Exploring the relation between backprojection images and earthquake source processes

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Abstract

Backprojection (BP) of teleseismic P waves is a widely-used method to study the evolution of earthquake radiation and is particularly effective for large earthquakes. We can harness key information on the spatiotemporal evolution during the rupture process from waveform similarity or coherency. Understanding the relation between earthquake physics and the spatiotemporal evolution from BP imaging, which are usually obtained from high frequency seismic waveforms, is of great importance. Theoretical studies indicate that the high-frequency bursts can be related to abrupt changes in rupture velocity (e.g. stopping of rupture or kinks on the fault). Moreover, the BP images are thought to be equivalent to either slip or slip rate on the fault, provided that the Green's functions from the sources to the receivers are incoherent delta functions. Furthermore, recent studies propose that the frequency dependent features of BP results can reflect the stress status, frictional and/or geometrical heterogeneity on the fault surface. It is promising that we can obtain more observational constraints and information about the earthquake dynamic source from the backprojection results combined with other independent techniques. In this study, we attempt to figure out the relation between the BP results and earthquake source process by testing both kinematic and dynamic source models. With these source models, we can synthesise the seismic waveforms and trace them back to the fault surface using the BP method. Therefore, we can directly compare the BP results with the already-known earthquake sources and further explore the possible relation to the source properties by varying our source models such as the friction laws, fault geometries. To simplify our problem and exclude the potential effects from complex earth structure, our tests are carried out in a purely elastic medium, whole space, allowing us to solve analytically for the far-field body waves. From these systematical tests and comparisons, we aim at building a comprehensive relation between the BP images and various source properties. Moreover, our results can provide significant help to better understand the physics of earthquake source process from seismic observations.

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1-minute summary

1. **Backprojection (BP) is a powerful seismic-array processing tool that provides observational constraints on the evolution of the seismic radiation during large earthquakes. To better interpret the BP images in terms of earthquake dynamics, a careful relation between the BP images and the kinematics of the source is needed.**

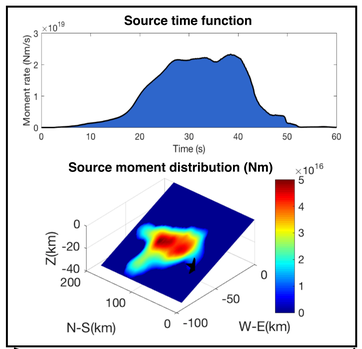
2. **We explore the relation between BP images and seismic radiation using synthetic waveforms from both kinematic and dynamic source models embedded in a pure elastic wholespace.**

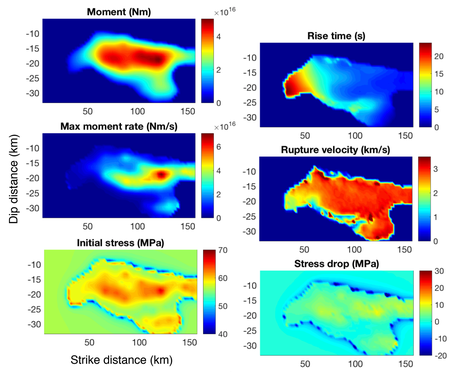
3. **Preliminary results show the BP image is mostly correlated to the distribution of peak slip/moment rate, for both kinematic and dynamic sources. However, it is also highly related to other factors thus should be carefully interpreted with coseismic observations.**

Methodology

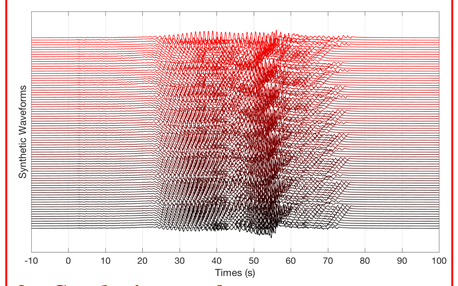
1. *Source models*

- Kinematic source models are generated by **FFSP** (source generator developed by *Liu et al.* [2006] and *Crempien and Archuleta* [2014])
- Dynamic source model is from *Dr. Huihui Weng* for the 2015 Gorkha Mw 7.8 earthquake based on slip weakening with parameters constrained by near-field ground motion observations.





2. *Synthetic waveforms:*



Waveforms are derived from the slip histories of the source models in the homogeneous, elastic wholespace.

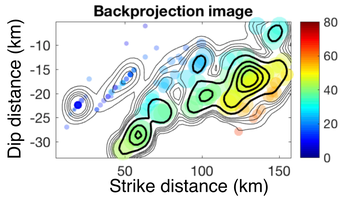
3. *BP in frequency domain*

$$\mathbf{B}(f) = \mathbf{A}(f)\mathbf{X}(f)$$

$$\mathbf{X}(f) = \mathbf{A}^{\mathbf{H}}(f)\mathbf{B}(f)/\mathrm{N}$$

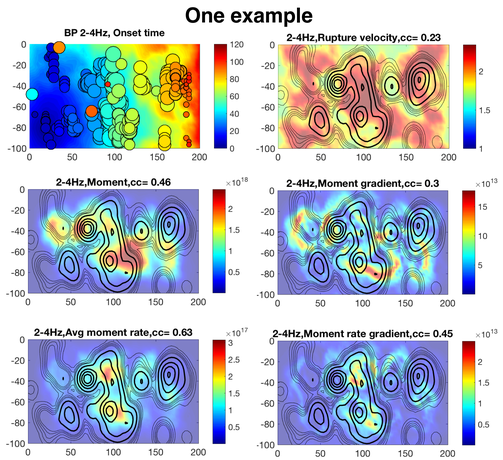
$\mathbf{B}(f)$: Velocity data in frequency domain
$\mathbf{A}(f)$: Propagation matrix (travel time shifting)
$\mathbf{X}(f)$: Distribution of BP power
H: Conjugate transpose N: Number of stations

4. *2D Image correlation (quantified comparisons)*

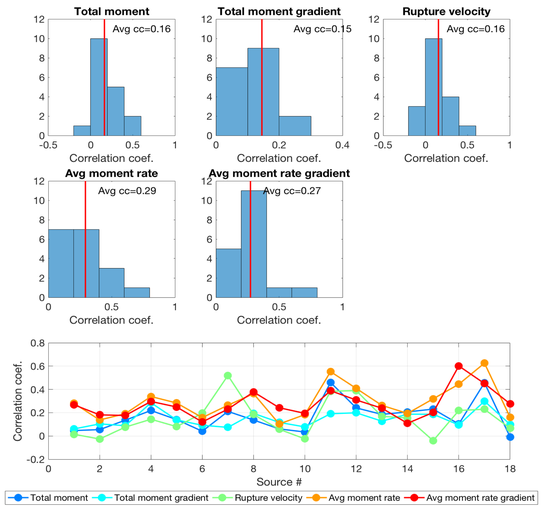


Results

1. *BP image & Kinematic sources*



⬆ **2-4 Hz integrated BP image (black contours)** is most correlated to average moment rate, spatial gradient (strain/stress rate?) and rupture velocity variation.

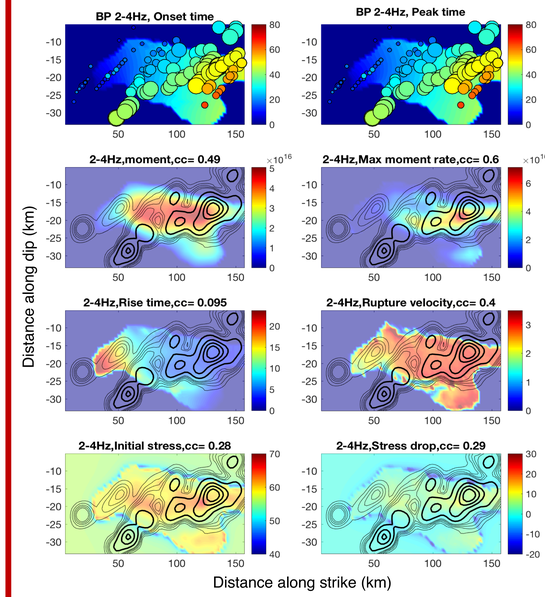


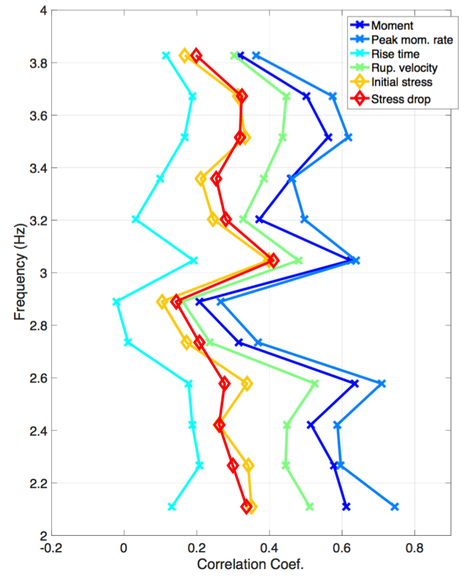
⬆ **Correlations with source parameters for all 18 generated kinematic sources in the integrated frequency band of 2-4Hz.**

➡ **Correlations (crosses) with source parameters for all sources in each narrow frequency band.** Correlation coefficients vary for different sources and there is no systematic frequency dependence on the correlation coefficients of each source parameters.

➡ **Average correlation coefficients (red lines)** seem to be relatively stable, implying the general correlation between BP image and all these parameters.

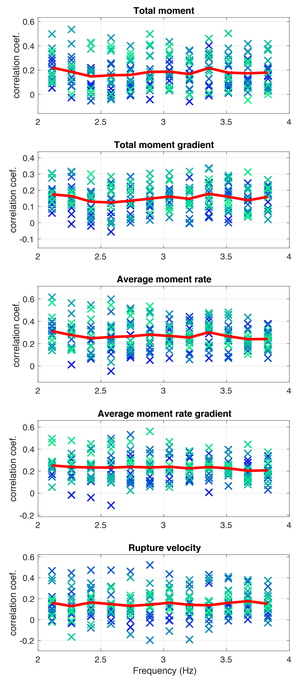
2. *BP image & Dynamic source model of 2015 Nepal Gorkha Mw 7.8 earthquake*





⬆ **Correlation between BP image and dynamic model within 2-4Hz**
Peak moment rate > Moment > Rupture velocity (?) > Stress drop ≈ Initial stress > Rise time

⬈ **Correlations with source parameters from the dynamic source in each narrow frequency band.** Systematic frequency dependence on the correlation coefficients is unclear for this dynamic model, the valley around 2.8Hz is mostly due to swimming artifacts of conventional BP.



Conclusion and Discussion

❖ **Both kinematic and dynamic source models indicate correlations between BP image and distributions of slip, slip rate, slip gradient (strain), slip rate gradient (strain rate) and rupture velocity heterogeneities.**

❖ **No single parameter dominates the characteristics of BP images, but rather a combination of them (moment, moment rate).**

❖ **Our results show no systematic frequency-dependent correlation patterns, which implies that the differences reported in BP images with variable seismic frequencies probably stem from other factors such as fault geometry, roughness and/or frictional properties etc.**

Future work:

- **Apply to more diverse kinematic source models for better parametrization (i.e. varying asperity size and amplitude of heterogeneity)**
- **Use advanced BP methods to gain better BP image with less artifacts**

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