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The challenging task of estimating rupture directivity of moderate earthquakes in near real-time

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Radiation from an extended seismic source when a rupture propagates in preferential directions is called the directivity effect. It is manifested by seismic spectral variations depending on the observation location. Directivity produces azimuthal and spectral variations in ground motion that can be used to infer information about the orientation of the fault plane or to investigate a predominant orientation of rupture propagation in a particular region or during a seismic sequence. In addition, directivity at low frequencies and during moderate-to-strong events can be responsible for potentially destructive pulses with large ground motions, while at high frequencies and during small-to-moderate events, the most pronounced effect is given by the shift in corner frequencies, which can lead to high-frequency energy arrivals in short time intervals (Abercrombie et al. 2017) .

Rupture processes of large earthquakes have been extensively examined by seismic waveform analysis (e.g., Hartzell and Heaton, 1983; Fukuyama and Irikura, 1986; Ye et al., 2016) and directivity effects have also been observed in moderate and small earthquakes (e.g., Boatwright, 2007; Chen et al., 2010; Abercrombie et al. 2017; Meng et al., 2020; Meng and Fan, 2021)

The importance of directivity in small to moderate earthquakes is widely recognised for both seismological studies on earthquake sources and engineering applications (e.g. Colavitti et al., 2022), and to estimate it in near real time would provide useful information for post-earthquake management. However, the determination of directivity effects and source parameters for small-to -moderate magnitude earthquakes remains a challenge. The accuracy of the results depends on the quality of the data, the coverage of the seismic network, the computational method used, as well as on the complexity of the rupture.

One of the most common techniques is to measure the duration of the source pulse (called Apparent Source Time Function) at each location and then model it by a line source (Fig 1). To overcome the problems associated with the presence of path and site effects some approaches rely on the deconvolution of waveforms by an empirical Green function (eGf), (Calderoni et al. 2015; Calderoni, Rovelli, and Di Giovambattista 2017; McGuire 2017; Meng et al. 2020) but finding the right eGf can sometimes be difficult.

A promising method to estimate the rupture directivity effect but also the related source properties is based on the calculation of second seismic moments (Meng et al. 2020). The method has been successfully applied to small and moderate earthquakes (magnitude range 3.5 - 5.2) in Southern California, yielding stable results for 28 out of 41 events (Meng et al. 2020).

In this study we estimate the rupture process and the source parameters of moderate events occurred during the 2016 - 2017 seismic sequence in central Italy, which is an excellent laboratory for normal fault earthquakes, particularly in the magnitude range of 3.4 and 6.5 (Colavitti et al. 2022). First, we applied the method based on the calculation of the second seismic moments using synthetic apparent source time functions calculated from a geometric source model obtained from a real event. We then applied both this methods (Fig 2) and conventional eGf deconvolution (Calderoni et al. 2015; 2017) separately to resolve the directivity of a moderate magnitude earthquake that occurred in central Italy in 2016 using data from RAN (Costa et al. 2022) and RSN network. Limitations and advantages are then discussed.

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