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Theoretical background of back-projection imaging and its relation to time-reversal and inverse solutions

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The back-projection (BP) method has become a popular tool to image the rupture process of large earthquakes since the success of Ishii et al. (2005), while it has not been clear what the BP image represents physically. We clarified the theoretical background of the back-projection (BP) imaging and related it to classical inverse solutions via the hybrid back-projection (HBP) imaging (Yagi et al., 2012). In the HBP method, which is mathematically almost equivalent to the time-reversal imaging, cross correlations of observed waveforms with the corresponding Green's functions are calculated. The key condition for BP to work well is that the Green's function is sufficiently close to the delta function after stacking. Then, we found that the BP image represents the slip motion on the fault, and approximately equals to the least squares solution. In HBP, instead of the Green's function in BP, the stacked auto-correlation function of the Green's function must be similar to the delta function to obtain a fine image. Because the auto-correlation function is usually closer to the delta function than the original function, we can expect that HBP works better than BP, if we can reasonably assume the Green's function. With another condition that the stacked cross-correlation function of the Green's functions for different source locations is small enough, the HBP image is approximately equal to the least squares solution. If these assumptions are not satisfied, however, the HBP image corresponds to a damped least squares solution with an extremely large damping parameter, which is clearly inferior to usual inverse solutions. From the viewpoint of inverse theory, an elaborate stacking technique (such as an N-th root stack) to obtain a finer resolution image inevitably leads to larger estimation errors.