Observation and Analytical Fitting of Fault Zone Resonance Modes Using Seismic Waveforms Recorded by Dense Across-Fault Array

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INTRODUCTION

Fault zone (FZ) structures contain important information on various aspects of earthquake and fault mechanics ranging from long-term evolutionary processes to brittle rock rheology and dynamic stress fields operating during the occurrence of earthquakes.

The current project had 2 goals:

1. Establish the theory of modeling Eigen-functions for FZ resonance modes (Love-wave-like signal).
2. Perform FZ imaging using data recorded by a large-N dense array at Blackburn Saddle (Fig. 1).

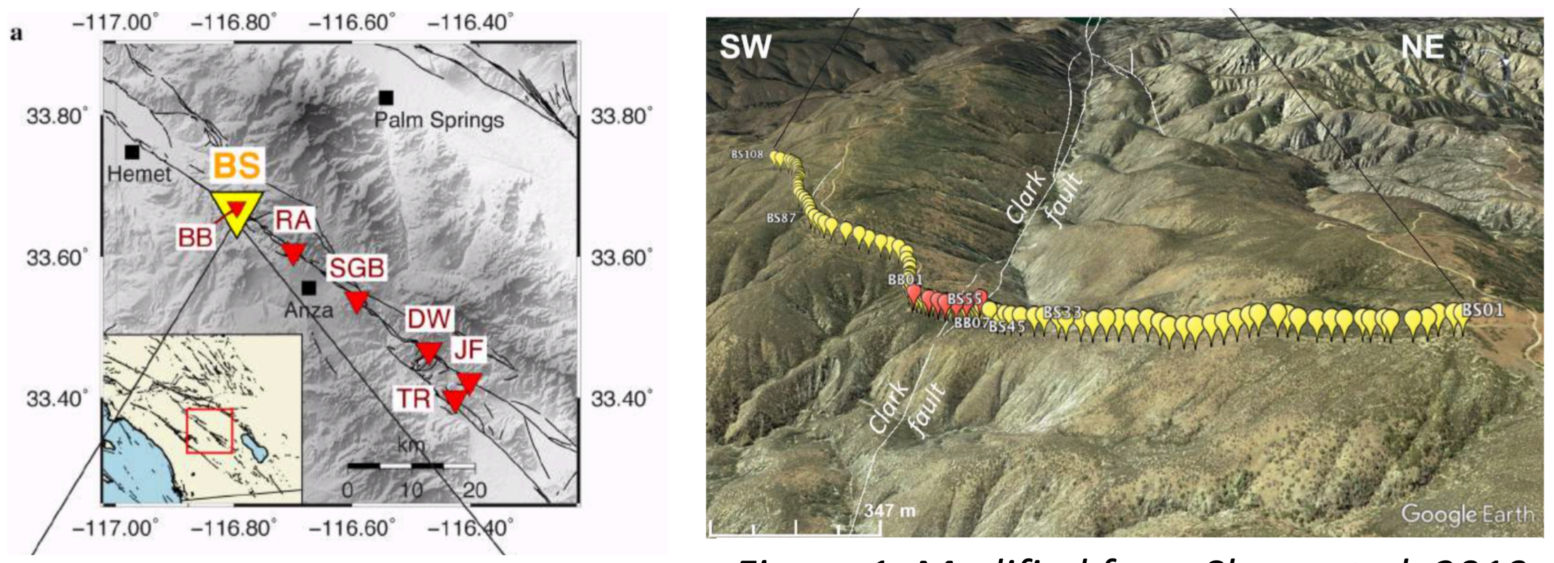


Figure 1. Modified from Share et al. 2019

METHOD

Simplified FZ model

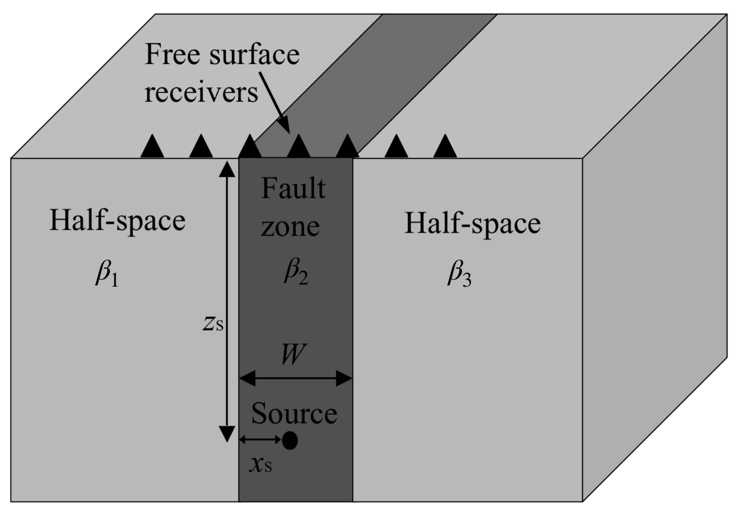


Figure 2. FZ model (modified from Ben-Zion et al. 2003)

Equations derived based on Ben-Zion & Aki 1990:

(1) Transcendental dispersion equation:

$$\tan(X) = \frac{\mu_2\sqrt{\beta_2^{-2}-c^{-2}}\cdot\left(\mu_1\sqrt{c^{-2}-\beta_1^{-2}}+\mu_3\sqrt{c^{-2}-\beta_3^{-2}}\right)}{\mu_2^2(\beta_2^{-2}-c^{-2})-\mu_1\mu_3\sqrt{(c^{-2}-\beta_1^{-2})\cdot(c^{-2}-\beta_3^{-2})}}$$

where $X = W\omega\sqrt{\beta_2^{-2}-c^{-2}}$

(2) Eigen-functions of resonance modes:

$$u_i(x\le 0,\omega) = \frac{2I_2}{I_1+I_2}e^{+\gamma_1 x}$$

$$u_i(0\le x\le W,\omega) = e^{+\gamma_2 x} + \frac{I_2-I_1}{I_1+I_2}e^{-\gamma_2 x}$$

$$u_i(x\ge W,\omega) = \left(e^{\gamma_2 W} + \frac{I_2-I_1}{I_1+I_2}e^{-\gamma_2 W}\right)\cdot e^{-\gamma_3(x-W)}$$

(3) Total displacement wavefield:

$$V(x,t) = e^{-i\omega t}\sum_{i=0}^{n-1} B_2^l(c_i)\cdot u_i(x,\omega) = |V(x)|\cdot e^{-i\omega[t-\tau(x)]}$$

where $\frac{B_2^l(c_i)}{B_2^l(c_0)} = R_i(x_s, z_s)$

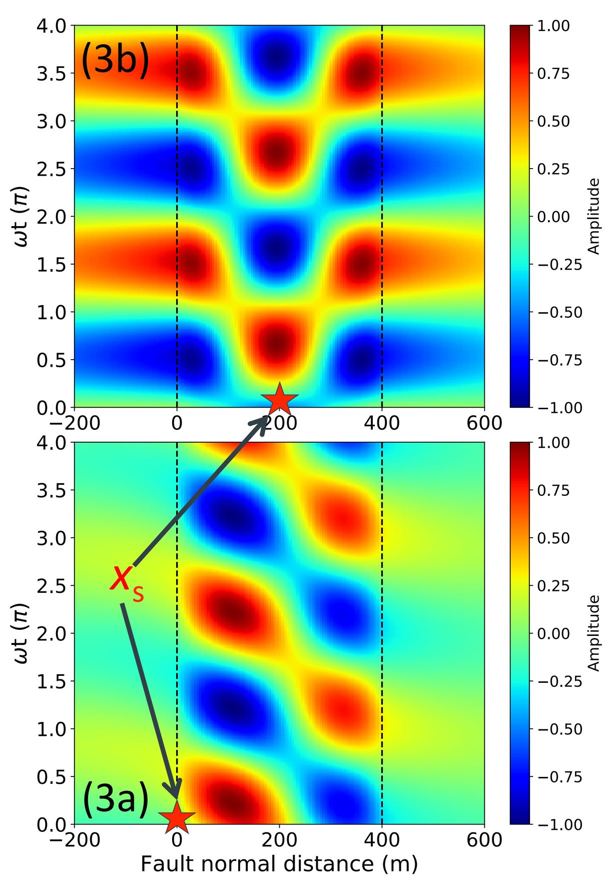
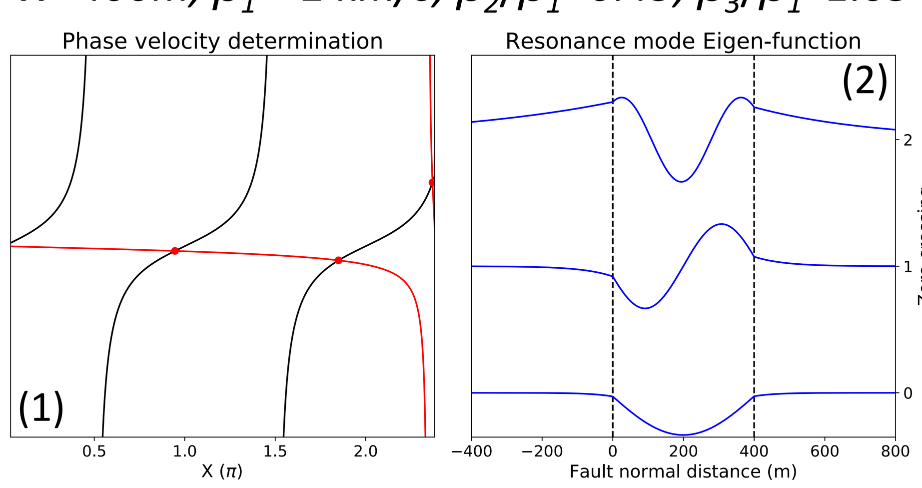


Figure 3. Synthetic test with FZ parameters: W=400m, β_1 = 2 km/s, β_2/β_1=0.45, β_3/β_1=1.03



Modeling particle motion of trapped wave resonance modes suggests a *flower-shape damage zone* and

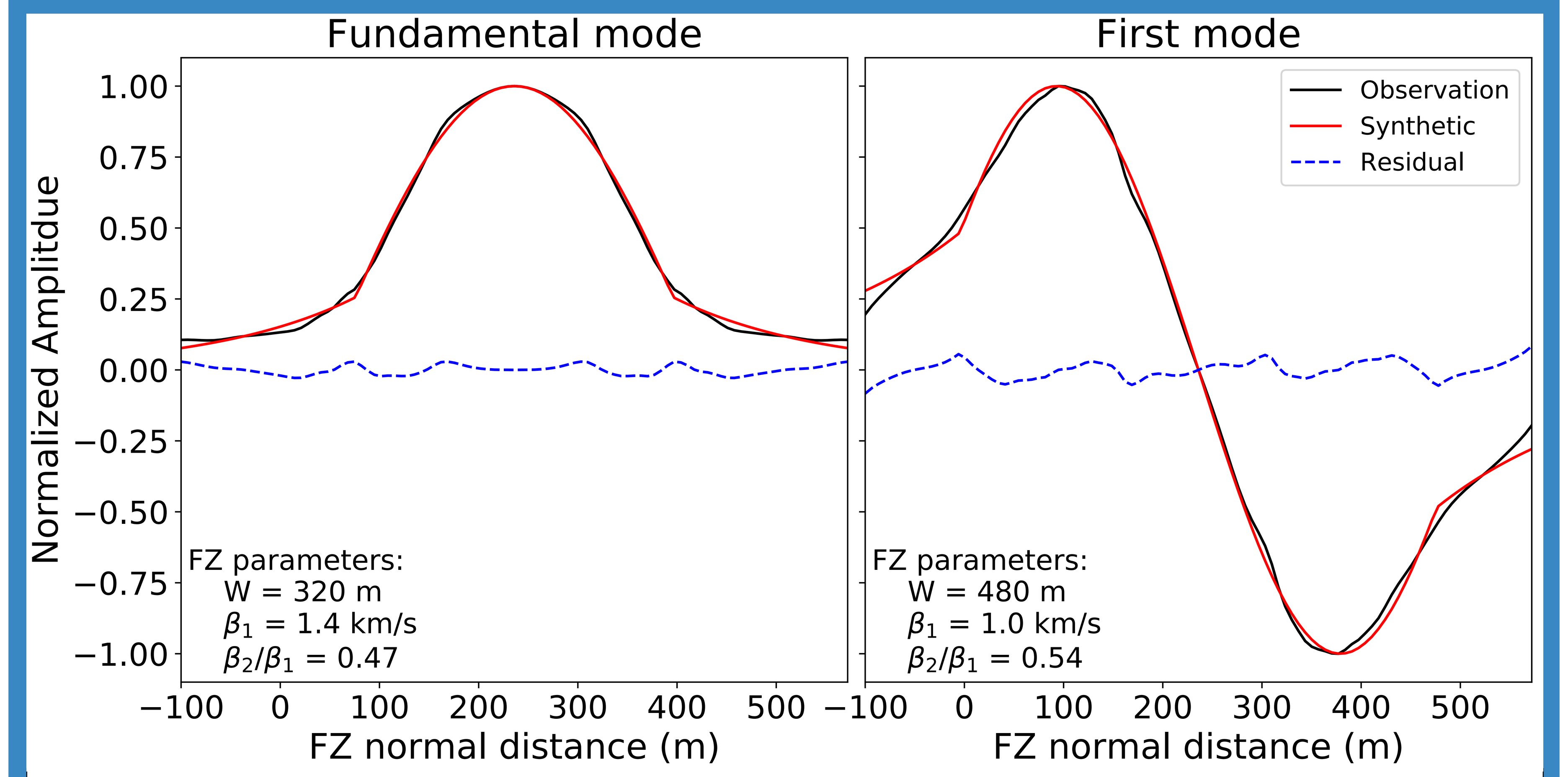
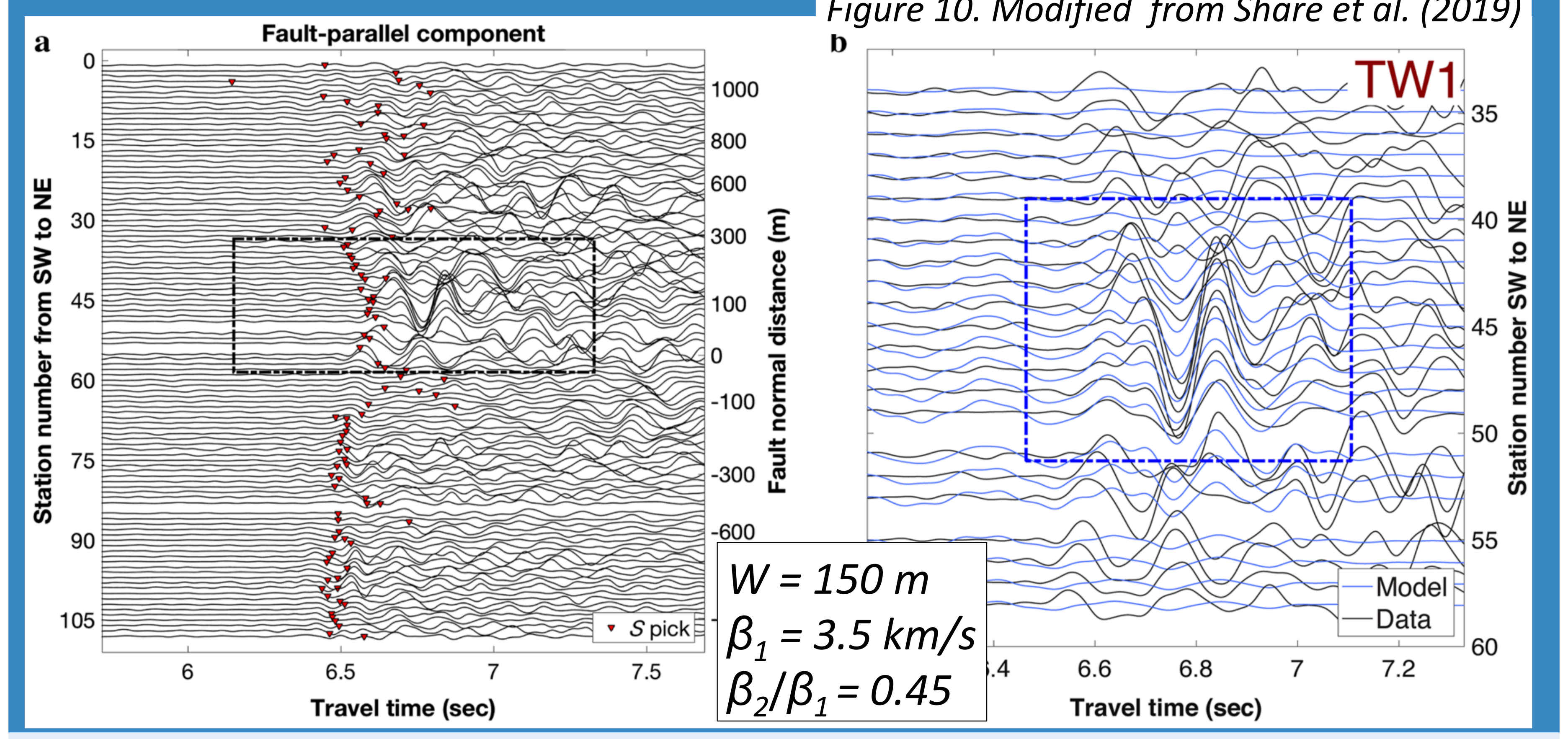


Figure 9. Best fitting FZ trapped wave resonance mode. FZ parameter space: W = 200 – 500 m with 10 m spacing; β_1 = 0.8 – 4.0 km/s with 0.2 km/s spacing β_2/β_1 = 0.3 – 0.7 with 0.01 spacing

yield *better fitting* than traditional waveform modeling approach

Figure 10. Modified from Share et al. (2019)



References:

1. Ben-Zion, Y. and K. Aki, Seismic radiation from an SH line source in a laterally heterogeneous planar fault zone, Bull. Seism. Soc. Am., 80, 971-994, 1990.
2. Ben-Zion, Y., Z. Peng, D. Okaya, L. Seeber, J. G. Armbruster, N. Ozer, A. J. Michael, S. Baris, and M. Aktar, A shallow fault zone structure illuminated by trapped waves in the Karadere-Duzce branch of the North Anatolian Fault, western Turkey, Geophys. J. Int., 152, 699-717, 2003.
3. Share, P-E., A, A. Allam, Y, Ben-Zion, F.-C. Lin and F. L. Vernon, Structural properties of the San Jacinto fault zone at Blackburn Saddle from seismic data of a dense linear array, Pure and Applied Geophysics, doi: 10.1007/s00024-018-1988-5, 2019.

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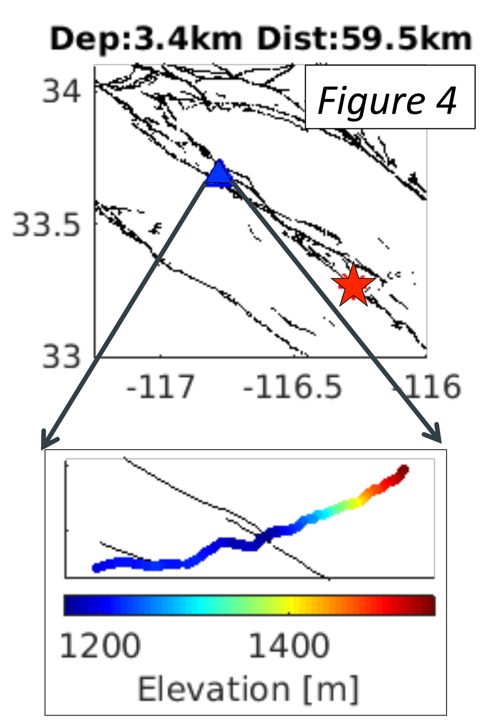
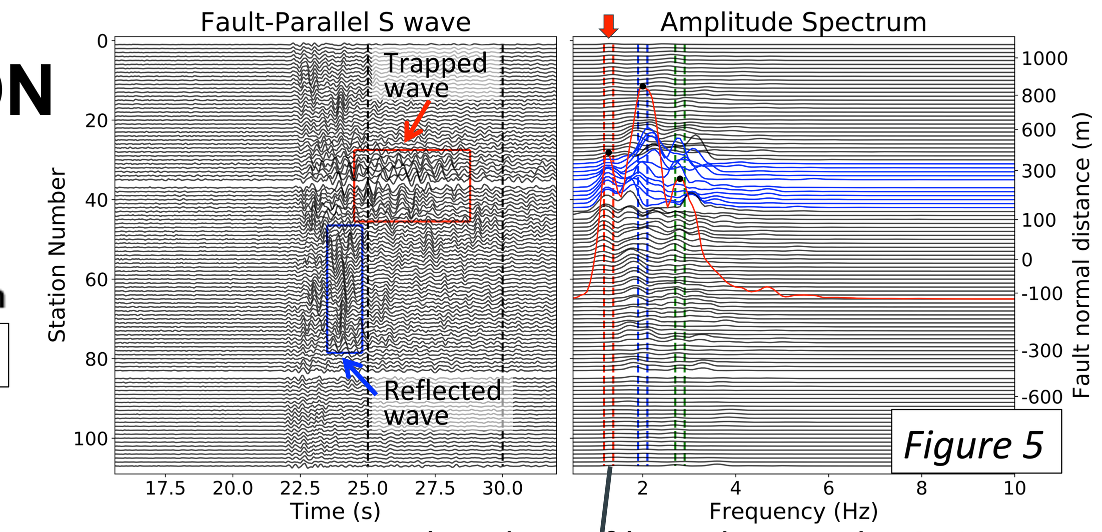
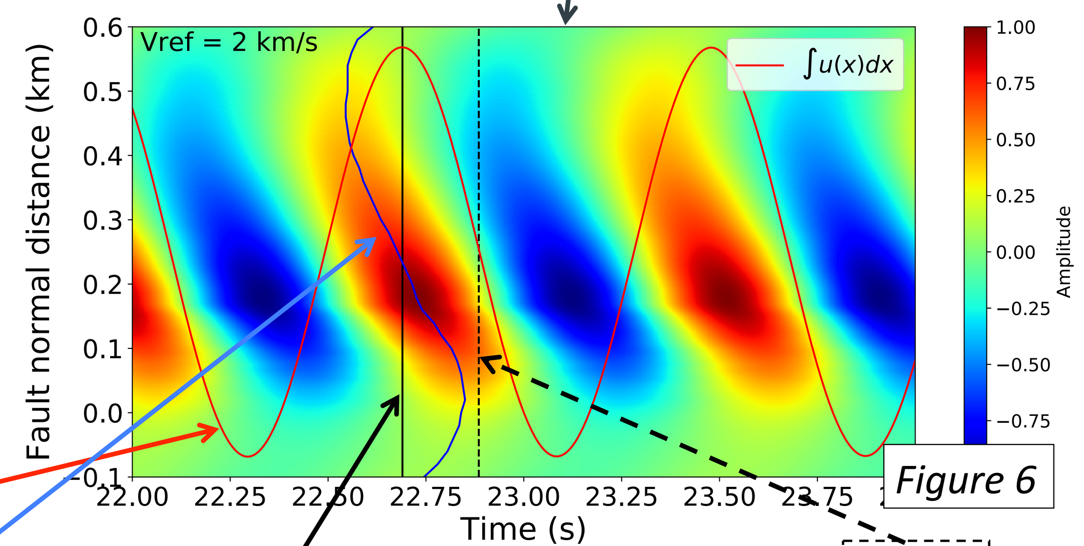
OBSERVATION





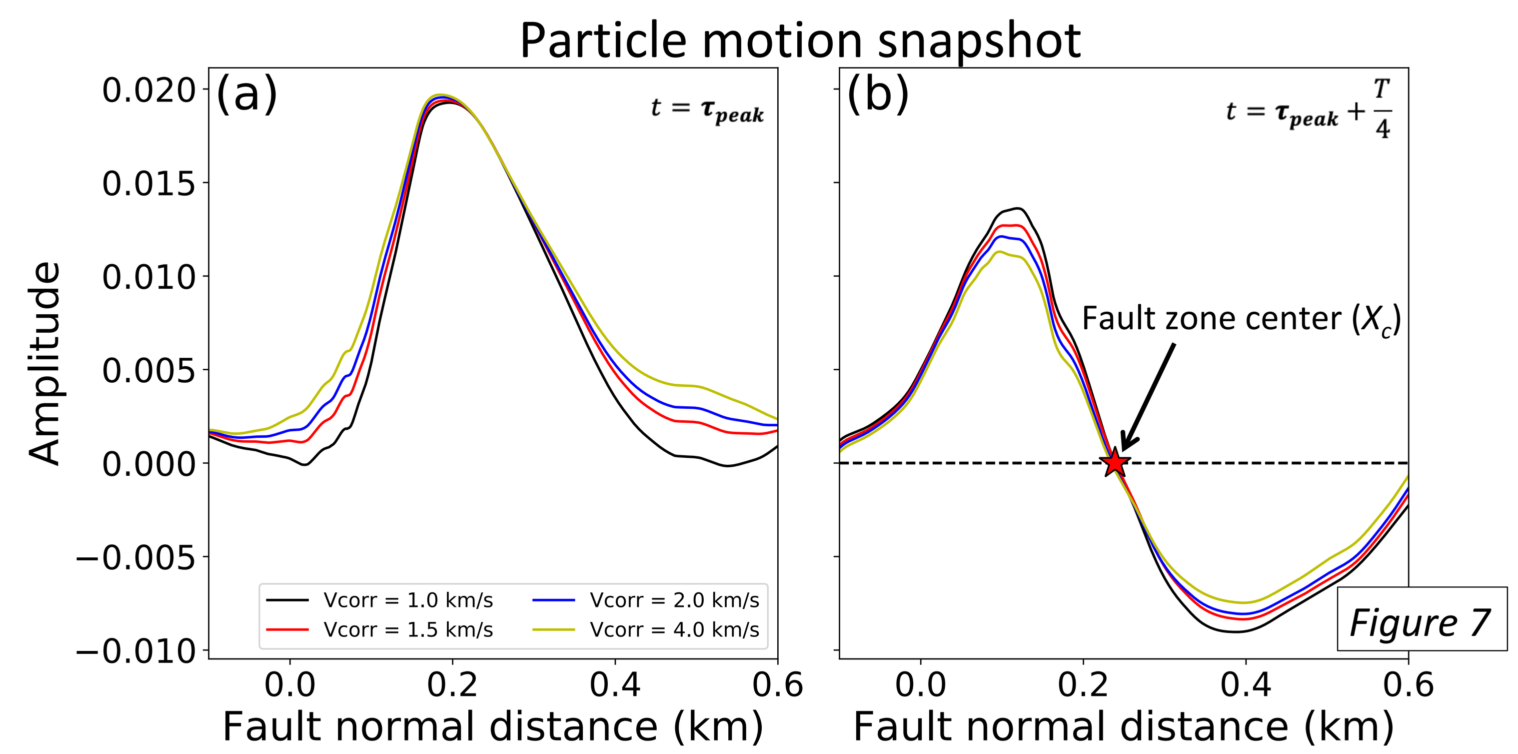
Narrow bandpass filtered around 1.3 Hz & Topography correction



(4) When β_3/β_1=1 and n=2 (only two modes):

$$\rho(t) = \mathrm{real}\left\{\int |V(x)|e^{-i\omega[t-\tau_0(x)]}dx\right\} = \mathrm{real}\left\{e^{-i\omega(t-\tau_{peak})}\int\left|B_2^l(c_0)\cdot u_0(x)\right|dx\right\}$$ and $\rho\left(t = \tau_{peak}+\frac{T}{4}\right) = 0$

MODE DECOMPOSITION



(5) Extract Eigen-functions of:

$$u_0(x,\omega) = C_1\cdot\left[V(x,\tau_{peak}) + V(2X_c - x,\tau_{peak})\right] \xrightarrow{\text{Fold \& Average}} \textit{Fundamental mode}$$

$$u_1(x,\omega) = C_2\cdot\left[V\left(x,\tau_{peak}+\frac{T}{4}\right) - V\left(2X_c - x,\tau_{peak}+\frac{T}{4}\right)\right] \xrightarrow{\text{Fold \& Subtract}} \textit{First mode}$$