Geophysical Research Abstracts
Vol. 17, EGU2015-5107, 2015
EGU General Assembly 2015

LPMLE3: A New Analytical Approach to Determine Vertical Groundwater-Surface Water Exchange Flux under Uncertainty and Heterogeneity

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Quantifying groundwater-surface water exchange flux has become an integral part in the study of hyporheic zone processes as well as in the evaluation of the transport and fate of contaminants and nutrients. Several methods have been developed to quantify vertical exchange fluxes from field measurements. One possibility is to use temperature measurements obtained from the top of a porous medium such as a streambed and at some depth and quantify water fluxes by solving the partial differential equation for coupled water flow and heat transport. To determine purely vertical flux from temperature-time series, various analytical 1D procedures have been devised (e.g. Hatch et al., 2006; Keery et al., 2007) that make use of information regarding amplitude attenuation and phase shift between two temperature measurements with a certain vertical spacing and one specific frequency. Other methods (Vandersteen et al., 2014; Wörman et al., 2012) solve for vertical water flow and heat transport in the frequency domain and can use more information from the recorded temperature signals.
All of these analytical approaches assume the subsurface to be a semi-infinite homogeneous halfspace. Here we introduce the LPMLE3 method (Local Polynomial Maximum Likelihood Estimator using three measurements), a new analytical approach that quantifies vertical fluxes in the frequency domain without being constrained by this assumption. By using multilevel temperature lances we collected temperature data from seven depths simultaneously at one location in the Slootbeek, a small Belgian lowland stream. Information from these seven sensors was used with the LPMLE3 method to calculate fluxes for finite domains. Each finite domain has a temperature boundary condition (sensor) at its top and bottom, while the flux is estimated for a third temperature signal (sensor) within this domain. The LPML3 method makes use of a local polynomial systems model and a maximum-likelihood estimator to estimate fluxes and parameter uncertainties. However, by assuming finite domains, thermal parameters only need to be considered locally constant, which is a more realistic assumption for a dynamic streambed.
Flux results from the Slootbeek obtained with the LPMLE3 were compared to results from seepage meter measurements and those obtained with the LPML method (Vandersteen et al., 2014). For the Slootbeek we can show that during a three-week period in November 2012 the vertical flux varies between -186 mm/d (gaining stream conditions) and -300 mm/d with varying uncertainty.

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