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Spectral decomposition of time-scales in hyporheic exchange

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Hyporheic exchange of heat and solute mass in streams is manifested both in form of different exchange mechanisms and their associated distributions of residence times as well as the range of time-scales characterizing the forcing boundary conditions. A recently developed analytical technique separates the spectrum of time-scales and relates the forcing boundary fluctuations of heat and solute mass through a physical model of the hydrological transport to the response of heat and solute mass. This spectral decomposition can be done both for local (point-scale) observations in the hyporhiec zone itself as well as for transport processes on the watershed scale that can be considered "well-behaved" in terms of knowledge of the forcing (input) quantities. This paper presents closed-form solutions in spectral form for the point-, reach- and watershed-scale and discusses their applicability to selected data of heat and solute concentration. We quantify the reliability and highlight the benefits of the spectral approach to different scenarios and, peculiarly, the importance for linking the periods in the spectral decomposition of the solute response to the distribution of transport times that arise due to the multitude of exchange mechanisms existing in a watershed. In a point-scale example the power spectra of in-stream temperature is related to the power spectrum of the temperature at a specific sediment depth by means of exact solutions of a physically based formulation of the vertical heat transport. It is shown that any frequency (ω) of in-stream temperature fluctuation scales with the effective thermal diffusivity (κ_e) and the vertical separation distance between the pairs of temperature (ε) data as $\omega \propto \kappa_e/(2\varepsilon^2)$, which implies a decreasing weight to higher frequencies (shorter periods) with depth. Similarly on the watershed-scale one can link the watershed dispersion to the damping of the concentration fluctuations in selected frequency intervals reflecting various environments responsible for the damping. The frequency-dependent parameters indicate that different environments dominate the response at different temporal scales.