Investigating the Mechanics of Water Flow and Bedload Sediment Transport in Rivers from Seismic Observations

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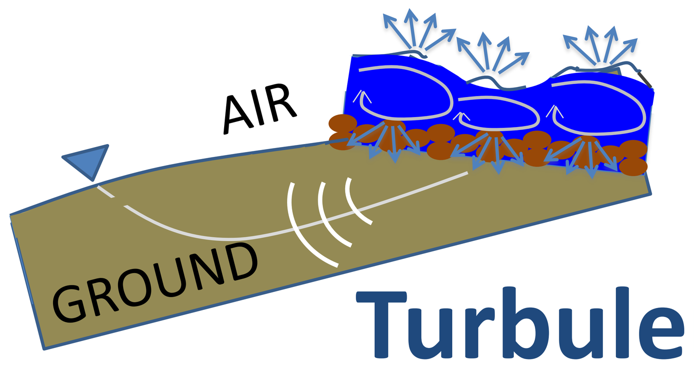
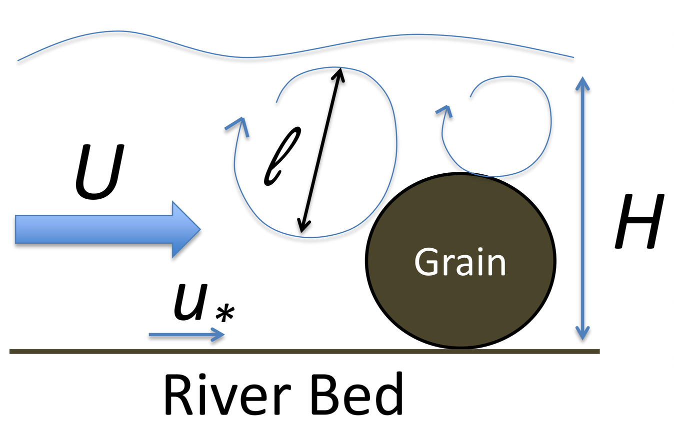


Turbulent Water Flow

Can we Model the Seismic Noise induced by Water Flow?

Hypothesis: Water pressure fluctuations are induced by turbulent flow impacting river bed protrusions

Model Sketch



Notations

- U : stream velocity (m/s)
- H : water depth (m)
- l : largest eddy size (m)
- u_* : shear velocity (m/s)
- D : grain diameter (m)
- f : frequency (Hz)
- u : fluctuating velocity (m/s)
- ε : viscous dissipation (m²/s³)
- u_f : fluctuating velocity in the frequency band df (m/s)

Governing Equations

- Power spectral density of the 3D **velocity fluctuations**

$$S_u(\mathbf{f}) = \frac{\overline{\mathbf{u_f^2}}}{d\mathbf{f}} = \epsilon^{2/3}\mathbf{f}^{-5/3}\vartheta(\mathbf{f})$$

with $\vartheta(\mathbf{f}) = \alpha\left(\frac{2\pi}{U}\right)^{-2/3}\exp\left(-\frac{3}{2}\pi\beta\alpha^{1/2}(\mathbf{f}H)^{-4/3}\left(\frac{2\pi}{U}\right)^{-4/3}\right)$

$\alpha = 1.5$ is set from laboratory experiments

- The amplitude of $S_u(\mathbf{f})$, i.e. β, is set such that

$$\int\int\int_0^\infty S_u(\mathbf{f})d\mathbf{f} = \frac{1}{2}\overline{u_i u_i} = \frac{3}{2}u^2 = \frac{3}{2}(Cu_*)^2$$

where $u_* = \sqrt{gH\sin\theta}$ and C a constant between 1 and 2 (*Lamb et al, 2008*)

- Power spectral density of **force fluctuations** acting on grain size ***D***

$$S_F(f,D) = 4\left(\frac{\bar{F}(D)}{U}\right)^2|\chi_{fl}|^2 S_u(f)$$

with $\begin{cases}|\chi_{fl}| = 1 & \text{if } \frac{2fD}{U} \ll 1\\ |\chi_{fl}| \sim \left[\frac{2fD}{U}\right]^{-4/3} & \text{if } \frac{2fD}{U} \gg 1\end{cases}$ and $\bar{F}(D) = \frac{1}{16}C_D\pi D^2\rho U^2$

- Predicted **ground velocity power** at the seismic station

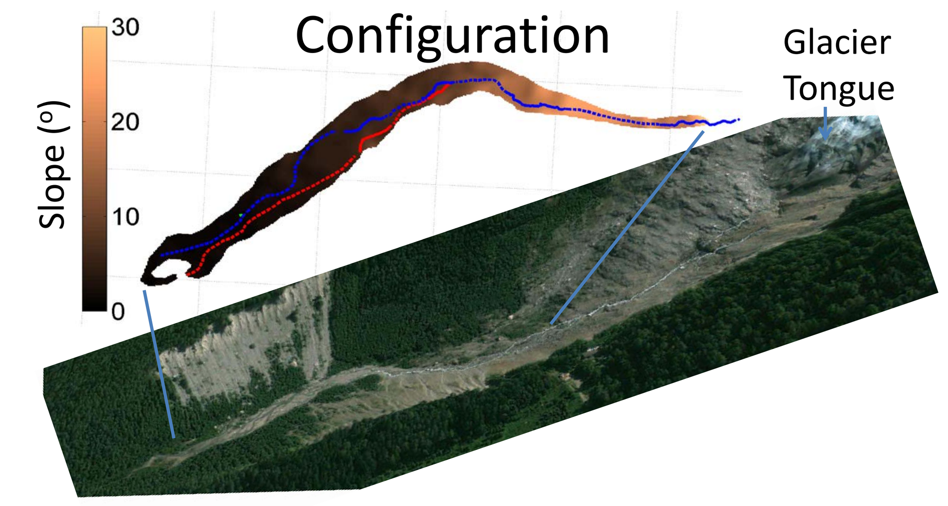
$$P(f,D) = \frac{U_g^2(f,D)}{df} = (2\pi i f)^2 S_F(f,D)G(f)^2$$

$$P(f,D) \sim u_*^2 U^3 \sim H^3$$

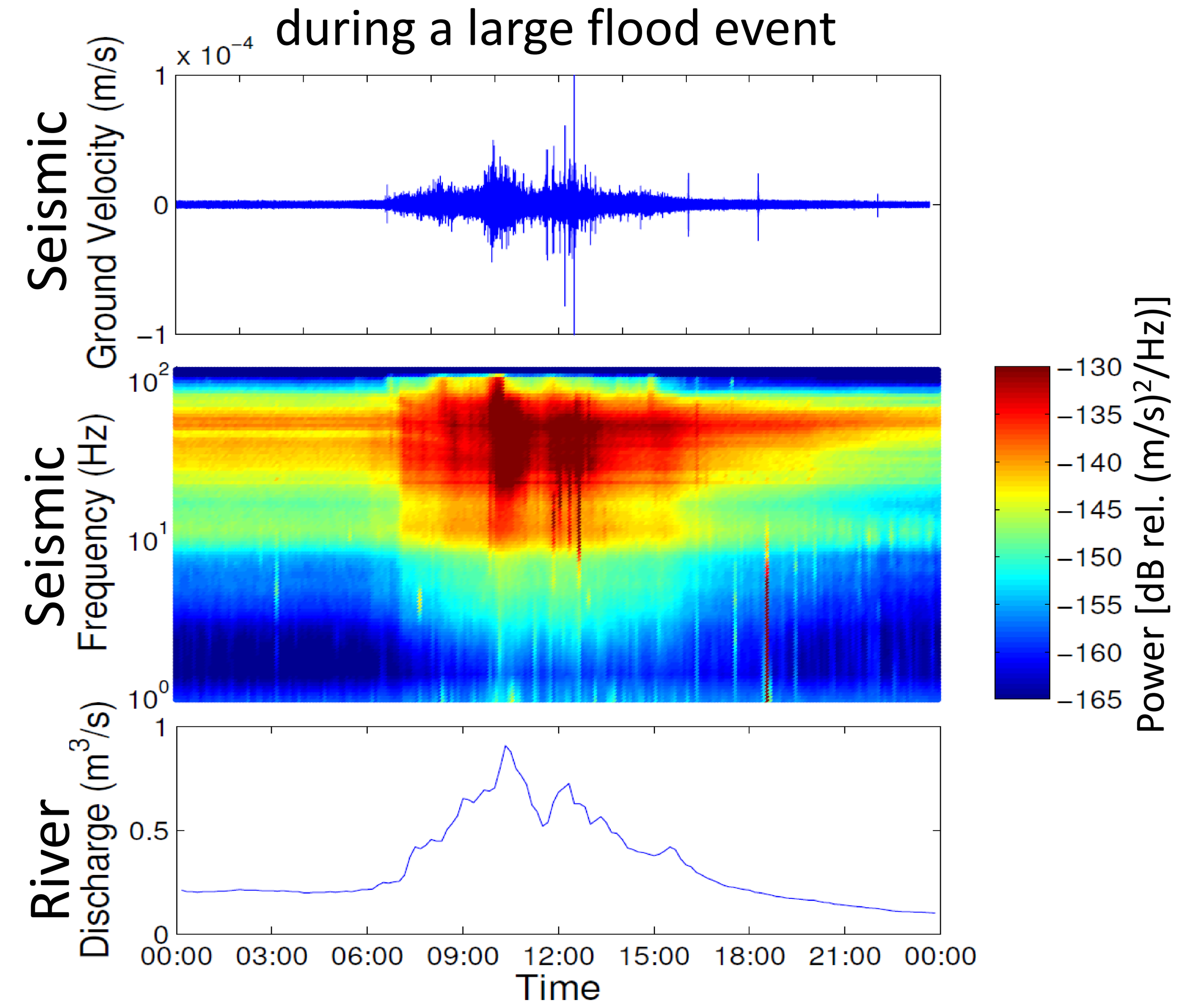
Seismic obs. may be appropriated to infer local water flow velocities

Scaling of Predicted Noise versus water height compared with Field and Lab Measurements

Les Bossons River (France)



Example of a seismic noise record during a large flood event



Picture of the bottom part of the stream

Ground motion

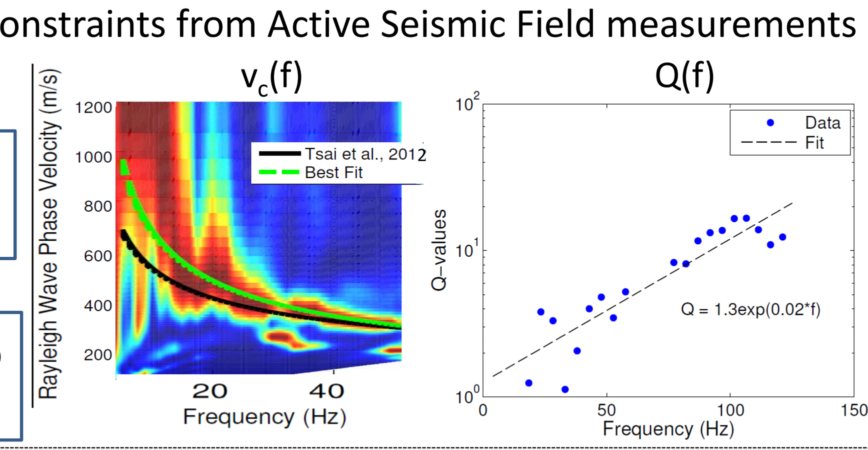
Rayleigh wave

$$|G(f,x;x_0)| \approx \frac{0.6k}{8\rho v_c v_u}\sqrt{\frac{2}{\pi kr}}\cdot e^{-\pi f r/(v_u Q)}$$

Love wave *Tsai et al., 2012*

$$|G(f,x;x_0)| \approx \frac{2k}{8\rho v_c v_u}\sqrt{\frac{2}{\pi kr}}\cdot e^{-\pi f r/(v_u Q)}$$

Constraints from Active Seismic Field measurements

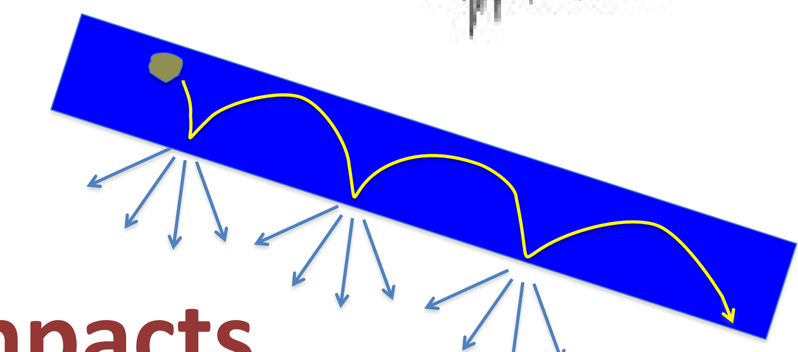


Final Model Of Water flow Noise Spectrum

$$P(f) = \int\frac{n}{t}P(f,D)dD$$

with $\frac{n}{t} = WU/D^2$

Using the Les Bossons geometry, fluvial parameters and wave propagation values



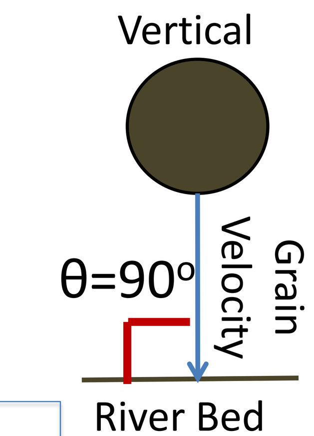
Grain Impacts

How can Seismic Monitoring Help to better Characterize the Mechanics of Bedload Transport?

Idealized Grain impact model (*Tsai et al., 2012*)

$$F\Delta t \approx 2mw_i$$

- F : impact force (N)
- Δt : contact time (s)
- m : grain mass (kg)
- w_i : impact velocity (m/s)



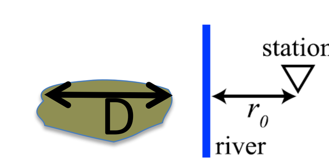
Assuming a **rate of impacts** = *f*(flow speed, hop time, …)
Tsai et al. (2012) inverted a **bedload flux.**

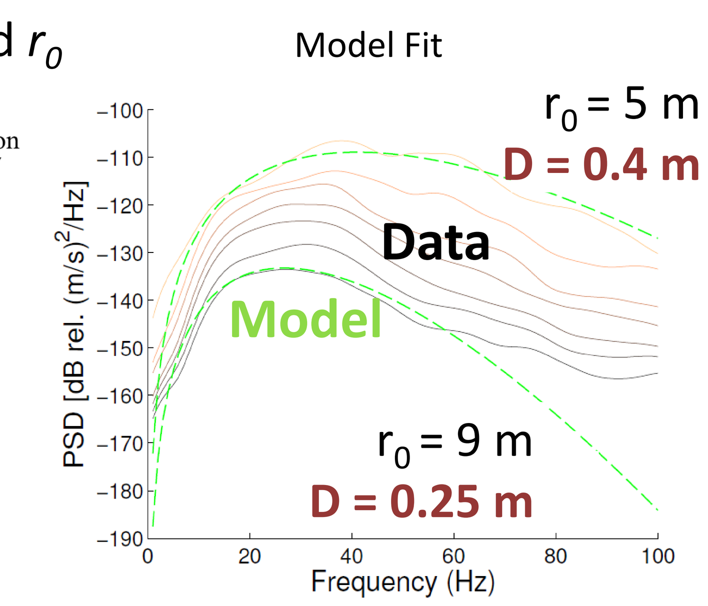
BUT For accurate inversions, impact mechanics needs to be constrained from observations

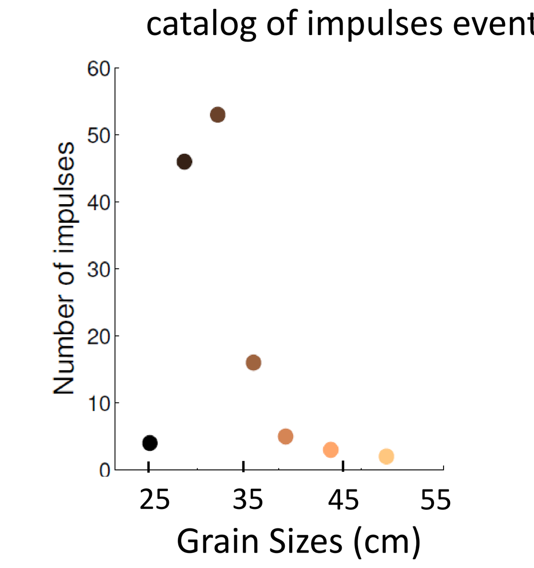
→ End tail of moving **grain size distribution -- D**

Impulses selection

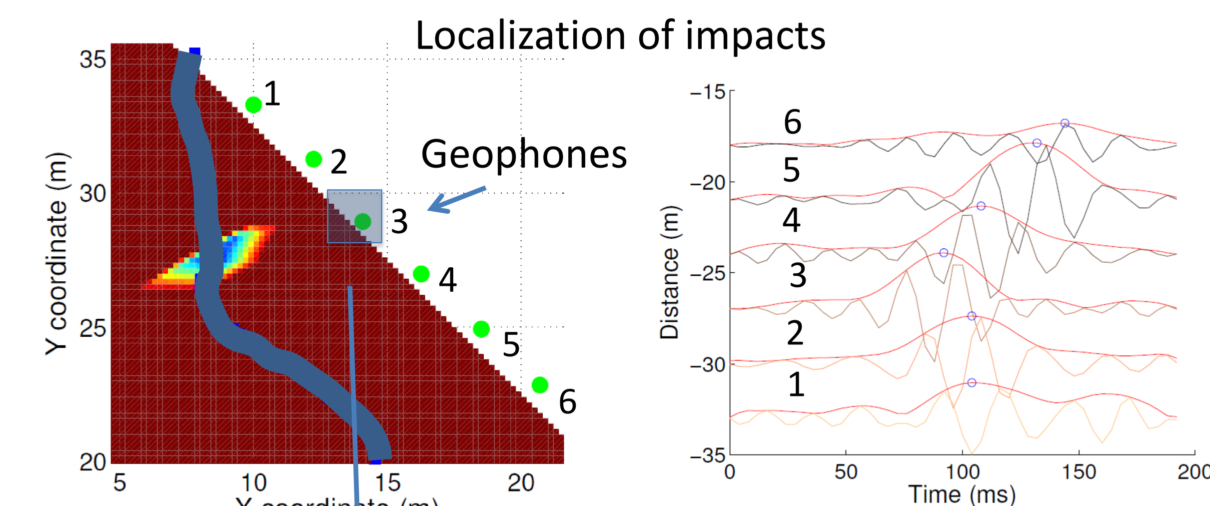
Tuning of *D* and r_0

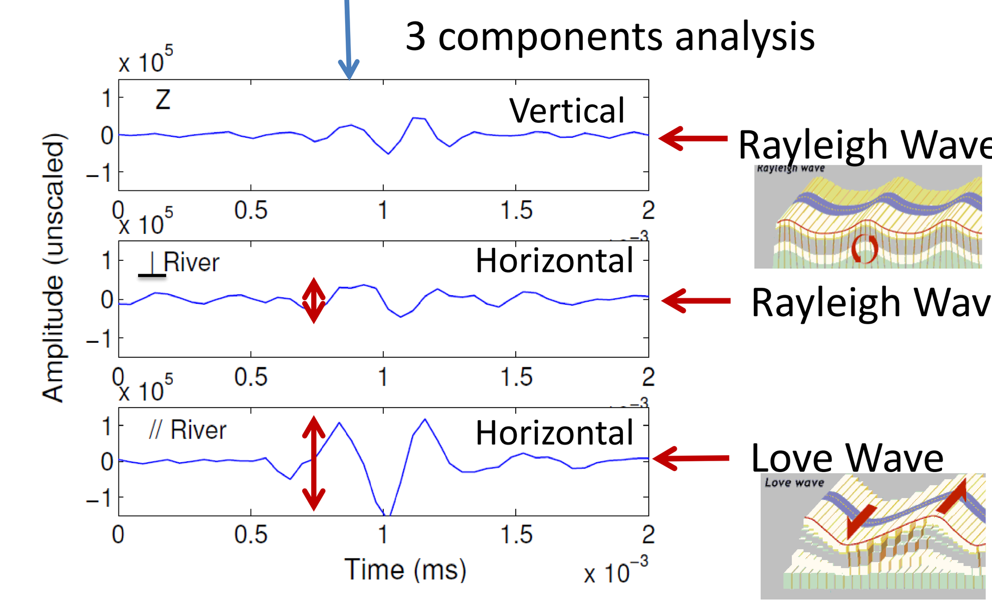


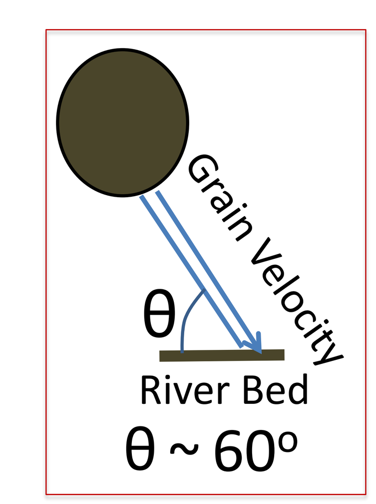




→ Grain **impact directionality -- θ**







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