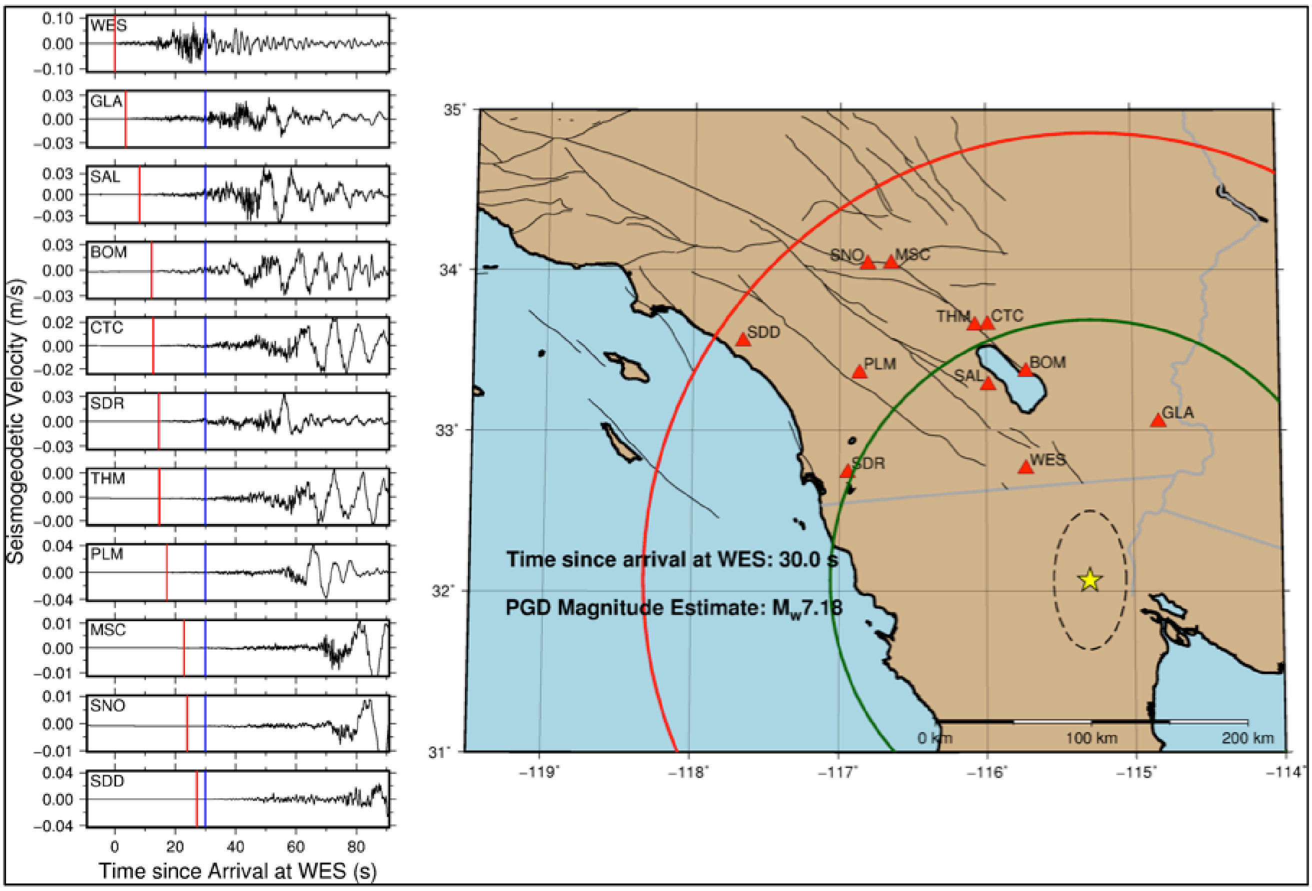
Rapid Magnitude Estimation in Earthquake Early Warning with Seismogeodesy

*Dara Goldberg[1], Yehuda Bock[1]

1.Scripps Institution of Oceanography

Earthquake early warning (EEW) is critical to reducing injuries and casualties in case of a large magnitude earthquake. Fault systems often coincide with populous cities, thus we require a P-wave detection method for effective early warning. Such a system must rely on near-source data to minimize the time between event onset and issuance of a warning. Current early warning systems typically rely on seismic instruments (seismometers and accelerometers). Global Navigation and Satellite System (GNSS) instruments are starting to be deployed, but are not yet fully exploited. Seismic instruments experience difficulty maintaining reliable data within close epicentral distance of large events. Large motions can exceed the dynamic range of broadband seismometers, and accelerometers conflate rotations and translations, causing spurious translational recordings that obscure the true nature of shaking. Moreover, the relation between ground motion amplitude and earthquake magnitude “saturates” for large earthquakes, causing magnitude underestimation that proved catastrophic for the 2011 M_w9.0 Great East Japan earthquake and resulting tsunami [*Hoshiba and Ozaki*, 2014; *Yun and Hamada*, 2014]. GNSS instruments capture the long period motions and have been shown to produce robust estimates of the true size of the earthquake source. However, GNSS alone is not precise enough to record first seismic wave arrivals, which is an important consideration for issuing an early warning. Our approach is to optimally combine direct measurements from collocated GNSS and accelerometer stations using a Kalman filter [*Bock et al.*, 2011] to estimate broadband coseismic displacement and velocity waveforms with complete spectral recovery from the static offset to the accelerometer Nyquist frequency, regardless of the intensity of shaking. This approach, referred to as seismogeodesy, includes the long period and static offset without interference from accelerometer errors or saturation for large magnitude events and, unlike GNSS alone, is precise enough to detect P-wave arrivals. We demonstrate the advantages of seismogeodesy for earthquake early warning via retrospective simulated real time examples for earthquakes in the western U.S., Japan and Chile. For event detection and location we use the seismogeodetic velocity. We also discuss the sensitivity of hypocenter location as a function of the distribution of monitoring stations near the source and demonstrate rapid magnitude scaling relationships [*Crowell et al.*, 2013; *Melgar et al.*, 2015]. The prototype early warning system developed at Scripps is being applied to local tsunami warning by the U.S. National Oceanic and Atmospheric Administration’s Tsunami Warning Centers. The critical input for tsunami warning is a rapid estimate of magnitude.

Keywords: earthquake early warning, seismogeodesy



Left: Seismogeodetic velocity waveforms at 11 GPS/seismic stations sorted by order of P-wave detection. Continuous blue vertical line denotes current epoch. Preceding red lines indicate when P-wave was detected from seismogeodetic velocity at each station.

Right: Once 4 stations have triggered, an estimate of the hypocenter can be made, denoted by the yellow star with one-sigma error ellipse on map. Hypocenter is updated with P-wave arrivals at additional stations. Propagation of P- and S-waves are shown by the partial circles (red and green, respectively), with the S-wave trailing the P-wave. In this scenario, it would take the S-wave front about 80-90s before arriving in the heavily populated areas of Riverside and Los Angeles Counties. Magnitude is estimated through Peak Ground Displacement (PGD) scaling relation using seismogeodetic displacement. Shown here is a frame 30s after P-wave detection at the first station.

