Improving GNSS for Future Natural Disaster Reduction:

Earthquakes & Tsunamis

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GNSS Science & Technology Applications

ICG-3

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Pasadena, California

Muloh, Sumatra

GPS site & photo by J. Galetzka
San Francisco - 5:12 AM on April 18, 1906...

3000 people were killed; 225,000 of the 400,000 living in San Francisco were left homeless. Much of the city was in ruins.

Photos courtesy Carol Prentice, USGS
December 26, 2004 Sumatra-Andaman earthquake and Indian Ocean Tsunami
Earthquakes are a global problem.
Earthquake Fatalities and Population Growth

Cumulative number of earthquake fatalities (millions)

Population (billions)

Courtesy of Prof. Roger Bilham (University of Colorado)
GNSS timing for precise earthquake location worldwide - also vital for tsunami alerts
San Andreas fault

- 35 mm/yr slip rate;
  - >70% of plate motion
  - 1685, 1812, 1857 eq’s
- Big Bend compression
  - 1971 Sylmar (M 6.7)
  - 1994 Northridge (M 6.7)
- California is now very heavily ‘wired’ with many GPS stations
- GPS measures plate motion strain accumulation and large earthquake displacements
- ‘Natural laboratory’ to study future ‘Big Ones’
- B4 - Imaged by airborne LiDAR - *GPS was crucial!*
Reid’s theory of “Elastic Rebound”

Triangulation networks were resurveyed in the 15 months following the 1906 earthquake.
Surveyors measure the location of mountain peaks

Pre-earthquake  Post earthquake
GPS network measures plate tectonic motions to an accuracy of better than 1 mm/yr

We can see whether the motion is ‘slow and steady,’ or perhaps more interestingly it may sometimes accelerate or decelerate.
San Andreas - place two bets
both ~120 km from Los Angeles (LA)

Coachella Valley segment is ~60 km to San Bernardino
Lone Juniper Ranch and Frazier Park High School

Prototype GPS fault slip sensor; up to 10 Hz

Spans the San Andreas fault near Gorman, California
"Good science, when applied in the way that the people of Alaska have done, made the difference between an emergency and a tragedy."

Charles Groat, Director, United States Geological Survey

Each day, the Trans-Alaska oil pipeline carries one million barrels of oil, about 17% of the domestic oil supply for the United States, valued at about $25 million. If the pipeline had ruptured during the 2002 Denali earthquake, the lost revenue and cost of repair and environmental cleanup would have been incalculable.

M 7.9 - similar to the anticipated San Andreas fault 'Big One'
San Andreas - instrument major lifeline infrastructure crossings
Cajon Pass I-15 Fault Crossing

Need a real-time GPS array right here...

need before (B4) and after imaging for rapid assessment of damage to lifeline infrastructure
Earthquake Early Warning
Tangshan, China
1976 - M 7.5
255,000 people died (official)

Northridge, CA
1994 - it can happen here

Earthquakes Don’t Kill People, Buildings Do...

Turkey 1999
Pre-earthquake:
- Reference static displacement
- Reference static rotation
- Mean and variance of dynamic characteristics

During earthquake:
- Changes in dynamic characteristics
- Hysteretic behavior
- Damage initiation

Post-earthquake:
- Permanent static displacement
- Permanent static rotation
- Mean and variance of dynamic characteristics

Multiple sensor package:
- Acceleration / Velocity
- Displacement (GPS)
- Rotation (tilt-meter)
REAL-TIME DAMAGE ASSESSMENT

- Satellite
- Telemetry
- Internet

Courtesy of Erdal Safak (USGS)

SENSOR PACKAGE
- Accelerometer
- Tiltmeter
- GPS sensor
Caltech Tectonic Observatory GPS Array: SuGAr
USAID funds to upgrade to real-time GNSS

On-land GPS stations are essential for real-time detection of large slip: Blewitt et al. (GRL, 2006)
GNSS buoy systems

- NOAA DART buoys are expensive and require regular maintenance
- GPS buoys developed by GFZ and Univ. Tokyo groups
- GPS can be used for large numbers of low-cost buoys to complement existing system
- NavCom-AXYS contract for US Navy (NAVOCEANO);
  2 cm inshore, 10 cm offshore
- NOAA-USGS testing program for warning application (MBARI)
- Tie in with existing earthquake and weather monitoring and alerts
Padang - what to do?

Photo by John Galetzka
Caltech Tectonic Observatory
Inexpensive package of GPS/INS can be added (after R&D and testing) to existing NOAA buoys offshore of So. Calif. to complement other instrumentation for earthquake and tsunami early warning systems.

SoCal - What to do?
GNSS Benefiting Humanity: Earthquake and Tsunami safety

- Global earthquake observation and tsunami alerts (ANSS)
- Airborne imagery positioning for fault zone characterization and damage assessment (B4)
- Tracking plates and strain accumulation and release (PBO)
- Earthquake early warning & rapid slip observation at lifeline fault crossings (Gorman SAF)
- Building monitoring and damage assessment; automatic ‘tagging’ (Factor Building)
- Fault displacement (SuGAr) and tsunami buoy measurement (MBARI)

Nearly everything we do is helped by GNSS

- GNSS will become even better than it is currently for these applications:
  - GPS L2C, L5 and L1C will improve over current capabilities (e.g., tri-laning)
  - GLONASS, QZSS, Galileo and other GNSS will help (e.g., increased coverage)
- GNSS could be improved beyond currently planned system enhancements:
  - Aiding through internet or wireless will enhance real-time precise results
  - Added signals could nearly eliminate the real-time ambiguity resolution problem