Synthetic analysis of seismic back-projection using 3D dynamic rupture simulations of the 2018, Palu Sulawesi earthquake

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Back-projection uses the time-reversal property of the seismic wavefield recorded at large aperture dense seismic arrays. Seismic energy radiation is imaged by applying array beam-forming techniques. The spatio-temporal rupture complexity of large earthquakes can be imaged simply and rapidly with a limited number of assumptions, which makes back-projection techniques an important tool of modern seismology. However, back-projection analyses exhibit frequency and array dependency (e.g. Wu et al., AGU19). In addition, the method relies on station network geometry and data quality and can suffer from imaging artifacts (e.g., Fan and Shearer, 2017) and back-projection results may not be consistently interpreted.

The Mw7.5 Palu, Sulawesi earthquake that occurred on September 28, 2018, ruptured a 180 km long section of the Palu-Koro fault. The earthquake triggered a localized but powerful tsunami within Palu Bay, which swept away houses and buildings. The supershear earthquake and unexpected tsunami led to more than 4000 fatalities. Ulrich et al. (2019) propose a physics-based, coupled earthquake-tsunami scenario of the event, tightly constrained by observations. The model matches key observed earthquake characteristics, including moment magnitude, rupture duration, fault plane solution, teleseismic waveforms, and inferred horizontal ground displacements. It suggests that time-dependent earthquake-induced uplift and subsidence could have sourced the observed tsunami within Palu Bay.

Back-projection has been used to track the rupture propagation of the Palu earthquake. Bao et al. (2019) image unilateral rupture traveling at a supershear rupture speed. Their results show array dependent ruptures, from a rather relatively linear rupture using the Australian array, to a spatio-temporally more scattered image using the seismic array in Turkey. In addition, they do not resolve any portion of the rupture as traveling at sub-Rayleigh speeds, while Wei et al. (AGU19) suggest a gradually accelerating rupture.

In this study, we build upon the dynamic rupture model of Ulrich et al. (2019) to investigate the reliability of standard back-projection techniques using a realistic and perfectly known earthquake model. In particular, we investigate whether or not rupture transfers across the segmented fault system, and the effect of specific geometric features of the fault system, such as fault bends, on rupture dynamics, leave a clear signal on the inferred beam power. Also, we investigate the effect of secondary phases, such as reflections from the free-surface or from fault segment boundaries, naturally captured by dynamic rupture modeling. In addition, we study the effect of small-scale
source heterogeneities on the back-projection results by including different levels of fault roughness in the dynamic rupture simulations. Finally, we investigate the array dependence of back-projection results.

Overall, this study should help to better understand which features of rupture dynamics back-projection can capture. Our results are a first step towards fundamental analysis to better understand which features can be captured by back-projection and to provide guidelines for back-projection interpretation.