The M9.0 Tohoku and M6.3 Christchurch earthquakes: What we’ve learned about the capabilities and limits of space geodesy.

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Outline

• What is space geodesy
• 2011 M9.0 Japanese earthquake (from a tectonic geodesy perspective)
  – what we thought we knew
  – what happened
  – what we think we know now
• Assessing damage from space
  – 2011 M6.3 Christchurch earthquake
Space Geodesy

• GPS = Global Positioning System
• InSAR = Interferometric Synthetic Aperture Radar

• Both used to measure how much the ground moves – but over longer time than a seismometer does.
Static and Kinematic GPS views of Maule quake

- Inter-seismic
- Co-seismic
- Post-seismic

Truly Co-seismic

CONZ East component
1 Hz

Day of Year

Seconds since M8.8 Earthquake

Centimeters

Meters
2007 Mw 8.0 Pisco (Peru) Earthquake: InSAR Data

- 6 InSAR images:
  - 3 L-band,
  - 2 wide-swath,
  - 2 with descending orbit.

Sladen et al., 2009
2010 Mw 7.0 Haiti Earthquake

- 230,000 deaths
- 280,000 building collapses and severe damages
- Billions of dollars in damages
- Local communication network overloaded
- Transportation limited

Hayes et al., (Nature Geo, 2010)
Tohoku-Oki Earthquake
Magnitude 9.0

Friday, March 11, 2011 at 05:46 UTC
Friday, March 11, 2011 at 02:46 PM at epicenter

Probabilistic Seismic Hazard Map of Japan

Maximum predicted intensity in 500 yrs
Reprinted in: Miyazawa and Mori, BSSA, 2009

Estimates Of Interseismic Coupling
Estimates Of Interseismic Coupling

Suwa et al., 2006

Hashimoto et al., 2009

Loveless & Meade, 2010

Differences:
- Whether or not vertical deformation data is used
- Amount of spatial smoothing applied
- Assumed role of on-land crustal faults

In general, we would benefit by more emphasis on what we don’t know
Dynamics of Ground Motion: 1hz

For animations, email Susan.E.Owen@jpl.nasa.gov
• Generated and delivered co-seismic displacements within 48 hours from over 1000 continuous GPS stations
• Used by USGS in first 72 hours to update estimate of magnitude
• Made publically available and downloaded >1400 times in first 2 days of posting
Fault Slip Model from GPS results

- Caltech ARIA team integrated GPS results with tsunami observations to estimate fault slip
99% VR GPS
80% VR DART

Sarah Minson (CATMIP)
Question about future quakes
Lots of other data available…

Even a few seismograms.
What have we learned?

• Mw 9.0, at least 60 m peak slip, 3 min duration
• Shallow, high slip earthquake with “unexpected” size for the region
• Potential for another great earthquake south of the 2011 event
• Geodetic “coupling” models need to clearly define what is known and what is not known.
• Space geodesy has a potential to contribute uniquely to rapid event assessment, response, and recovery – now is the time to tap this potential
Damage Assessment using Radar Remote Sensing

Day & Night, Cloud Free Data
Examples of Building Damage

URM
2010 Mw 7.0 Haiti Earthquake (New York Times)

NDRC
1971 Mw 6.6 San Fernando Earthquake (USGS)

Steel
1995 Mw 6.9 Kobe Earthquake (USGS)

Wood
1994 Mw 6.7 Northridge Earthquake (J. W. Dewey)
Building Block in Pasadena, California

Building demolition ≈ Building collapse

Demolition: 2007/04/23 – 2008/01/22
Building Block in Pasadena, California

Building demolition ≈ Building collapse

Demolition: 2007/04/23 – 2008/01/22
Damage Proxy Map (Downtown Pasadena, California)
2006/12/31 – 2007/02/15 – 2008/02/18
Google Earth (Downtown Pasadena, California on 2007/10/23)
Combining it with GIS
Reverse Geocoding

Geopy + Google geocoder:
S1: (34.150055, -118.151389) → 25 Walnut St., Pasadena, CA 91103
S2: (34.148033, -118.145444) → 235 E Holly St., Pasadena, CA 91101
S3: (34.147467, -118.139595) → 527 E Union St., Pasadena, CA 91101
S4: (34.141923, -118.153428) → 144 Valley St., Pasadena, CA 91105
S5: (34.143786, -118.145282) → 100-190 S Marengo Ave, Pasadena, CA 91101
Christchurch Area, New Zealand

Damage Proxy Map (ALOS PALSAR A335): 2010/10/10 – 2011/01/10 – 2011/02/25

Google Earth (GeoEye) Image: 2011/02/26
2011 M6.3 Christchurch Earthquake
Christchurch Cathedral

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25

Google Earth Image: GeoEye

EQ M6.3

2010/09/03

2011/02/23

Damage Proxy Map

Christchurch Cathedral on the day of the earthquake (REX/The Telegraph)
Cathedral of the Blessed Sacrament

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

Cathedral of the Blessed Sacrament was partly collapsed. (David Wethey/NZPA/Associated Press)
Canterbury TV Building

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

Rescuers working throughout the night at the Canterbury TV building where up to 100 people are feared lost as they look to recover bodies rather than rescue survivors. (www.news.com.au)
The collapsed Pyne Gould Guinness building trapped dozens of people. “We’ve been pulling 20 or 30 people out of those buildings right throughout the night,” police Superintendent Russell Gibson said Wednesday morning.

(Mark Mitchell/AFP/Getty Images)
Landslide
Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

Luxury homes teeter on the edge after huge landslides in Redcliffs, near Christchurch (Photo by Torsten Blackwood from AFP).
Liquefaction near Bridge Street

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

EQ M6.3

2010/09/03 2011/02/22

Cloud

2011/02/23

Damage Proxy Map

ARIA – JPL/Caltech
Liquefaction near Burwood

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

EQ M6.3

2011/02/22

Cloud

2009/03/04

ARIA – JPL/Caltech
Severe Liquefaction in Bexley

Damage Proxy Map: 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth Image: GeoEye

Cars stuck in the mud, Bexley (Brett Phibbs/AFP/Getty Images)

Water Inundated Bexley (Mark Mitchell/New Zealand Herald/Associated Press)
THE ARIA CENTER

ARIA = Advanced Rapid Imaging and Analysis

• Responding to an international need to fully exploit anticipated explosion in remote sensing observations, especially space geodesy, and to use these observations synergistically with conventional methods
• Partner with and educate end users
• ARIA-EQ***, ARIA-Magma, ARIA-Fire,…
• Focus
  – Quickly bringing algorithms from research to application
  – Low latency ➔ push limits of automation and computation
  – Contribute to situational awareness in the aftermath of large disasters
The Advanced Rapid Imaging & Analysis (ARIA) Center for Natural Hazards

Integrating:
- Space Geodesy
- Seismology
- Modeling

Science & “near real time” assessment

Potential Partners?

InSAR and GPS

Earthquake and tsunami source models

Subsurface fault slip: 7 meters peak value

Preparing for the future...

2007 Mw 8.0
Pisco, Peru
Summary

• The 2011 M9.0 Tohoku earthquake was a humbling reminder that we should not overestimate how well we understand active faults. Accurately depicting uncertainty is necessary.

• Space geodesy is increasing our ability to accurately
  • estimate hazards before an earthquake
  • determine what happened on which fault in an earthquake
  • assess damaging effects of the earthquake

• ARIA is working towards delivering space geodesy in near real time to both the science and the public