Body wave extraction by using sparsity-promoting time-frequency filtering

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INTRODUCTION

- Seismic waves carry considerable information about the subsurface structure.
- Because the body waves masked by surface waves, their extraction is more challenging.
- In this study, we use sparsity-promoting in time-frequency domain to extraction the body waves.

THEORY

Polarization Analysis in the Time–Frequency (TF) Domain:

For $X = [x_1, x_2, x_3] \in R^{L\times 3}$ (1)

1) Computing TF decomposition of 3 components:

$$TF_{STFT}(k,l) = \sum_{k=0}^{2n} x(\hat{k})\omega(\hat{k}-k)\exp\left(\frac{-2\pi j\hat{k}l}{L}\right) \quad (2)$$

$$\omega(\hat{k}-k) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(\hat{k}-k)^2/2\sigma^2} \quad (3)$$

$$l = 0,1,\ldots,n \text{ and } k = 0,1,\ldots,L.$$

2) Computing polarization parameters in the TF-domain:

$$C(k,l) = \begin{bmatrix} C_{11}(k,l) & C_{12}(k,l) & C_{13}(k,l) \\ C_{21}(k,l) & C_{22}(k,l) & C_{23}(k,l) \\ C_{31}(k,l) & C_{32}(k,l) & C_{33}(k,l) \end{bmatrix} \in R^{3\times 3} \quad (4)$$

$$\hat{C}_{ij}(k,l) = \begin{cases} 2\mathrm{Re}(TF_i(K,l) \circ TF_j(K,l)^*)/L^2 & l \neq 0 \\ (TF_i(K,l) \circ TF_j(K,l)^*)/L^2 & l = 0 \end{cases}, \quad (5)$$

➡ $(\hat{\mathbf{C}}(k,l) - \lambda_i(k,l)\mathbf{I})\mathbf{u}(k,l) = 0$ (6)

Regularized Sparsity-Promoting TF Decomposition

$$x = G\alpha \quad (7)$$

$$\boldsymbol{\alpha} = \arg\min \tfrac{1}{2}\|\boldsymbol{G\alpha} - \boldsymbol{x}\|_2^2 + \mu\|\boldsymbol{\alpha}\|_1 \quad (8)$$

Adaptive filtering in the TF-domain

- *Rectilinearity attribute:*

$$Re(k,l) = 1 - \frac{\lambda_2(k,l) + \lambda_3(k,l)}{\lambda_1(k,l)} \quad (9)$$

$$\psi_{Re}(Re(k,l)) = \begin{cases} 1 & -1 < Re(k,l) < \alpha \\ \cos\left(\frac{\pi(Re(k,l)-\alpha)}{2(\beta-\alpha)}\right) & \alpha < Re(k,l) < \beta \\ 0 & \beta < Re(k,l) < 1 \end{cases} \quad (10)$$

- *Directivity attribute:*

$$D_i(k,l) = \left|u_1^T(k,l)e_i\right|, \quad i \in \{T,R,Z\} \quad (11)$$

$$\psi_D(D_i(k,l)) = \begin{cases} 1 & 0 < D_i(k,l) < \gamma \\ \cos\left(\frac{\pi(D_i(k,l)-\gamma)}{2(\lambda-\gamma)}\right) & \gamma < D_i(k,l) < \lambda \\ 0 & \lambda < D_i(k,l) < 1 \end{cases} \quad (12)$$

- *Amplitude attribute:*

$$A(k,l) = \sqrt{2\lambda_1(k,l)} \quad (16)$$

$$\psi_A(A(k,l)) = \begin{cases} 1 & 0 < A(k,l) < \zeta \\ \cos\left(\frac{\pi(A(k,l)-\zeta)}{2(\eta-\zeta)}\right) & \zeta < A(k,l) < \eta \\ 0 & \eta < A(k,l) < 1 \end{cases} \quad (13)$$

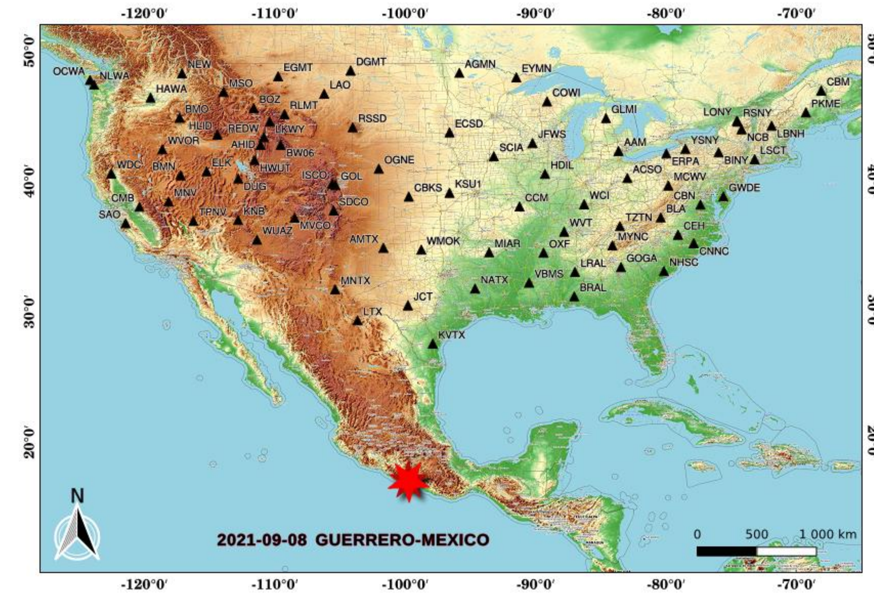
Regularized Sparsity-Promoting Time Frequency Filtering:

$$\psi_R = 1 - \{1-\psi_{Re}\} \circ \{1-\psi_D\} \circ \{1-\psi_A\} \quad (14)$$

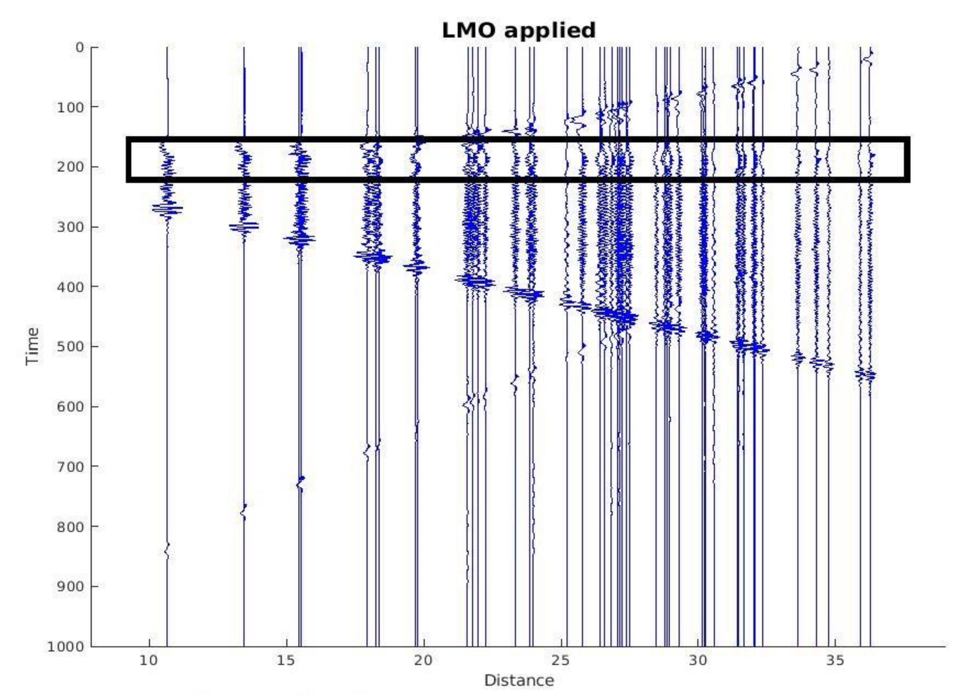
$$\psi_E = 1 - \psi_R \quad (15)$$

NUMERICAL EXAMPLE

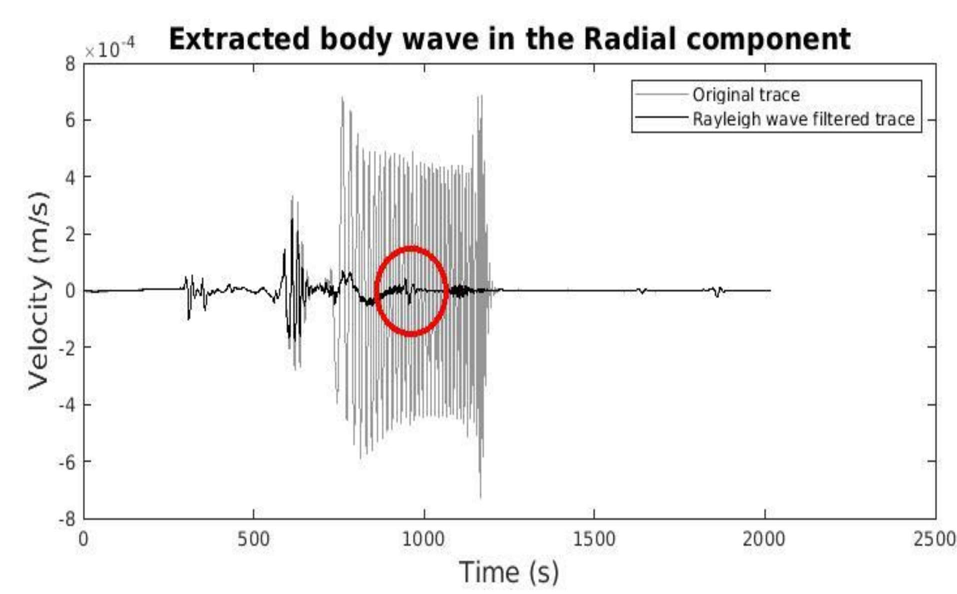
- We implement it on synthetic data example to extract the body waves. The source mechanism corresponds to the source mechanism of the *Mw* = 7.0 earthquake occurred in the 21.8 km of Guerrero, Mexico, as a result of revers dip-slip faulting.The 3-D synthetic seismic data are generated using the 1-Dak135f earth model with spectral-element method assuming 3-D (an)elastic, anisotropic wave propagation in the spherical domain.



- This picture shows the filtered waveforms to extract body waves. The traces are plotted as a function of epicenteral distance, and a linear move out were apply by 5.8km/s to aline the body wave.



- the radial component of the earthquake, which weak body waves accurately extracted from the high amplitude surface waves.



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