Quantifying Sediment Transport with Seismic Measurements

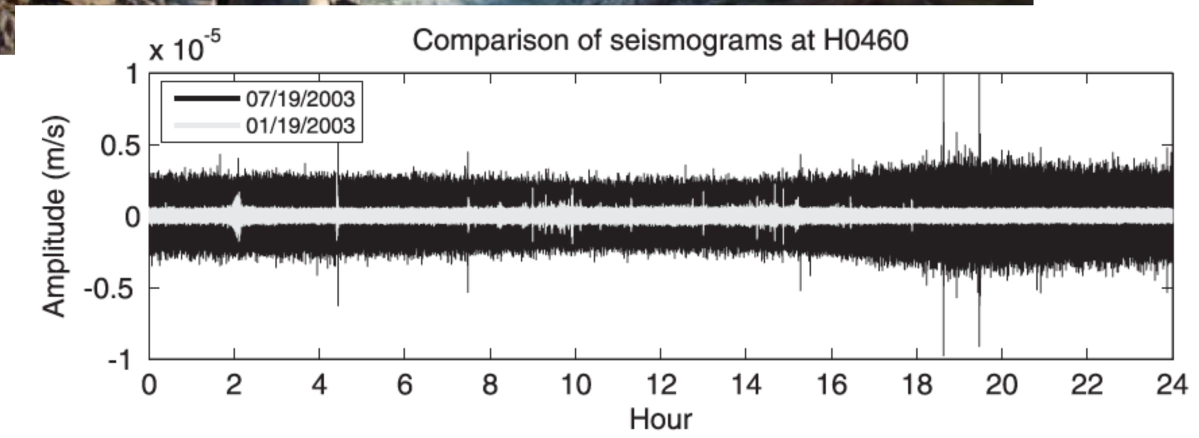
Victor C. Tsai, Brent Minchew, Michael P. Lamb, Jean-Paul Ampuero
Seismological Laboratory, California Institute of Technology

Prologue/Background

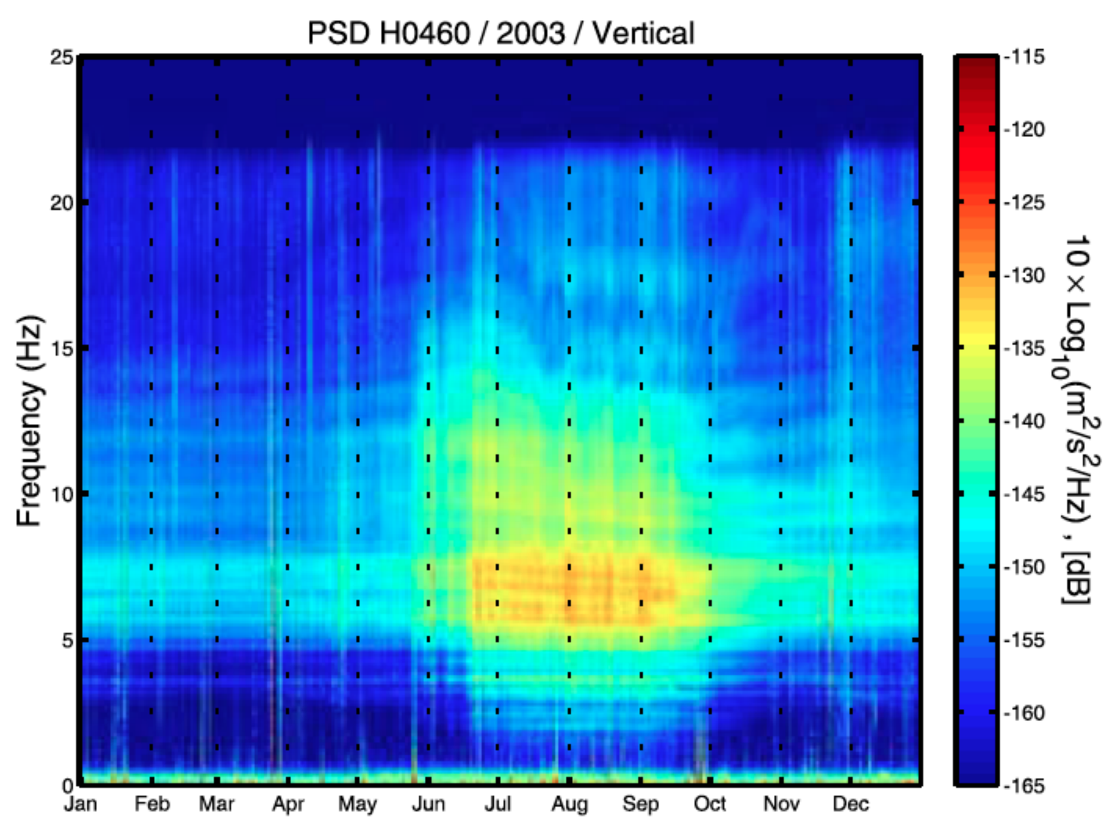
- Sediment transport consists of suspended load and bedload (saltating particles)
- Bedload is typically difficult to measure
- Since bedload impacts cause ground motion, **can we use seismic data to infer bedload flux**?

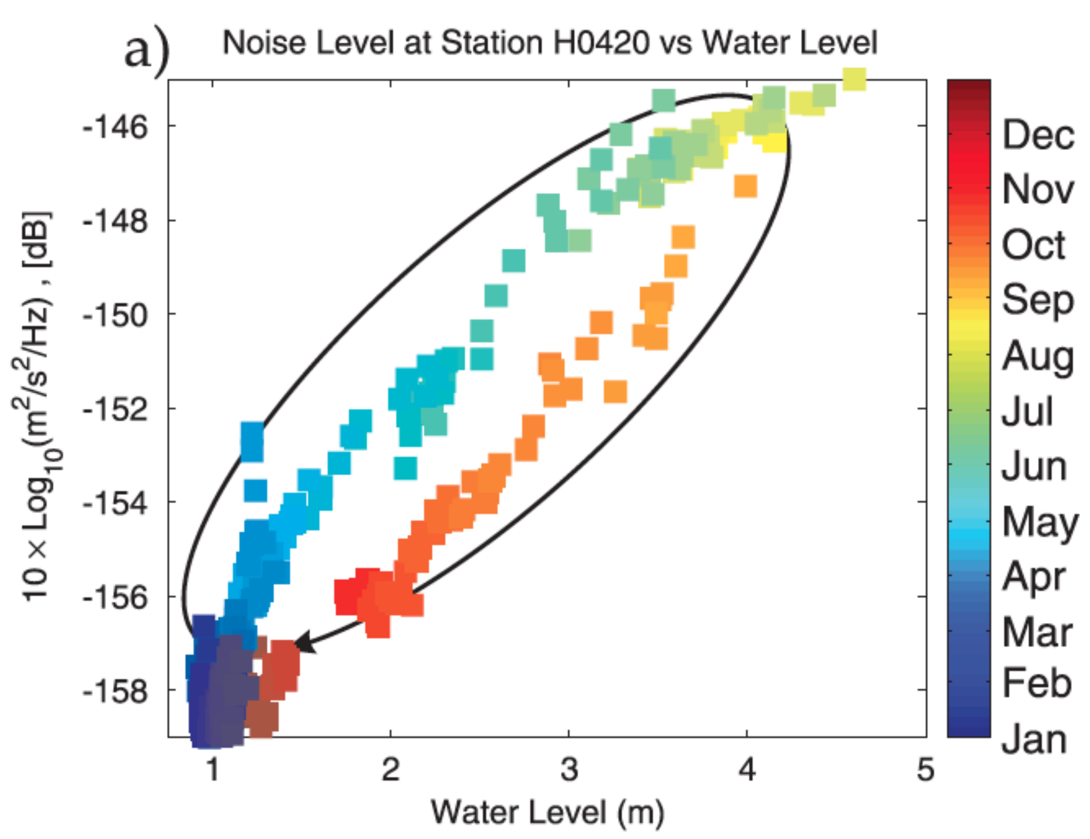
Observations of Burtin et al.

- Data from a seismic transect near the Trisuli River in Nepal
- (The Trisuli is one of the major trans-Himalayan rivers. It has steep slopes and large, seasonal sediment flux)



- Power spectral density (PSD) plots, showing noise energy

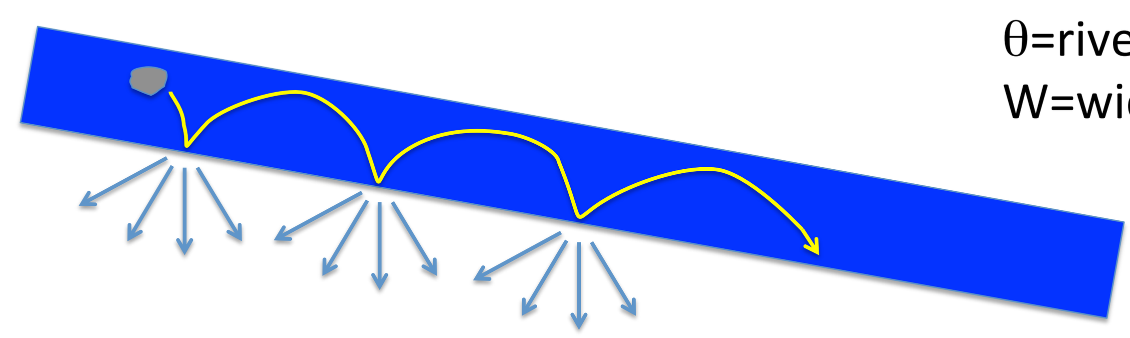




- Observations from Nepal suggest that **bedload contributes significant ambient noise energy**

Modeling Seismic Noise from Sediment Transport

- To use seismic observations to solve for sediment flux, **we need a physical model to relate sediment flux to seismic noise**
- **We construct a simple idealized model based on vertical particle impacts**, as schematically drawn below



- **Impact rate** depends on flow speed, hop time, …

$$\frac{dn}{dt} = \frac{CWq_b\bar{w}}{VU_bH_b}$$ (q_b=sediment flux, w=settling velocity, U_b=horiz. particle speed, H_b=bedload height)

- **Impact strength** depends on particle impulse (mass, speed)

$$F\Delta t \approx 2mw_i$$ (m=particle mass, w_i=vertical impact speed)

- Ground motion assumed to mostly be **Rayleigh waves** for which we assume a simple analytical Green's function

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

- With these assumptions, **noise power P_v can be predicted**:

Integrate all impacts

$$P_v(f;D) \approx \frac{dn}{dt}\frac{\pi^2 f^3 m^2 w_i^2}{\rho^2 v_c^3 v_u^2}\chi(\beta)$$

$$\chi(\beta) = \ldots$$

- This expression assumes a linear river, and is frequency (f) and grain size (D) dependent, and also depends on a number of other parameters like phase velocity (v_c) and attenuation (Q)
- **Note dependence on m^2 and w_i^2.** This implies large particles and faster impacts are more important!

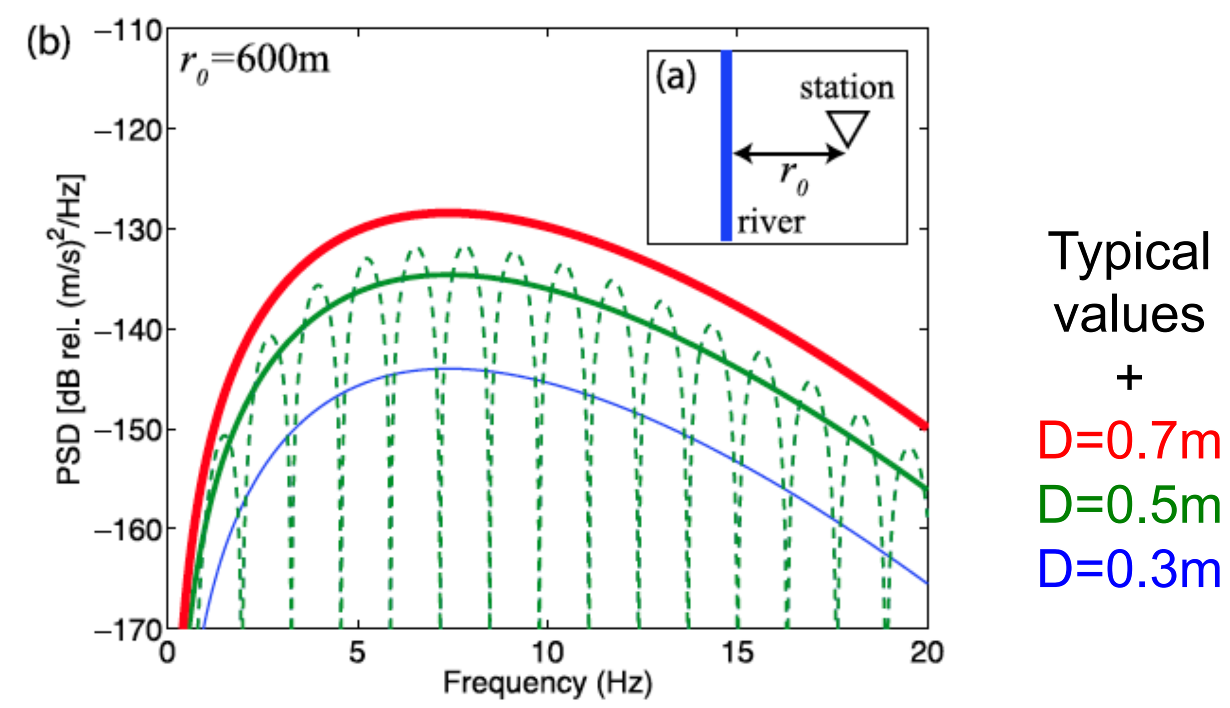
References

- Burtin, A., L. Bollinger, J. Vergne, R. Cattin, and J. L. Nabelek (2008), *J. Geophys. Res.*, 113, B05301.
- Tsai, V.C., B. Minchew, M.P. Lamb, J.-P. Ampuero (2012), *Geophys. Res. Lett.*, 39, L02404.

Model Results/Predictions

- Given **D**, $\mathbf{q_b}$, θ, H, W, v_c, …

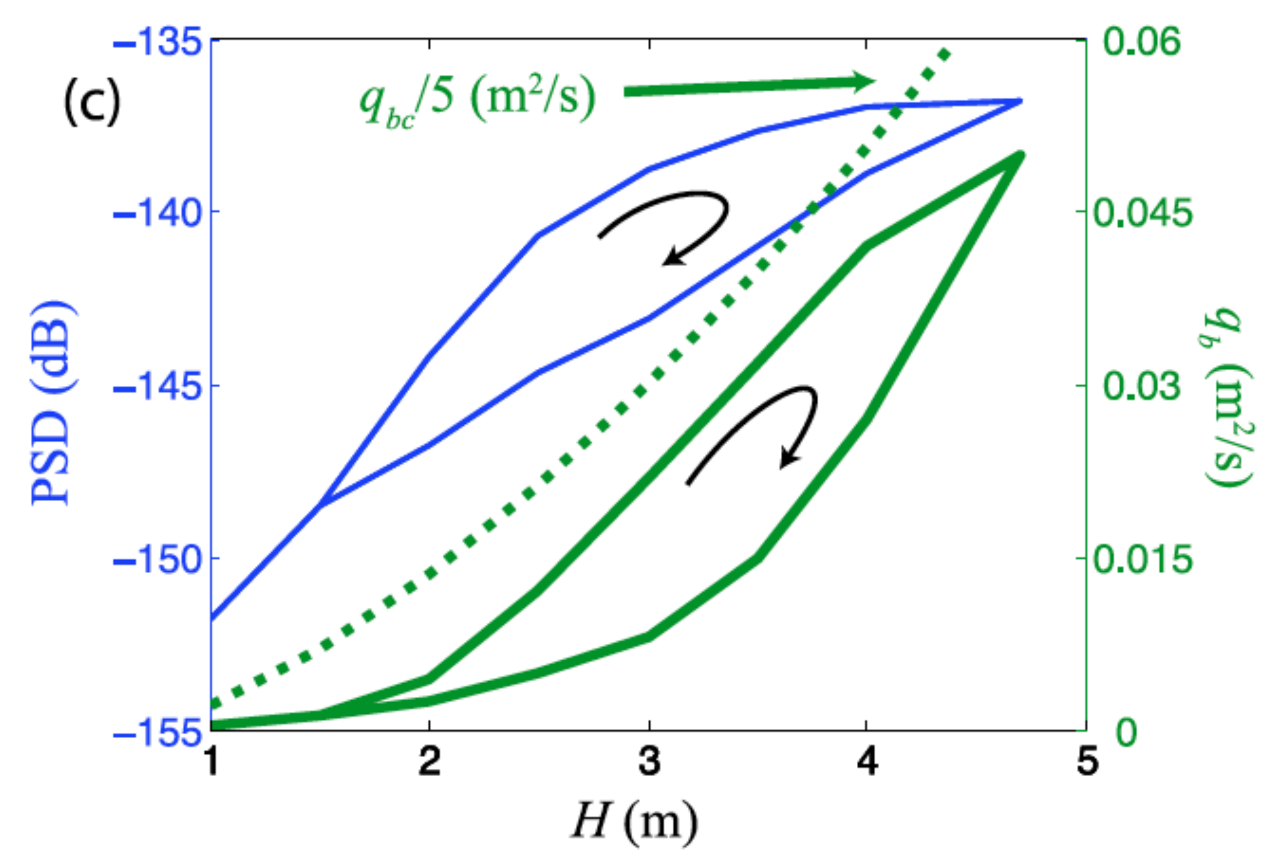
We predict seismic power spectral density (PSD)



- Solid curves smoothed. Dashed curve includes effect of hop time on frequencies. Predictions are for single grain sizes noted at right
- Since we now have a forward model, we can invert seismic for q_b. In other words:
  Given **D**, **PSD**, θ, H, W, v_c, …

We predict bedload sediment flux (q_b)

- Need to assume grain size distribution, and currently we assume water flow noise is insignificant (may not be a good assumption over falling limb)



- Green solid curve is our prediction of q_b from the data of Burtin et al. (shown at left, and idealized as the blue curve)
- **We predict bedload sediment flux!**
- But are we right?? (Future work… calibration, etc.)