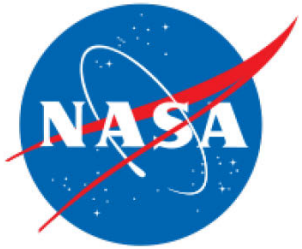


The M9.0 Tohoku and M6.3 Christchurch earthquakes: What we've learned about the capabilities and limits of space geodesy.

Susan Owen

Jet Propulsion Laboratory

Contributors: Mark Simons (Caltech) , Frank Webb (JPL), Sang-Ho Yun (JPL), Eric Fielding (JPL), Jennifer Cruz (JPL)

Outline

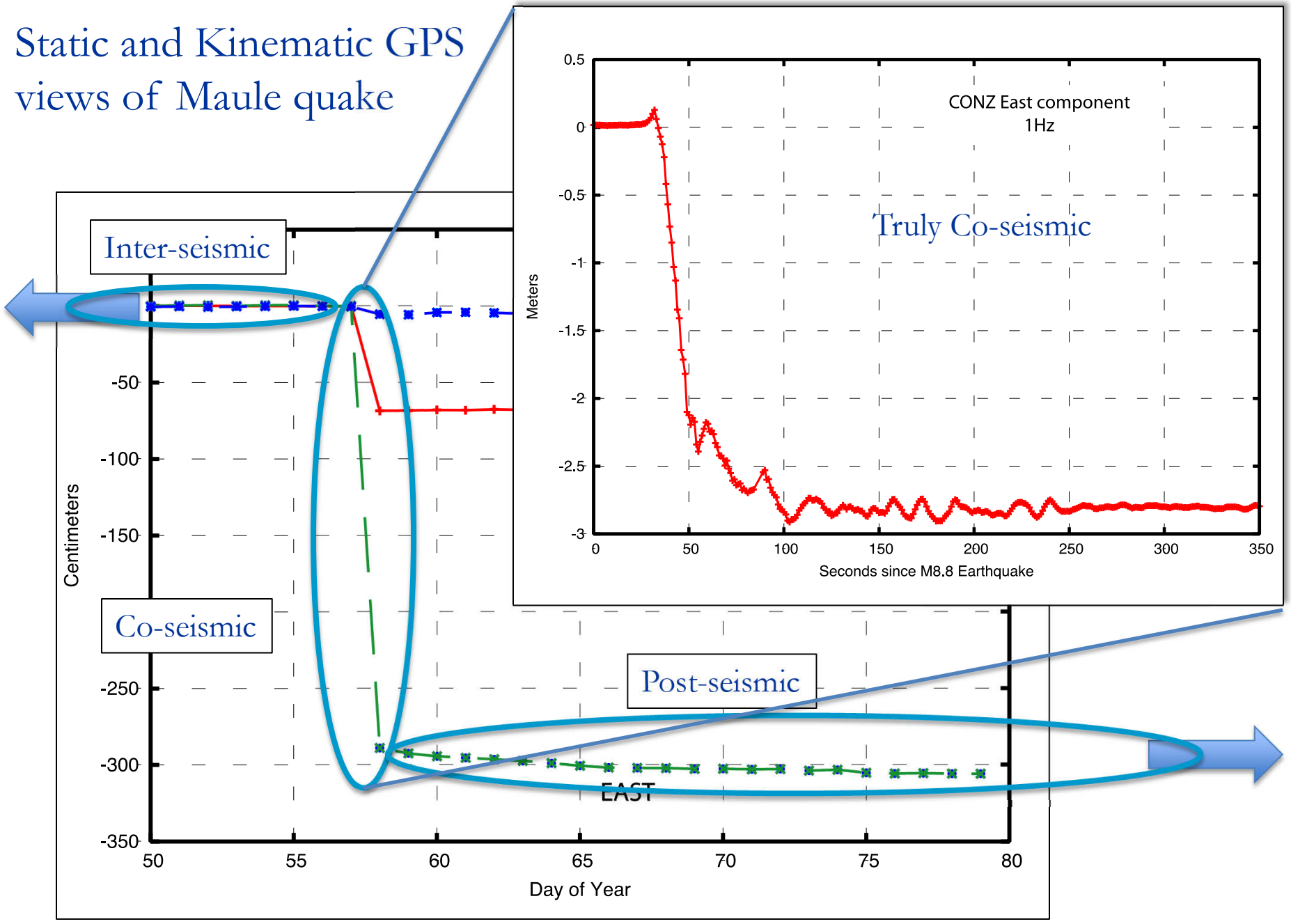
- What is space geodesy
- 2011 M9.0 Japanese earthquake (from a tectonic geodesy perspective)
  - what we thought we knew
  - what happened
  - what we think we know now
- Assessing damage from space
  - 2011 M6.3 Christchurch earthquake

Space Geodesy

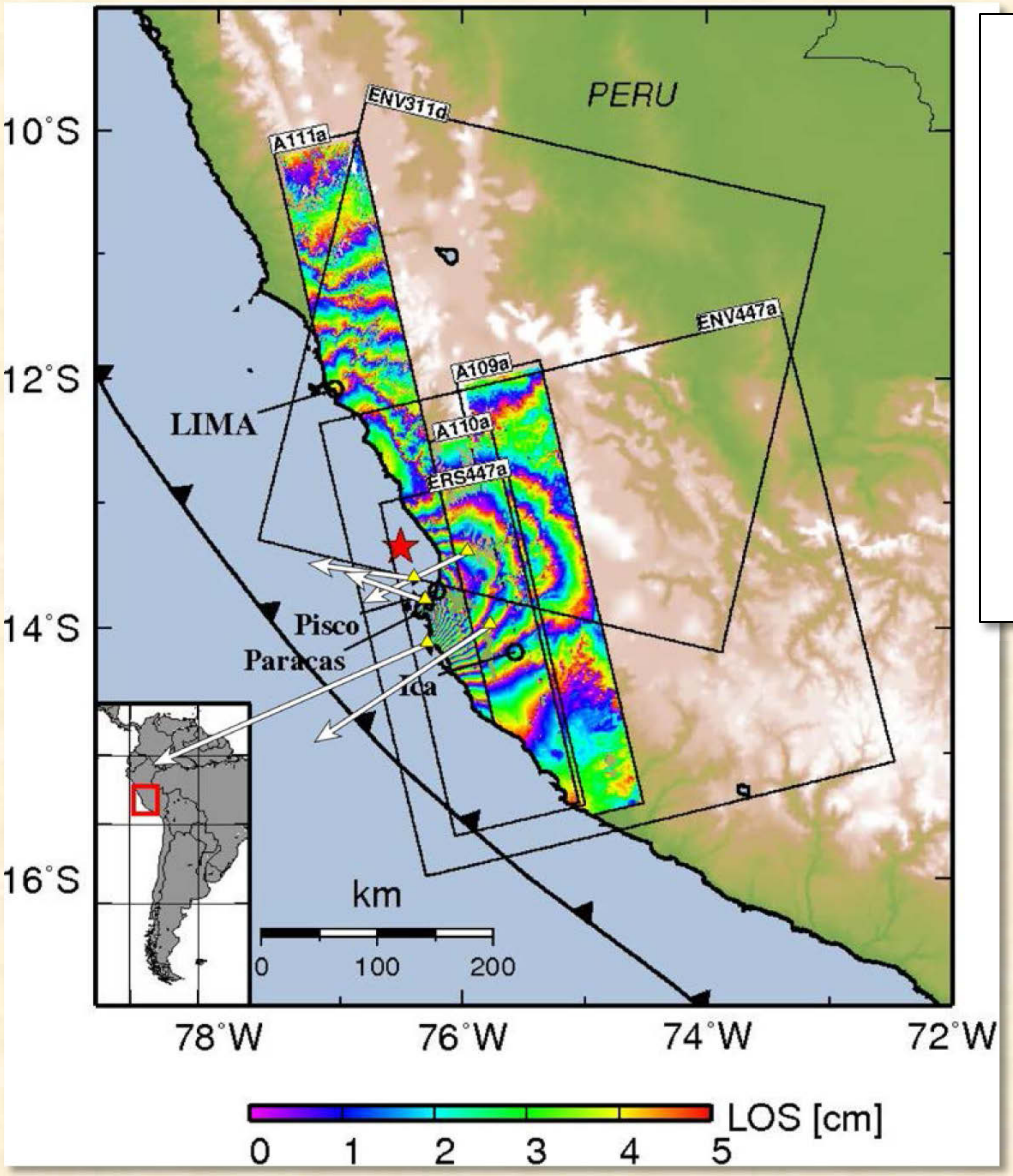
- GPS = Global Positioning System
- InSAR = Interferometric Synthetic Aperature Radar

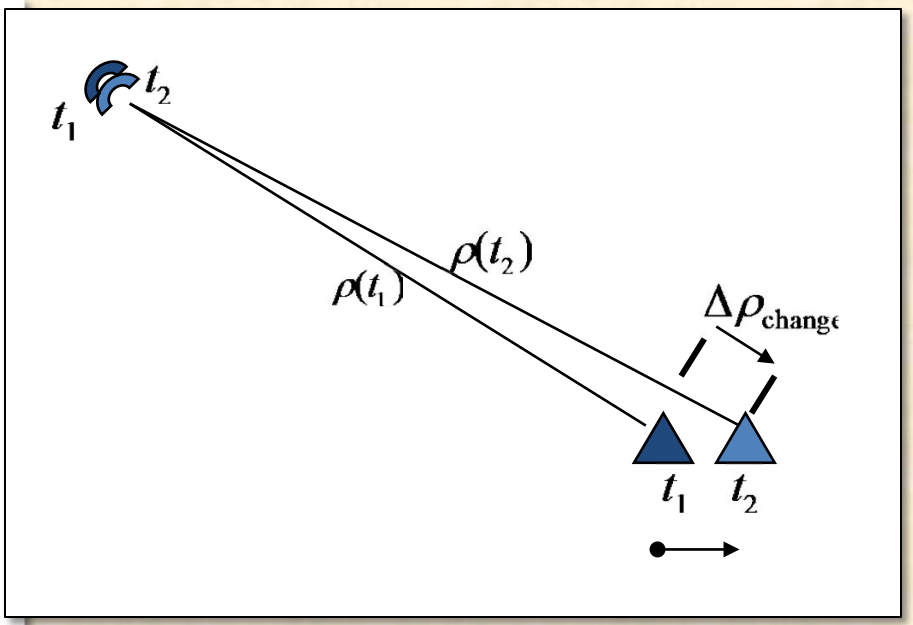
- Both used to measure how much the ground moves – but over longer time than a seismometer does.

Static and Kinematic GPS views of Maule quake



2007 Mw 8.0 Pisco (Peru) Earthquake: InSAR Data

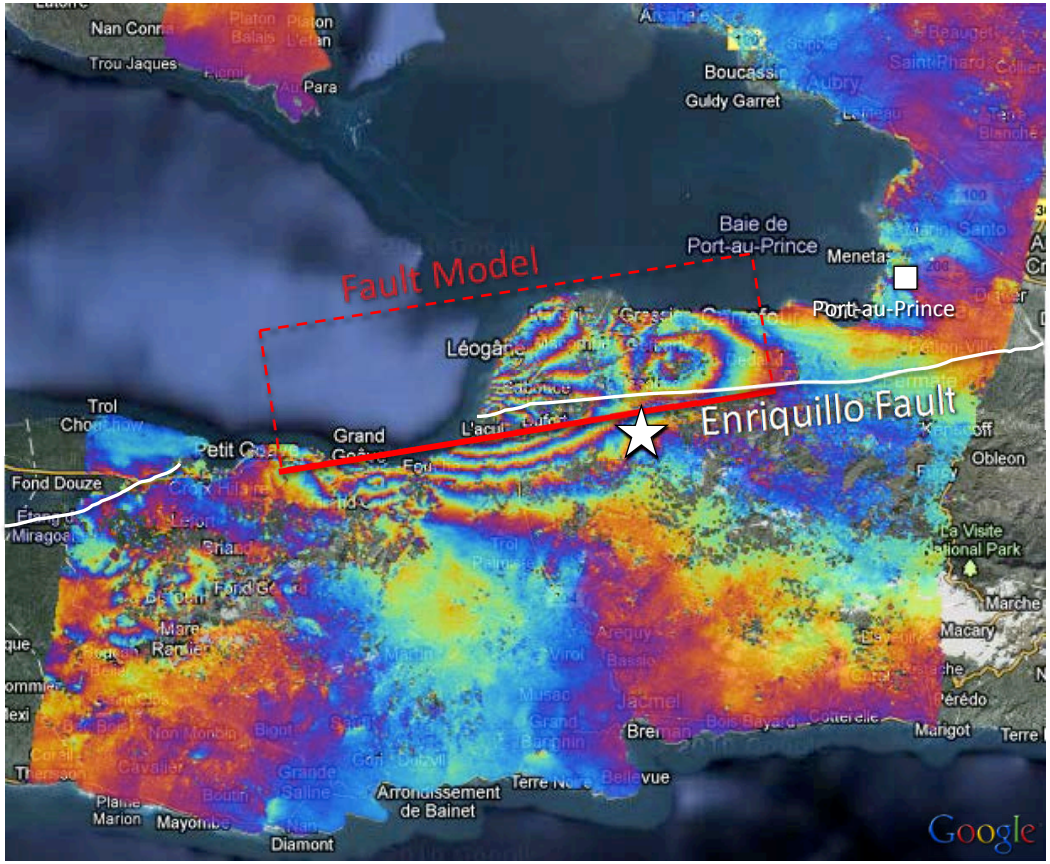




- 6 InSAR images:
  - 3 L-band,
  - 2 wide-swath,
  - 2 with descending orbit.

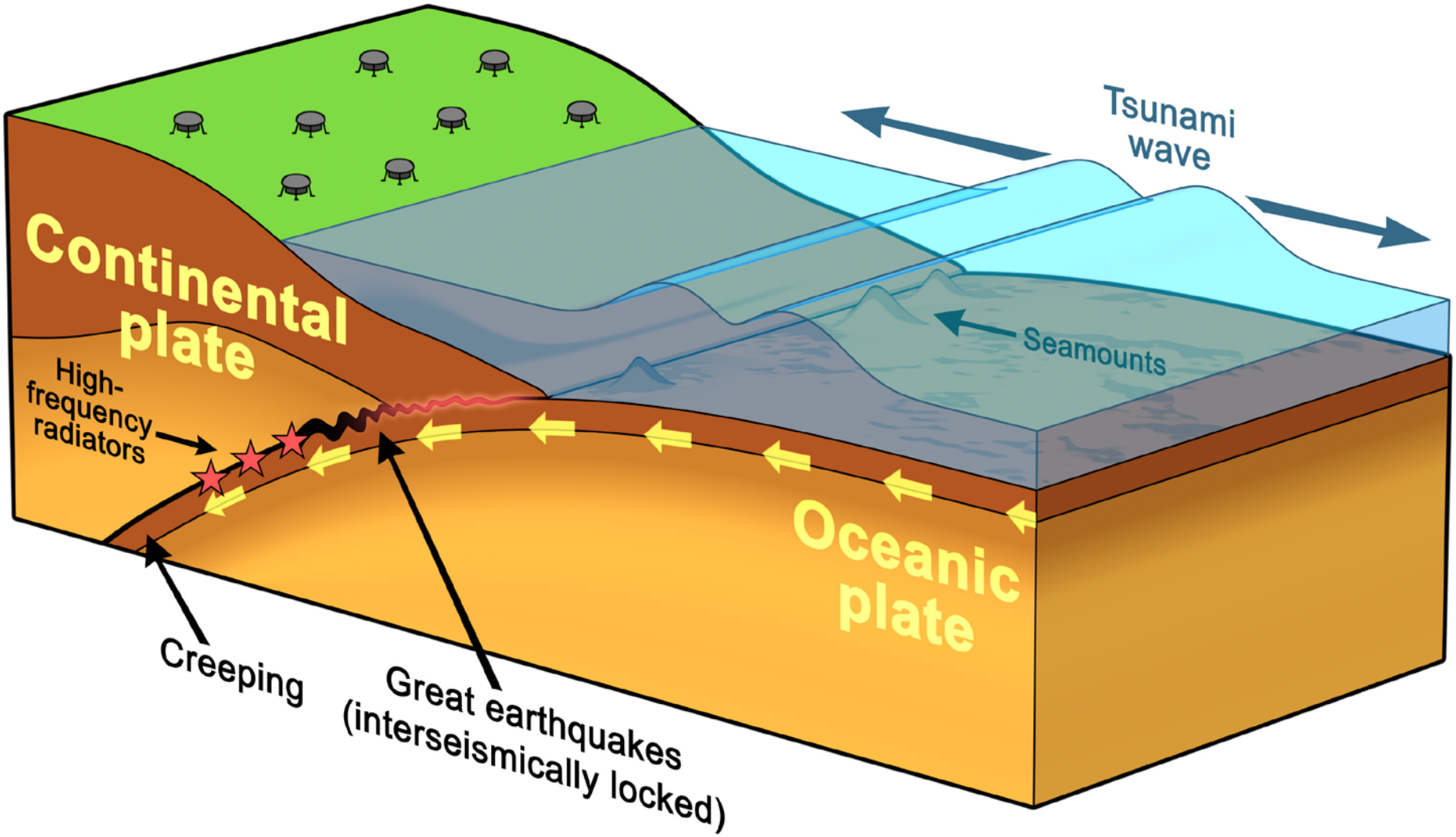
Sladen et al., 2009

2010 Mw 7.0 Haiti Earthquake



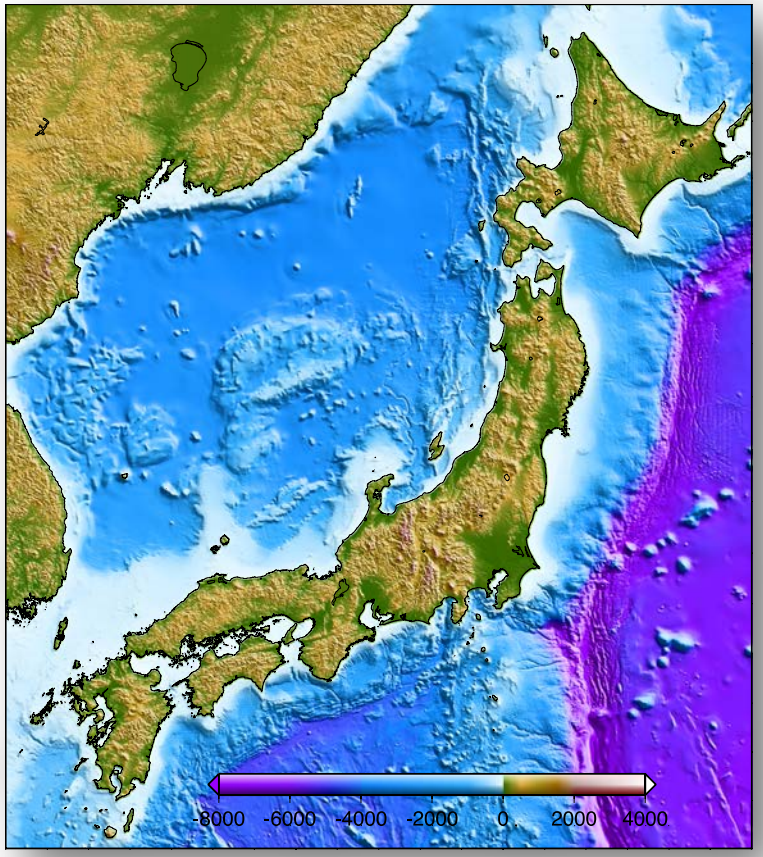
Hayes et al., (Nature Geo, 2010)

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


Tsunami wave
Continental plate
Seamounts
High-frequency radiators
Oceanic plate
Creeping
Great earthquakes (interseismically locked)

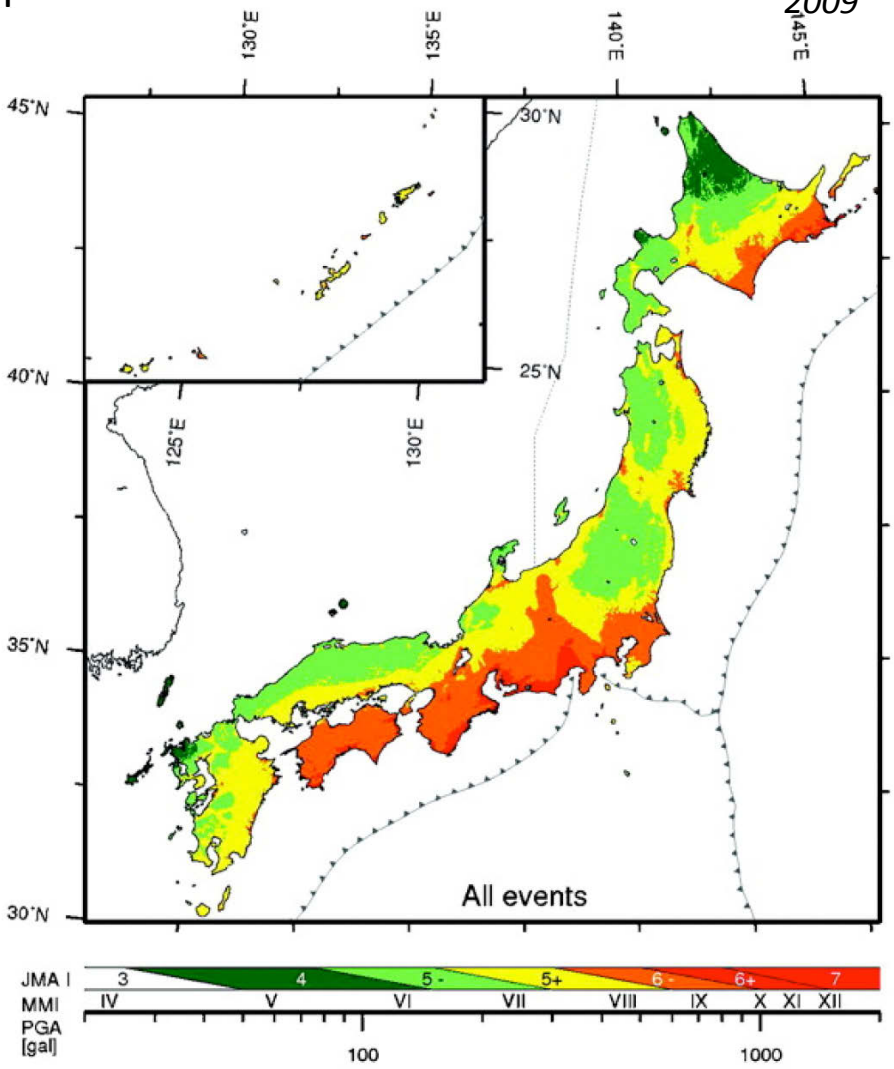
Tohoku-Oki Earthquake
Magnitude 9.0

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



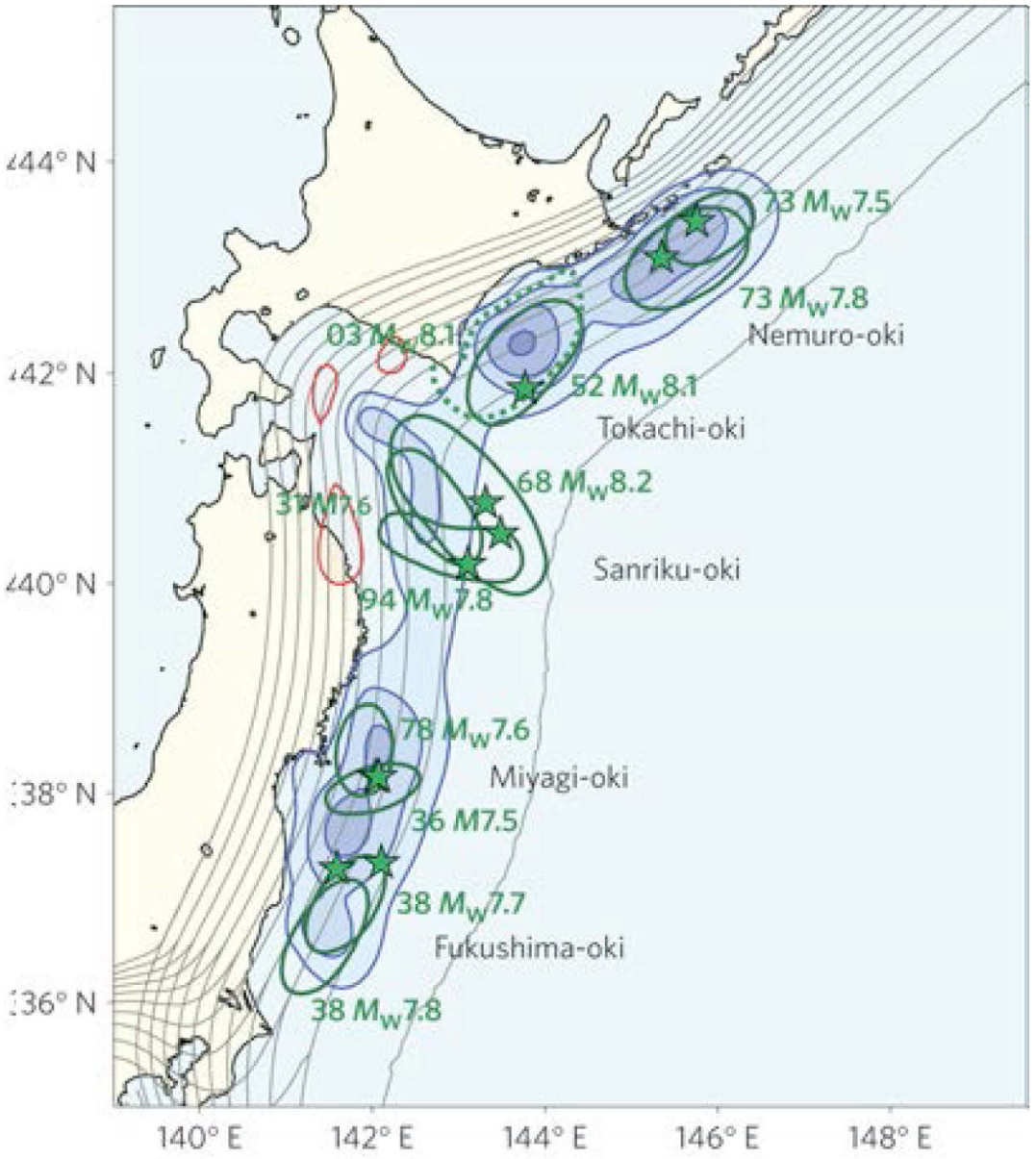
Probabilistic Seismic Hazard Map of Japan

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



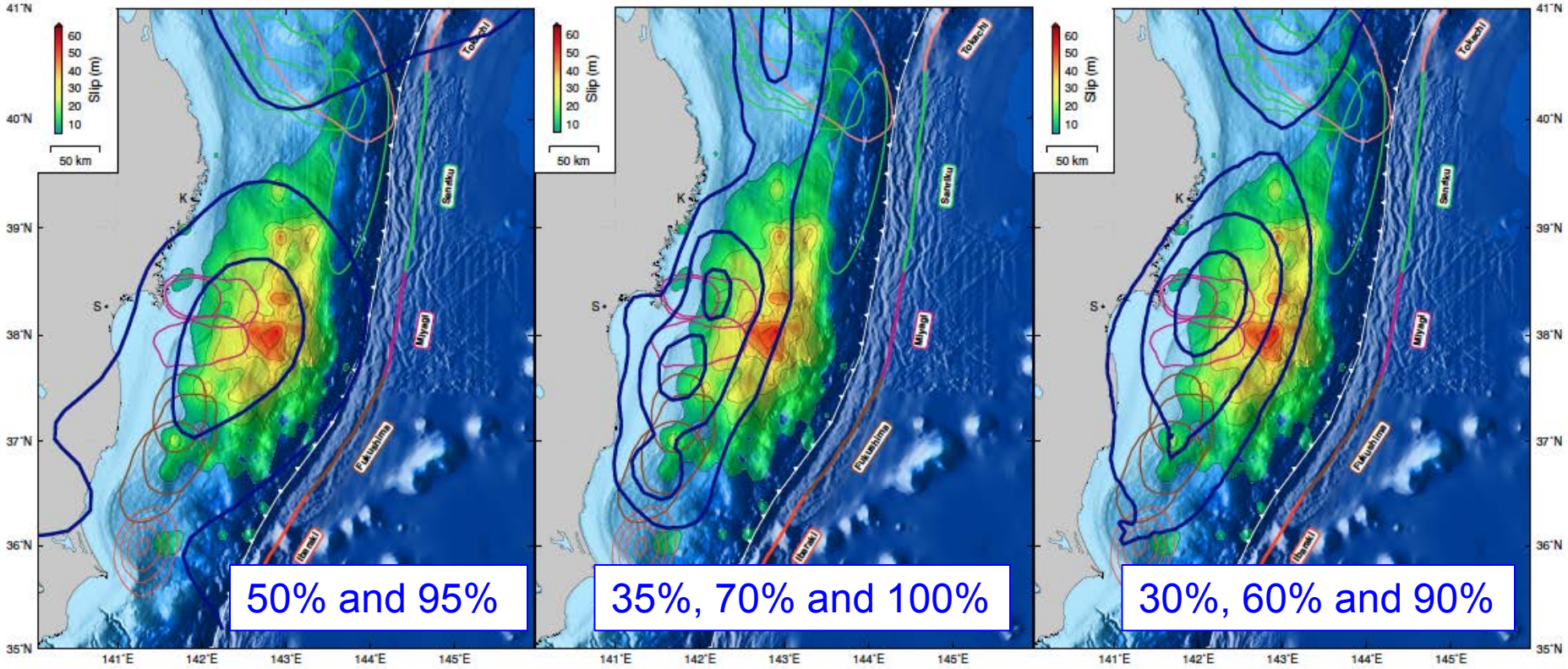
Estimates Of Interseismic Coupling

C. Hashimoto, A.Noda, Takeshi Sagiya & M.Matsu'ura, Interplate seismogenic "stuck" zones along the Kuril–Japan trench inferred from GPS data inversion *Nature Geoscience* **2**, (2009)doi:10.1038/ngeo421



Estimates Of Interseismic Coupling

Suwa et al., 2006 | *Hashimoto et al.*, 2009 | *Loveless & Meade*, 2010

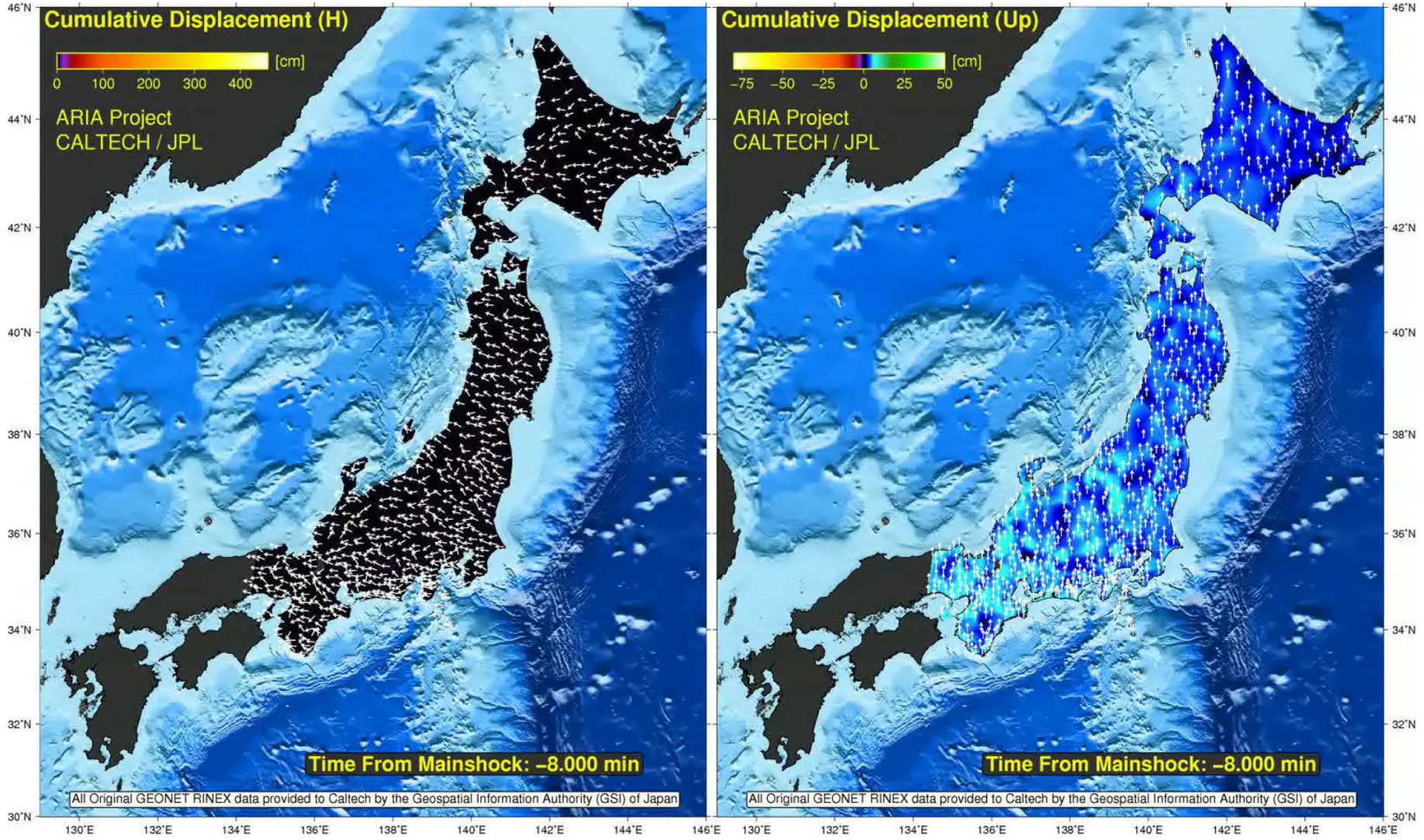


Differences:

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

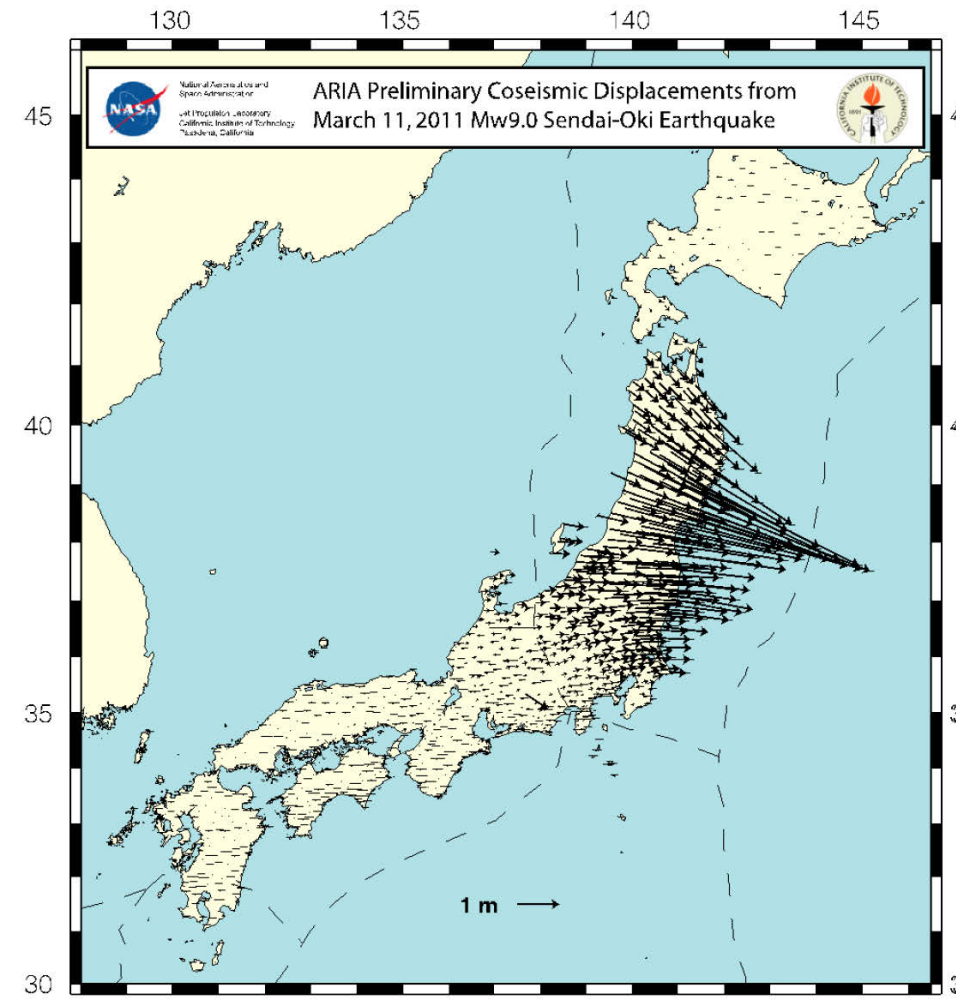
In general, we would benefit by more emphasis on what we don't know

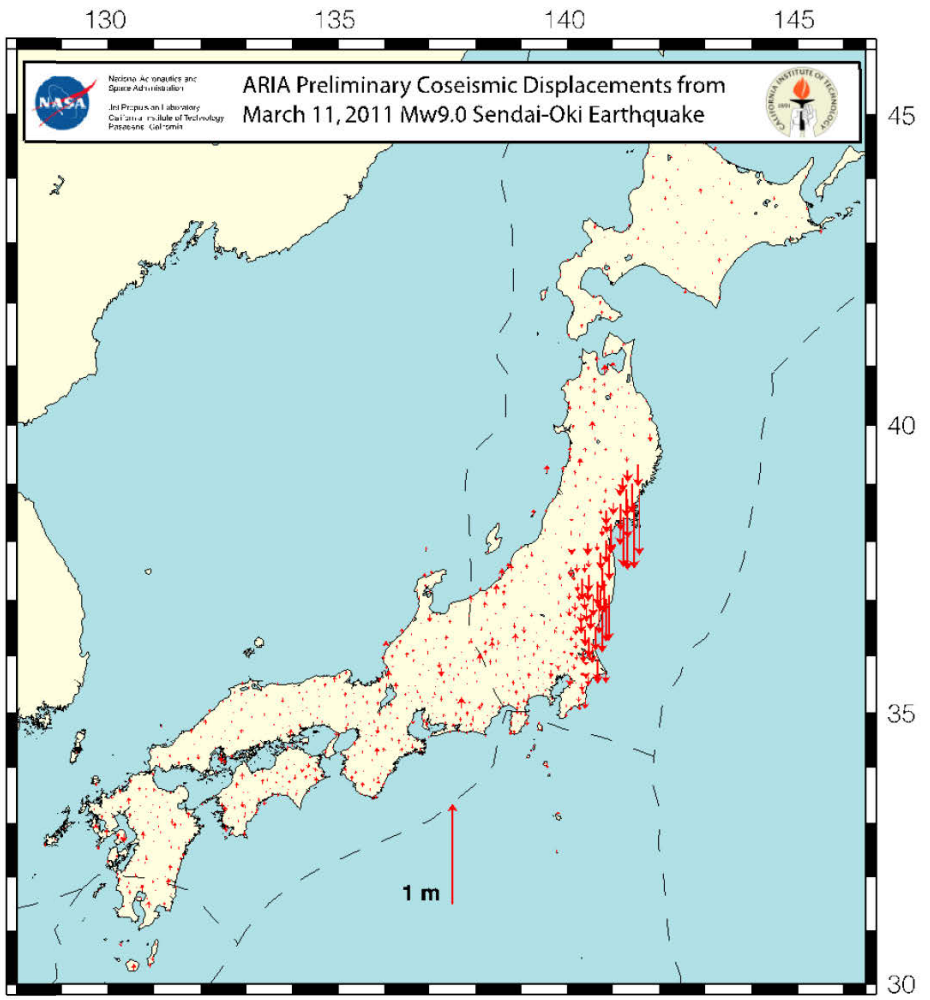
Dynamics of Ground Motion: 1hz



For animations, email Susan.E.Owen@jpl.nasa.gov

Rapid Displacement Maps





- Generated and delivered co-seismic displacements within 48 hours from over 1000 continuous GPS stations
- Used by USGS in 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**

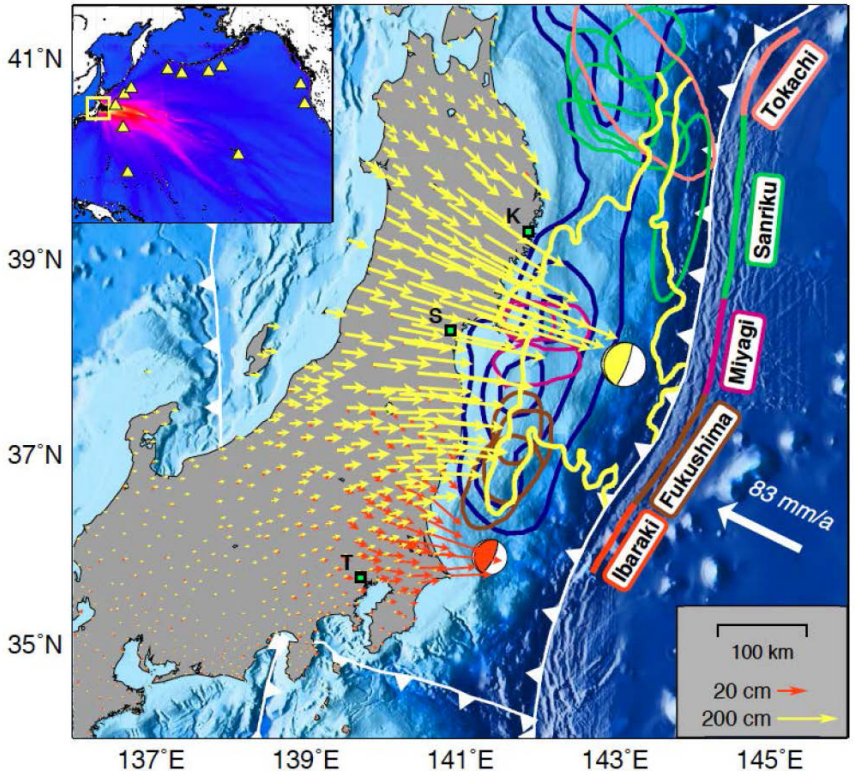
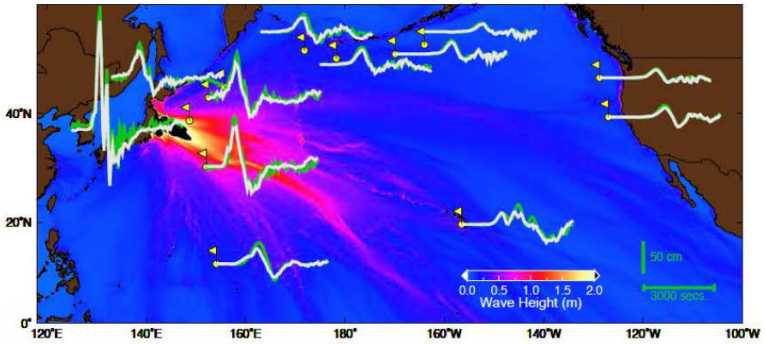
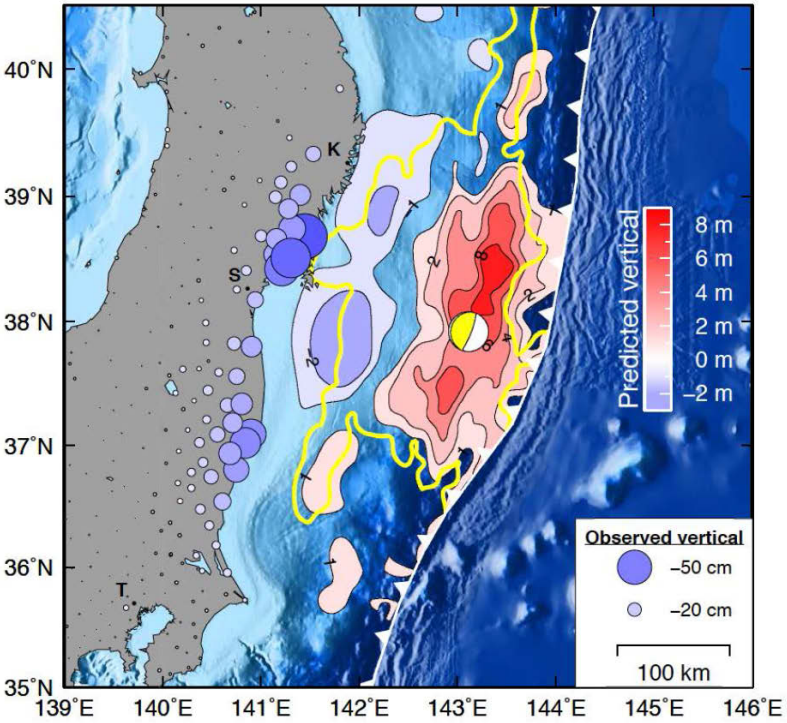
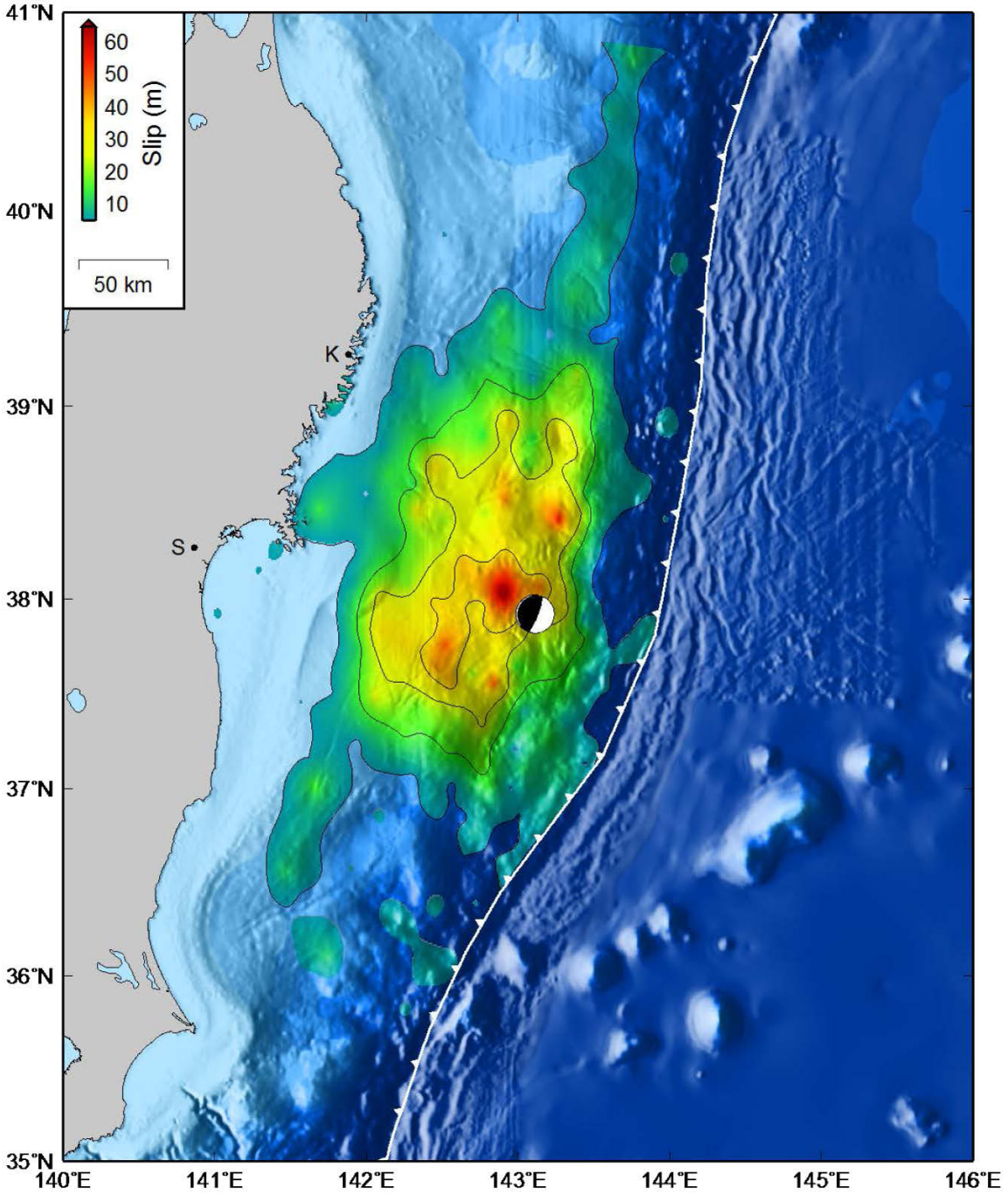


Figure 1





99% VR GPS
80% VR DART



Sarah Minson (CATMIP)

Question about future quakes

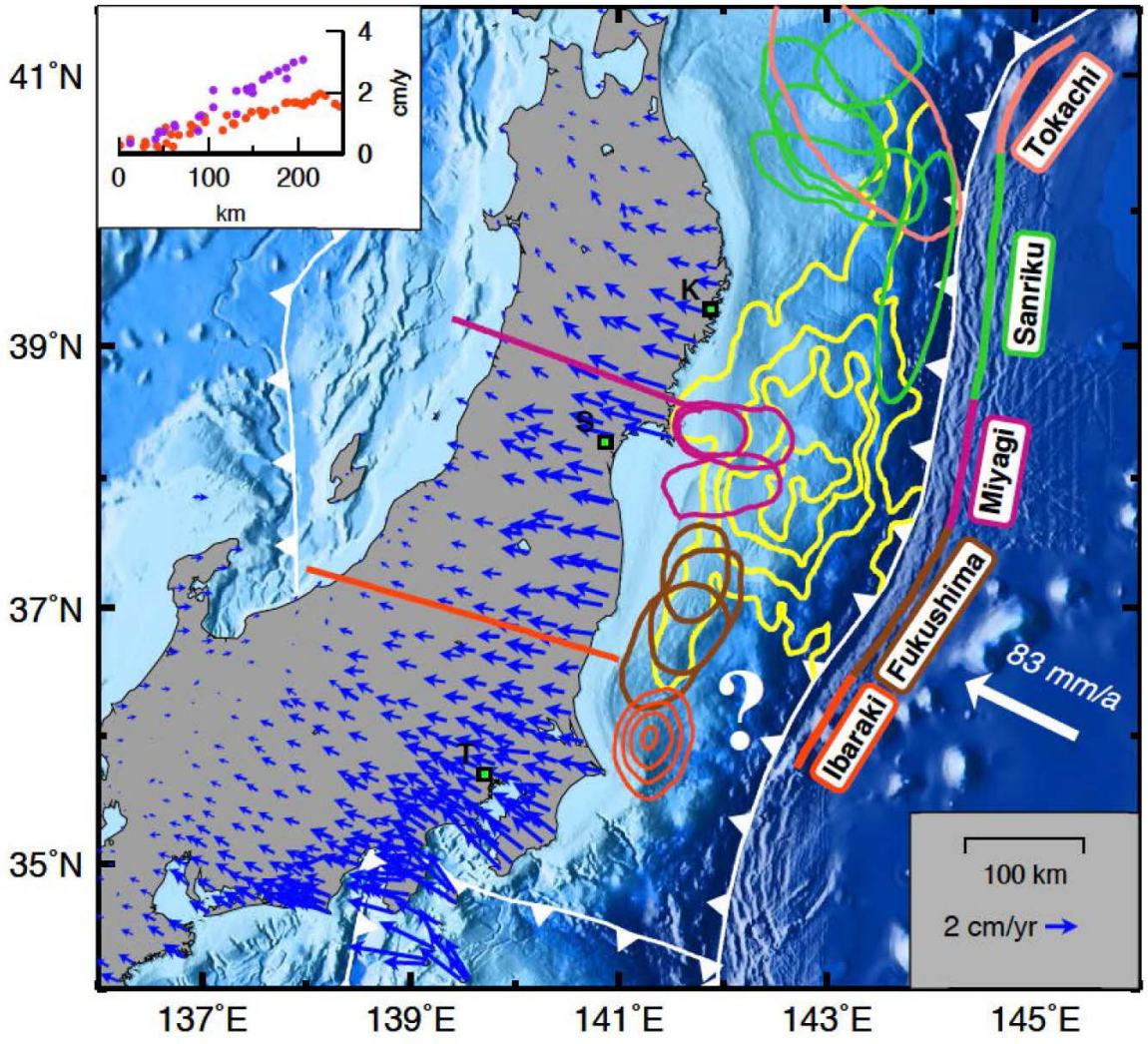
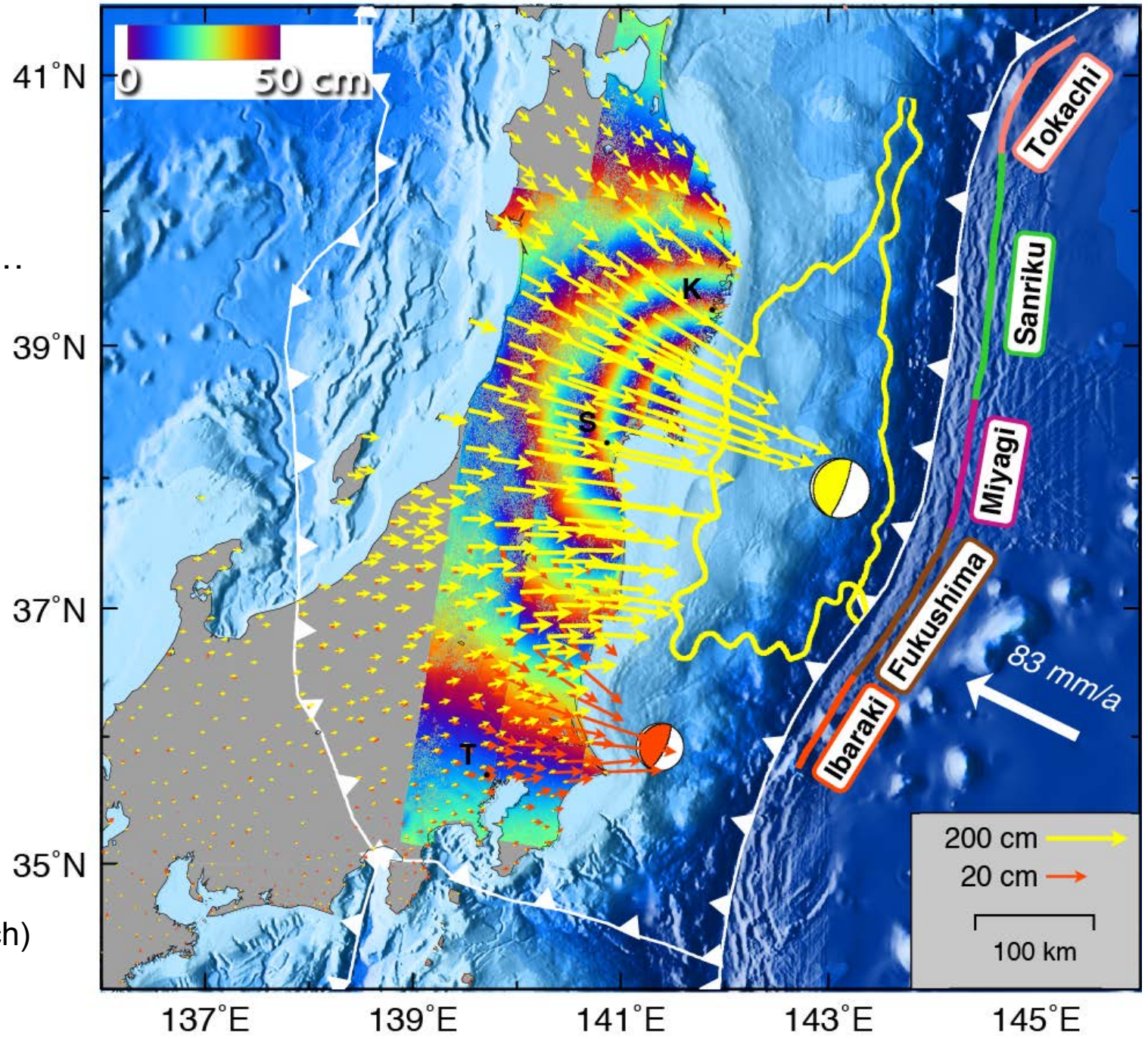


Figure 6

Lots of other data available…

Even a few seismograms.

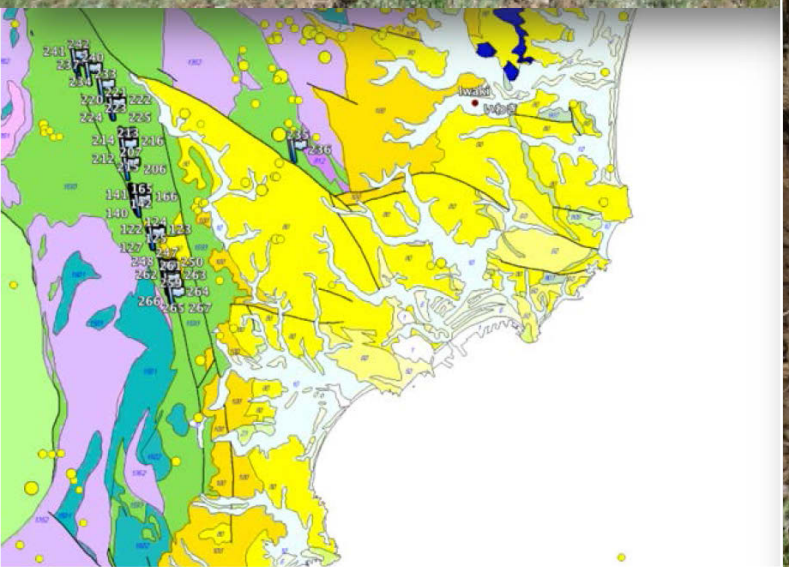


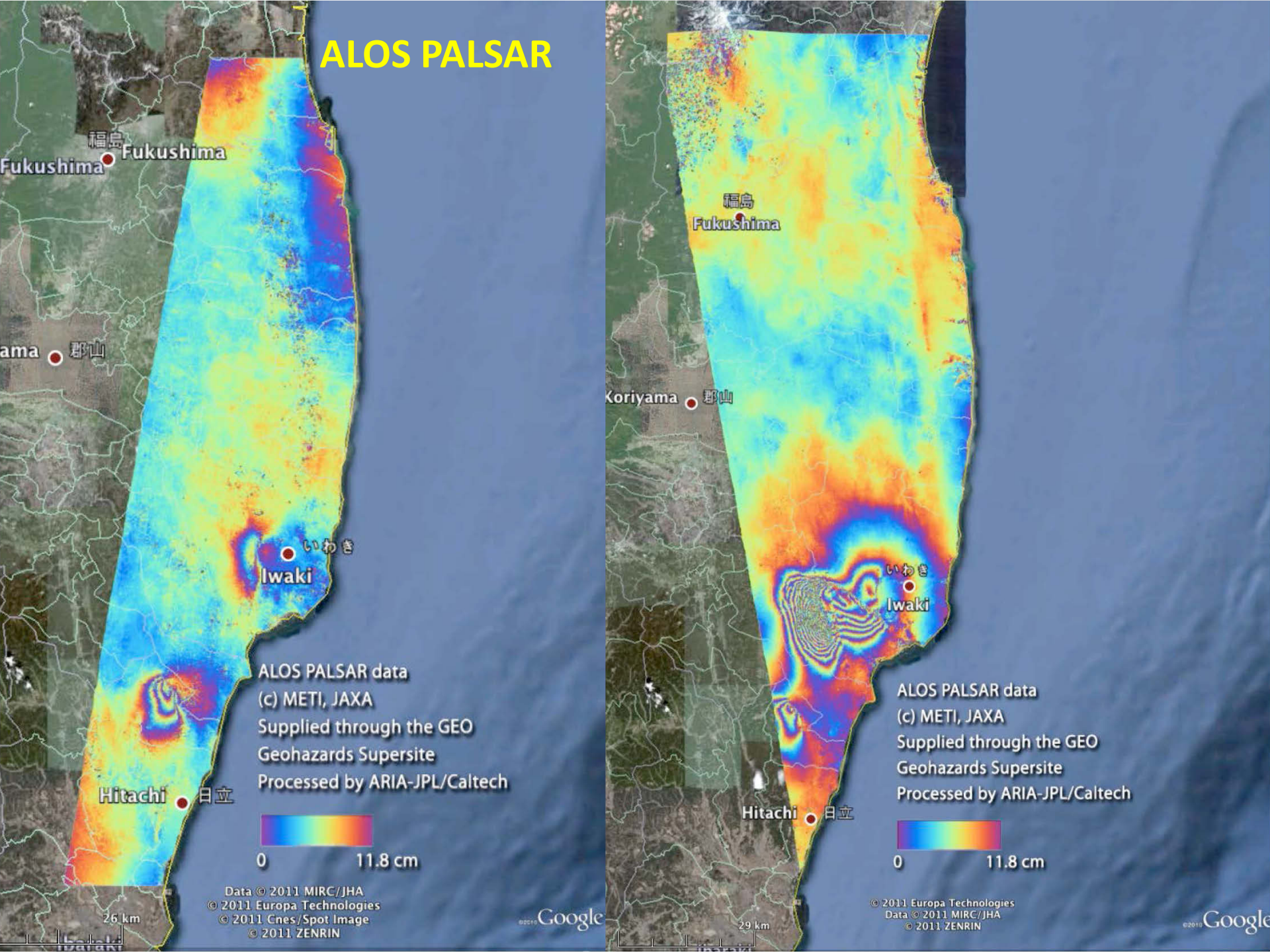
P. Agram
&
E. Fielding

ARIA (JPL/Caltech)

Photographs: Shinji Toda

4 x M5.8-6.0 2011/03/23



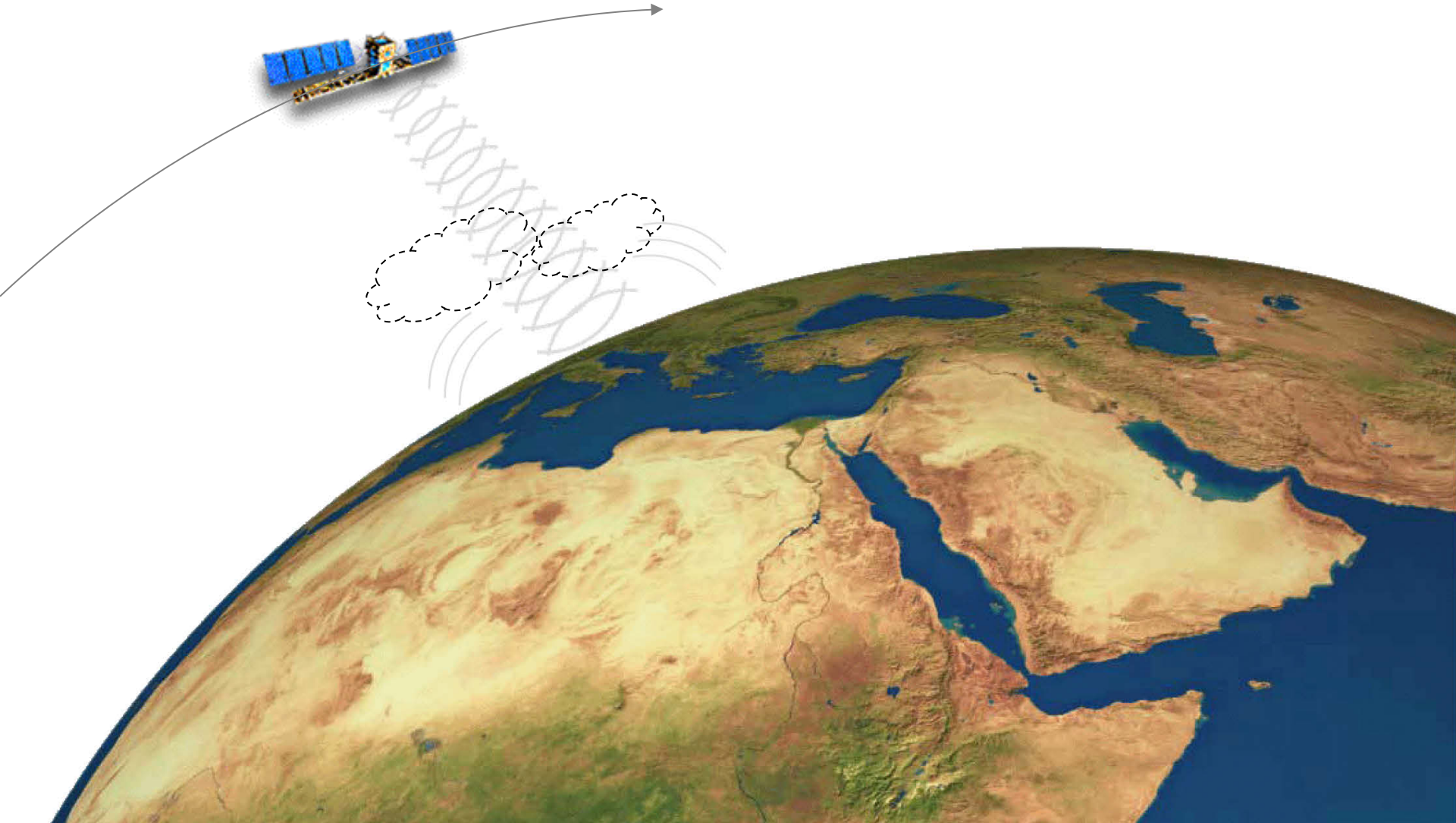

ALOS PALSAR
福島
Fukushima
Fukushima
郡山
いわき
Iwaki
Hitachi
日立
ALOS PALSAR data
(c) METI, JAXA
Supplied through the GEO
Geohazards Supersite
Processed by ARIA-JPL/Caltech
0
11.8 cm
Data © 2011 MIRC/JHA
© 2011 Europa Technologies
© 2011 Cnes/Spot Image
© 2011 ZENRIN
26 km
Google
福島
Fukushima
郡山
いわき
Iwaki
Hitachi
日立
ALOS PALSAR data
(c) METI, JAXA
Supplied through the GEO
Geohazards Supersite
Processed by ARIA-JPL/Caltech
0
11.8 cm
© 2011 Europa Technologies
Data © 2011 MIRC/JHA
© 2011 ZENRIN
29 km
Google

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

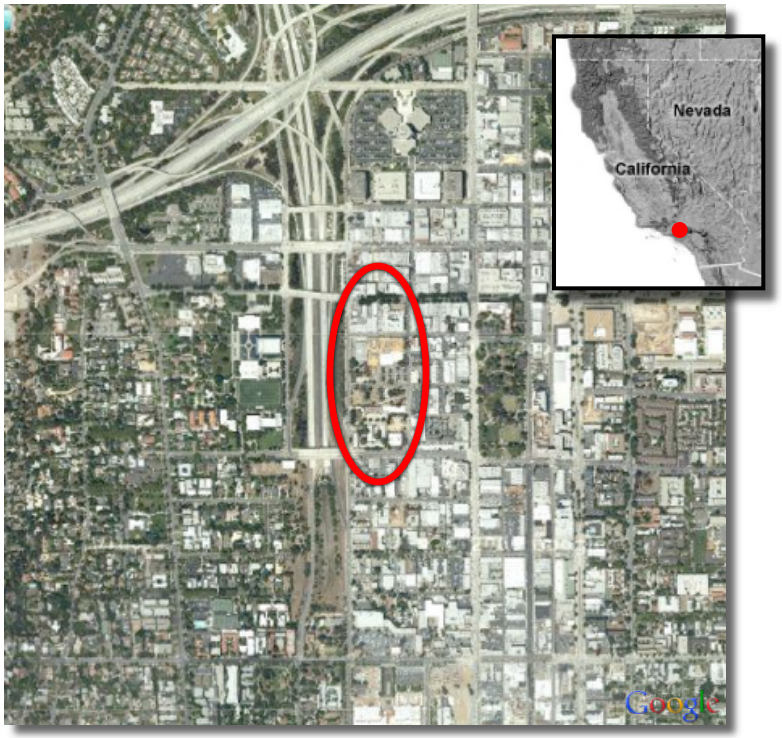
1995 Mw 6.9 Kobe Earthquake (USGS)

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

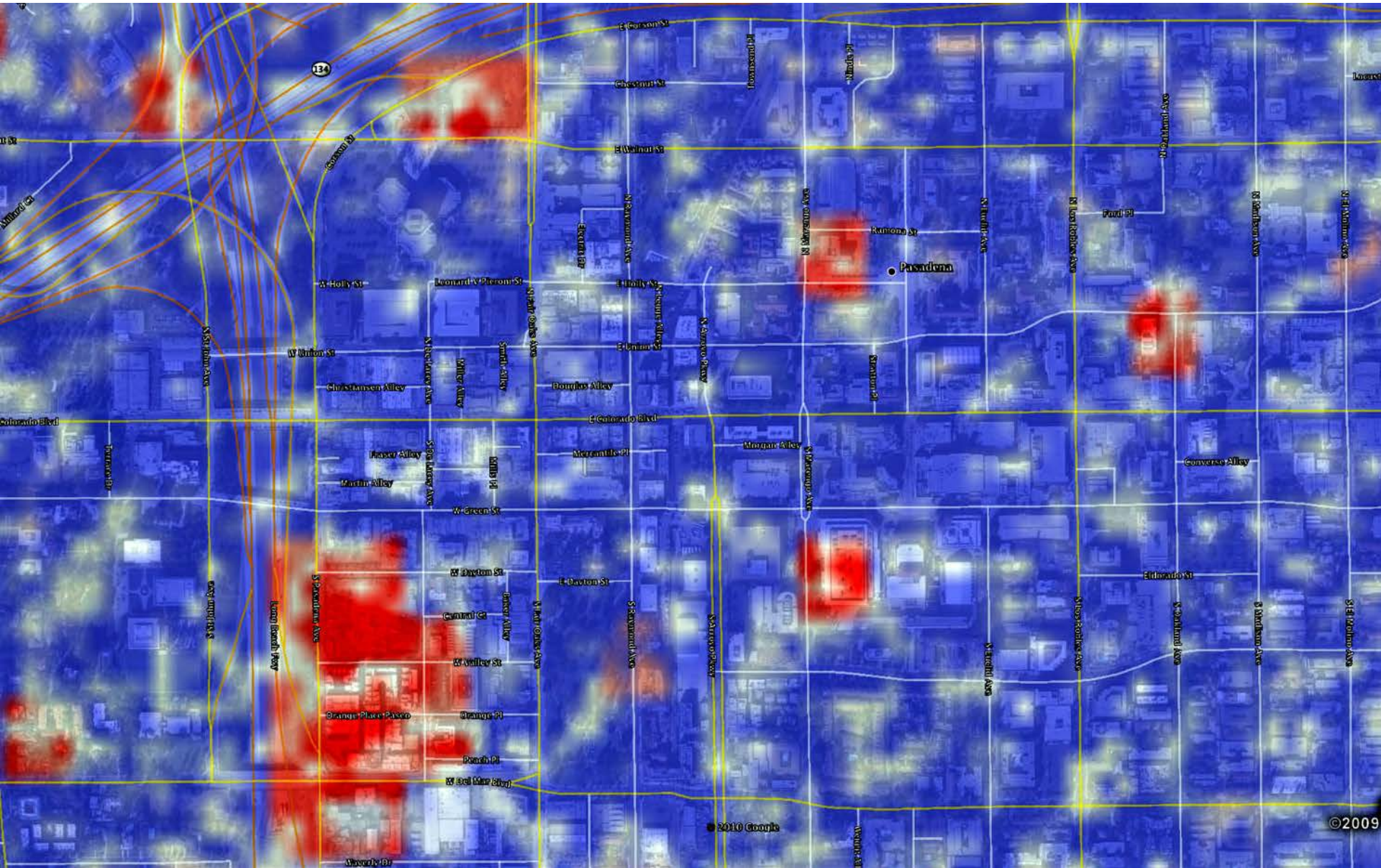
2007/10/23

2009/11/15

Demolition: 2007/04/23 – 2008/01/22

Damage Proxy Map (Downtown Pasadena, California)

2006/12/31 – 2007/02/15 – 2008/02/18

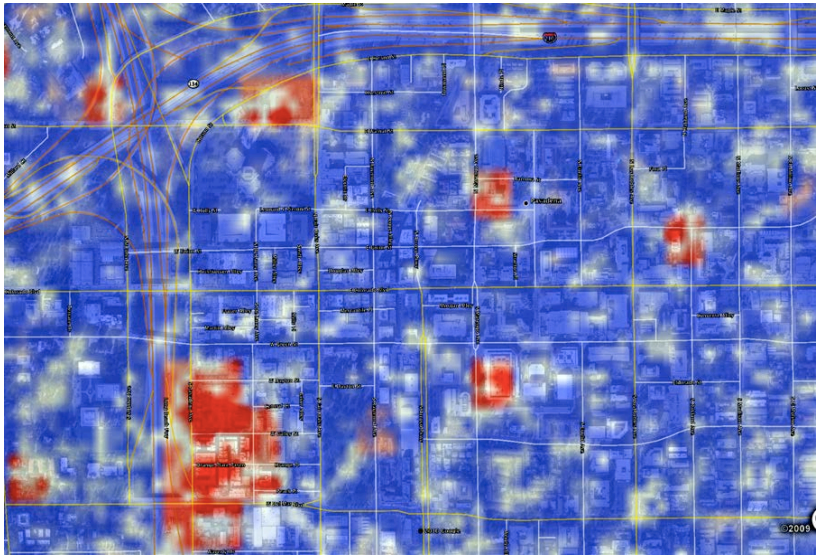


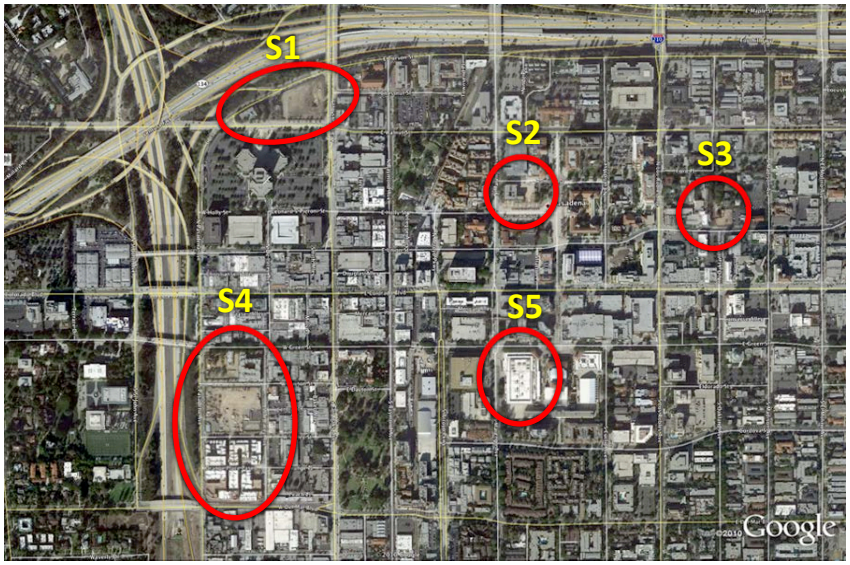
Google Earth (Downtown Pasadena, California on 2007/10/23)

Google Earth (Downtown Pasadena, California on 2009/11/15)

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

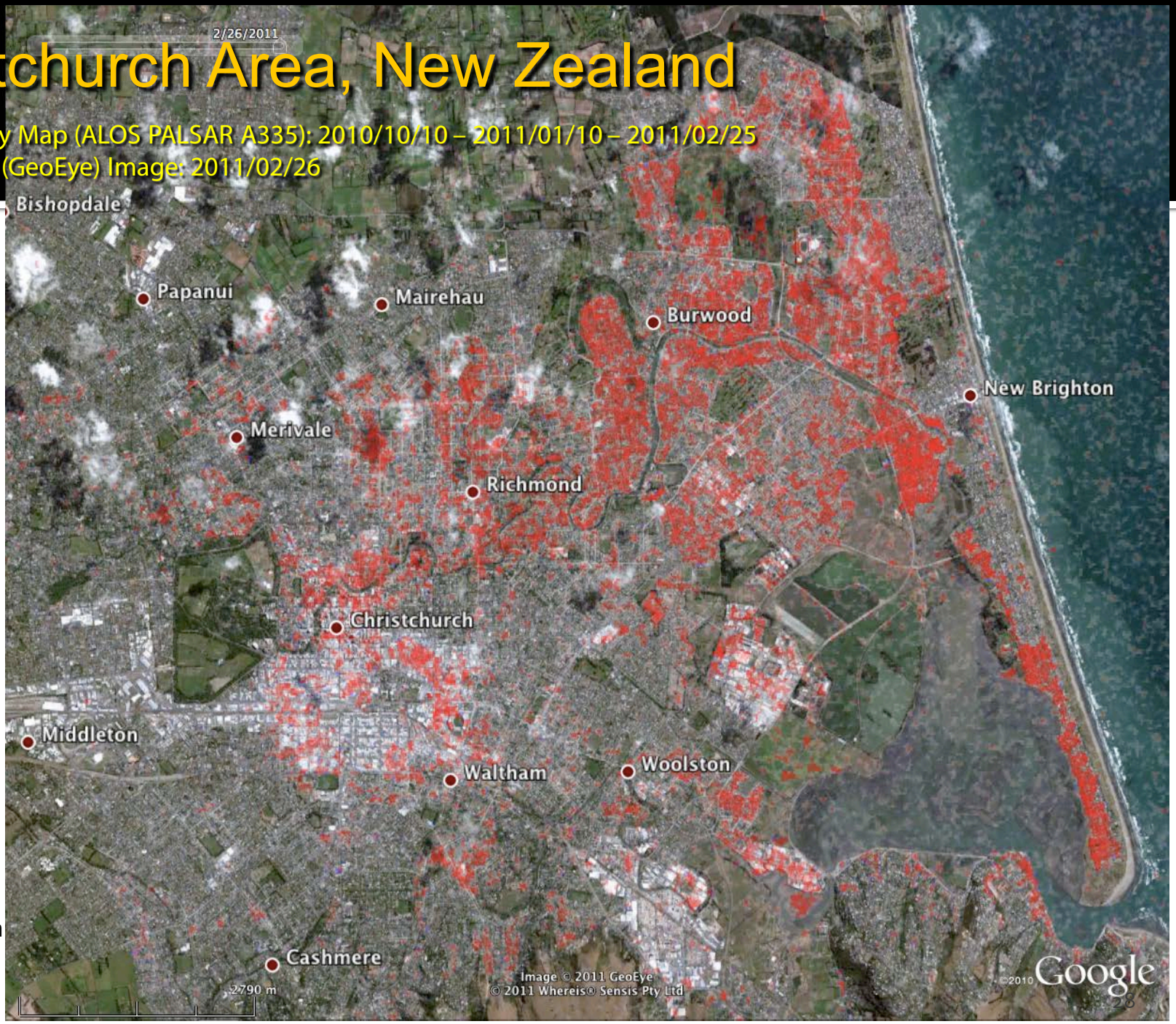
S3: (34.147467, -118.139595) → 527 E Union St., Pasadena, CA 91101

S4: (34.141923, -118.153428) → 144 Valley St., Pasadena, CA 91105

S5: (34.143786, -118.145282) → 100-190 S Marengo Ave, Pasadena, CA 91101

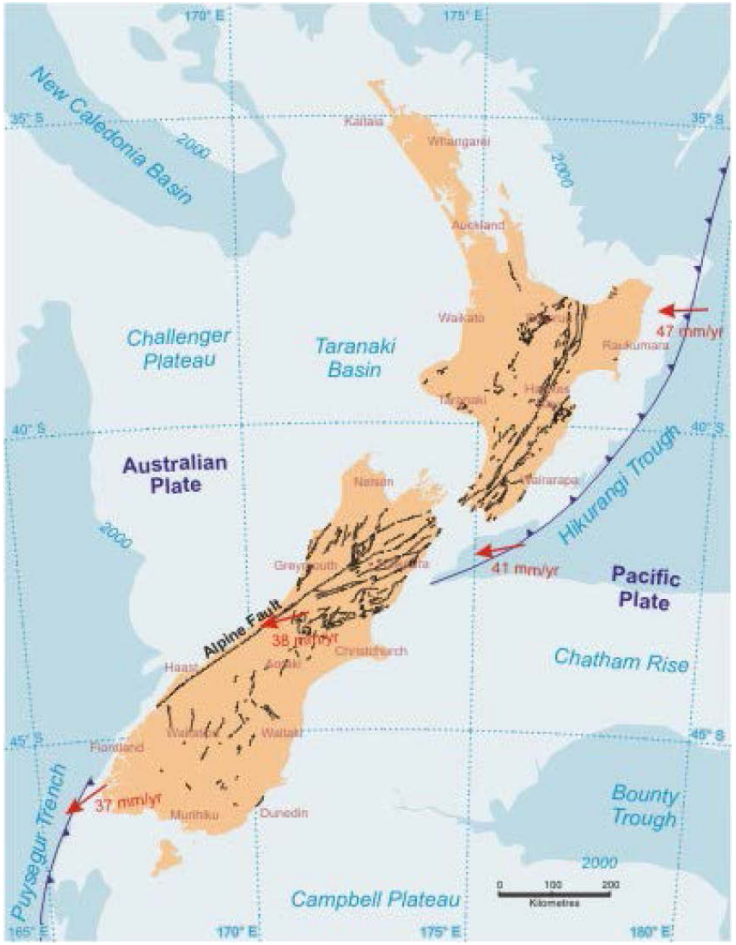
Christchurch Area, New Zealand

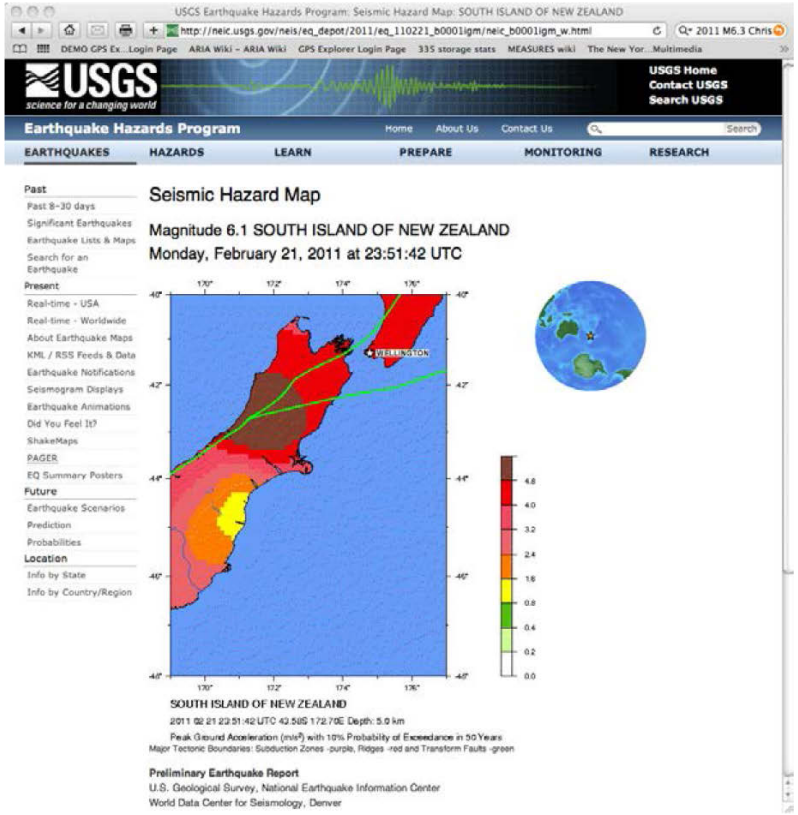
Damage Proxy Map (ALOS PALSAR A335): 2010/10/10 – 2011/01/10 – 2011/02/25
Google Earth (GeoEye) Image: 2011/02/26



ARIA – JPL/Caltech

2011 M6.3 Christchurch Earthquake





Christchurch Cathedral

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

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

2010/09/03

2011/02/23

Damage Proxy Map

EQ M6.3

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)

2010/09/03

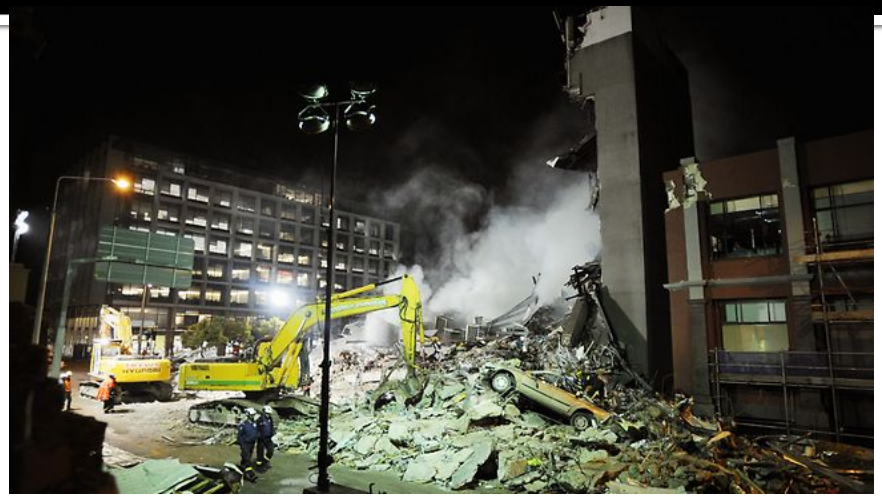
2011/02/23

Damage Proxy Map

EQ M6.3

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)

2010/09/03

EQ M6.3

2011/02/26

Damage Proxy Map

Pyne Gould Building

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

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)

2009/03/04

2011/02/26

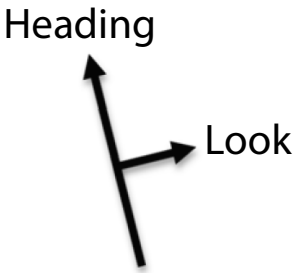
Damage Proxy Map
building damage + liquefaction

EQ M6.3

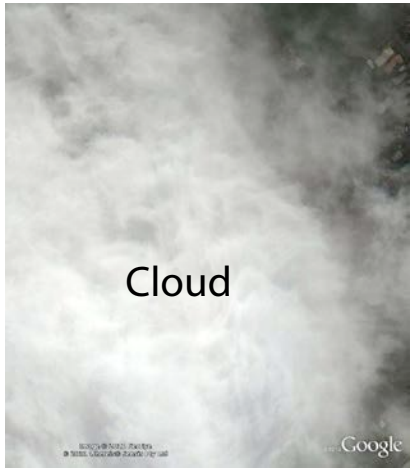
Landslide

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).



2010/09/03



2011/02/23

EQ M6.3

2011/02/26

Damage Proxy Map

Liquefaction near Bridge Street

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

2010/09/03

2011/02/22

EQ M6.3

2011/02/23

Damage Proxy Map

Liquefaction near Burwood

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

2009/03/04

2011/02/22

EQ M6.3

2011/02/23

2011/02/26

Damage Proxy Map

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)

2009/03/04

2011/02/23

EQ M6.3

Damage Proxy Map

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**

Seismological Laboratory
California Institute of Technology

JPL

The Advanced Rapid Imaging & Analysis (ARIA) Center for Natural Hazards

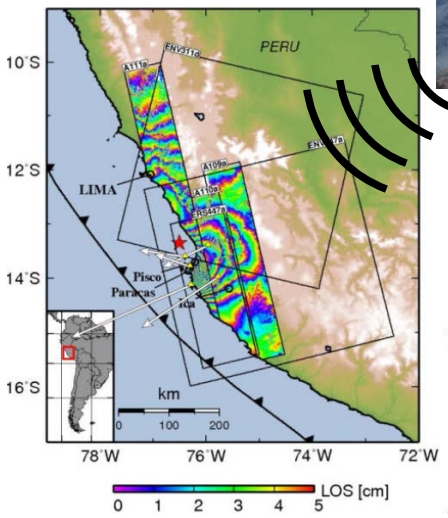
JPL

Integrating:
Space Geodesy
Seismology
Modeling

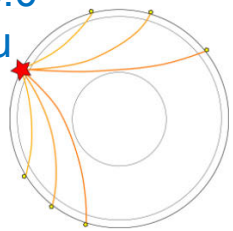
Seismological Laboratory
California Institute of Technology

→ *Science & "near real time" assessment*

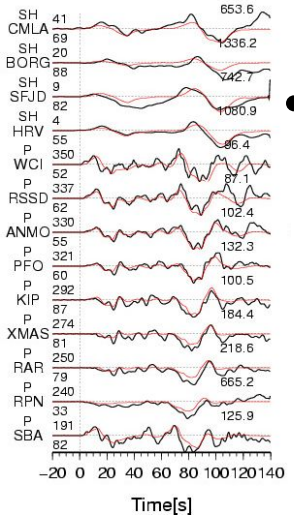
InSAR and GPS



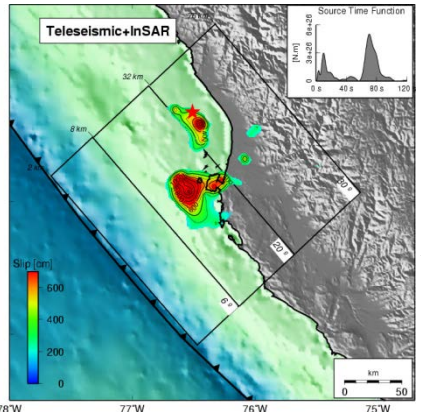
2007 Mw 8.0
Pisco, Peru



Seismology



Earthquake and tsunami source models



Subsurface fault slip:
7 meters peak value

Preparing for the future…

Potential Partners?

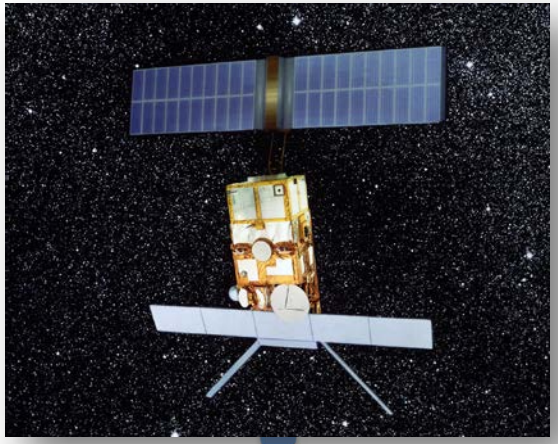
NASA

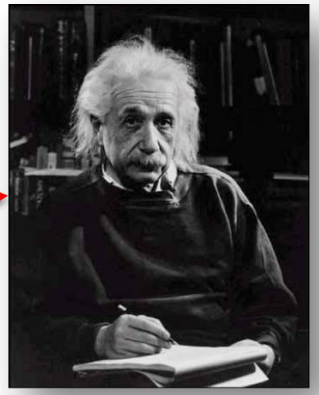
USGS science for a changing world

U.S. Department of Homeland Security

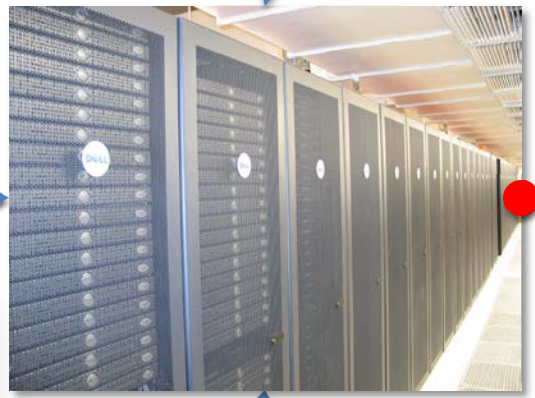
NSF

Cal EMA
California Emergency Management Agency





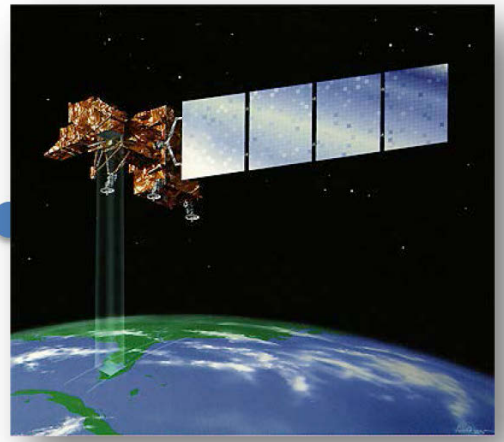
A graduate student



Months

Hours/Days

ARIA



Seismological Laboratory
California Institute of Technology

JPL

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