and groundwater >18% of the year, particularly during summer. There was a general increase in exceedance within the periodically wetted gravel bar sediment toward the gravel bar surface, further evidencing downward heat transfer to the wetted HZ. Average CO_2 flux from the GB was significantly higher than that of streamwater during summer and winter, with significantly higher temperatures and CO_2 outgassing rates occurring at the GB tail as compared to streamwater and the head and mid of the GB throughout the year. Higher cumulative (over 6 h) GB seasonal temperatures were associated with increased CO_2 evasion fluxes within the OSB, particularly during summer. This enhanced CO_2 flux may result from the input of warmer CO_2-rich groundwater into the HZ in autumn, while downward heat transfer in summer may enhance GB metabolism and therefore CO_2 evasion. Furthermore, catchment CO_2 outgassing fluxes significantly exceeded that of the stream, with higher diurnal CO_2 outgassing fluxes observed for all 13 GBs within the Ybbs and Erlauf catchments as compared to their respective streams. We found DOC concentration did not significantly correlate to CO_2 outgassing. But, vertical temperature gradient as a measure of heat flux to the hyporheic zone explained 55% and 69% of the variability in observed CO_2 efflux from the OSB gravel bar (seasonal samplings during summer 2015 – winter 2016) and 11 catchment gravel bars (2 GBs excluded due to equipment malfunction) respectively. These results highlight the effect of temperature on physical and biochemical stream processes, particularly in cold-water streams, due to the occurrence of more frequent and intense warm temperature events, as well as altered flow regimes, likely consequences of climatic change.