Operational Real-time GPS in Earthquake Early Warning

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Integrating geodetic data into seismic earthquake early warning (EEW) is critical for accurately resolving magnitude and finite fault dimensions for large earthquakes (M>7). We have developed G-larmS, the Geodetic alarm System, as part of our efforts to incorporate geodetic data into EEW for Northern California. G-larmS an extensible geodetic EEW infrastructure that takes input from a real-time GPS processors, such as TrackRT or RTNET, and analyzes the real-time positioning time series to generate static offsets and quality parameters, which are passed to a modeling algorithm. It is tightly integrated into seismic alarm systems (CISN ShakeAlert, ElarmS) as it uses their P-wave detection alarms to trigger its own processing and sends warning messages back to the ShakeAlert decision module.

G-larmS is currently running in an operational mode at the Berkeley Seismological Laboratory (BSL), where we are using TrackRT to produce high sample rate displacement time series for 62 GPS stations in the greater San Francisco Bay Area with 3-6 second latency. TrackRT follows a network processing approach, with displacements generated relative to a reference station. We employ a fully triangulated network scheme, which provides resiliency against an outage or telemetry loss at any individual station, for a total of 165 baselines (*Fig 1)*. Once G-larmS is triggered by the seismic EEW system, it estimates the static offset at each station pair from the TrackRT output and inputs these into an inversion for fault slip, which is updated once per second. The software architecture and clear interface definitions of this Python implementation enable straightforward extensibility and exchange of specific algorithms that operate in the individual modules.

Here, we present the setup and report results of the first months of operation in Northern California. We review G-larms' performance during the 2014 M_w6.0 South Napa earthquake in California *(Fig. 1)*. During this event the first distributed slip model and a magnitude estimate of M_w5.5 were available 24 s after the event origin time, which could be reduced to 14 s after a bug fix (~8 s S-wave travel time, ~6 s data latency). From G-larmS' solutions for subsequent small magnitude aftershocks we infer that M_w~6.0 is the resolution limit of the current network.

We also test how differential positions over relatively short baselines (like those produced at the BSL) compare to absolute positions in the case of a very large earthquake. We perform this analysis using data from the 2011 M_w 9.0 Tohoku earthquake and invert for slip along the subduction zone interface.

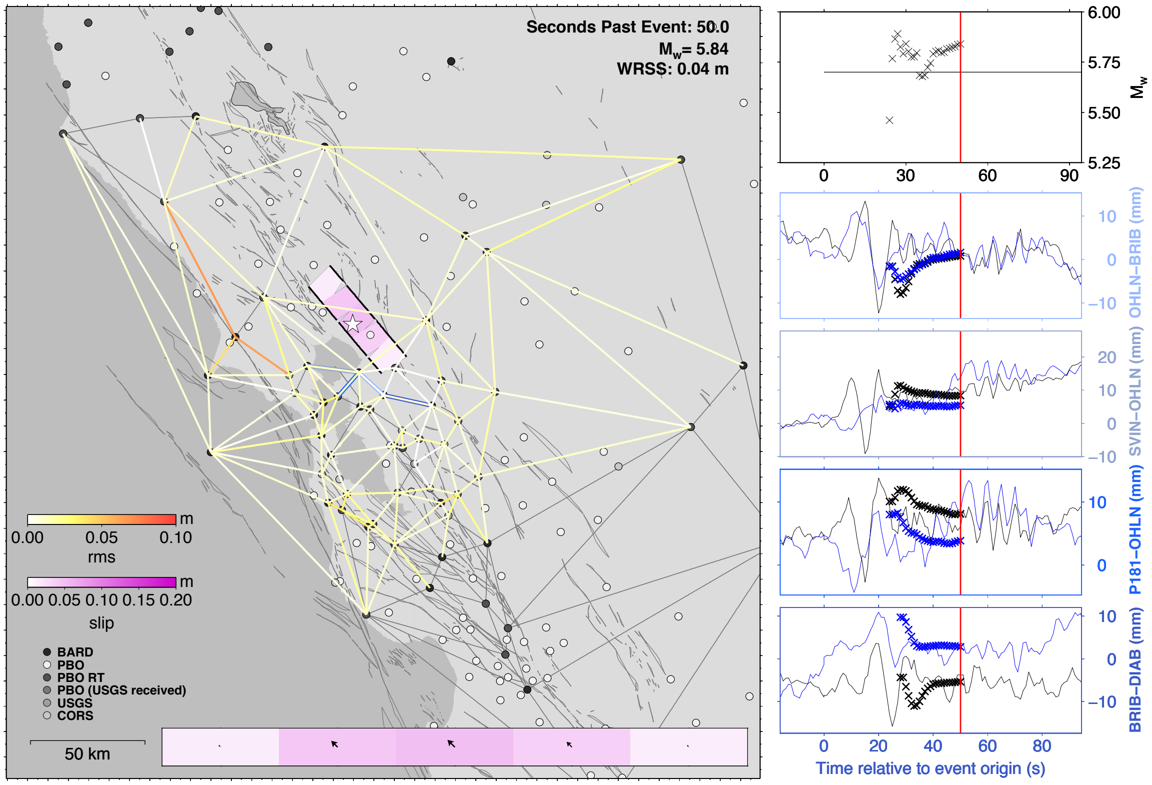

Fig 1. Real-time solution produced 50 s after the event origin time (first solution was at 24 s, event location given by white star). **(Left Panel)** Model at 50 s after the event. White to yellow colored baselines indicate model misfit. Projection of vertical fault is shown in map view. Pink colors indicate slip amplitude. N-S (left to right) fault cross section is at the bottom of the panel: vectors give rake (right lateral) normalized to maximum rake of the final solution. **(Right panels)** Top: Time series of GPS-based magnitude, horizontal line shows initial ShakeAlert magnitude; bottom four panels show north (blue) and east (black) displacement time series for bold, colored baselines in left panel. Crosses mark offsets derived along these baselines (time shift between GPS solutions and offsets is due to 6 seconds data acquisition and processing latency). (*Grapenthin et al, GRL, 2014*).