Real-Time GPS for Real-time Science
Rapid Magnitude Estimation from GPS Displacement

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Motivation: Tsunami Warning
Goals of Local Tsunami Warning

- Locate
- Identify size
- Identify mechanism
- Initiate evacuation
Goals of Local Tsunami Warning

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Why is constraining the magnitude so difficult in real-time?
Instrumentation

**Broadband**
- Singly Integrate Velocities
- Magnitude Saturation
- Clips in Near Field
- P-wave Detection
- Lose Static Offset
- 250 Hz

**Accelerometer**
- Doubly Integrate Accelerations
- Lose Static Offset
- Magnitude Saturation
- Integration Biases
- P-wave Detection
- 100-200 Hz

**GPS**
- Direct Displacements + Static Offset
- No Magnitude Saturation
- Cannot Detect P-wave
- 1-10 Hz

**Seismogeodetic**
- Kalman Filter: displacement
- Velocity
The Utility of GPS for Magnitude Estimation

- Direct measurement of displacement
- Static offset scales with magnitude
- Peak displacement scales with magnitude
- Results in a few minutes
- Not fully utilized for early warning

Grapenthin and Freymueller, 2011
How Early Can we Estimate Magnitude?

Nucleation Duration:

Ellsworth and Beroza, 1995

Maximum P-wave Period:

Olsen and Allen, 2005
How Early Can we Estimate Magnitude?

Maximum P-wave Period:  
Rydelek and Horiuchi, 2006

Maximum Displacement:  
Meier et al., 2016

Moment Rate Function:  
Meier et al., 2017
How Early Can we Estimate Magnitude?

Instrumentation

Need broadband instrumentation capable of identifying first seismic wave arrivals and accurately measuring displacements.

Magnitude Estimation

Identify earliest reliable metric for magnitude scaling.

Rupture Evolution

If earliest metric is available prior to rupture completion (deterministic), what is the physical basis?
Dataset

- 14 earthquakes
- $5.7 \leq M_w \leq 9.1$
- 1200+ GNSS Stations (GEONET)
- 1700+ Strong-Motion Sites (KiK-net/ K-NET)
- Triggered strong-motion stations, occasionally late
- Too few collocated sites to complete study with true seismogeodesy
Dataset: Simulating Seismogeodesy
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Evolution of Displacement
Evolution of Displacement

![Graph showing the relationship between hypocentral distance and displacement amplitude with varying values of Mw.](image-url)
No clear scaling from early observations
Evolution of Displacement

- No clear scaling from early observations
- Separation between events of different magnitude occurs first at close stations, then at farther stations
No clear scaling from early observations

Separation between events of different magnitude occurs first at close stations, then at farther stations

Observations from larger earthquakes exceed those from smaller earthquakes only when the smaller earthquake reaches peak ground displacement
When can we expect to observe PGD?
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- Magnitude 9 event takes much longer to reach PGD
- Most events asymptote the expected S-P line
- At close distances, $T^\text{PGD}-T^P$ exceeds S-P line
- The distance at which $T^\text{PGD}-T^P$ meets S-P appears to increase with increasing magnitude
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- What would we see if we had instrumentation at closer distances?
Model Configuration
How Does Slip Manifest?

- Assume pulse-like slip
- Magnitude-dependent pulse width (rise time)
- Magnitude-dependent fault dimensions
- Fill in what happens at close distances
- Do results look like the observations?

Pulse-like Slip

Rise time: local duration of slip
Pulse width is magnitude-dependent
Results
Results
Results
Results
Results

- Near-fault observations are sensitive to the rise time.
- Near-fault observations are impacted by nearby fault patches and the pattern of slip.
- Receivers at distance observe the integrated fault signal.
- Stations <90km observe PGD with ~35s of observation, up to a $M_w$8.5, despite a rupture duration of ~65s.
Implications for Early Warning with GNSS

- Earthquake magnitude can be reliably estimated once PGD has been observed.

- At close distances, PGD is delayed by increasing fault dimension and rise time.

- If observed at close enough distances, PGD can be observed prior to rupture completion, implying a weak determinism.

- PGD estimates will be available faster with direct displacement measurements from GNSS.

- Collocated seismogeodetic instrumentation will allow proper earthquake detection and magnitude scaling improving real-time local tsunami warning.