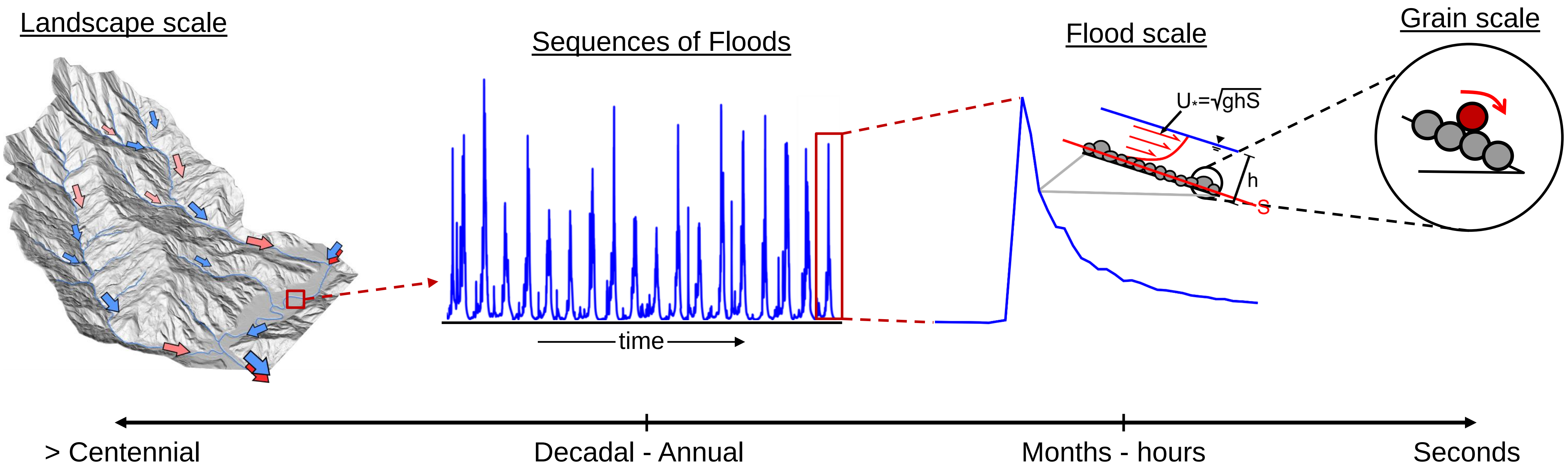
Understanding the impacts of hydrograph transience on sediment transport



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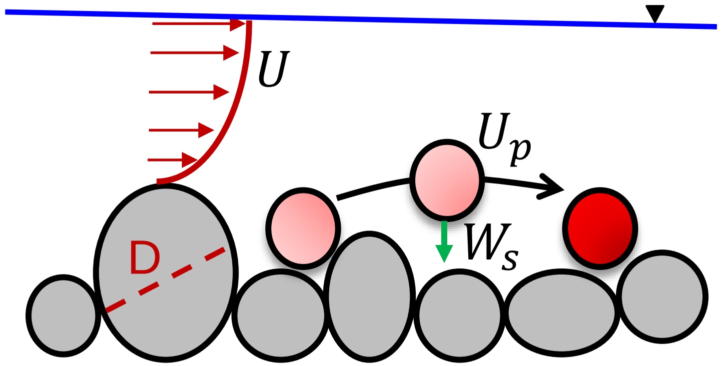
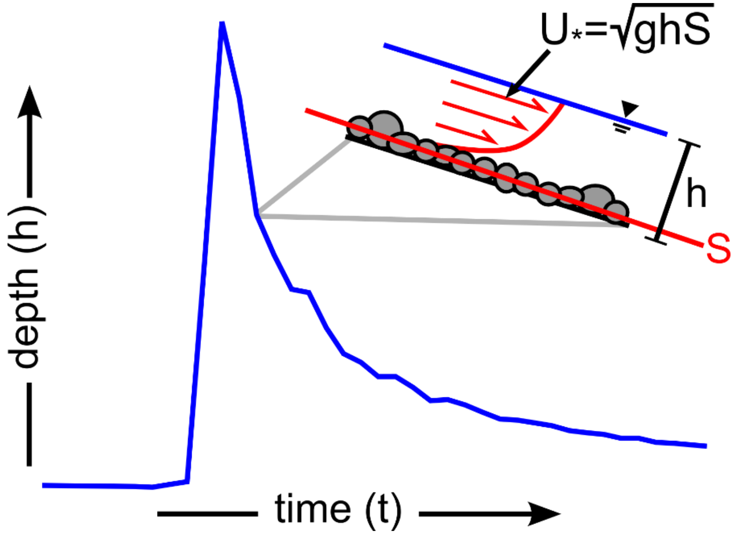
Quantifying forcing at different scales

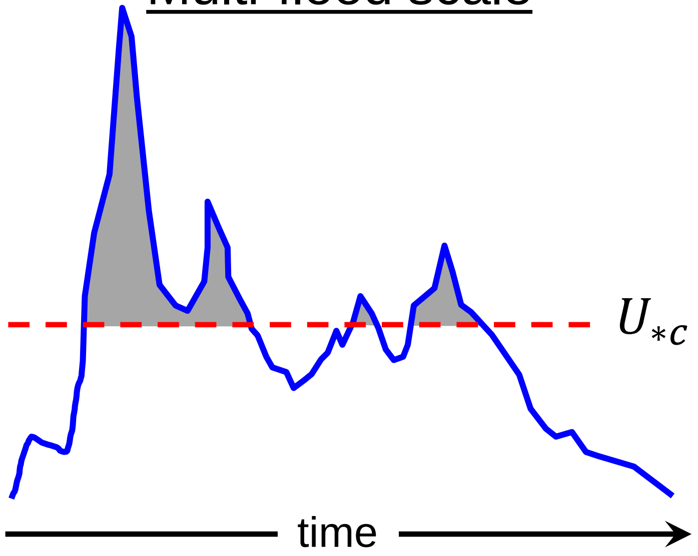
Grain Scale



Flood scale



Multi-flood scale



Force balance on a moving grain

$$\frac{U_p}{W_s} \sim \frac{(U_* - U_{*c})}{\sqrt{f}}$$

Force balance on the bed

$$N_p \sim (U_*^2 - U_{*c}^2)$$

(Charru et al., 2004; Lajeunesse et al., 2010)

Reach scale stress & flow

$$\tau = \rho U_*^2 \qquad \left(\frac{8}{f}\right)^{1/2} = \frac{U}{U_*}$$

$$\tau_* = \frac{\tau}{(\rho_s - \rho) g D}$$

Depth slope approximation

$$\tau = \rho g h s$$

Integrate to estimate displacement for a series of flood impulses

Displacement version

$$I_* = \int (U_* - U_{*c}) dt / D_{50}$$

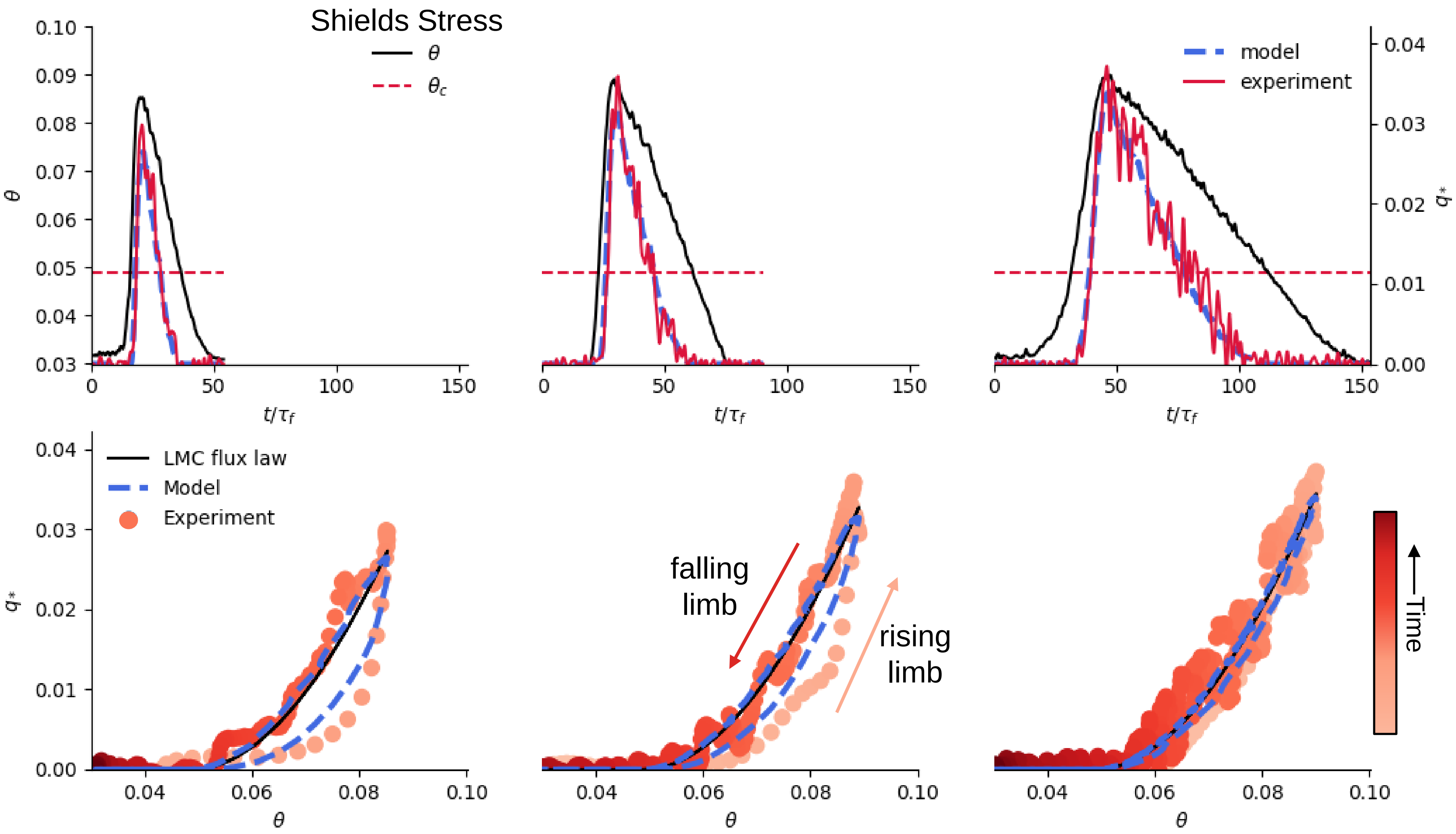
Flux version

$$T_* = \int_{t_s}^{t_f} (U_*^2 - U_{*c}^2)^{3/2} dt / g D_{50}^2$$

Grain scale – Hysteresis within bed load transport at instantaneous flux scale

Key points.
Naturally occurring processes pose challenges for sediment transport models based on time & space averaged quantities. Hysteresis is one such outcome, seen here in our experiments due to the transient forcing of the experimental flood wave (black line).

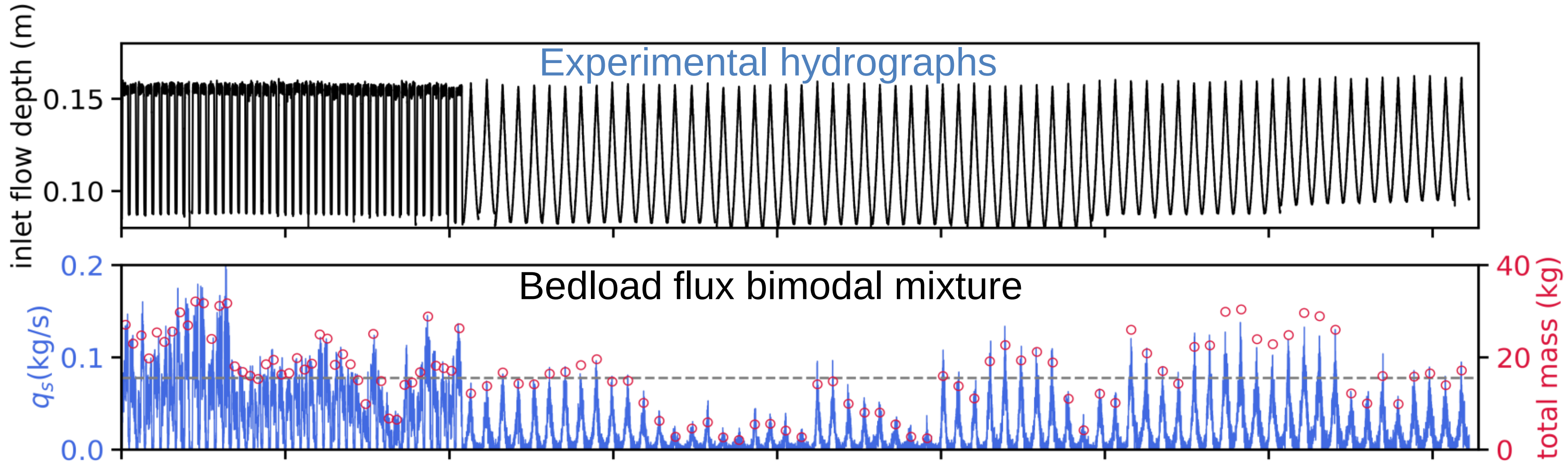
The erosion & deposition transport model (Charru et al., 2004, dashed blue line) includes hysteresis naturally due to differing timescales between erosion (~instantaneous) and deposition (eroded particles take time to transport and deposit). A preliminary test of the model on transient flow reveals an encouraging agreement with data.



<u>LMC flux law</u> $q_* = 10.1(\theta - 0.049)(\theta^{0.5} - 0.049^{0.5})$

(Lajeunesse et al., 2010)

Experimental flood scale – impulse accounts for variability in transient forcing for sediment mixtures



Dimensionless integrated potential bedload flux

$$T_{*B} = \int_{t_s}^{t_f} \left(U_*^2 - \langle U_{*c}\rangle_i^2\right)^{3/2} dt / g\langle D\rangle_i^2$$

Dimensionless integrated bedload flux

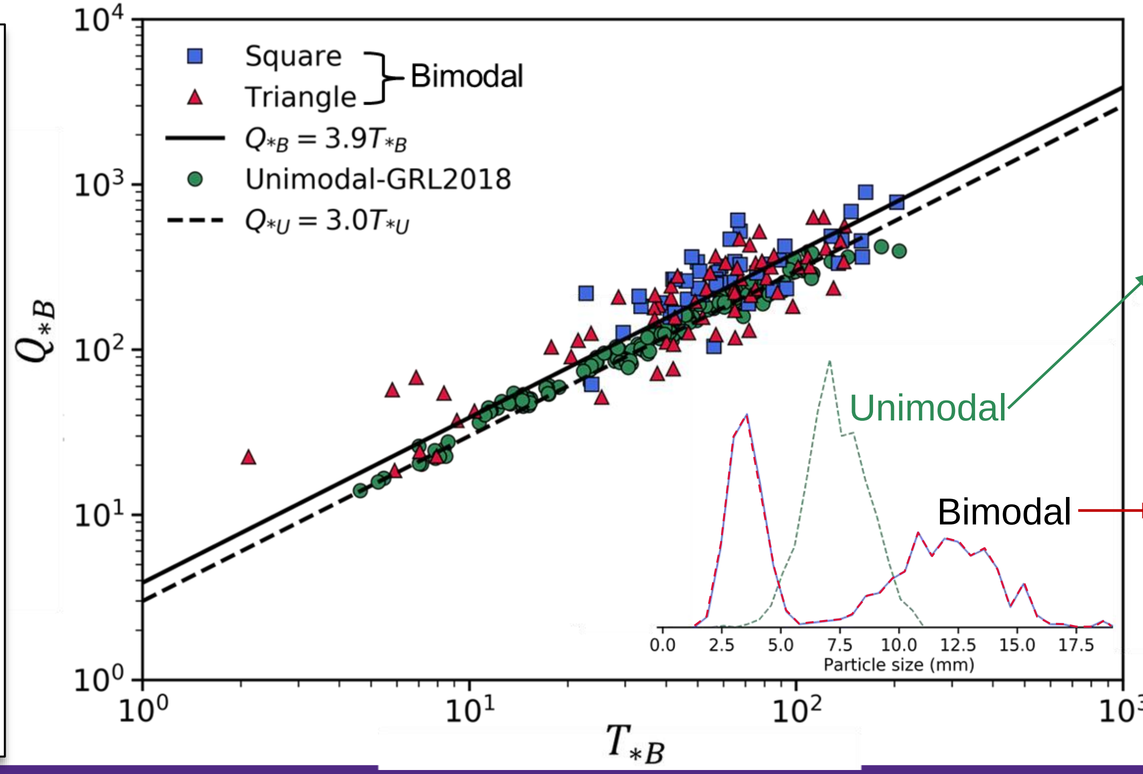
$$Q_{*B} = \int_{t_s}^{t_f} (q_b) dt / \langle D\rangle_i^2$$

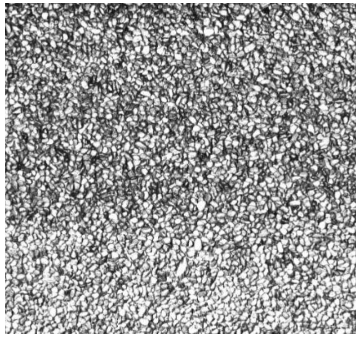
Fitting parameters for bimodal runs in red.

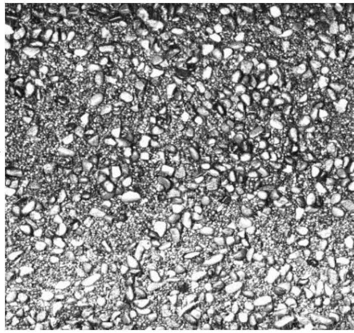
Key points. Experiments with repeated steady and unsteady hydrograph shapes demonstrate that sediment bed grain size distribution adds more complexity than transience in the flow.

Despite substantially more complex bed dynamics for the bimodal case, the integrated bedload flux can be understood through the impulse once accounting for changes in the threshold of motion and the evolution of the bed grain size.

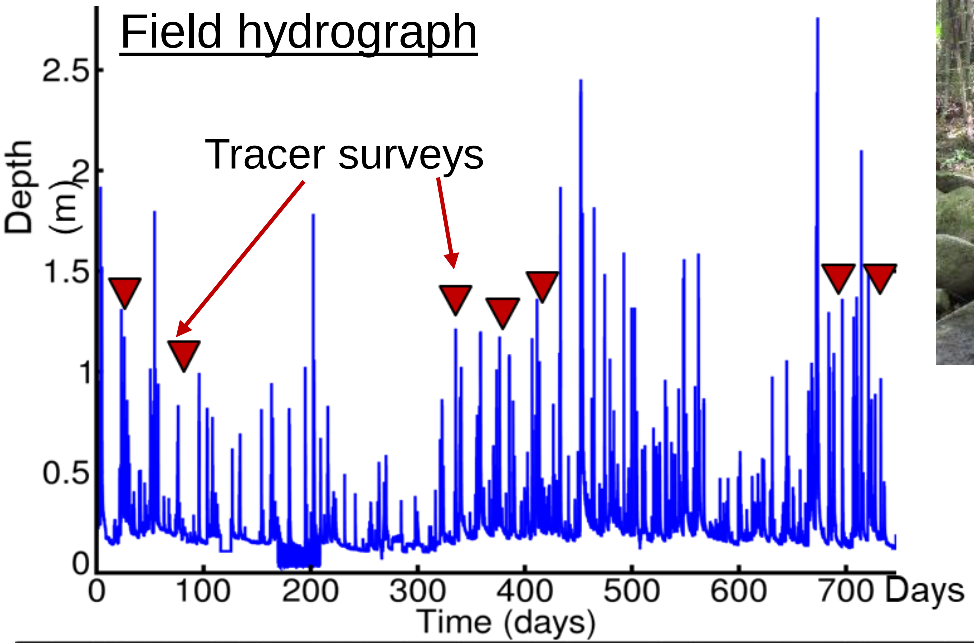
Impulse parameter bridges from grain scale to flood scale and sequences of floods for laboratory experiments.

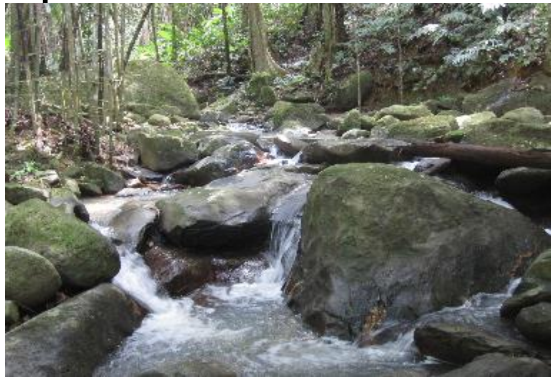




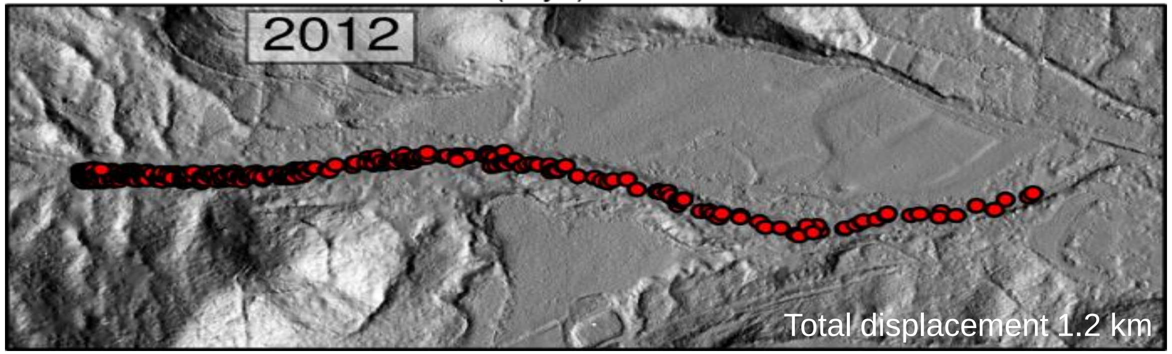


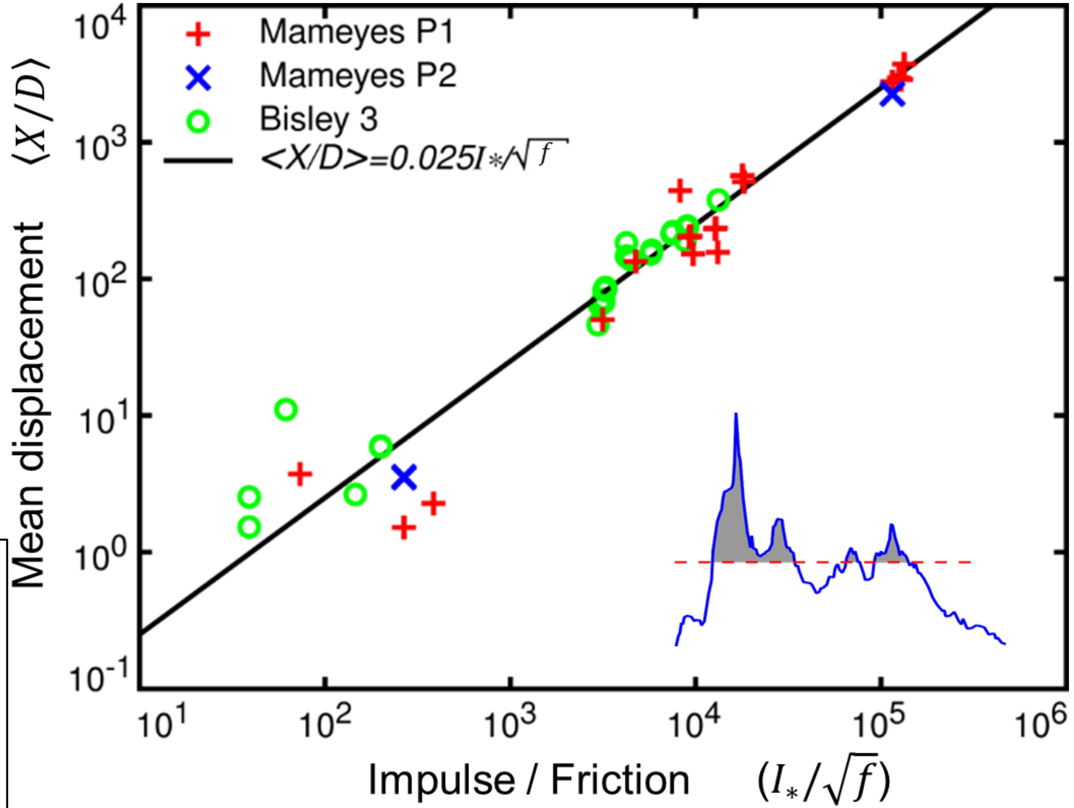
Sequences of floods - Tracer particle displacement across multiple years





Bisley subcatchment
Mameyes main channel

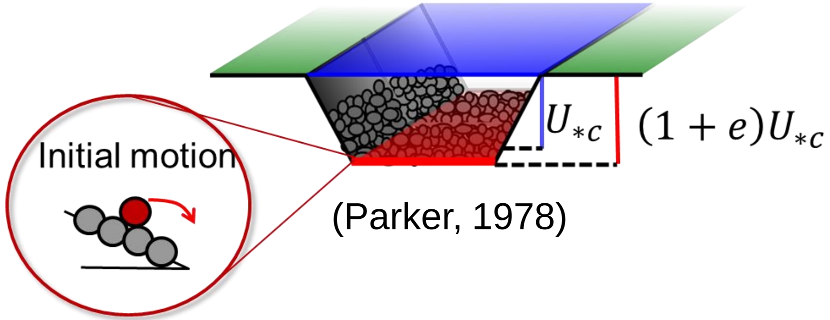




Key point. Impulse parameter connects tracer displacement across multiple time and space scales demonstrating that average sediment displacement is determined by the excess integrated fluid momentum imparted to the bed. At multi-annual timescales the integral within the impulse reduces to the average shear stress above the threshold of motion (which is the bankfull flood) times the duration of the hydrograph that is above the threshold of motion.

Decadal to Landscape scale – river channel self-organization allows longer term forcing simplifications

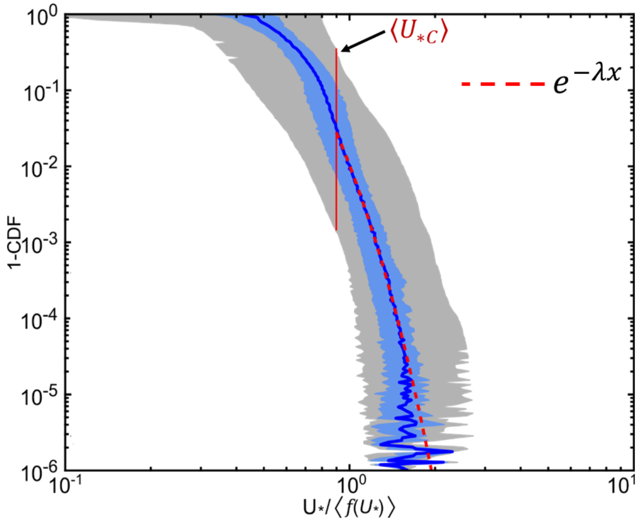
Channel Stability



(Parker, 1978)

The bankfull flow represents the threshold of channel instability. Channels are adjusted to be near this threshold on average or they destabilize.

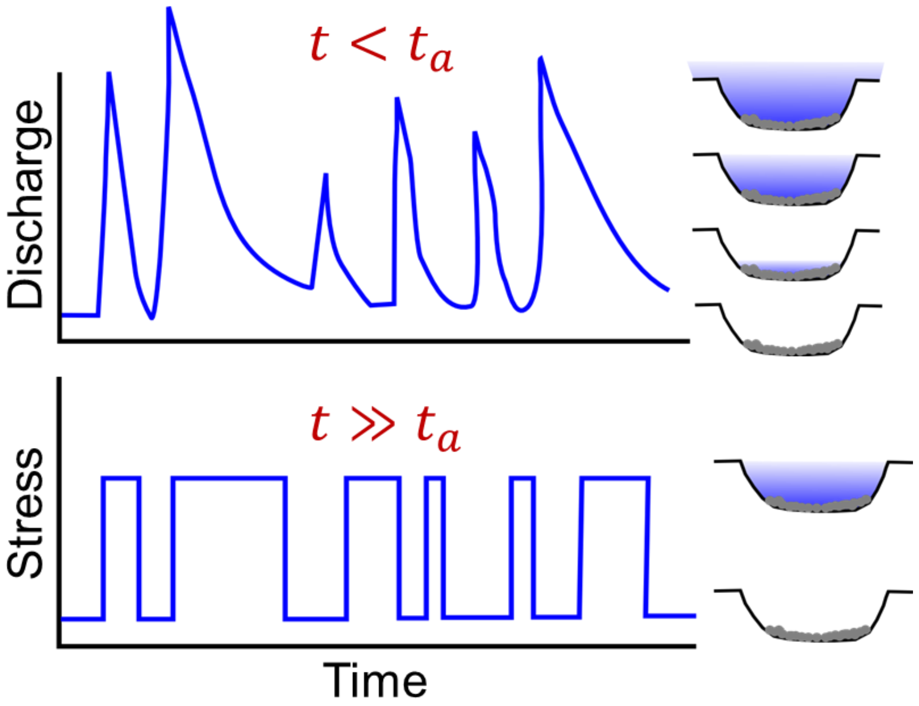
Stress Filter Effect



Scaling for 183 rivers shows rapidly diminishing stresses for flows greater than threshold. The average value of these flows is the bankfull flood.

Frequent high flows will lead to channel adjustment and a return to near the threshold of motion. This causes river self-organization to limit high stresses (a function of flow depth) by allowing large discharges to spill overbank. This filtering effect allows the hydrograph to be replaced by an average value at timescales greater than the adjustment time (t_a) of the channel. A common simplification implemented in early landscape evolution models. In effect this self-organization is the null hypothesis for fluvial landscape evolution.

Long term simplification of forcing in landscape evolution



$t \gg t_a \quad climate \sim \tau_{bf} f_c t$

At timescales greater than the time over which channels adjust the total flux is expected to scale as the bankfull flood times the fraction of time that the hydrograph is above threshold, reducing climate to an intermittency factor.

(Paola et al., 1992)

Abstract. Sediment transport is an inherently challenging process to predict due to a variety of granular and hydrodynamic phenomena. These challenges are only enhanced in natural systems where the forcing of the hydrograph and the availability of sediment is decidedly unsteady. Here we show through several field and laboratory experiments comprised of sediment flux and tracer displacement under unsteady hydrographs that their dynamics can be understood through the application of an integrated forcing metric (impulse), where the impulse represents the integrated excess transport capacity of a flood or a sequence of floods. When viewed through this framework we show that the cumulative bed load flux and tracer displacement from the particle flight length scale up to multi annual timescales are linearly related with the impulse parameter despite highly unsteady forcing. By considering the integrated forcing and sediment flux the transience of the hydrograph can be recast into a simple linear relation with parallels to long term landscape evolution models, where the details of the hydrograph are approximated as a characteristic flood stress times an intermittency factor. Through the use of an impulse metric we gain new insights that are obscured when only considering the instantaneous fluxes.

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