Geophysical Research Abstracts
Vol. 20, EGU2018-16855, 2018
EGU General Assembly 2018

Bed load variability and hysteresis in gravel bed rivers: a laboratory investigation

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Measurement and estimation of bed load transport in gravel bed rivers are highly affected by its spatial and temporal fluctuations. Such variability is primarily driven by the flow regime but is also associated with a variety of inherent channel processes such as flow turbulence, grain entrainment and bedforms migration. These internal and external controls often act at comparable time scales, and are therefore difficult to disentangle, thus hindering the study of bed load variability under unsteady flow regime. Laboratory experiments were performed in a 24 m long, 3 m wide, mobile bed flume, where typical hydromorphological conditions of gravel bed rivers were reproduced. Experiments included square-wave hydrographs, and triangular hydrographs with three different durations. Each experiment was repeated for at least 30 times, thus allowing for a statistically sound description of the recorded bed load flux. We found that the inherent variability of bed load flux strongly depends on the sampling interval, and it is significantly higher in complex, wandering or braided channels. This variability can be filtered out by computing the mean response over the experimental replicates, which allows us to highlight two distinctive phenomena: (i) an overshooting (undershooting) response of the mean bed load flux to a sudden increase (decrease) of discharge, and (ii) a clear clockwise hysteresis in the sediment rating curve during a flood event. This two phenomena represent two sides of the same coin, as they can both be associated with a lag in the morphological adaptation to unsteady flow. To interpret this mechanism, we developed a conceptual mathematical model that includes the fundamental feedbacks between reach averaged bed load transport and channel morphology. The model explains how the hysteresis effect depends on the duration of the flood relative to the time scale of the morphological adaptation. Overall, this work provides basic information for evaluating, monitoring, and managing gravel transport in morphologically active rivers.