Linking Oceanic Tsunamis and Geodetic Gravity Changes of Large Earthquakes

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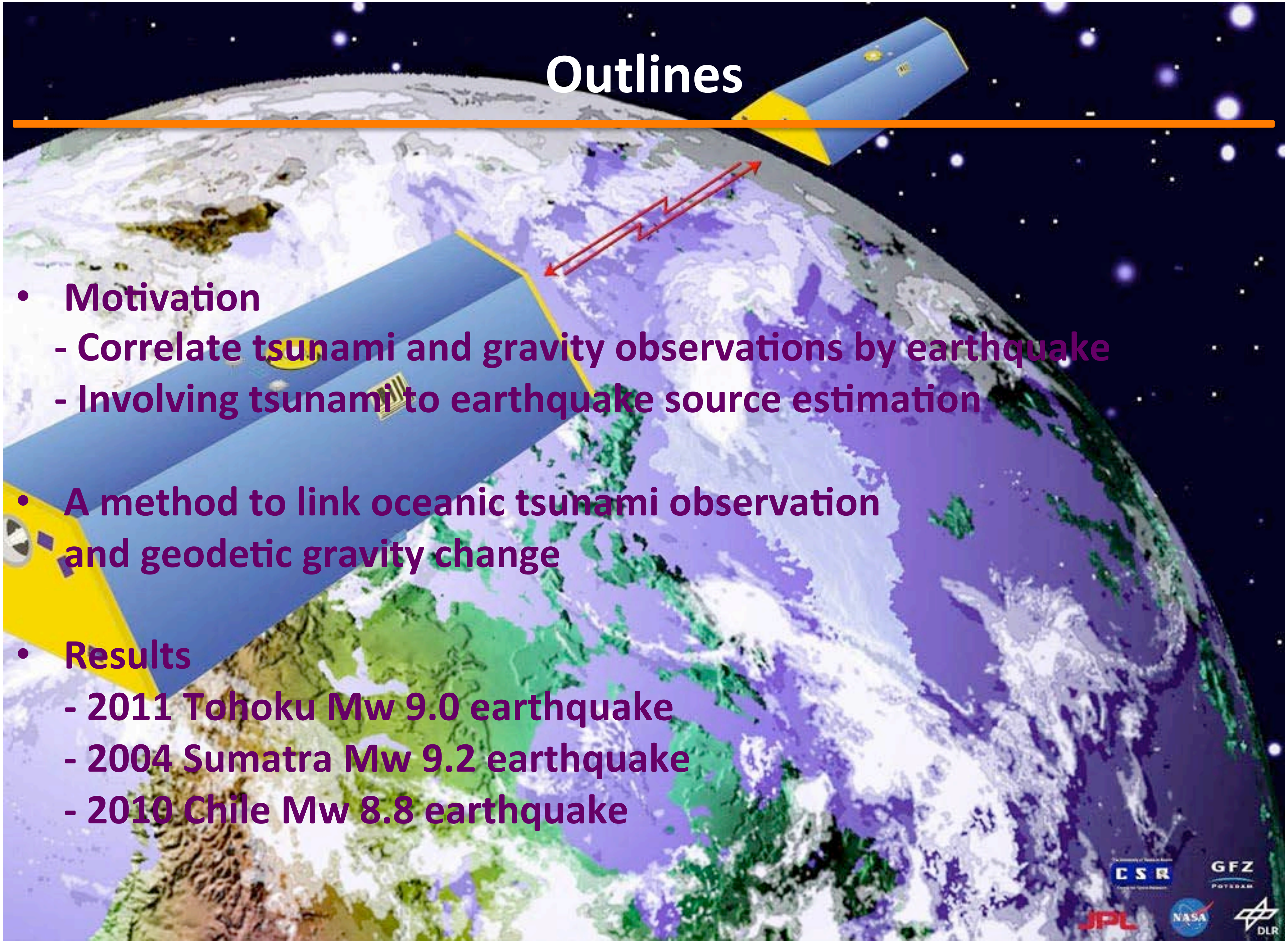
Outlines



- **Motivation**
  - Correlate tsunami and gravity observations by earthquake
  - Involving tsunami to earthquake source estimation

- **A method to link oceanic tsunami observation and geodetic gravity change**

- **Results**
  - 2011 Tohoku Mw 9.0 earthquake
  - 2004 Sumatra Mw 9.2 earthquake
  - 2010 Chile Mw 8.8 earthquake

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Changes in the Earth's rotation and low-degree gravitational field induced by earthquakes

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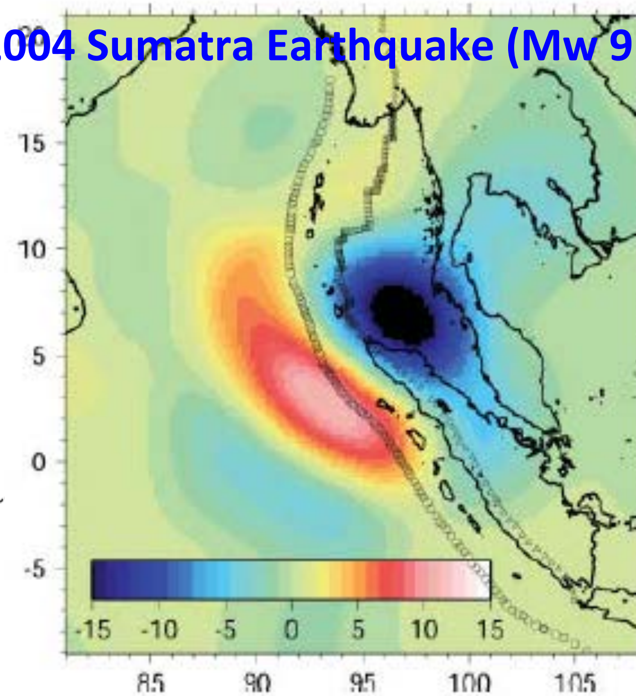
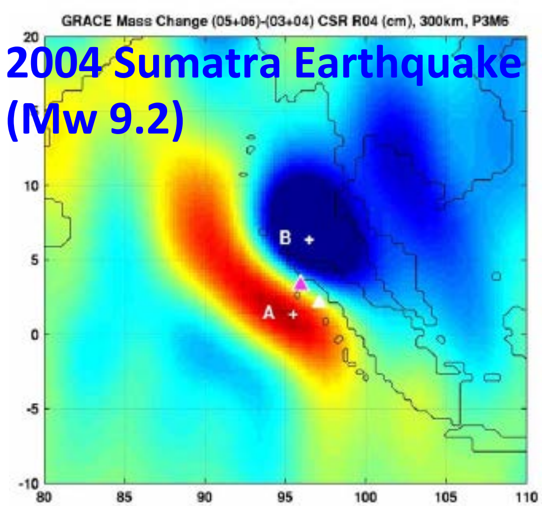
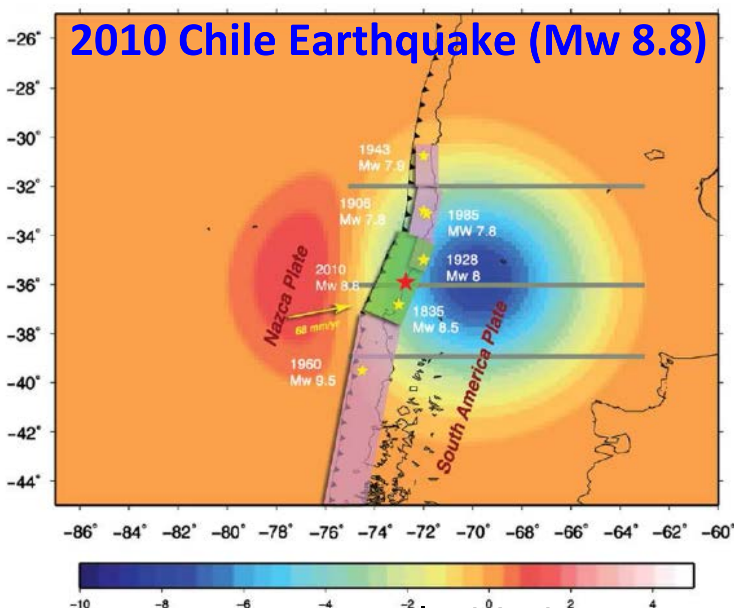


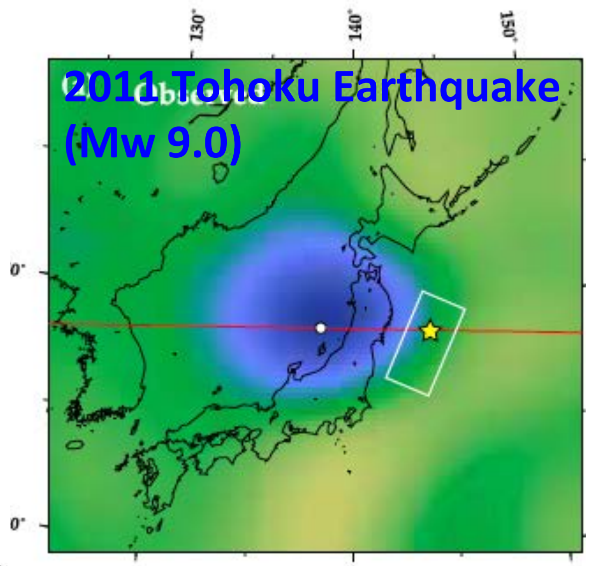
Han et al., 2006



Chen et al., 2007



Wang et al., 2012

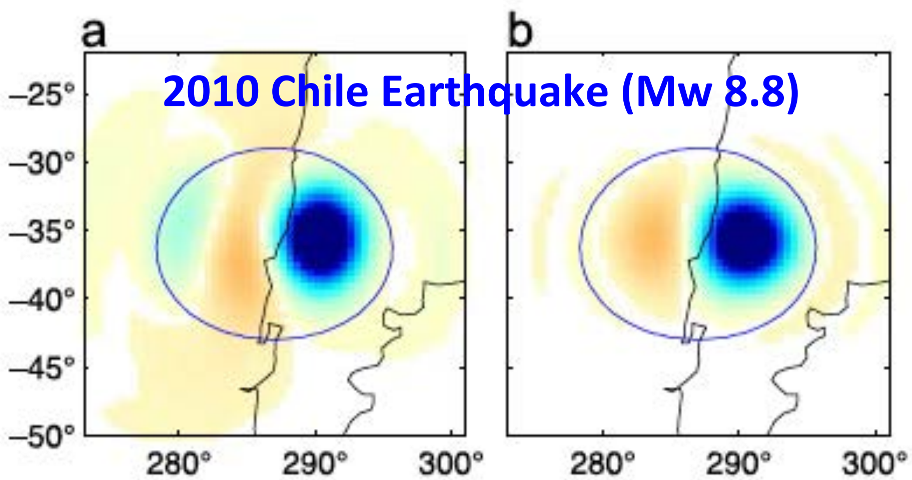


Matsuo and Heki, 2011

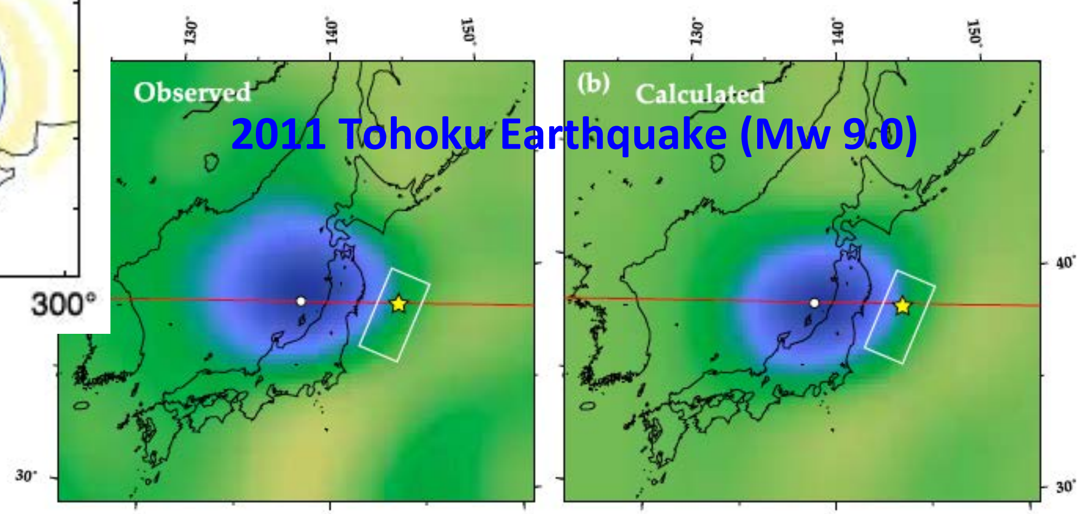
Slip Distribution Is (Usually) Needed to forward model Coseismic Gravity

Most other estimated coseismic slip distributions that exist are estimated

- Land GPS measurements (e.g., Ozawa et al. 2011 ; Simons et al. 2011)
- Teleseismic waves (e.g., Lay et al. 2011 ; Hayes 2011 ; Shao et al. 2011)
- Combination of seismic and geodetic data (e.g., Wei et al. 2012).



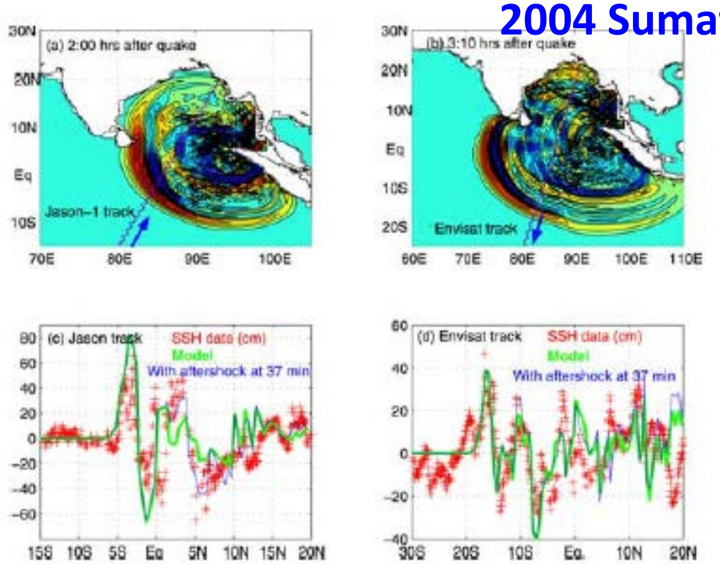
Wang et al., 2012



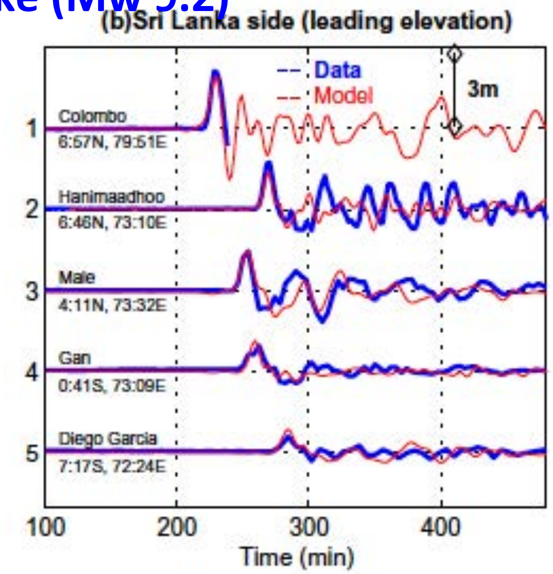
Matsuo and Heki, 2011

Involving Tsunami Observation

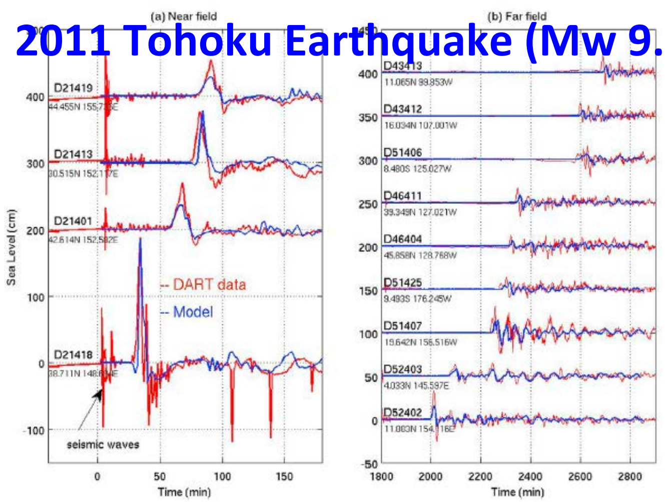
2004 Sumatra Earthquake (Mw 9.2)



Song et al., 2005



2011 Tohoku Earthquake (Mw 9.0)



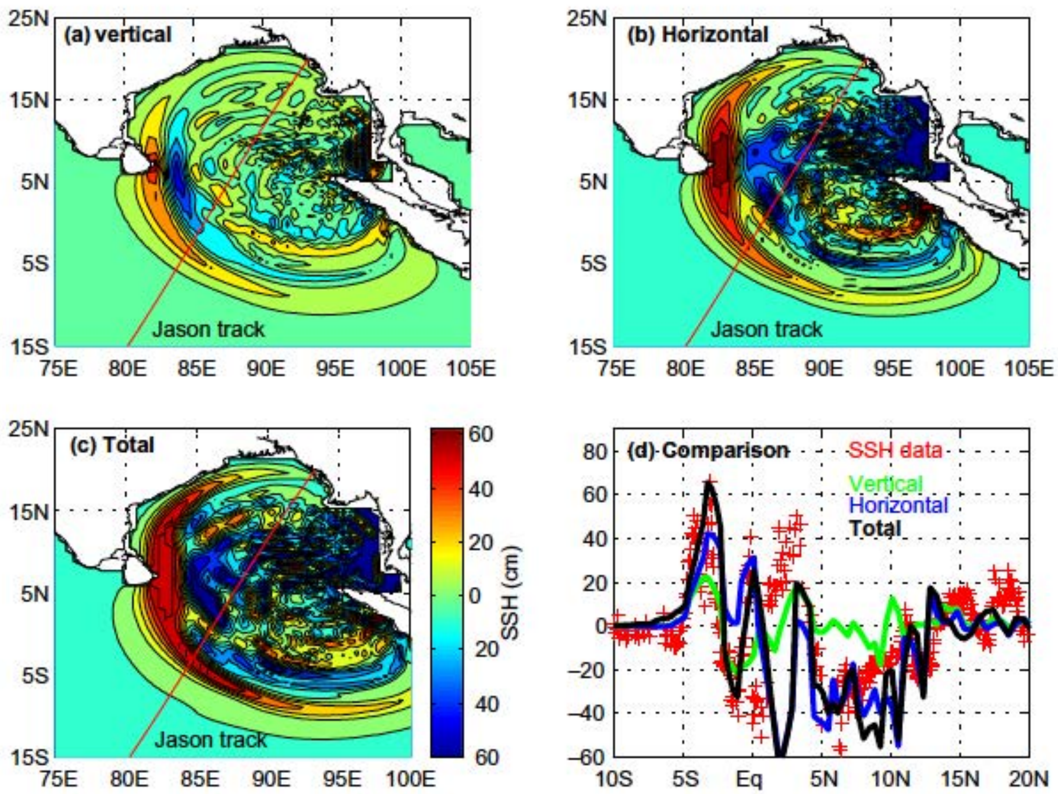
Song et al., 2012

Tsunami Observations:

- Altimetry
- Tide-gauge
- Deep-Ocean Assessment and Reporting of Tsunamis (DART) buoys

Tsunami Modeling

Three-dimensional hydrodynamic model of **Song and Hou (2006)**



Simulations of the 2004 tsunami at 2:00 h after the initial quake:
(a) forced by vertical motion only;
(b) forced by horizontal motion only;
(c) forced by both vertical and horizontal motions
(d) comparison with satellite observations (red crosses) along the Jason track.

Involving Tsunami Observation

Three-dimensional hydrodynamic model: Song and Hou (2006)

Oceanic tsunami observations

- coastal tide gages,
- DART buoys
- Satellite altimetry: Jason-1, Jason-2 and ENVISAT satellites that passed over the Pacific Gravity Changes of Large Earthquakes Ocean after the main shock.

Land-based GPS measurements

constrain

Three-dimensional seafloor displacements

Empirical profile extrapolation (Song 2007)

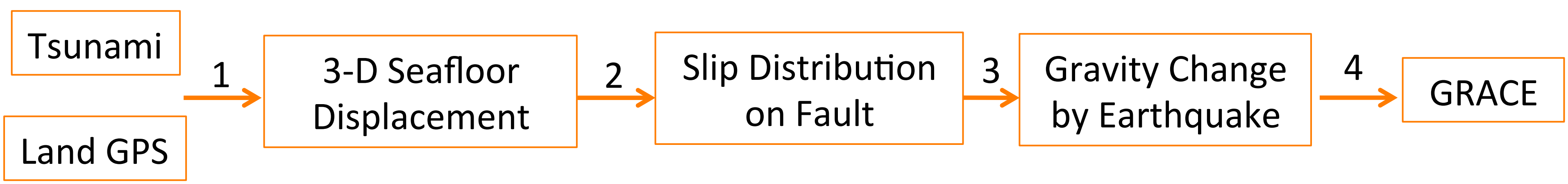
Link Oceanic Tsunami and Geodetic Gravity Change

1. Estimate coseismic seafloor displacements from land-based GPS measurements, satellite altimetry measurements, and DART tsunami observations.

2. Constrain the coseismic slip distribution along the subduction slab with the coseismic seafloor displacements estimated in step 1;

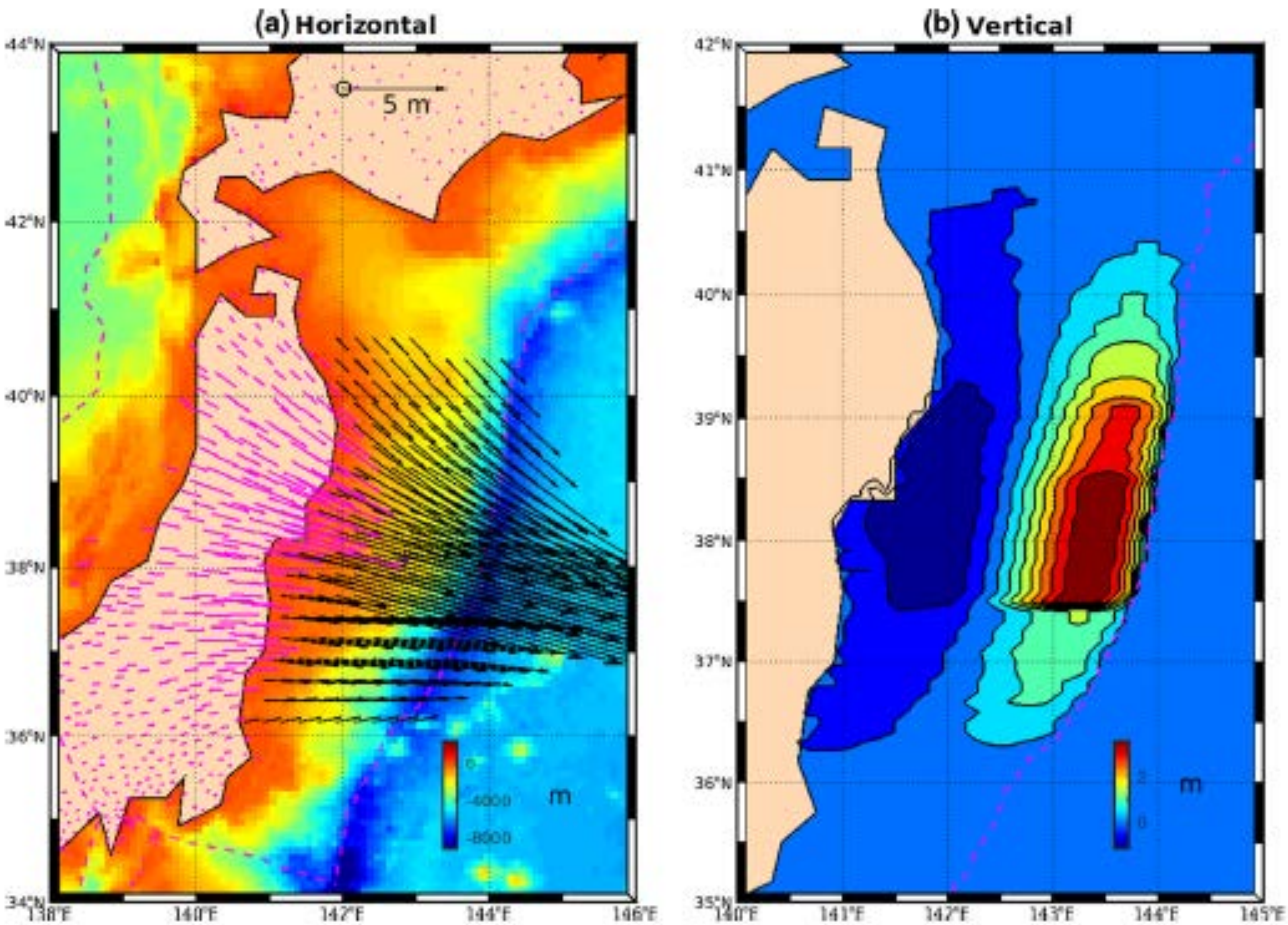
3. Forward model the coseismic gravity change based on the slip distribution; and

4. Appropriately post-process (truncate and smooth) the modeled coseismic gravity changes to compare with GRACE observations.



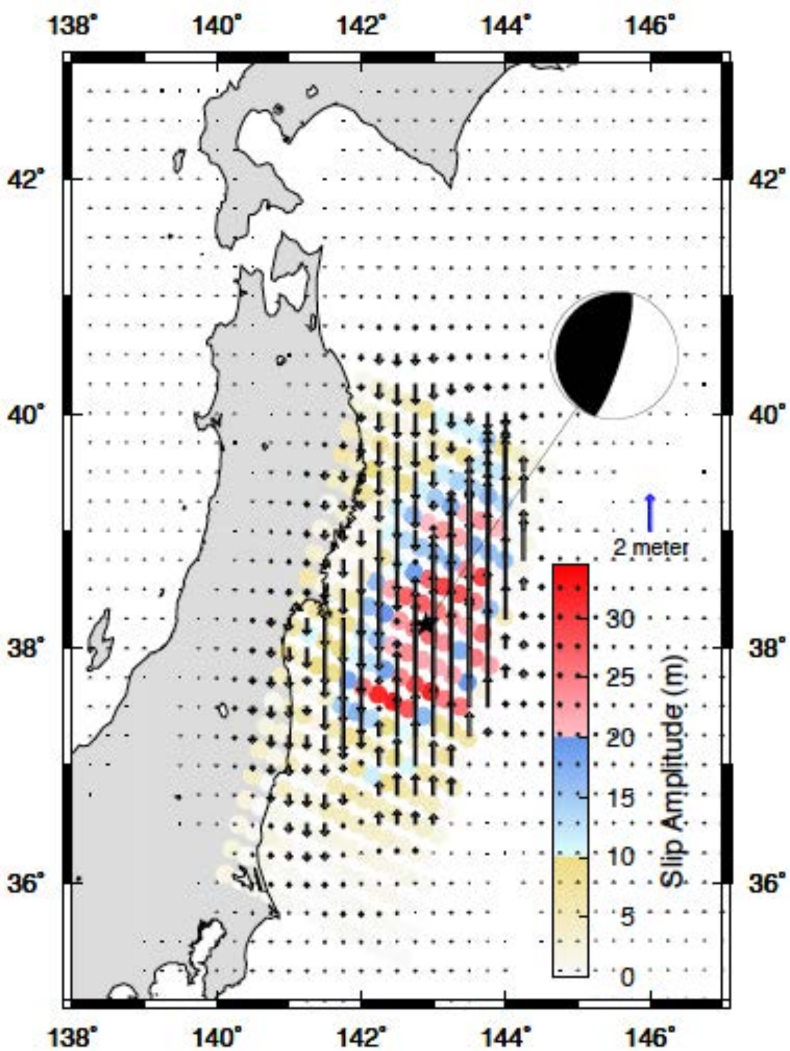
Use the 2011 Tohoku Mw 9.0 earthquake as a first example!

2011 Tohoku Earthquake Mw 9.0

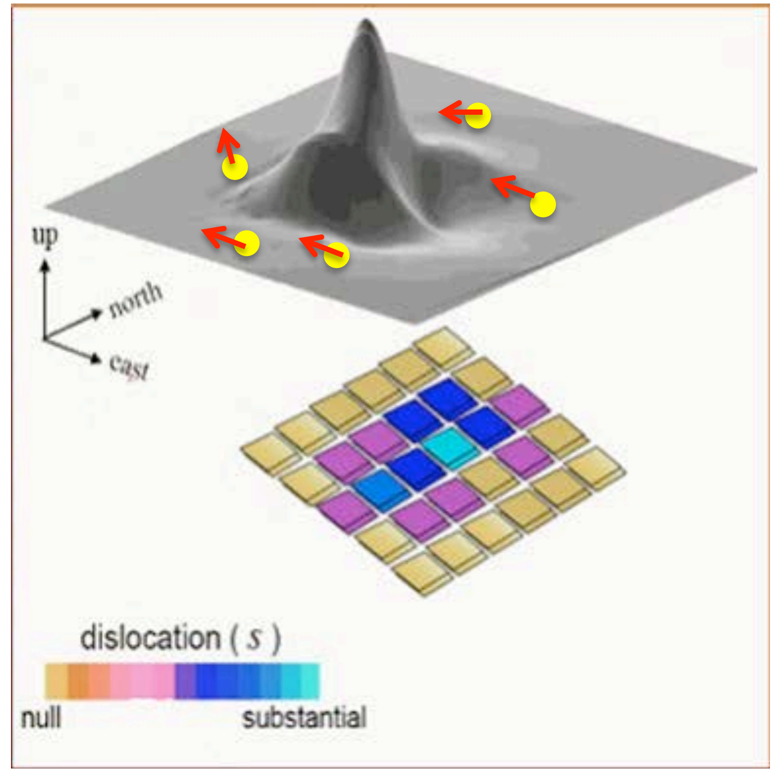


Coseismic horizontal (left) and vertical (right) seafloor displacements, **constrained from oceanic tsunami and land-based GPS data**

Slip Distribution on subducting fault



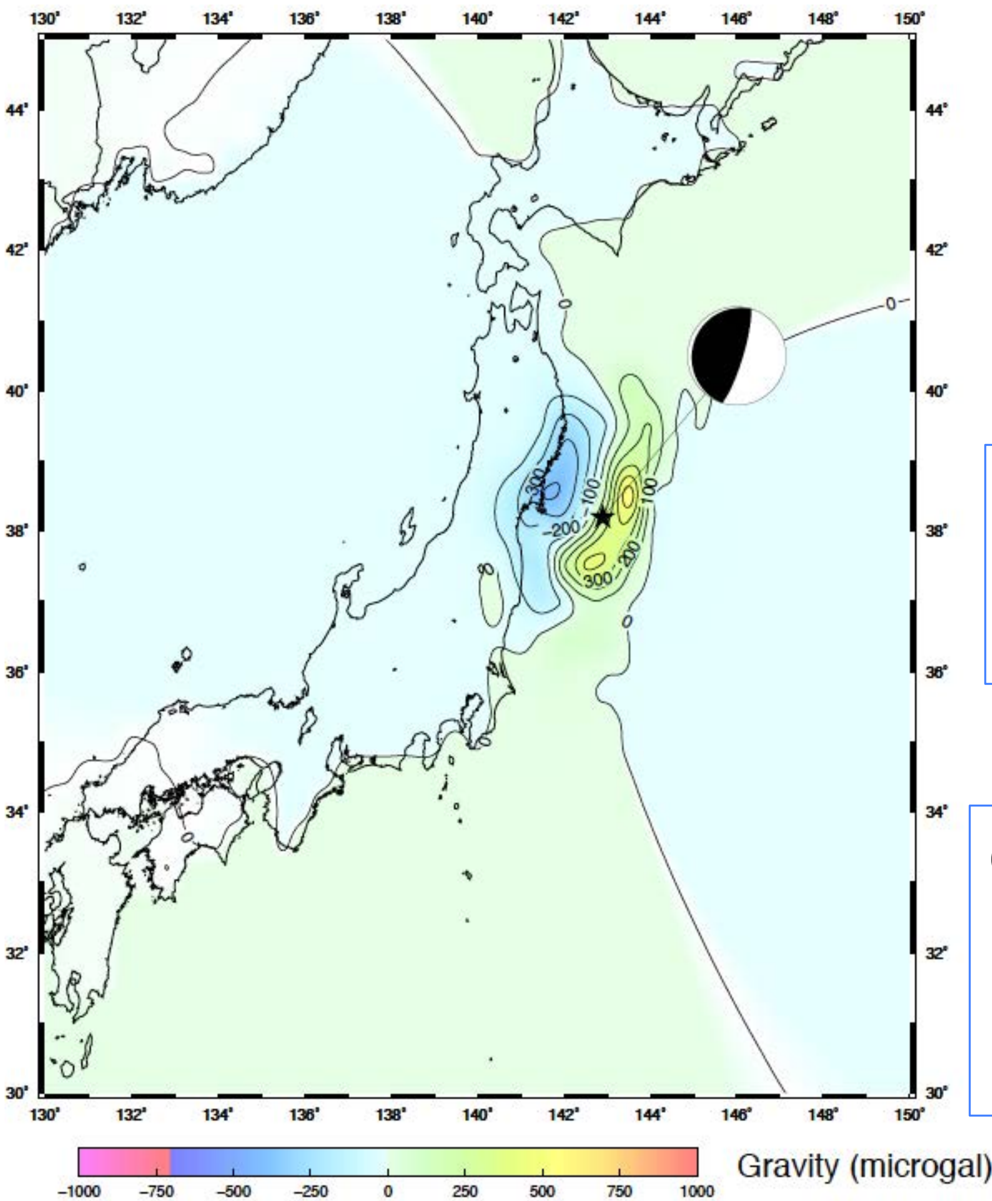
Slip distribution (color circles) of the Tohoku 2011 earthquake along the subducting plate estimated from seafloor displacements!



$$\underbrace{\|W(Gx-b)\|^2}_{\text{Misfit(WRSS)}} + \beta^2 \underbrace{\|Lx\|^2}_{\text{Roughness}} \rightarrow \min$$

G is the Green's function (Okada, 1985) relating slip on the fault *x* to coseismic displacement on the seafloor *b.*

L: Laplacian operator to limit rapid and unrealistic slip on fault.



Forward calculate coseismic gravity change:

- PSGRN/PSCMP program (Wang et al. 2006)
- PREM Earth model

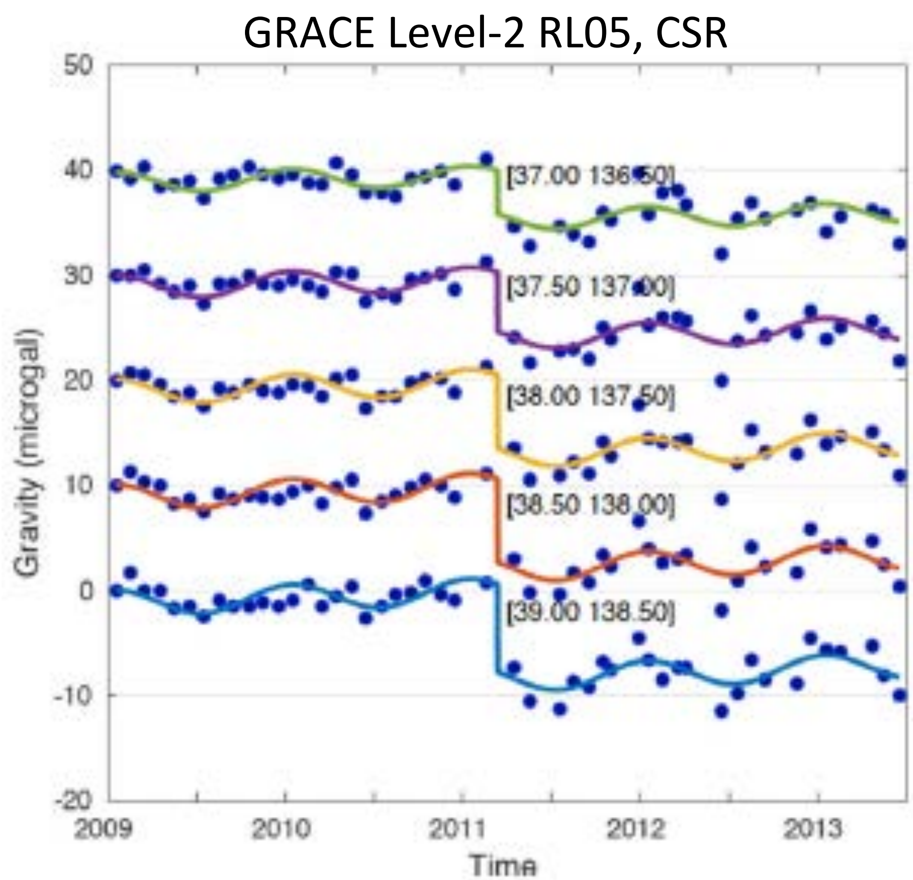
Corrections made:

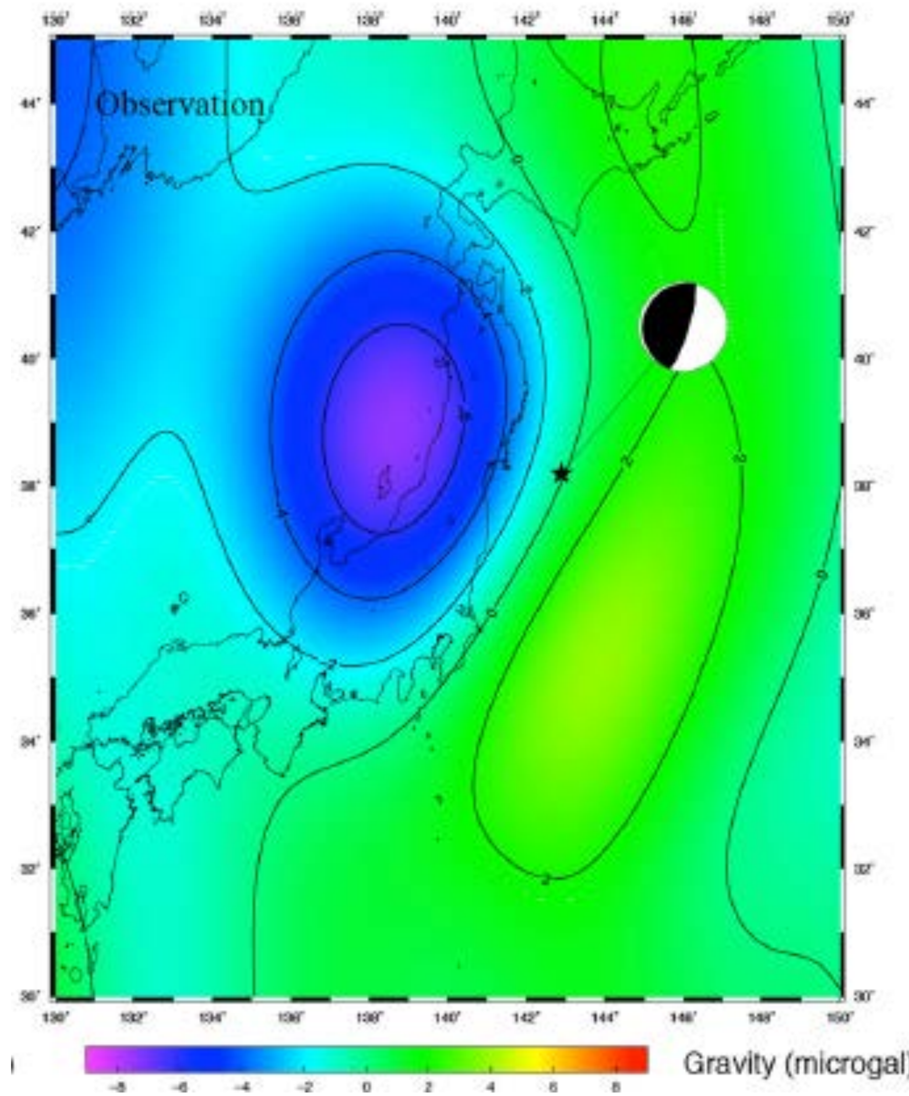
- Ocean water displacement

Compare with GRACE

- Truncate
- Smooth

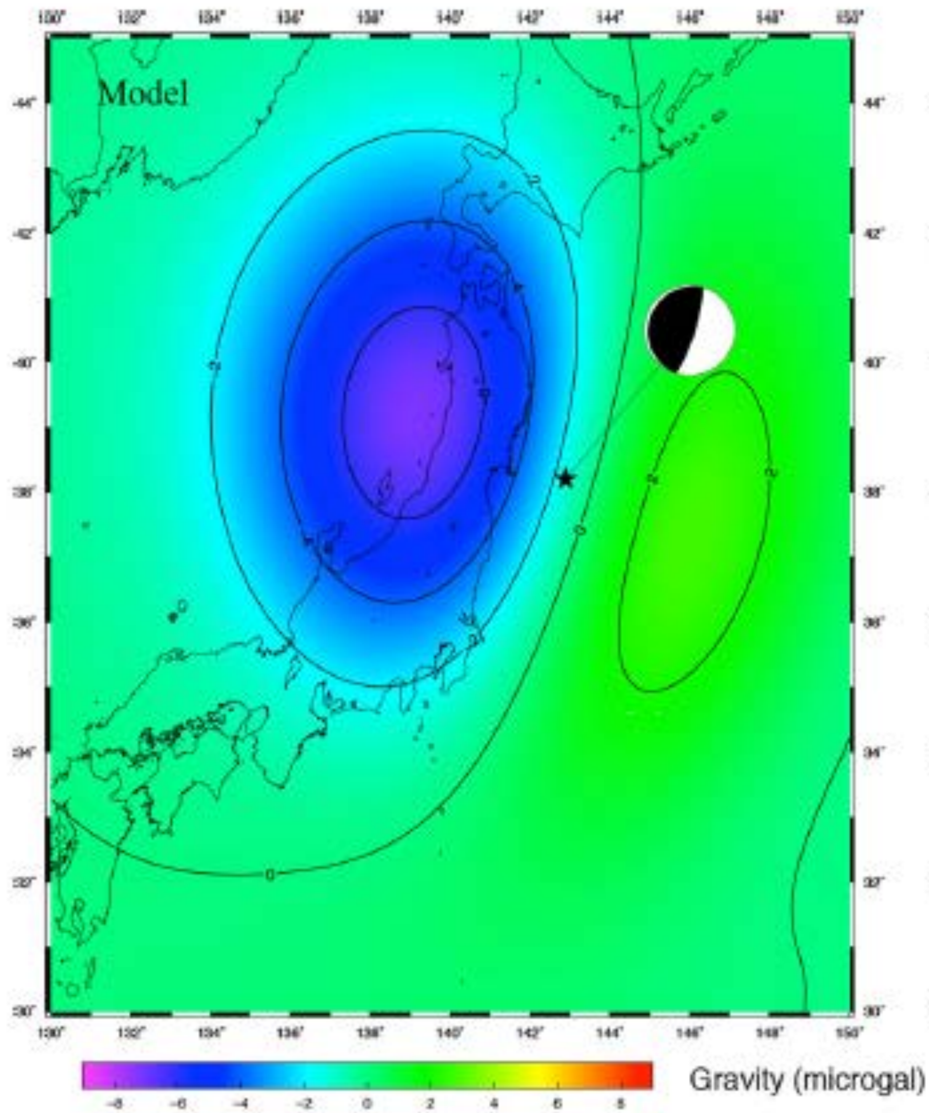
GRACE Observation



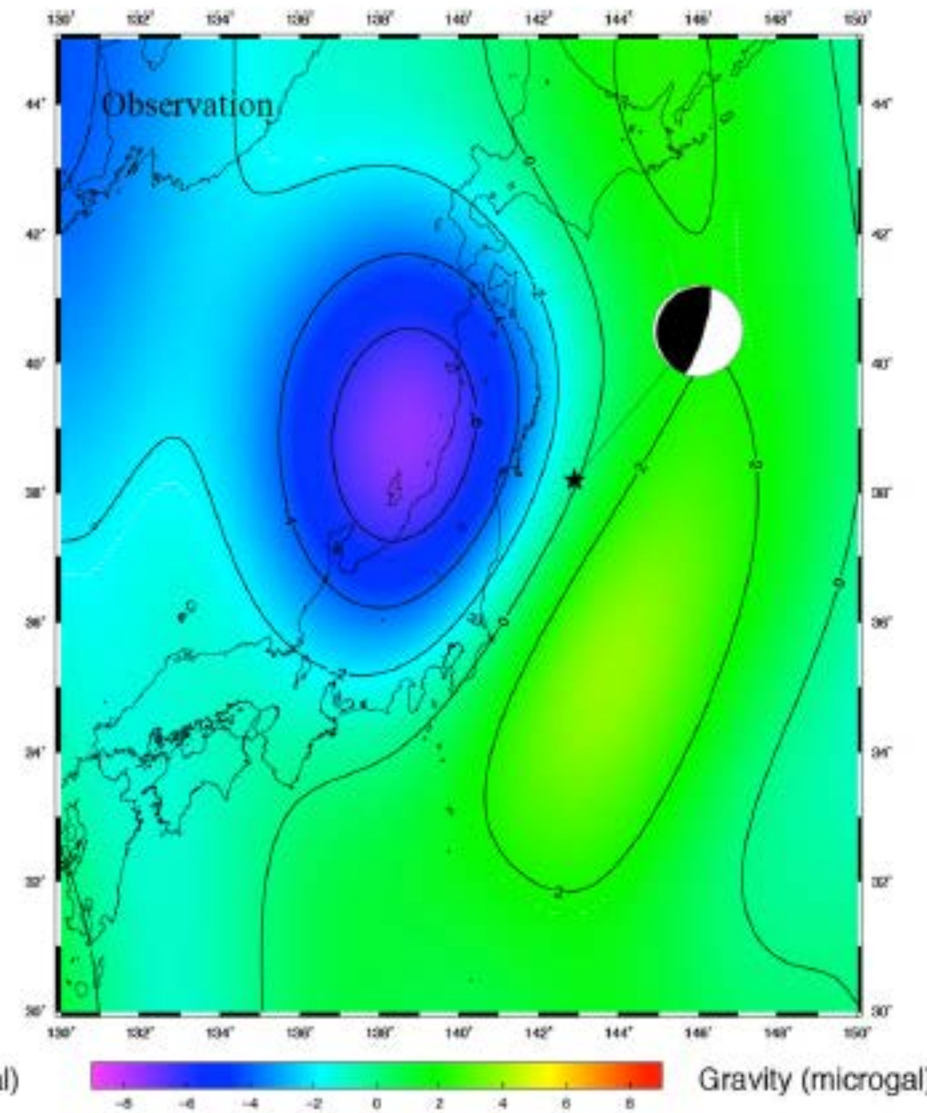


Step function is assigned at the time when the earthquake occurred in order to evaluate the coseismic change.

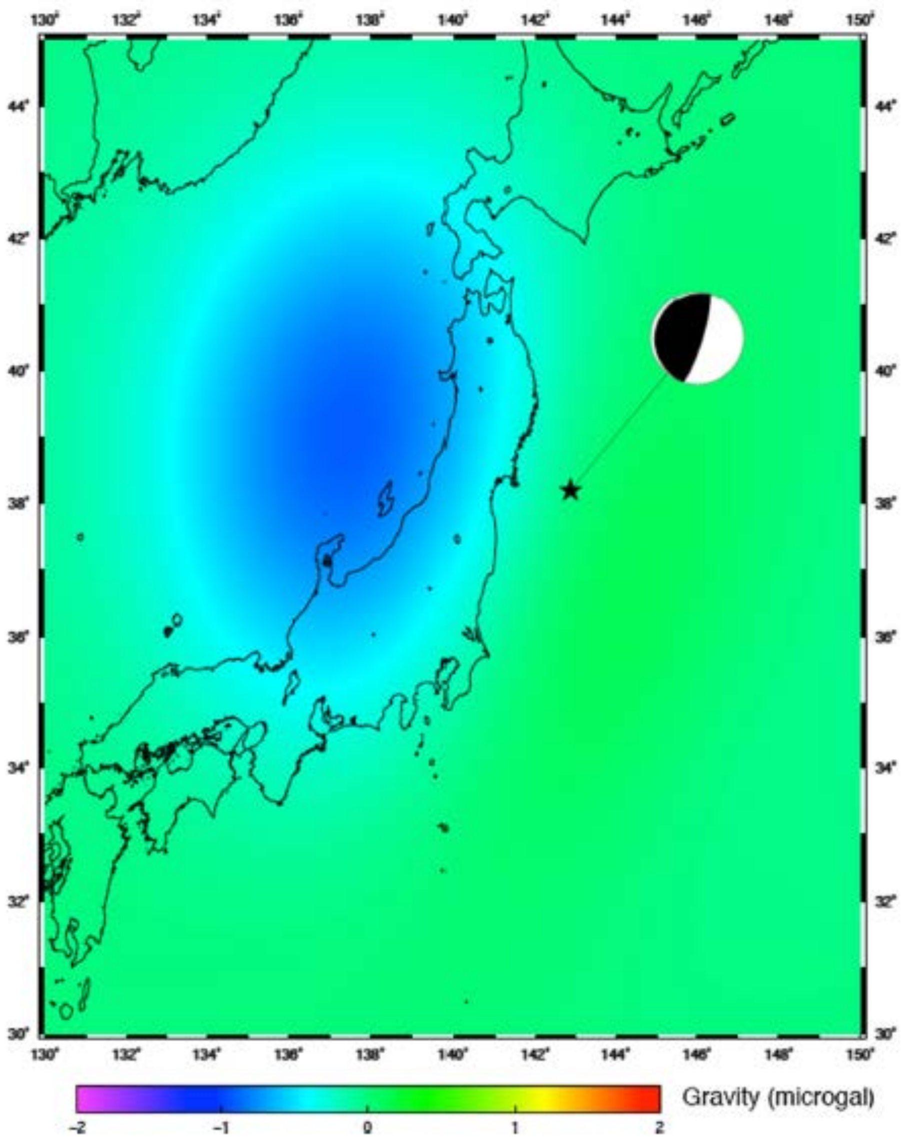
Model
Truncate d/o = 60,
Gaussian smoothing r= 350 km



Observation



Postseismic Gravity Change (by afterslip)



Earthquake: March 11, 2011

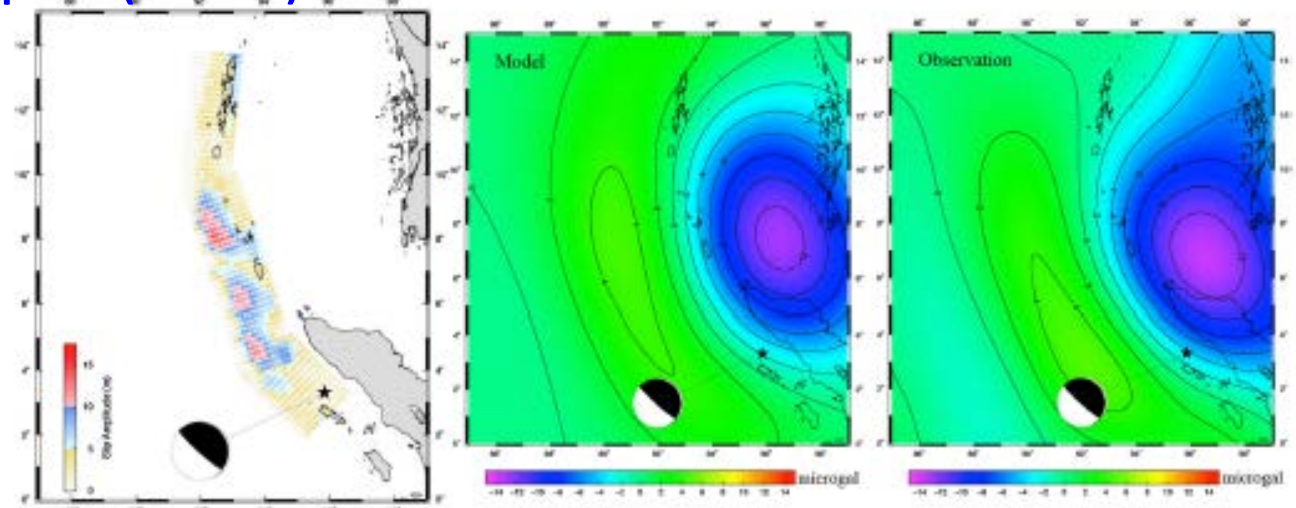
Afterslip distribution from March 12 to March 25, 2011 (Ozawa et al, 2011)

Resultant Postseismic Gravity Change by afterslip

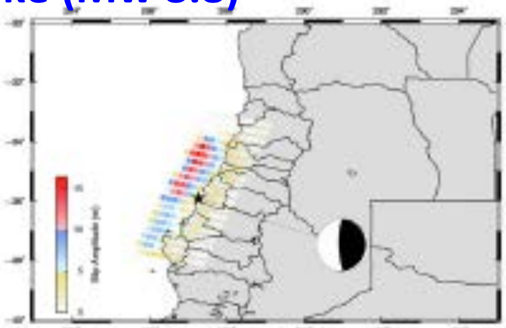
Afterslip produces **~1 μ gal** gravity change, which is about **10%** percent of the coseismic gravity change.

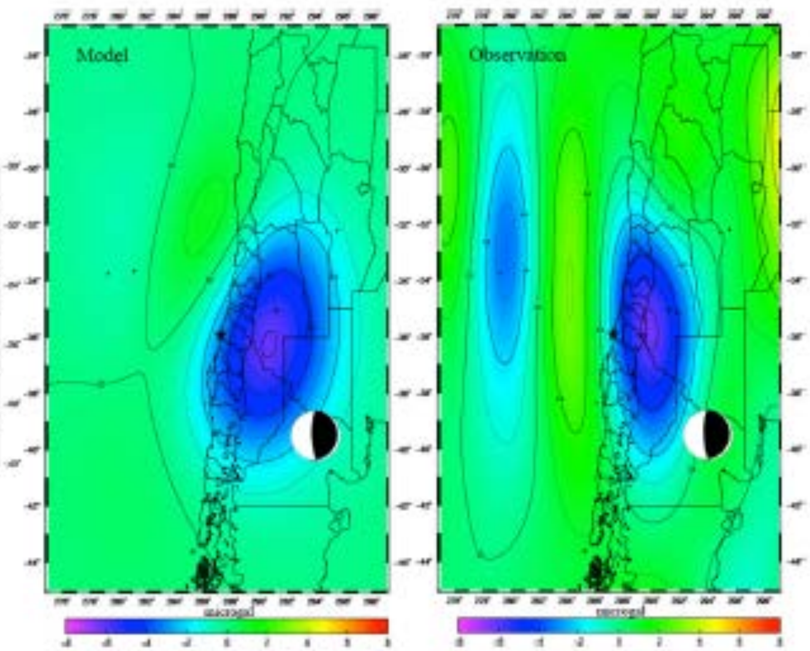
Other Large Earthquakes

2004 Sumatra Earthquake (Mw 9.2)



2010 Chile Earthquake (Mw 8.8)





Summary

We have introduced a method to link together oceanic tsunami observations and geodetic gravity (GRACE) measurements.

The method takes the three-dimensional tsunami formation mechanism into consideration and uses both tsunami observations and land-based GPS measurements to derive the three-dimensional seafloor displacements caused by submarine earthquakes

Our data analysis and modeling of the 2004 Sumatra Mw 9.2 earthquake, the 2010 Maule Mw 8.8 earthquake and the 2011 Tohoku Mw 9.0 earthquake demonstrate that using tsunami-derived seafloor displacements and the corresponding coseismic slip model yields coseismic gravity changes that are consistent with those observed by GRACE satellites.