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Abstract: Earthquake monitoring and early warning system for hazard assessment and mitigation has traditional been based on seismic instruments. However, for large seismic events, it is difficult for traditional seismic instruments to produce accurate and reliable displacements because of the saturation of broadband seismometers and problematic integration of strong-motion data. Compared with the traditional seismic instruments, GPS can measure arbitrarily large dynamic displacements without saturation, making them particularly valuable in case of large earthquakes and tsunamis. GPS relative positioning approach is usually adopted to estimate seismic displacements since centimeter-level accuracy can be achieved in real-time by processing double-differenced carrier-phase observables. However, relative positioning method requires a local reference station, which might itself be displaced during a large seismic event, resulting in misleading GPS analysis results. Meanwhile, the relative/network approach is time-consuming, particularly difficult for the simultaneous and real-time analysis of GPS data from hundreds or thousands of ground stations.
In recent years, several single-receiver approaches for real-time GPS seismology, which can overcome the reference station problem of the relative positioning approach, have been successfully developed and applied to GPS seismology. One available method is real-time precise point positioning (PPP) relied on precise satellite orbit and clock products. However, real-time PPP needs a long (re)convergence period, of about thirty minutes, to resolve integer phase ambiguities and achieve centimeter-level accuracy. In comparison with PPP, Colosimo et al. (2011) proposed a variometric approach to determine the change of position between two adjacent epochs, and then displacements are obtained by a single integration of the delta positions. This approach does not suffer from convergence process, but the single integration from delta positions to displacements is accompanied by a drift due to the potential uncompensated errors. Li et al. (2013) presented a temporal point positioning (TPP) method to quickly capture coseismic displacements with a single GPS receiver in real-time. The TPP approach can overcome the convergence problem of precise point positioning (PPP), and also avoids the integration and de-trending process of the variometric approach. The performance of TPP is demonstrated to be at few centimeters level of displacement accuracy for even twenty minutes interval with real-time precise orbit and clock products.
In this study, we firstly present and compare the observation models and processing strategies of the current existing single-receiver methods for real-time GPS seismology. Furthermore, we propose several refinements to the variometric approach in order to eliminate the drift trend in the integrated coseismic displacements. The mathematical relationship between these methods is discussed in detail and their equivalence is also proved. The impact of error components such as satellite ephemeris, ionospheric delay, tropospheric delay, and geometry change on the retrieved displacements are carefully analyzed and investigated. Finally, the performance of these single-receiver approaches for real-time GPS seismology is validated using 1 Hz GPS data collected during the Tohoku-Oki earthquake (Mw 9.0, March 11, 2011) in Japan. It is shown that few centimeters accuracy of coseismic displacements is achievable.

Keywords: High-rate GPS; real-time GPS seismology; a single receiver; PPP; variometric approach; temporal point positioning; error analysis; coseismic displacement; fault slip inversion;