Using Real Time GPS to Deliver Earthquake Early Warning in California

UC Berkeley
Geophysical Networks

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Berkeley
University of California
Seismological Laboratory
Sound science, Societal relevance
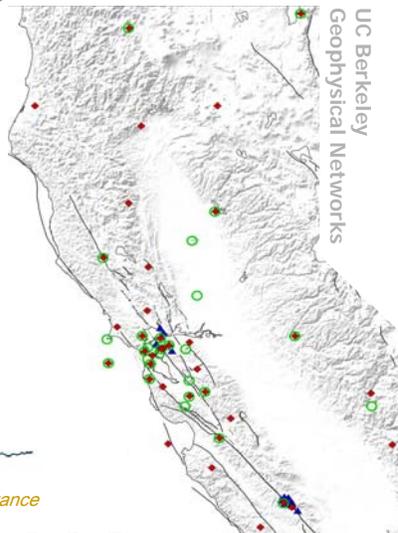
Berkeley Seismological Laboratory

Mission

UC Berkeley
Geophysical Networks

Fundamental earthquake and earth structure research
Support fundamental research into all aspects of earthquakes, solid earth processes and their effects on society through the collection, archival and delivery of high quality geophysical data and through fostering a dynamic research environment that connects researchers across disciplines and to geophysical observations systems.

Real-time earthquake hazard information
Provide robust and reliable real-time data and information on northern California earthquakes to government, public and private institutions, and to the public, in partnership with the US Geological Survey, CalEMA and other collaborating institutions.

Broad education
Enable the broad consumption of earthquake information and solid earth science through education and outreach to all sectors of society.

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Sound science, Societal relevance

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Core infrastructure

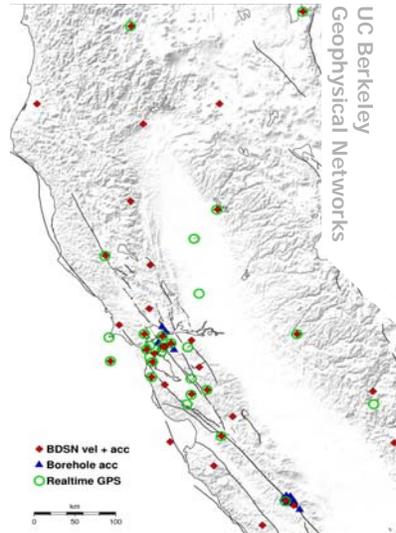**Broadband high dynamic range geophysical networks**

BDSN: co-located broadband velocity + accelerometer

Borehole networks: low-noise accelerometers at Parkfield and Northern Hayward Fault

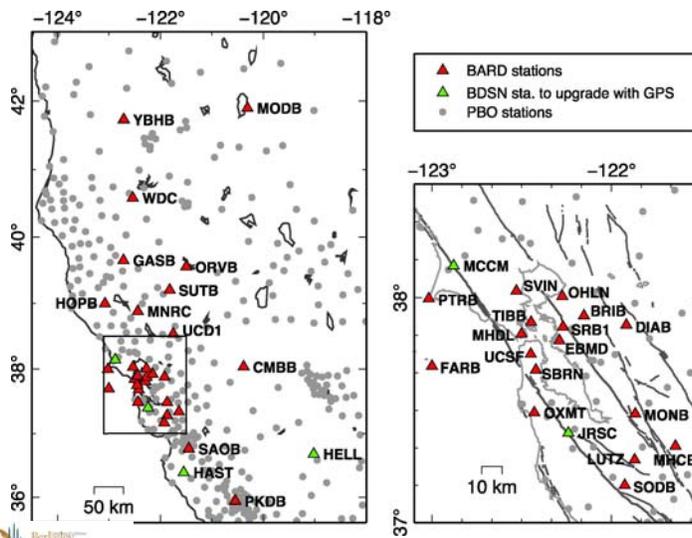**Realtime GPS:** High sample rate displacement. Often co-located with seismometers

Ocean bottom: Broadband velocity. Telemetered – ocean floor cable

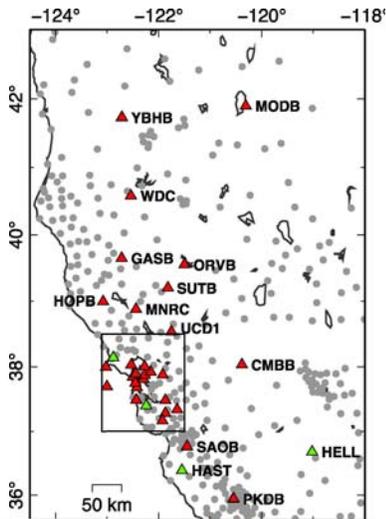➔ **range of instrumentation allows for development of new tools**

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Legend:
- ♦ BDSN vel + acc
- ▲ Borehole acc
- ◯ Realtime GPS

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BARD Continuous GPS Network

Legend:
- ▲ BARD stations
- ▲ BDSN sta. to upgrade with GPS
- • PBO stations

Station labels (left map): YBHB, MODB, WDC, GASB, ORVB, SUTB, HOPB, MNRC, UCD1, CMBB, SAOB, HAST, HELL, PKDB

Station labels (right map): MCCM, PTRB, SVIN, OHLN, TIBB, BRIB, MHDL, SRB1, DIAB, UCSF, EBMD, FARB, SBRN, OXMT, JRSC, MONB, LUTZ, MHCB, SODB

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BARD Continuous GPS Network

Highlights

- Established in 1992
- All data available: http://ncedc.org
- All stations 1hz
- 1hz sampling phased in since 2003
- Most stations openly available in real-time.
  - BINEX and RTCM3 formats
  - http://seismo.berkeley.edu/bard/realtime
- In progress: Real-time position estimates

More Info:
Ingrid Johanson, BARD Network Manager
ingrid@seismo.berkeley.edu

Berkeley & CISN California Integrated Seismic Network ANSS

Integrated networks
Integrated earthquake information

USGS
Caltech
UC Berkeley

UC Berkeley Geophysical Networks

Slide 1
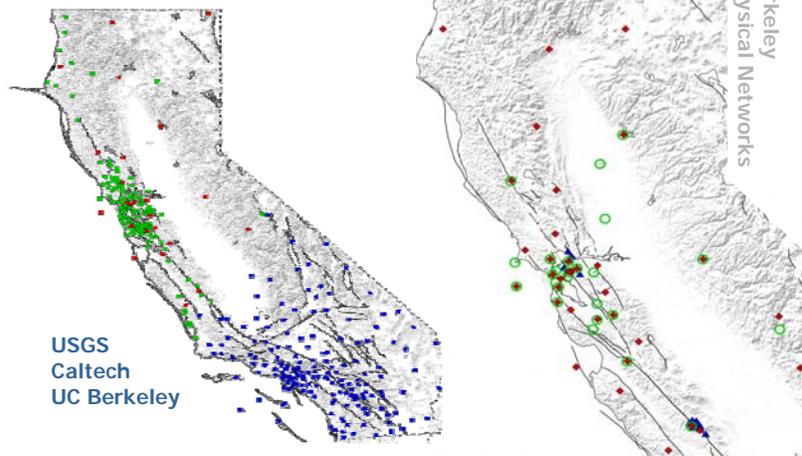
What people *need* to know – *Realtime*

ShakeMap: **Observed shaking**

CISN ShakeMap : 11 km E of Milpitas, CA
Tue Oct 30, 2007 08:04:54 PM PDT M 5.4 N37.43 W121.78 Depth: 9.2km ID:40204628

www.cisn.org
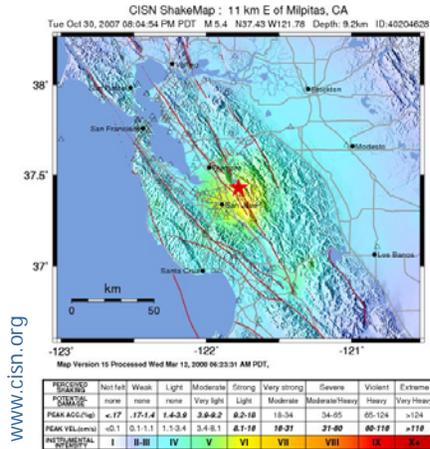
What was the impact on my facility?

Onsite instrumentation

Post-earthquake timeline

0.5 min	Earthquake location
1.5 min	Initial Magnitude
8-10 min	ShakeMap

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Slide 2

What is Earthquake Early Warning?

Earthquake Strong Shaking in 5 seconds Get under desk
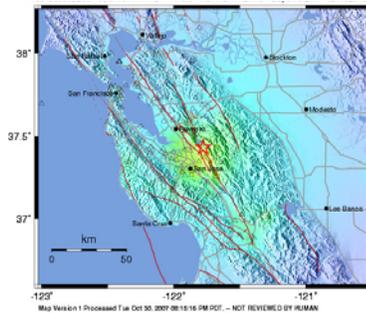
Today: ShakeMap
in 8-10 minutes

Current realtime earthquake information
- location
- magnitude
- ground shaking distribution

Soon: AlertMap

seconds to tens of seconds before shaking

- people move to safe zone (under table)
- slow and stop trains (BART)
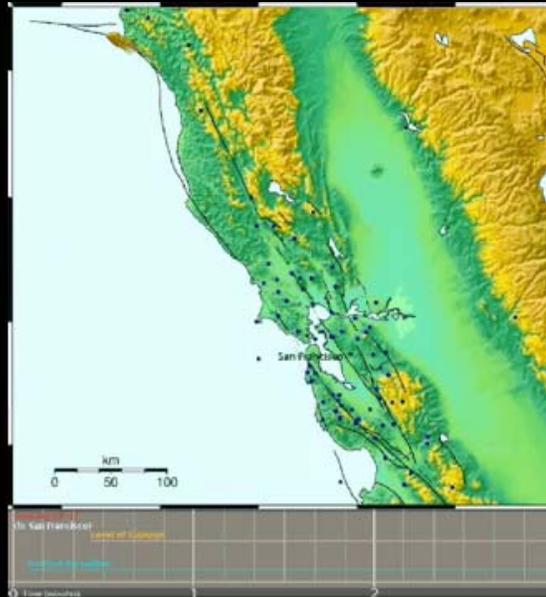- isolate hazards (equipment, chemicals)

new science + modern communications

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Warning timeline

Realtime animation:
Magnitude 8 on the
San Andreas fault

➔ **The most damaging earthquake for the Bay Area**

➔ **~1 min warning**

YouTube: http://www.youtube.com/watch?v=Qf9DeYBlwMI
Download mp4: http://seismo.berkeley.edu/~rallen/research/WarningsInJapan/SanAndreasFromNorth_v2_bb.mp4

Progress toward California's Shake**/Alert**

Aug 2006 – Aug 2009: USGS funds…

Phase I: Development and testing of realtime algorithms

Parallel statewide testing of multiple methodologies

1st Proof of concept event: Warning before the shaking in San Francisco
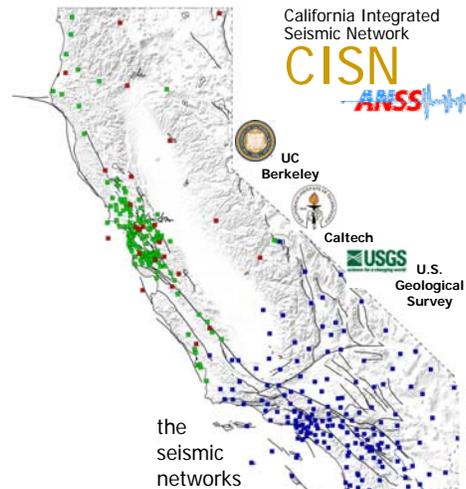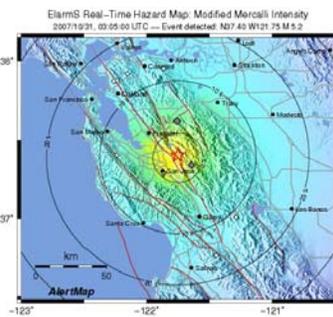
Alum Rock earthquake
M_w 5.4, October 30, 2007

California Integrated Seismic Network

CISN
ANSS

UC Berkeley

Caltech

USGS U.S. Geological Survey

the seismic networks

Progress toward California's **Shake**/Alert

Aug 2006 – Aug 2009: USGS funds...

Phase I: Development and testing of realtime algorithms

Parallel statewide testing of multiple methodologies

Aug 2009: USGS funds...

Phase II: Implementation of an end-to-end test system

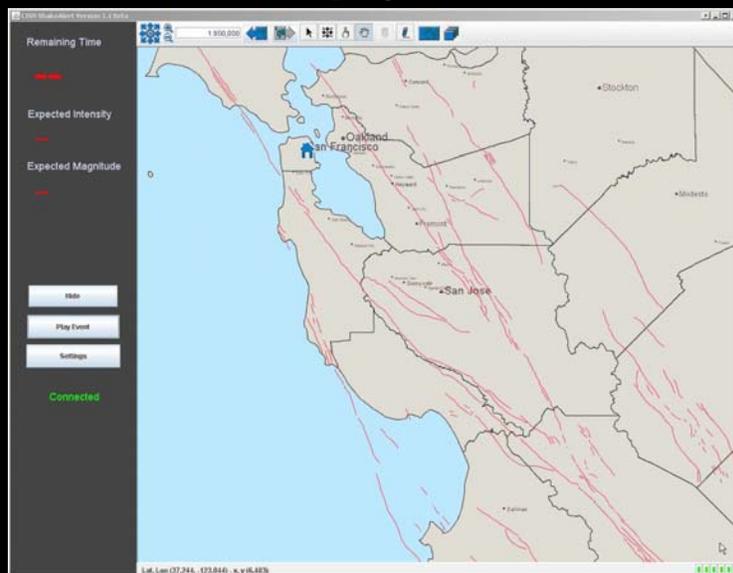A single CISN early warning output to a group of test users
Upgrade of station hardware for faster delivery

1. **Integrated methodology ➔ ShakeAlert**
2. **Work with users ➔ deliver alerts**
3. **Big earthquakes ➔ a more robust system ➔ GPS?**

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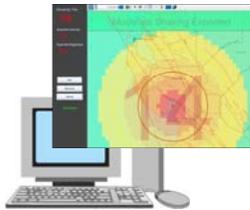**Shake**/Alert User Display   Loma Prieta simulation

Looking for early-adopters

- **Need to develop warning delivery system in partnership with users**
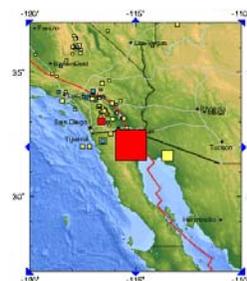- **Using the *Earthquakes Research Affiliates* program**

Possible user groups
- **transportation**
- **industrial sites**
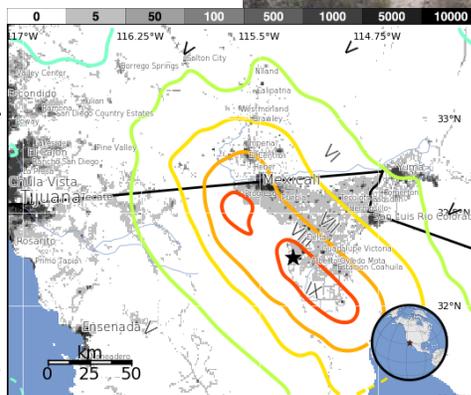- **public sector**
- **schools**
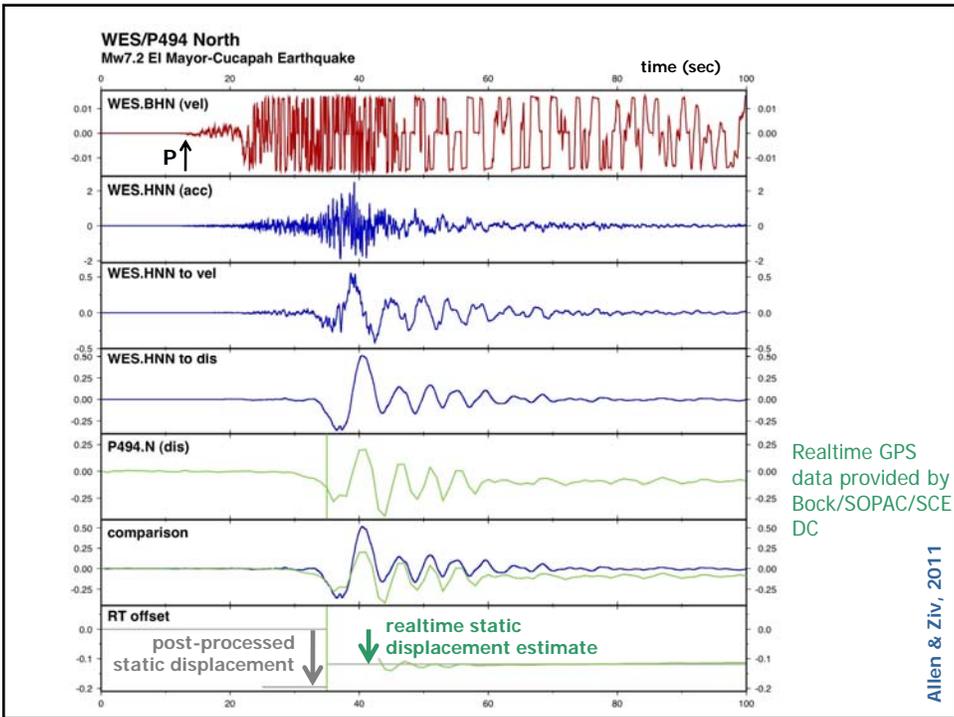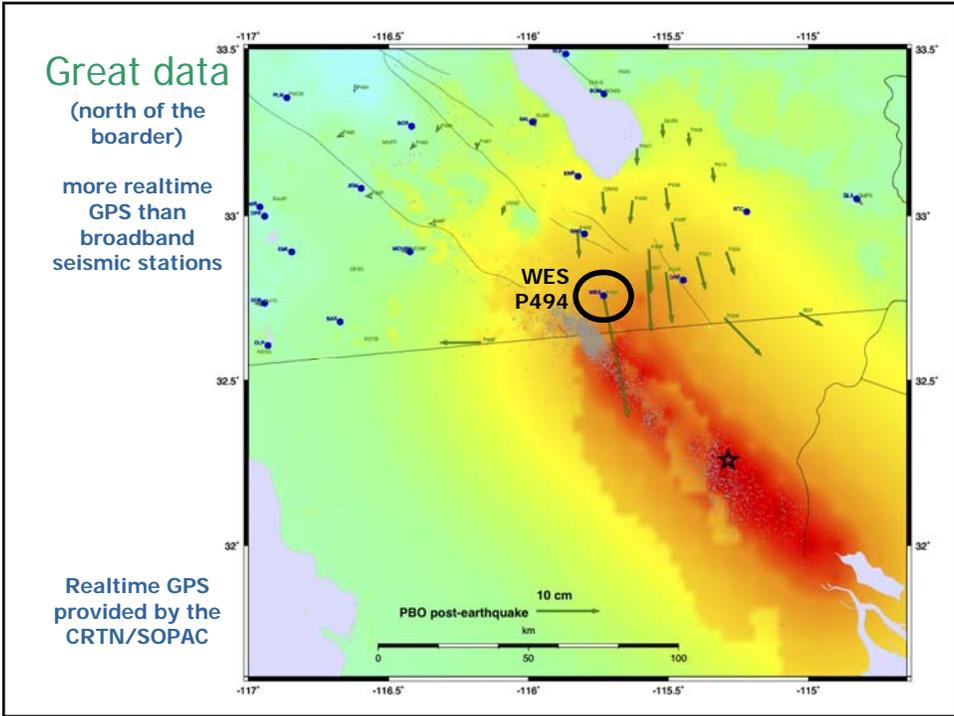

M_w 7.2 Mexicali earthquake

April 4th 2010
just south of the California-Mexico boarder
aka El Mayor-Cucapah Earthquake

Tom Rockwell

USGS PAGER

Great data
(north of the boarder)

more realtime GPS than broadband seismic stations

Realtime GPS provided by the CRTN/SOPAC

WES P494

WES/P494 North
Mw7.2 El Mayor-Cucapah Earthquake

Realtime GPS data provided by Bock/SOPAC/SCEDC

Allen & Ziv, 2011

post-processed static displacement

realtime static displacement estimate

East (compared to North)
•similar large dynamic displacement
•small static offset – well recovered

Allen & Ziv, 2011

Vertical
• large dynamic and static GPS displacements
• not consistent with seismic or post-processing
➔ realtime GPS vertical components
are not reliable

Allen & Ziv, 2011

Realtime estimates of static displacement
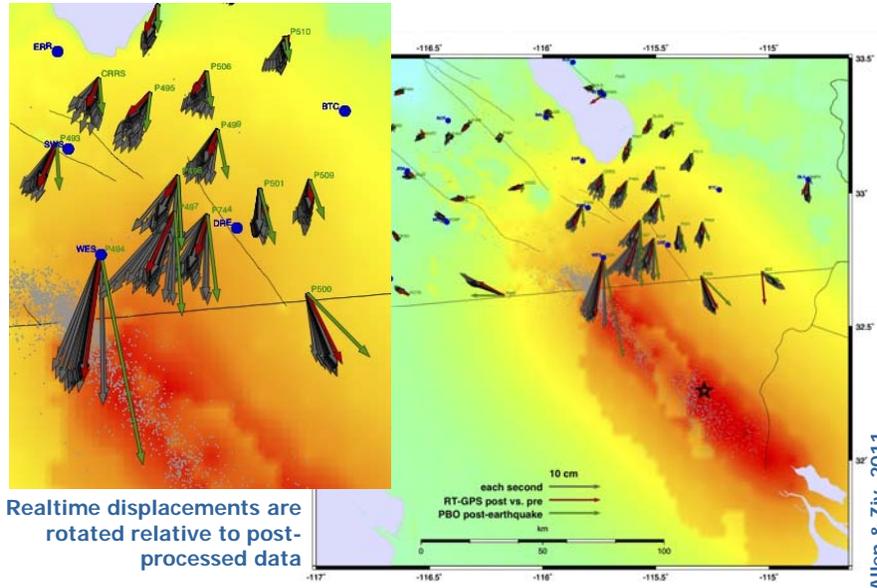
Realtime displacements are rotated relative to post-processed data

each second
RT-GPS post vs. pre
PBO post-earthquake

Allen & Ziv, 2011

Realtime inversion
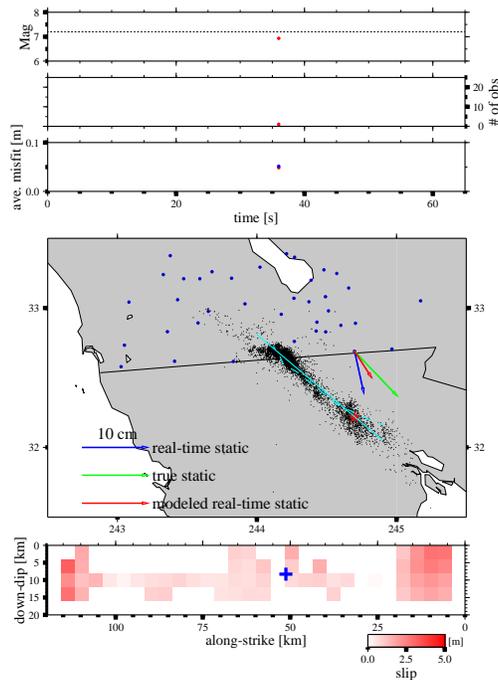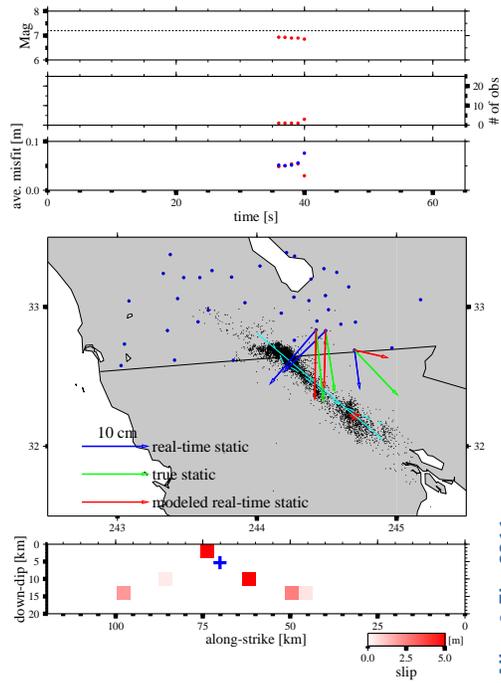
Data: amplitude of static horizontal displacement

Assuming: the fault is known based on fault maps and seismic epicenter

Constraining:
- **seismic moment**
- **slip distribution**

OT + **36 sec**

M 6.9

10 cm
— real-time static
— true static
— modeled real-time static

slip

Allen & Ziv, 2011

Realtime inversion

Data: amplitude of static horizontal displacement

Assuming: the fault is known based on fault maps and seismic epicenter

Constraining:
- **seismic moment**
- **slip distribution**

OT + **40 sec**

M 6.8

Allen & Ziv, 2011

Realtime inversion

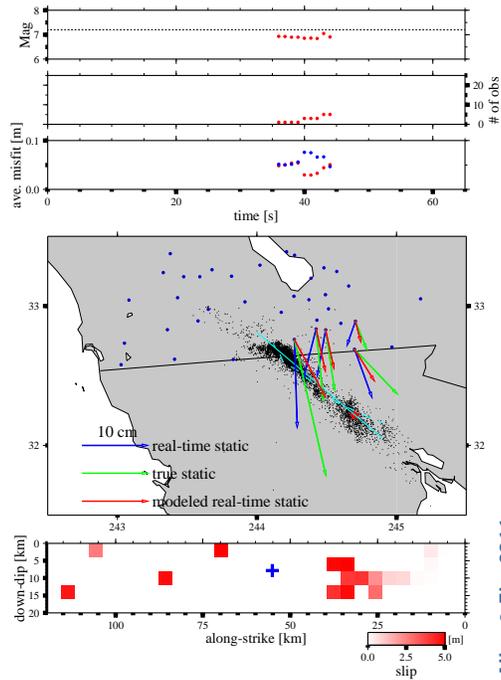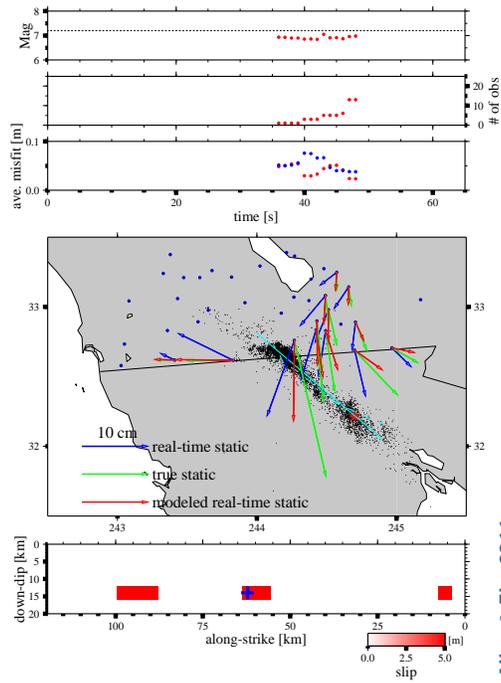**Data: amplitude of static horizontal displacement**

Assuming: the fault is known based on fault maps and seismic epicenter

Constraining:
- **seismic moment**
- **slip distribution**

OT + **44 sec**

M 6.9

Allen & Ziv, 2011

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Realtime inversion

Data: amplitude of static horizontal displacement

Assuming: the fault is known based on fault maps and seismic epicenter

Constraining:
- **seismic moment**
- **slip distribution**

OT + **48 sec**

M 7.0

Allen & Ziv, 2011

Realtime inversion

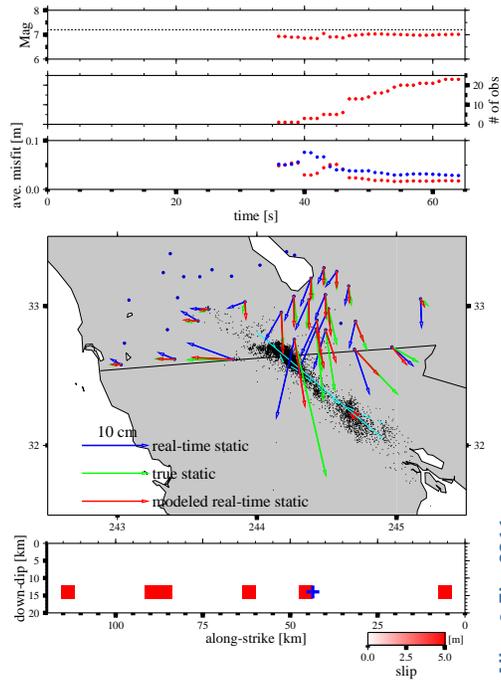**Data: amplitude of static horizontal displacement**

Assuming: the fault is known based on fault maps and seismic epicenter

Constraining:
- **seismic moment**
- **slip distribution**

OT + **64 sec**

M 7.0

Allen & Ziv, 2011

Realtime inversion

Data: amplitude of static horizontal displacement

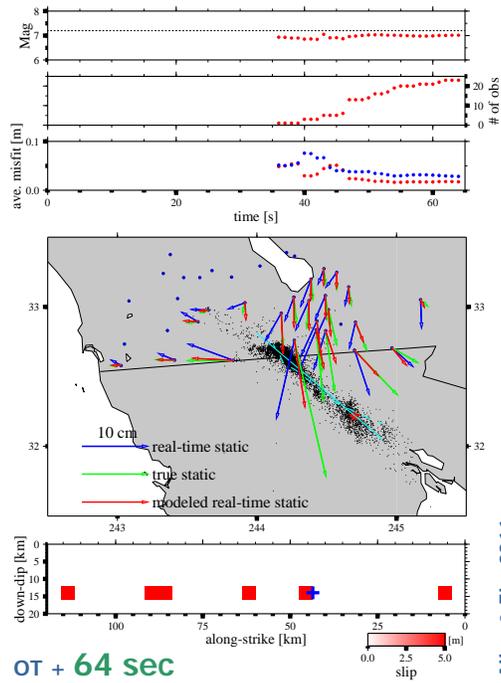**Assuming: the fault is known based on fault maps and seismic epicenter**

Constraining:
- **seismic moment**
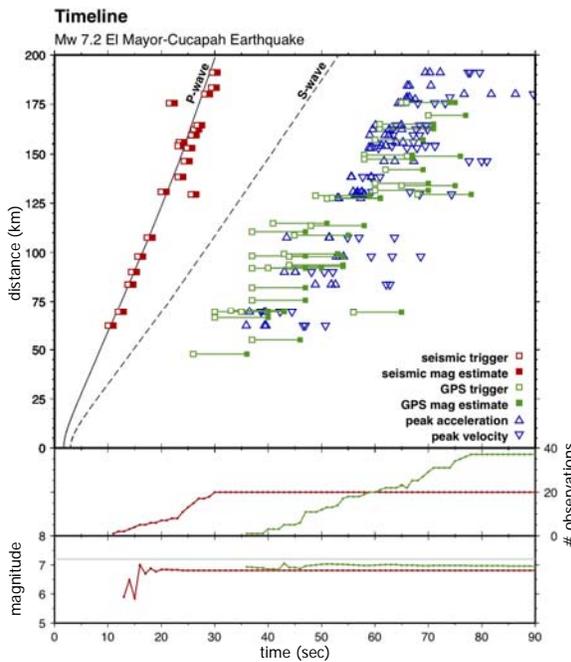- **slip distribution**

Performance summary

1st magnitude estimate: M 6.9
  – range of estimates M 6.8 to 7.0

Slip distribution is variable and not well constrained

OT + **64 sec**

Allen & Ziv, 2011

Overall performance

Timeline
Mw 7.2 El Mayor-Cucapah Earthquake

Can realtime GPS contribute to earthquake early warning? **Yes**

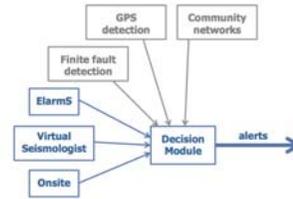**GPS constraints are available around the the time of peak shaking at the same location**

GPS provides a useful and independent magnitude estimate

Allen & Ziv, 2011

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Summary

Progress of the CISN early warning project

- A seismically-based warning system is now operational in a test mode
- Warning are being delivered to the computers of seismologists
- Now developing relationships with "early-adopter" industrial partners

Application of realtime GPS to early warning

- GPS provides a useful and independent magnitude estimate
- GPS constraints are available around the the time of peak shaking at the same location