Six-degree-of-freedom seismogeodesy by combining high-rate GNSS, accelerometers and gyroscopes

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High-rate GNSS receivers, sampling satellite signals at over 1-Hz rate, can record strong ground motions and directly in the form of displacements instead of velocities or accelerations. In this case, broadband displacement waveforms down to 0 Hz can be obtained nominally; the benefit is that static offsets can be identified accurately from high-rate displacements with minimal contamination by the very early postseismic signals. The drawback of high-rate GNSS, however, consists in its orders of magnitude higher noise than that of seismometers, almost on all frequency bands concerning seismic studies. Combining collocated high-rate GNSS and accelerometers can be a remedy and produces broadband seismogeodetic displacements. However, accelerometer data must be heavily downweighted due to their baseline errors originating primarily in instrument rotations, and therefore their contribution to seismogeodetic displacements is seriously underestimated. We further introduced a gyroscope into this classic seismogeodesy to mitigate baseline errors and formulated advanced six-degree-of-freedom (6-DOF) seismogeodesy without undervaluing accelerometer data. A shake table holding one GNSS antenna, four accelerometers, and one gyroscope was used to simulate waveforms from the 2010 Mw 7.2 El Mayor-Cucapah earthquake. We found that the displacements derived from the 6-DOF seismogeodesy were up to 68% more accurate than those from the classic seismogeodesy over 0.04–0.4 Hz. Moreover, broadband rotations containing the permanent components were also generated, which were unachievable by integrating gyroscope data. We believe that the 6-DOF seismogeodesy is capable of improving both source rupture studies of large earthquakes and high-rise monitoring under strong seismic waves.