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Quantifying earthquake source parameter uncertainties associated with local site effects using a dense array

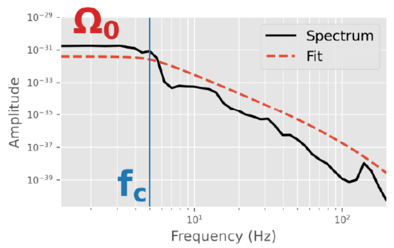
Hilary Chang[1]*, Rachel E. Abercrombie[2], Nori Nakata[1], Colin N. Pennington[3], Kilian B. Kemna[4], Elizabeth S. Cochran[3], Rebecca M. Harrington[4]

*Contact: hilarych@mit.edu

1 Massachusetts Institute of Technology
2 Boston University
3 USGS science for a changing world
4 Ruhr Universität Bochum RUB

Introduction

- To characterize the earthquake source, we can model a **single earthquake spectrum** to obtain source parameters.



Ω_0 : Long-period spectral amplitude
t : Travel time
Q : Quality factor (Q=600)
γ : Boatwright model (γ=3)
ρ : Density (2700 kg/m³)
$U_{\Phi\theta}$: Radiation pattern (0.38)
r : Radius of crack

Use n=3.5, k=0.38

1. Corner frequency (f_c)

$$\Omega_i(f) = \frac{\Omega_0 e^{-(\pi f t/Q)}}{[1+(f/f_c)^{\gamma n}]^{1/\gamma}}$$

2. Seismic moment (M_0)

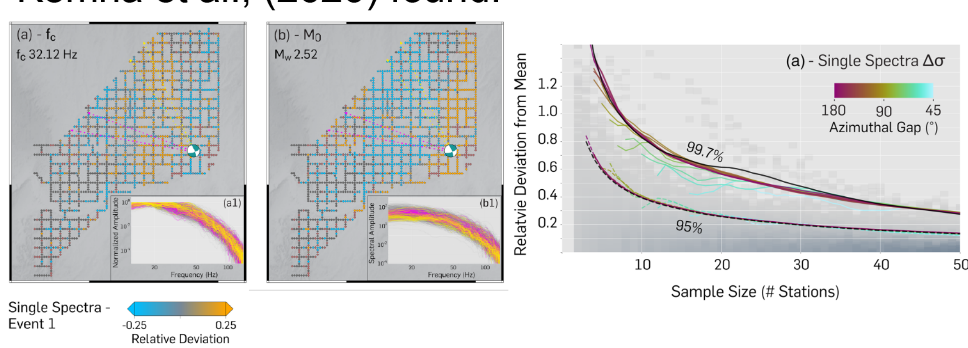
$$M_0 = \frac{4\pi\rho c^3 R \Omega_0}{U_{\phi\theta}}$$

3. Stress drop ($\Delta\sigma$)

$$\Delta\sigma = \frac{7}{16}\frac{M_0}{r^3}$$
$$r = \frac{k\beta}{f_c}.$$

- Study area: LASSO
  - The LArge-n Seismic Survey in Oklahoma
  - **1829 stations** (25 km x 32 km).
  - **1104 local earthquakes** (Apr-May, 2016) likely related to waste-water injection; M < 3, depth 1.5 - 5.5 km (Cochran et al., 2020)

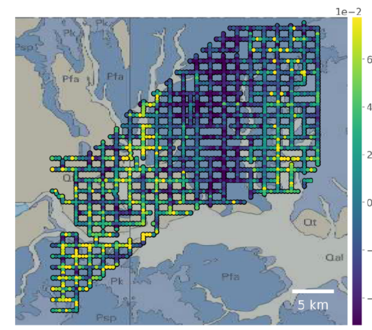
- Kemna et al., (2020) found:



  - Spatial deviation patterns of f_c and M_0 (focal mechanism? site effect?)
  - Deviation of Δσ can be 30% even with >20 stations.

Estimate site-effect

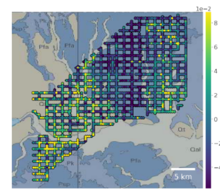
- **How does near surface site-effect influence these estimations?**
  - We quantify site-effect using mean Peak-Ground-Velocity (PGV)
    - Estimated from 14 regional earthquakes (~130 km away); filter range 10-15 Hz.
    - Up to ~25% spatial deviation
    - Correlated with local geological formations
      - Young alluvial sediments
      - Old shale



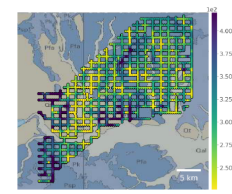
Mean log10 PGV spatial deviation

- Other site-effect proxies:

Root-Mean-Square amplitude (RMS): Similar to PGV

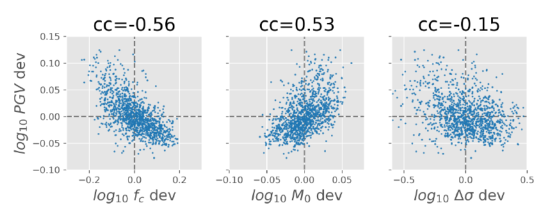


Topographic slope: Noisy (< 40 m elevation variation for 90% of this region)



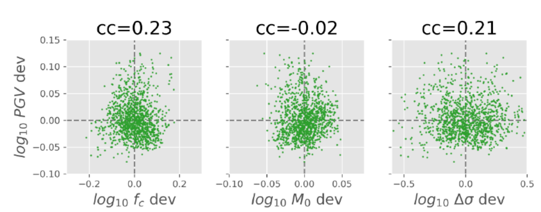
Source parameter correction

- We find f_c and M_0 are apprantly correlated with PGV



The dots are station measurements for Event 1.
(cc: Cross-correlation coefficient)
(dev: Relative deviation from mean)

- If we assume the 1st order linear relation is due to site-effect, we can empirically correct the source parameters by

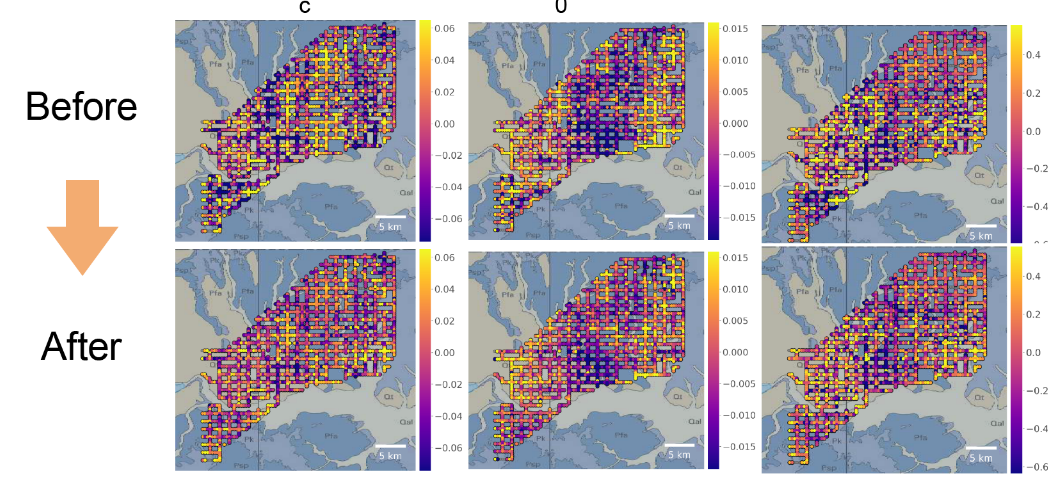


1. Removing the trends between f_c vs PGV, and M_0 vs PGV. (All in $\log_{10}$ and dev values)
2. Recalculating Δσ.

- We correct source parameters for the 962 events obtained using the single-spectrum method in Kemna et al., (2020).

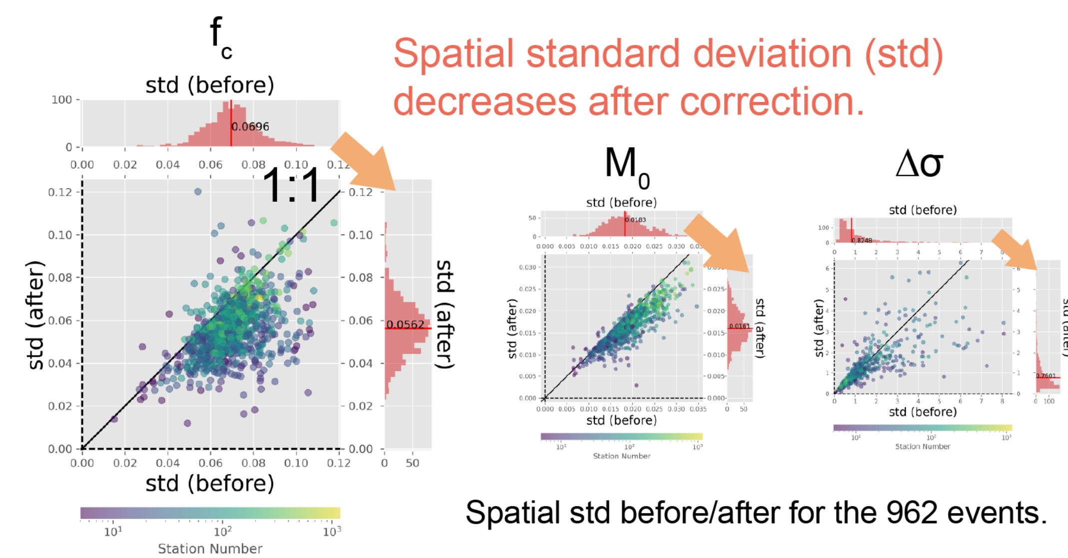
Results and conclusion

- After correction, spatial variability of estimated f_c, M_0, and Δσ decreases.



Deviation across LASSO, taking the mean of 962 events. (All in $\log_{10}$ and dev values)

Spatial standard deviation (std) decreases after correction.



Spatial std before/after for the 962 events.

- The amounts of relative spatial deviation that are associated with site-effect to the 1st order:
  - **$\log_{10}f_c$:18%, $\log_{10}M_0$: 12%, $\log_{10}\Delta\sigma$: 8%**
- The waveforms change between subregions which prevents us from analyzing P-arrival time delay by matching a simple template.
- Future work: Ambient noise would provide better presicion for analyzing shallow velocity variations.

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Cochran, E. S., Wickham-Piotrowski, A., Kemna, K. B., Harrington, R. M., Dougherty, S. L., & Peña Castro, A. F. (2020). Minimal clustering of injection-induced earthquakes observed with a large-n seismic array. Bulletin of the Seismological Society of America, 110(5), 2005-2017.