J-RAPID Symposium March 6 and 7, 2013
Group 1 Geo-science 13:15-14:15, March 6, 2013

JST J-RAPID & ANR FLASH Joint Research Project

DYNTOHOKU: Dynamics of the 2011 Tohoku-Oki earthquake

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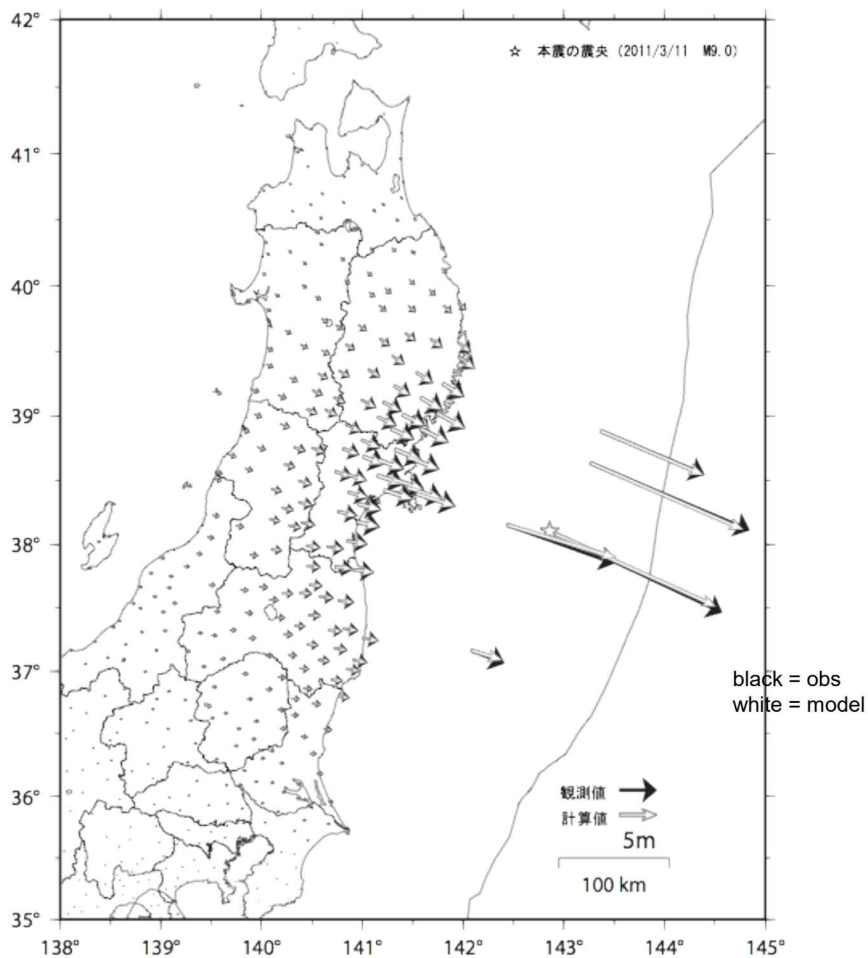
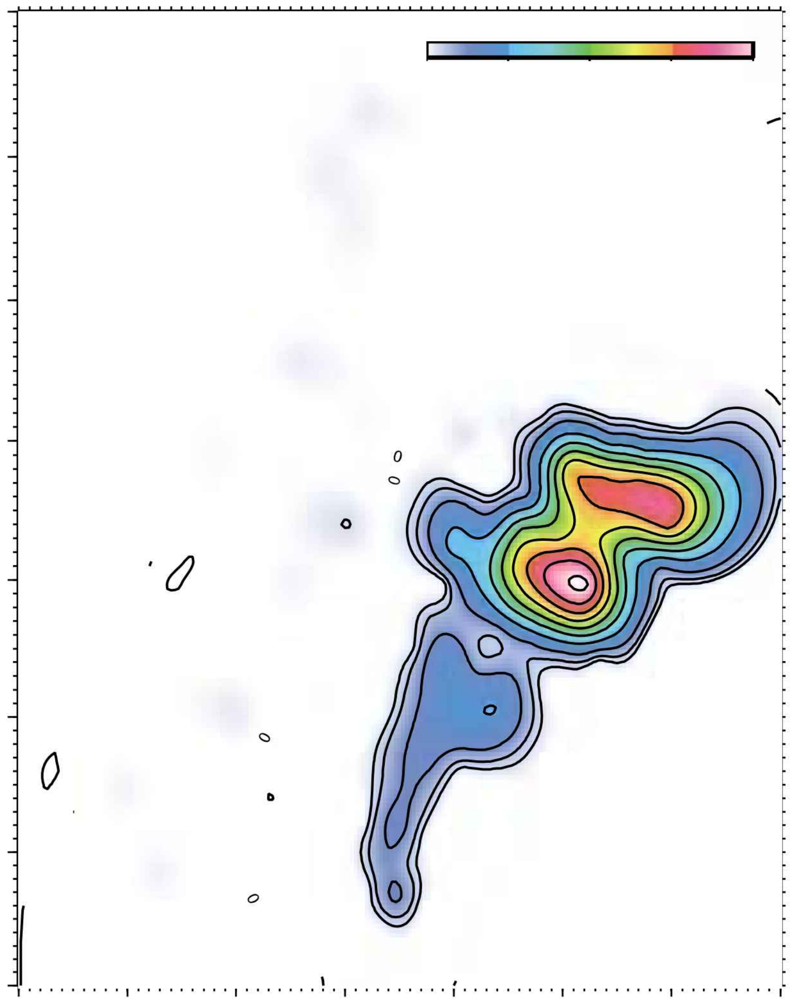
Dynamics of the Tohoku-Oki EQ

- **Modeling the rupture process**
  - Slip inversion using seismograms and GPS
  - Locating high-frequency sources
- **Fracture dynamics of shallow plate interface**
  - Multiscale patch model to explain complex rupture
  - New simulation codes for realistic dynamics
- **Long-term deformation**
  - Postseismic deformation and afterslip distribution
  - Viscoelasticity and far-field postseismic deformation

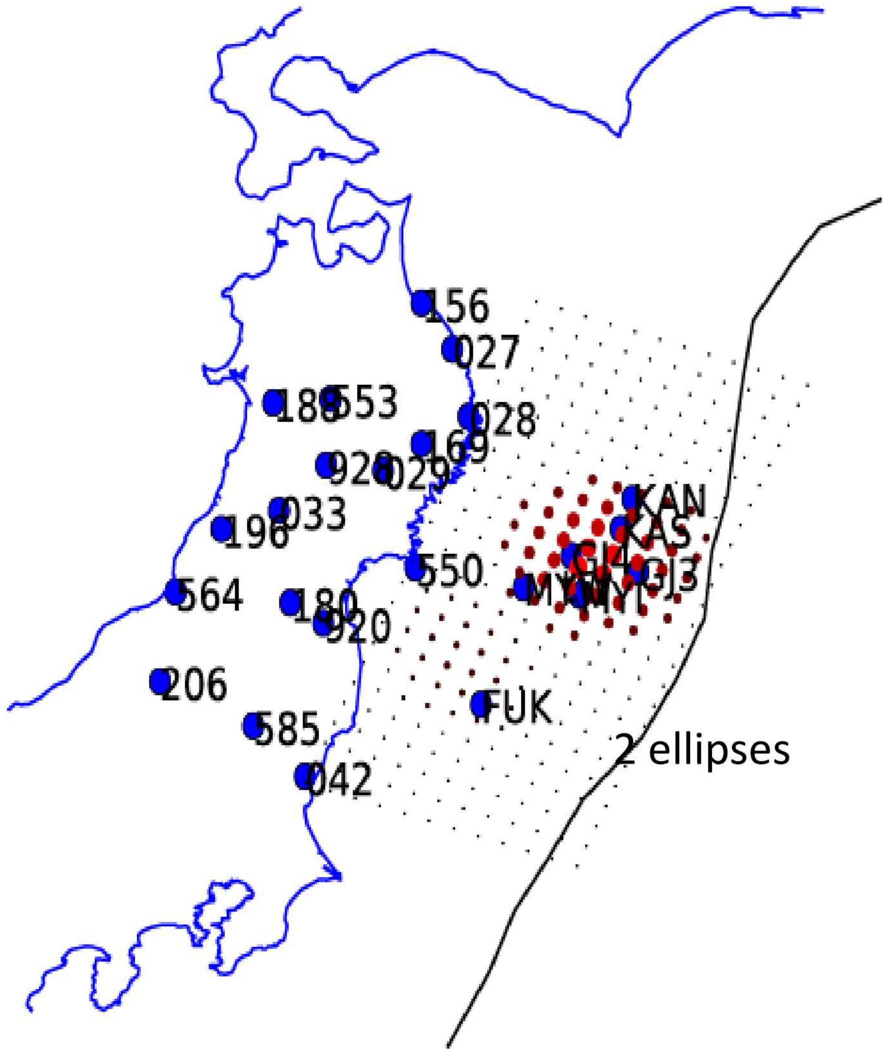
Requires more than 50 m of slip on the fault over a zone of about 100x100 km

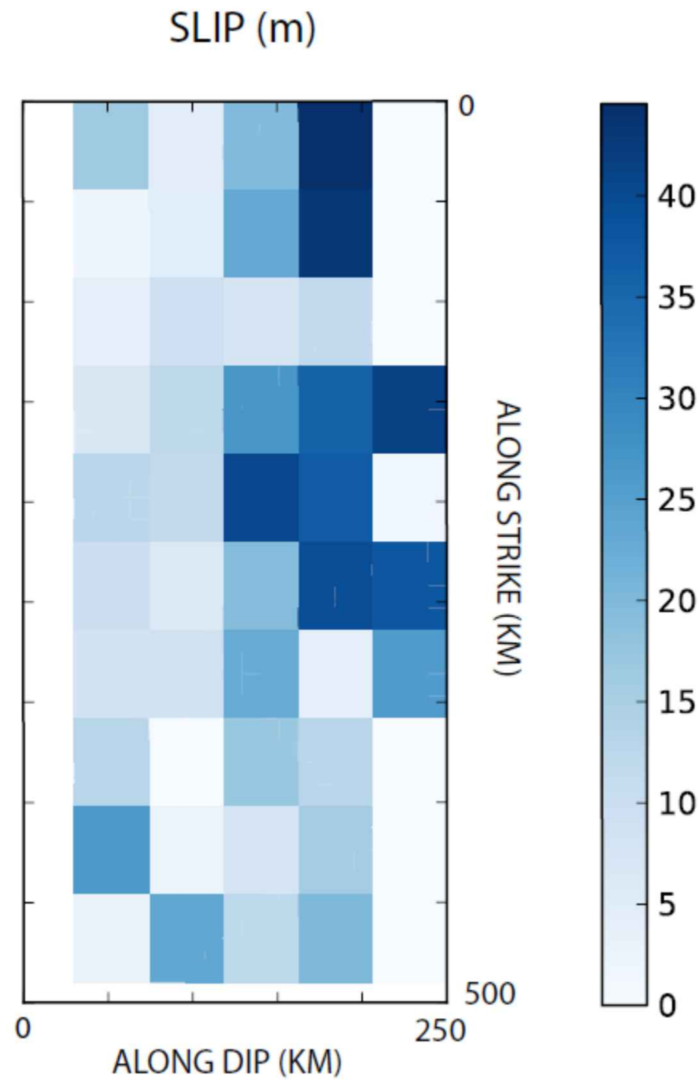




Inversion by GSI (T. Nishimura)

Non linear inversion of cGPS+ocean bottom GPS data

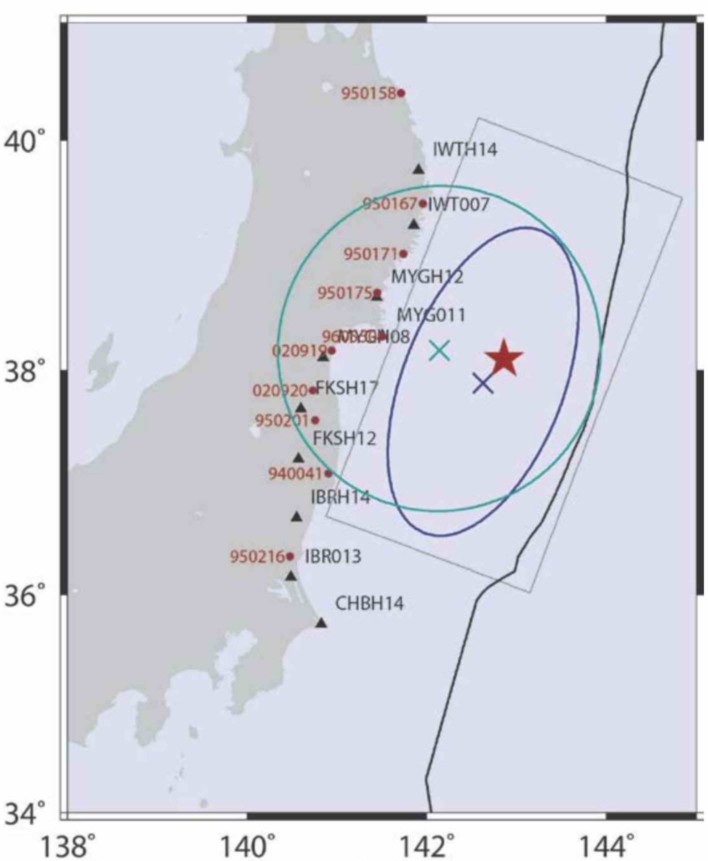


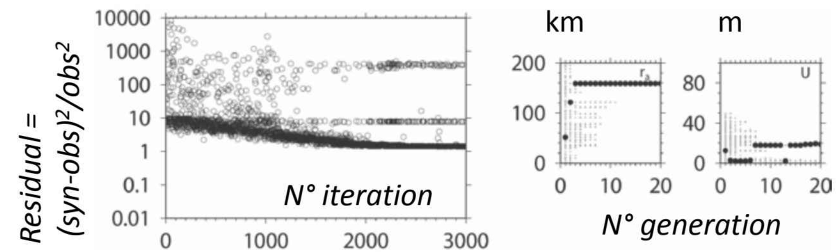


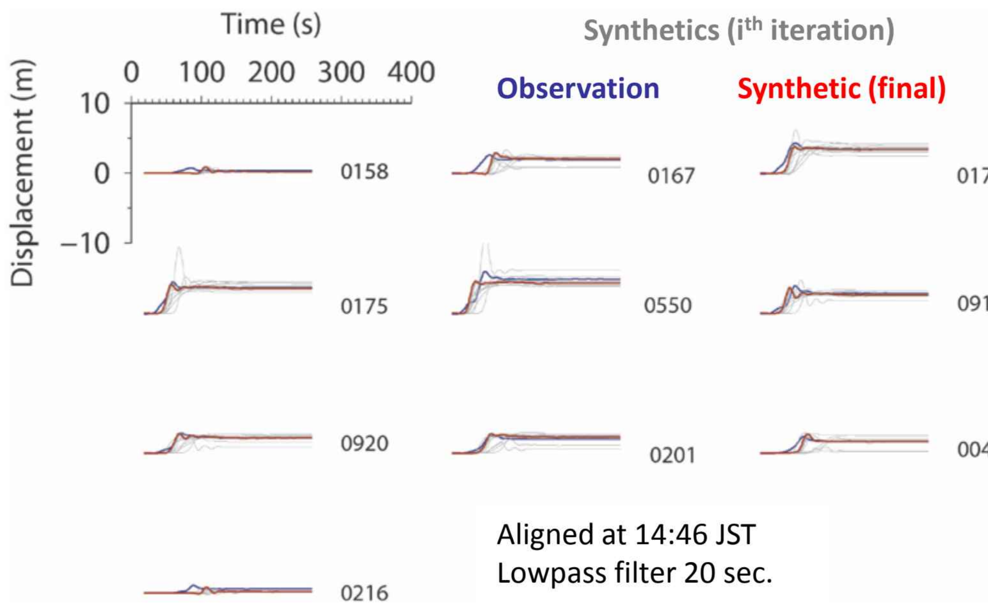
Multi-scale Heterogeneity by Inversion

Parameterisation by patch(es).
Ellipse -> Circle
7 params -> t0, tr, x0, y0, r, vr, U

Nonlinear inversion (GA) for 10 continuous GPS stations.



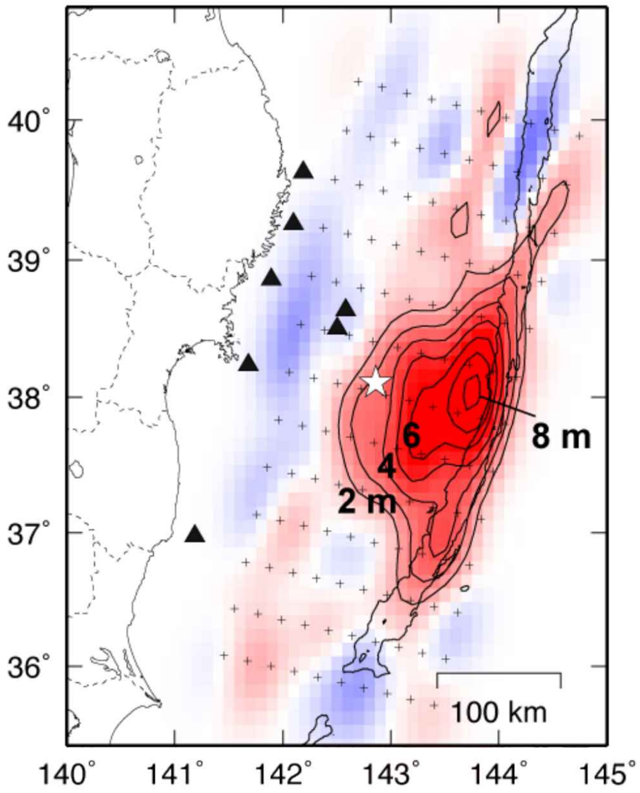


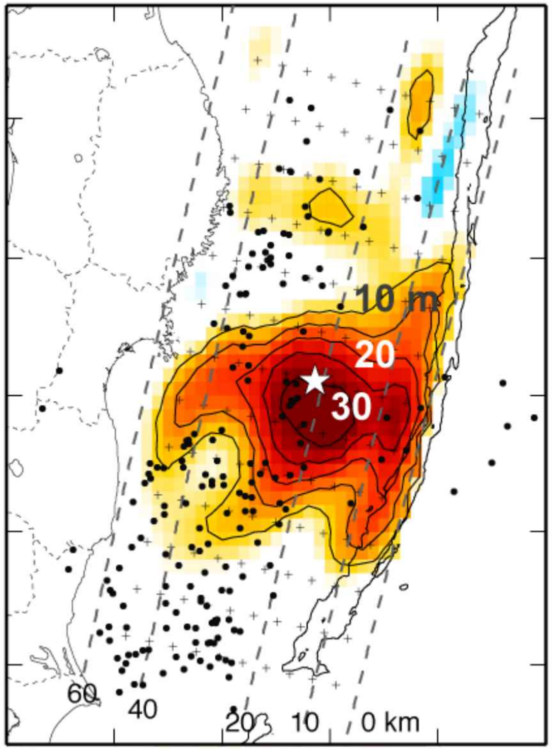


Aligned at 14:46 JST
Lowpass filter 20 sec.

Thomas Ulrich & Hideo Aochi @ BRGM - DYNTOHOKU

Tsunami source of the 2011 Tohoku-Oki Earthquake





Initial tsunami height distribution

the high-water (> 2 m) region with a width of ~ 100 km

\+ the peak with a height more than 8 m locates near the trench

Coseismic Slip

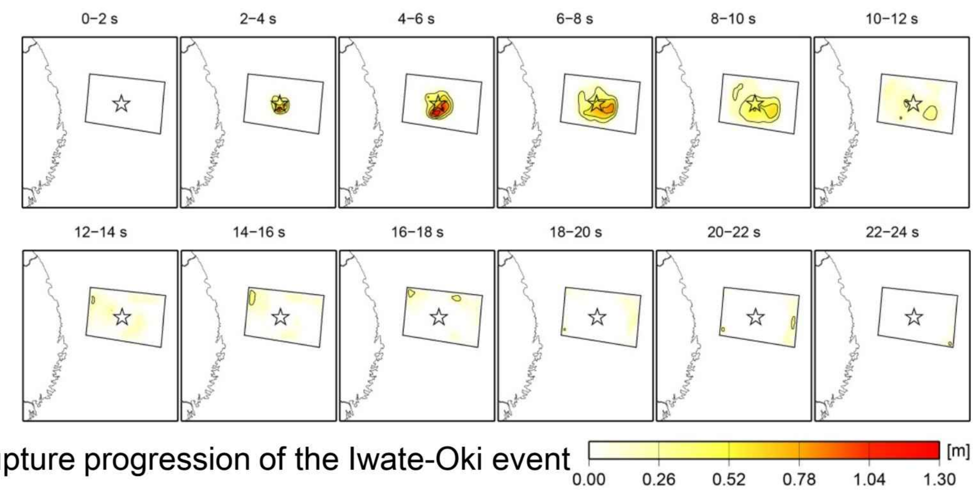
large slip (~30 m) in deep part (~ 20 km)

＋ large slip (~25 m) in shallow part（< 10 km）

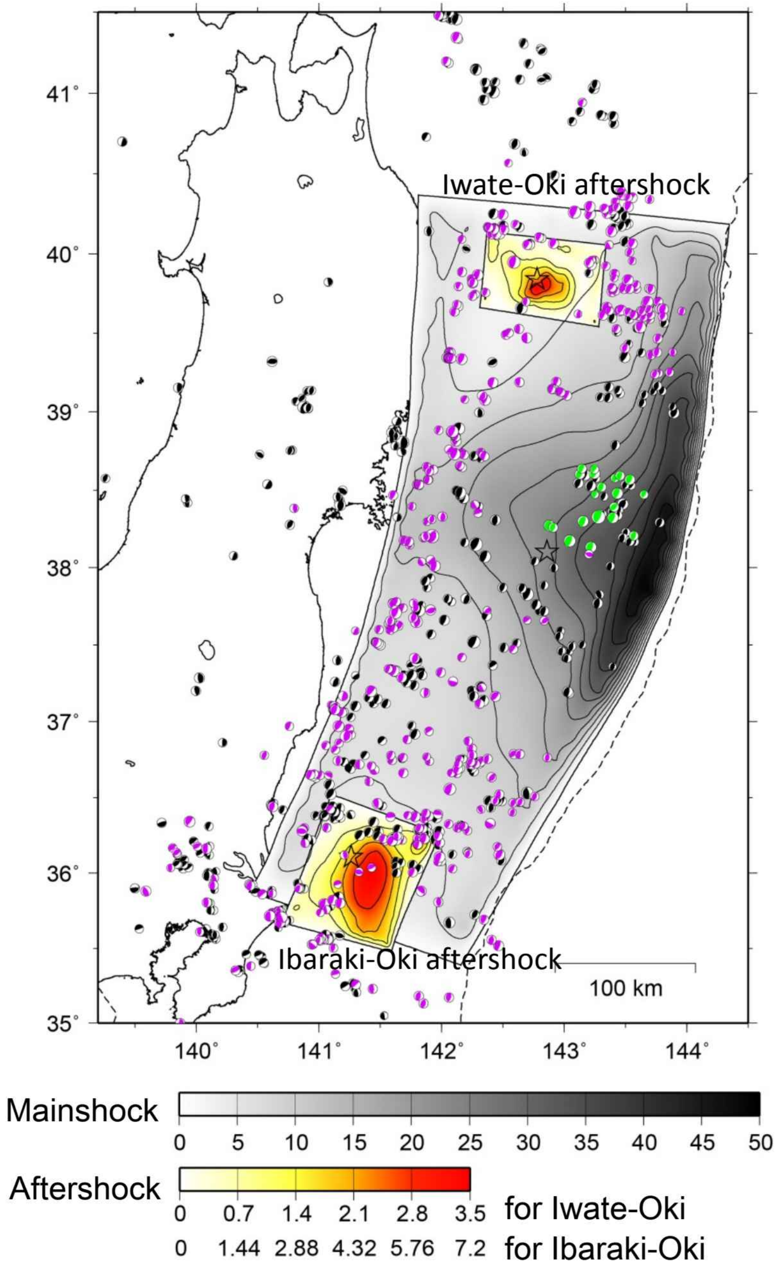
Saito et al. 2011 GRL

Rupture processes of the mainshock and aftershocks

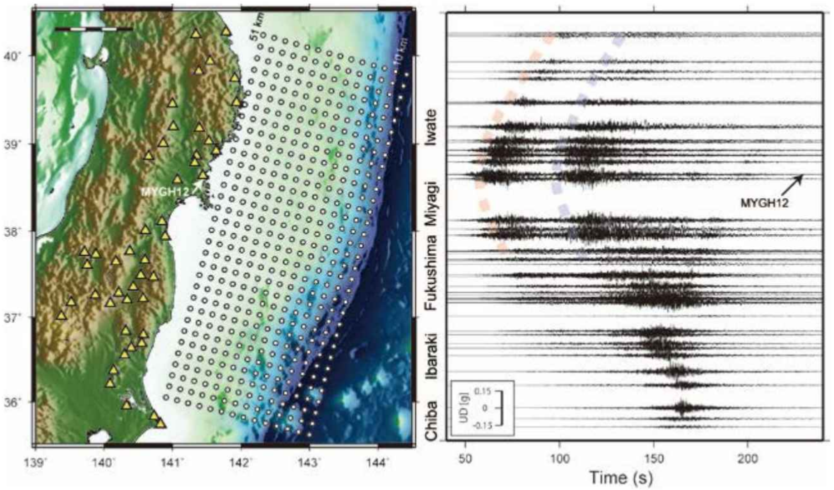
- **□** Iwate-Oki aftershock (22 minutes later)
  - M_0=1.55×10^{20} Nm (Mw7.4)
  - The large slip area seems to have ruptured in the 1960 and 1989 earthquakes (Mw7.3)
- **□** Ibaraki-Oki aftershock (29 minutes later)
  - M_0=9.90×10^{20} Nm (Mw7.9)
  - Several M7-class earthquakes occurred near the rupture area but there is no events whose large slip obviously occurred within the large slip of this event.
- Reverse-fault earthquakes occurred around the large slip areas before (black) and after (purple) the Tohoku-Oki earthquake.
- The rupture progression processes of the two aftershocks are relatively simple.

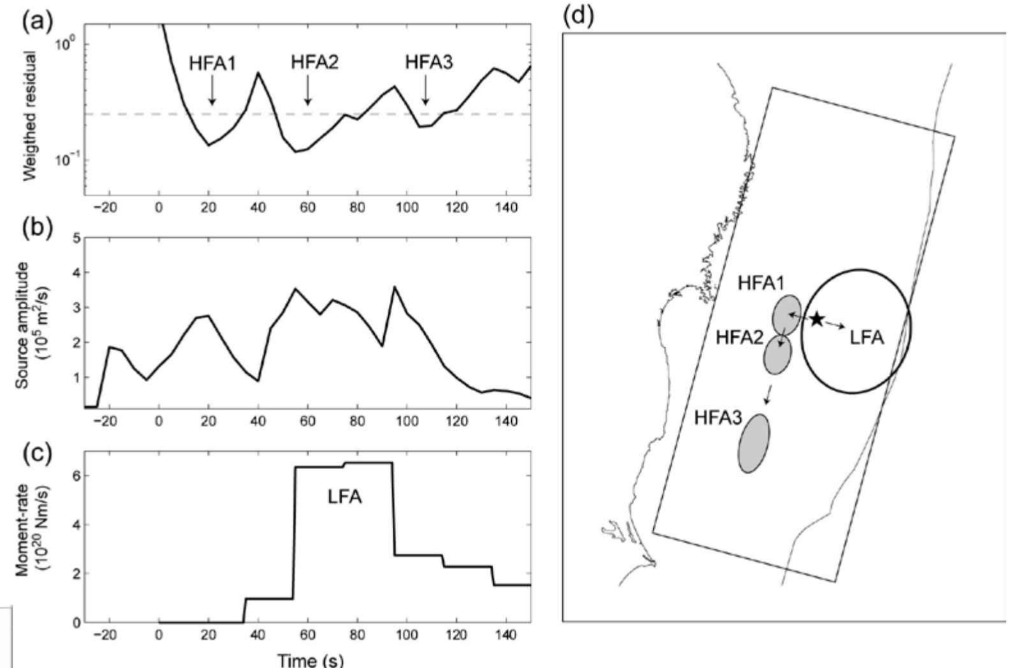


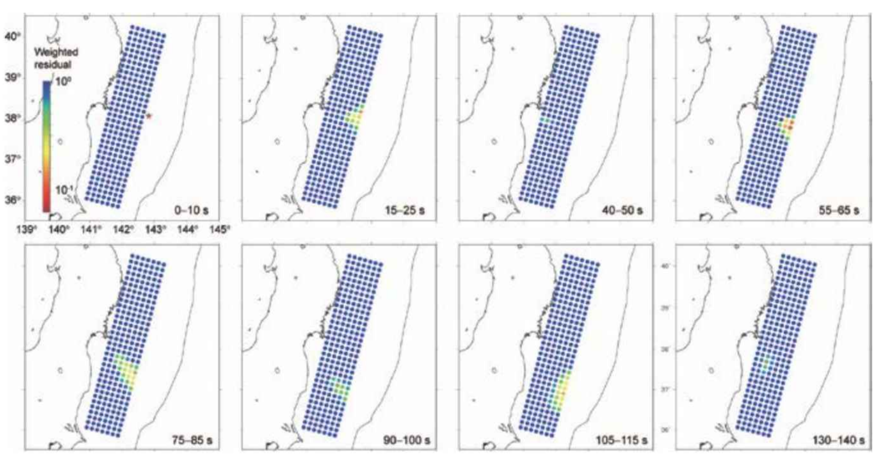
Rupture progression of the Iwate-Oki event



High-frequency source radiation during the 2011 Tohoku-Oki earthquake





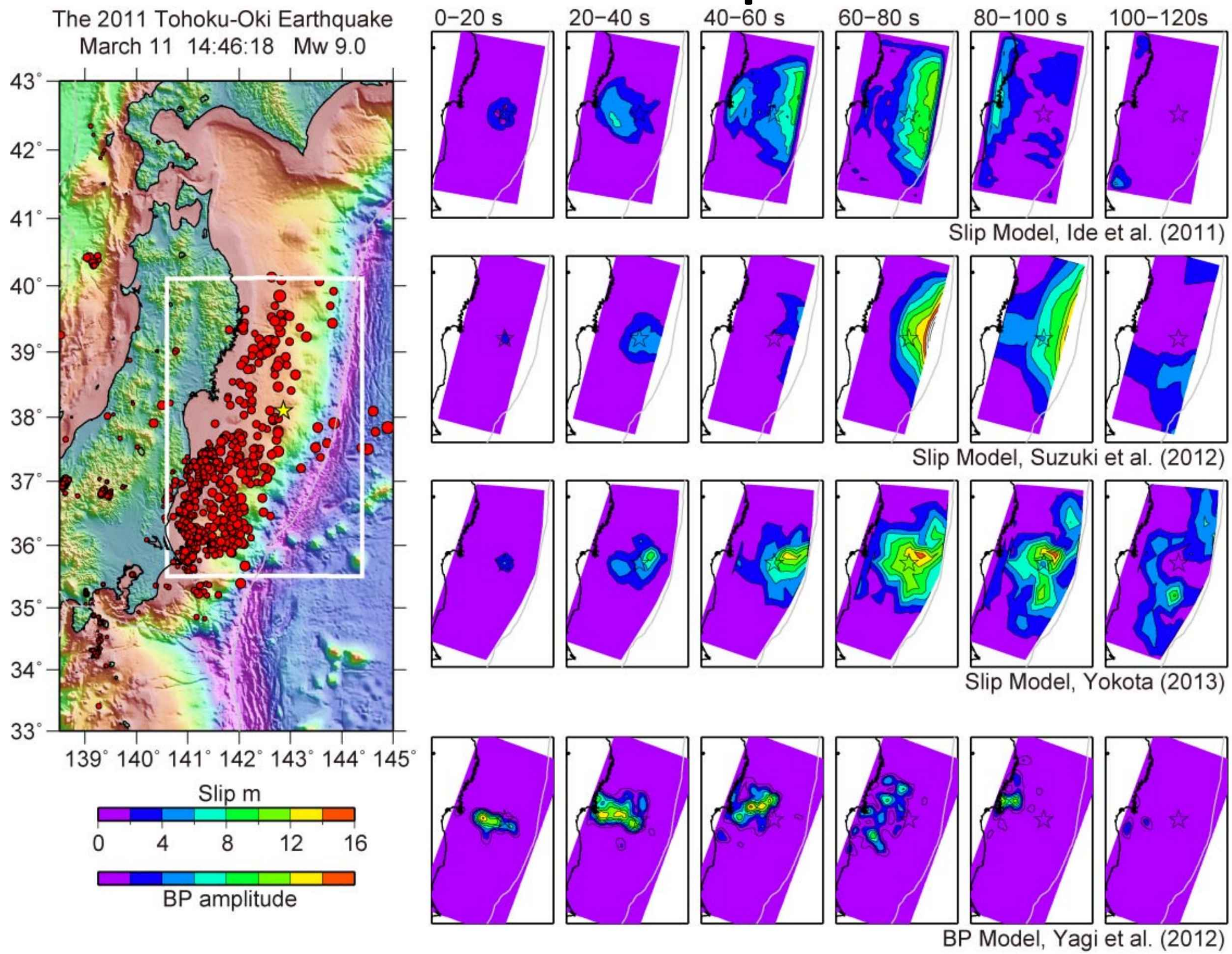


The amplitude source location (ASL) method using high-frequency amplitudes of KiK-net strong motion seismograms revealed three high-frequency sub-events.

Kumagai et al. (JGR, 2013)

Variations in Slip Models

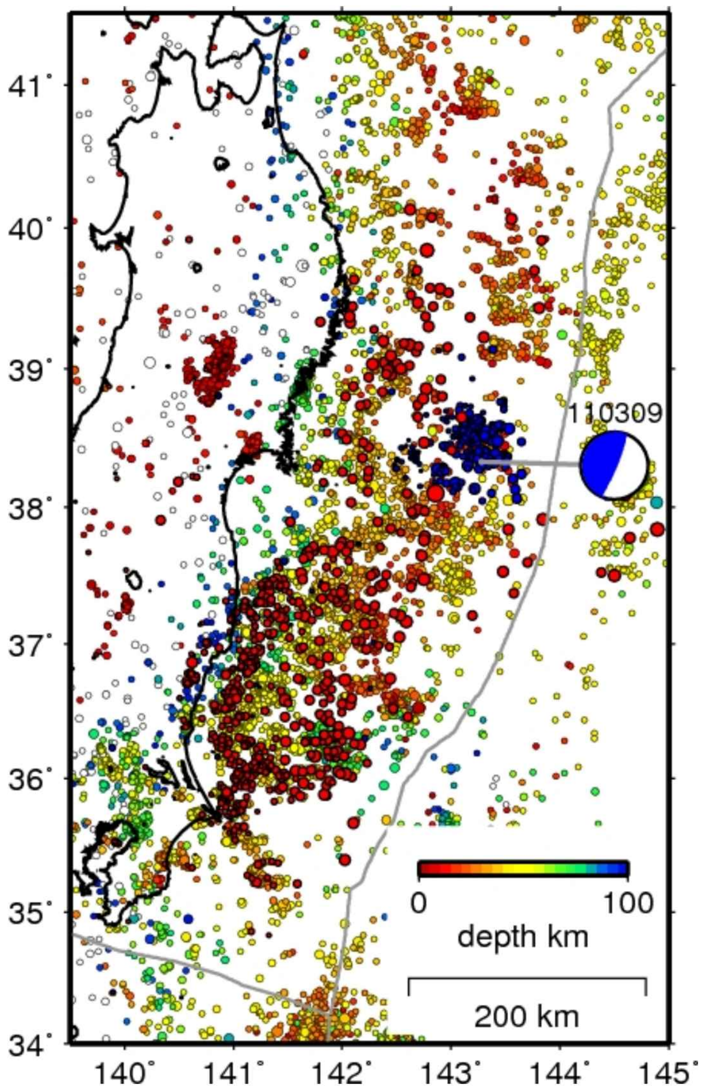
Ide (TOG, 2013)

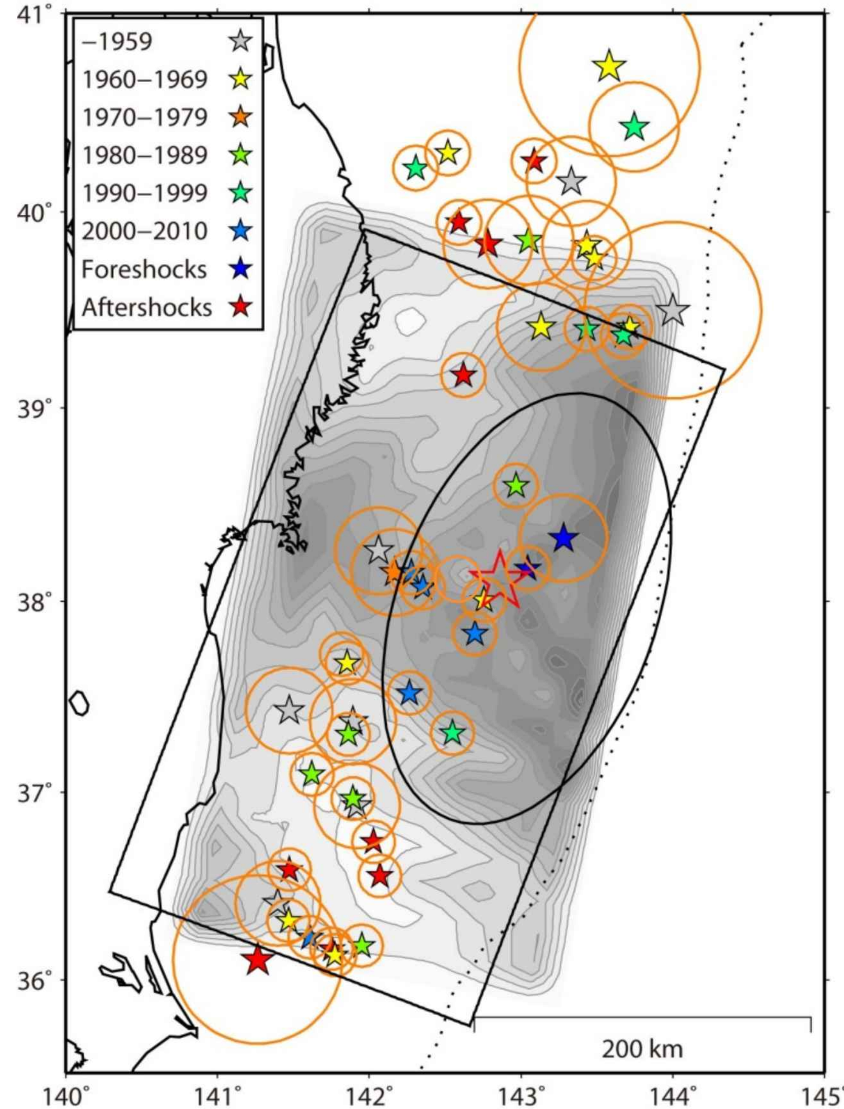


Modeling the rupture process

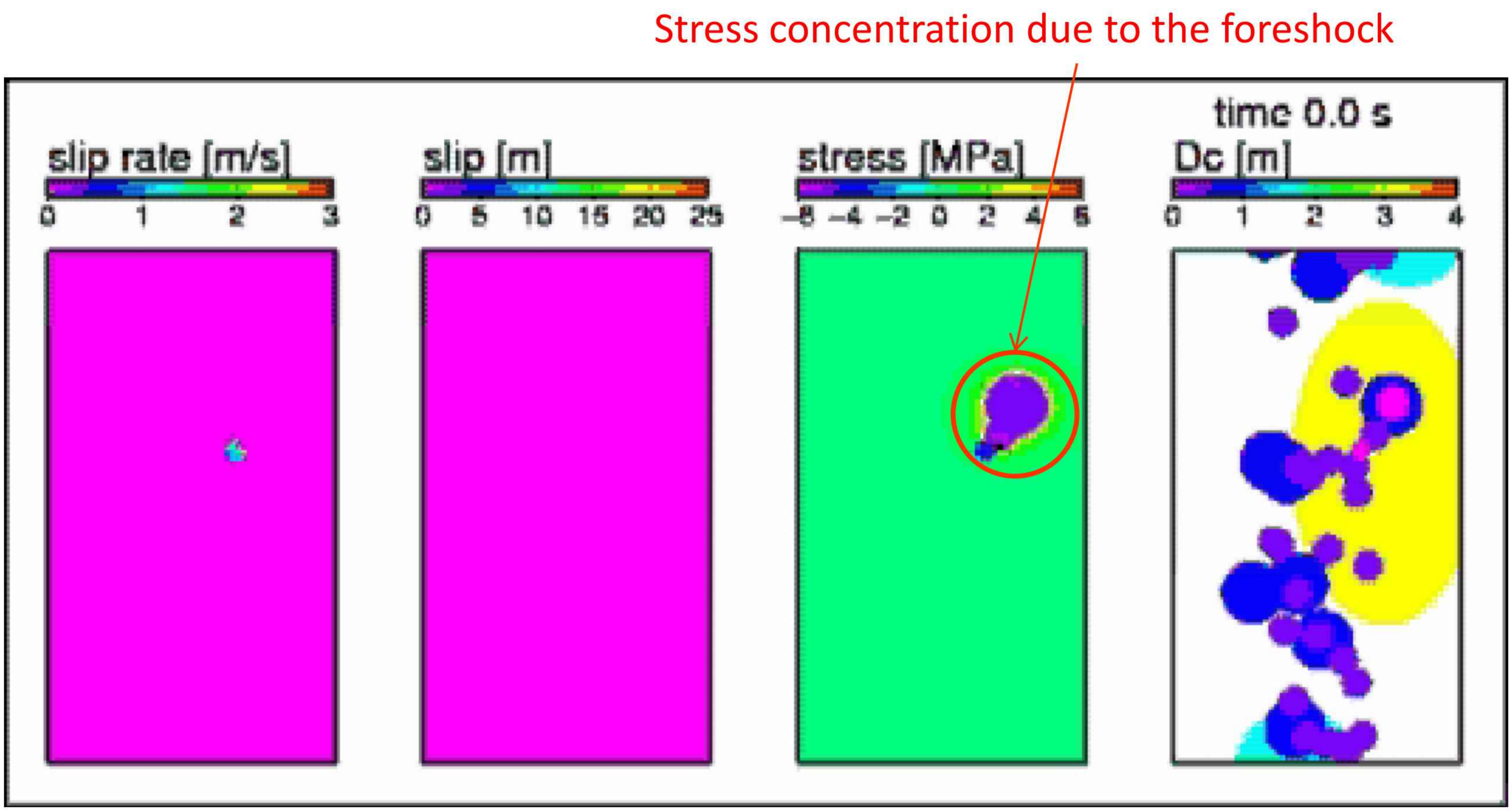
- Generally consistent results with previous ones
  - GPS & Tsunami suggest a very large slip near the trench axis
  - Seismograms require at least three high-frequency sources
  - Switch-back like rupture propagation between shallow and deep regions
- Significant difference of timing among models
  - Due to the bias of reference location and time

Hypocenters → Segments





Dynamic rupture process

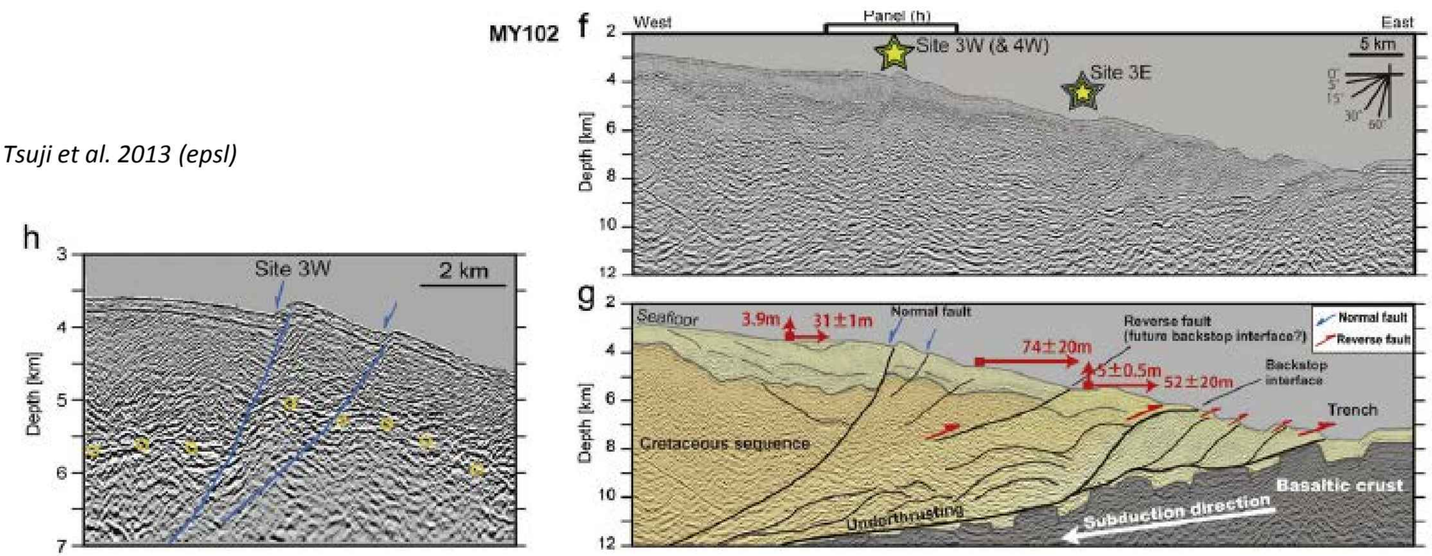


Dynamic Rupture modeling of Tohoku Eq. :

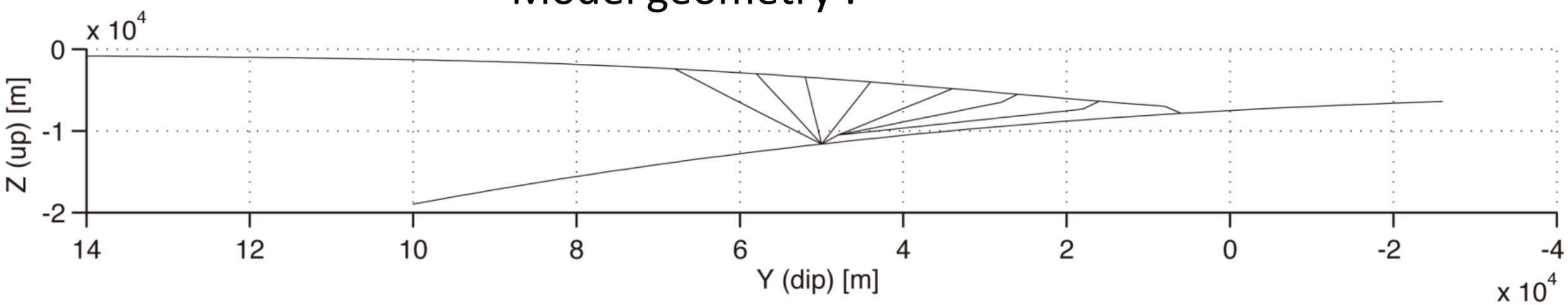
Questions :

- splay faults broken coseismically ?
- which geometry : normal fault or reverse fault ? -> several test cases
- consequences on surface deformation, stress state...

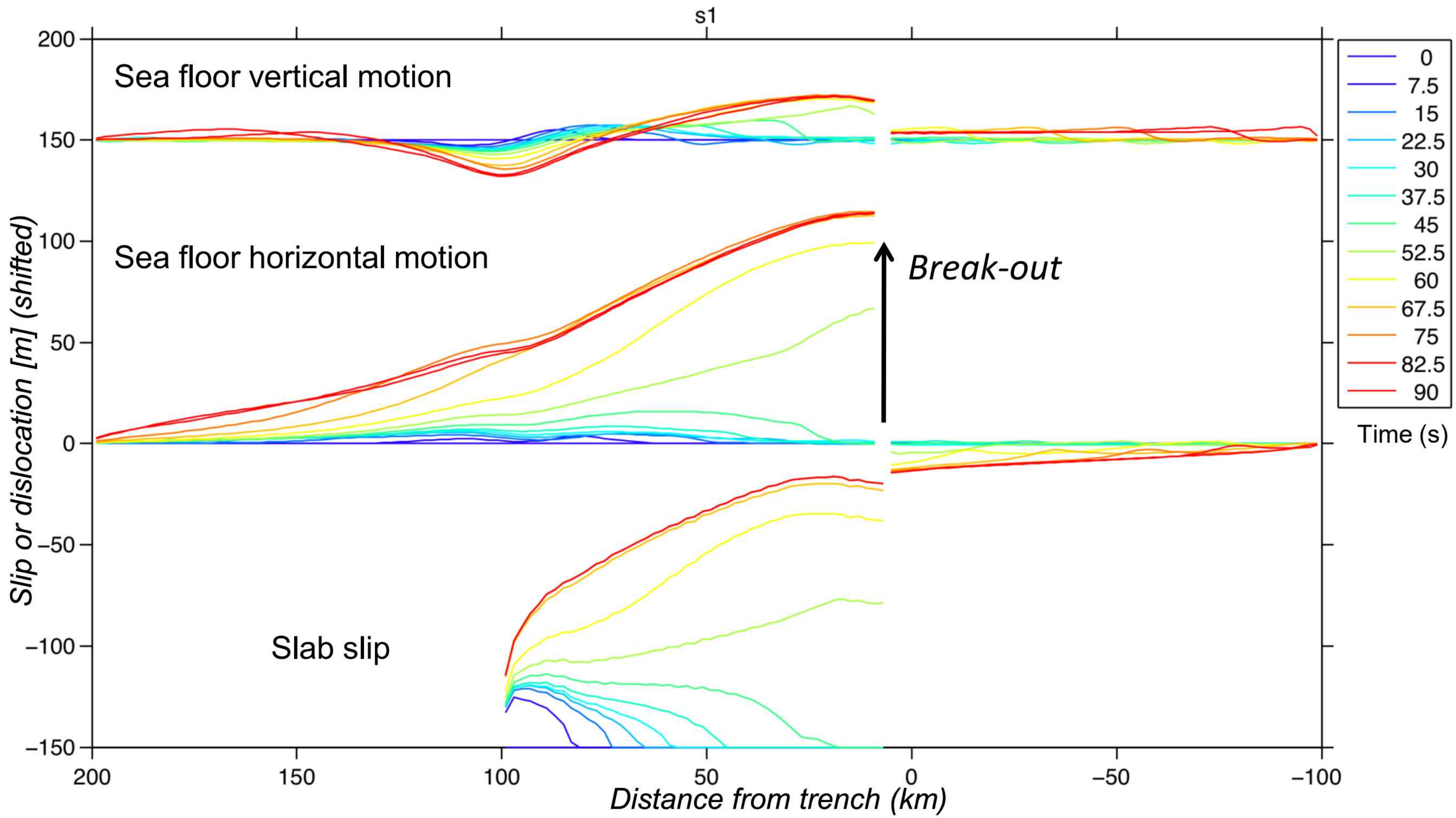
Tsuji et al. 2013 (epsl)



Model geometry :

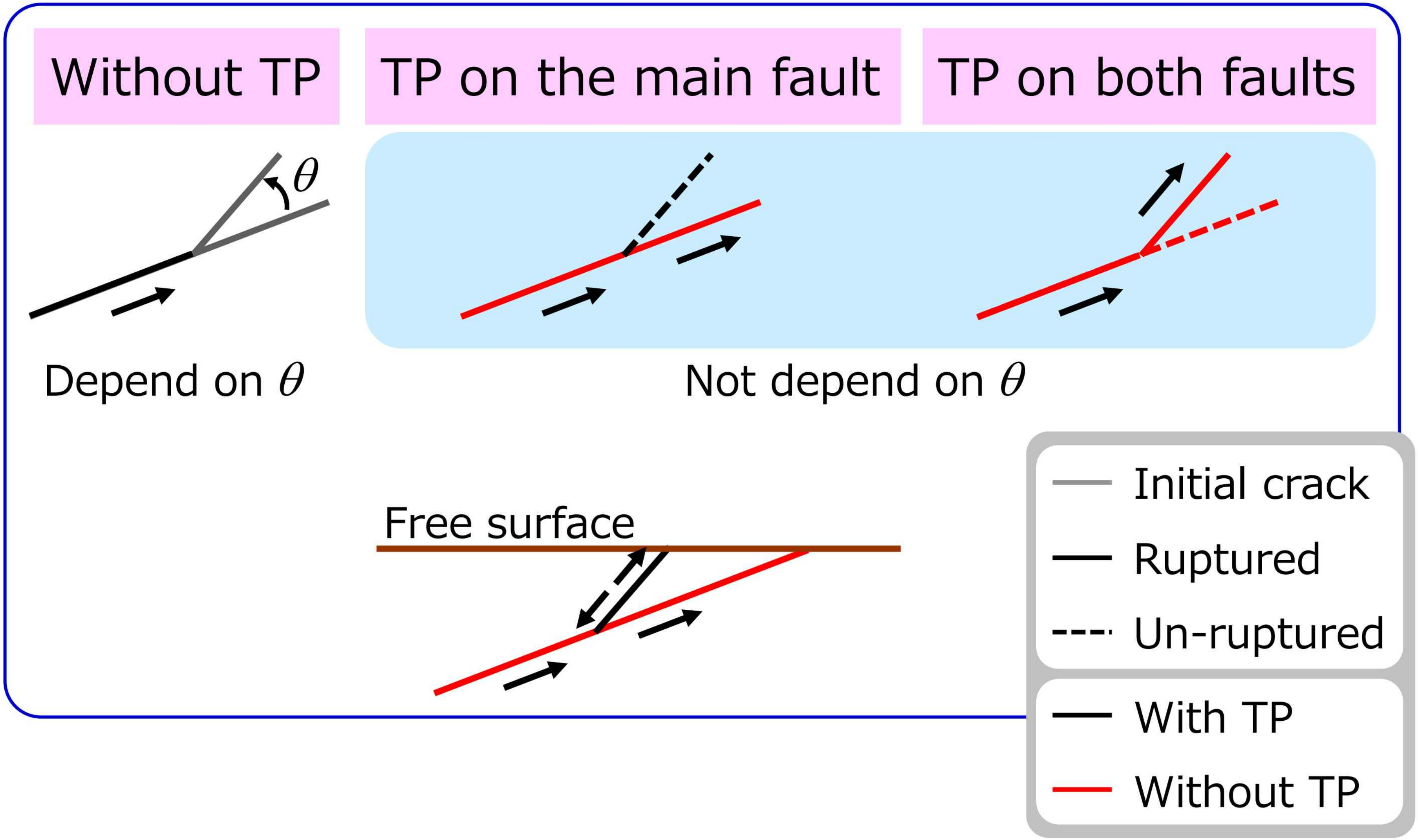


Dynamic Rupture computation :

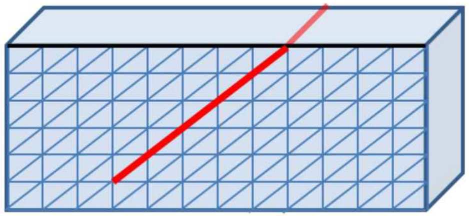


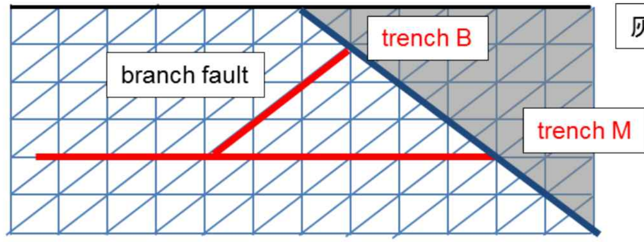
Strong break-out effect is responsible for large slip and large motion, and extensional stress build-up on all secondary faults at shallow depth

Dynamic fault branching with thermal pressurization (TP)



Branching fault , free surface, and plastic deformation in 3D



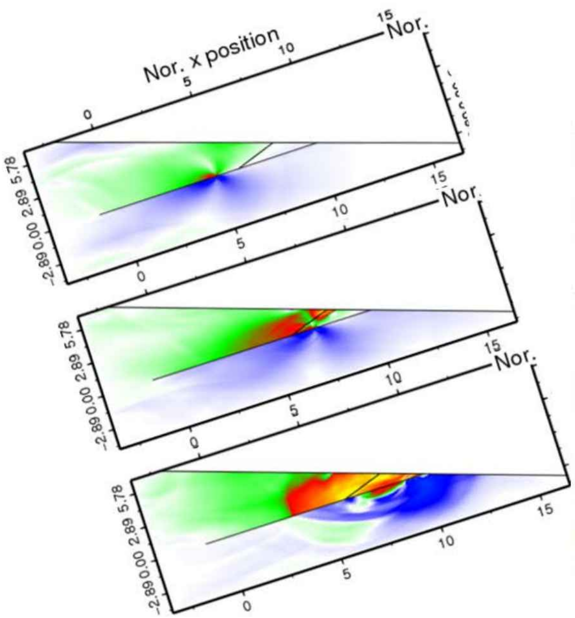


灰色部分 = 計算しない

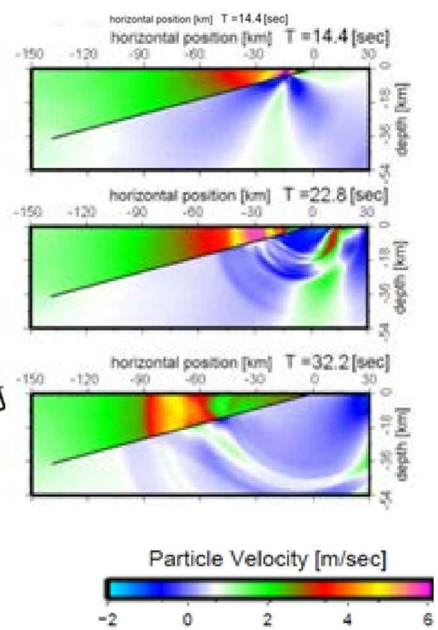
Using 3D wedge elements, we model the plate interface and a branching fault
We also assume slip-wekaning law

・The rupture of branching fault make very large deformation

With a branch fault

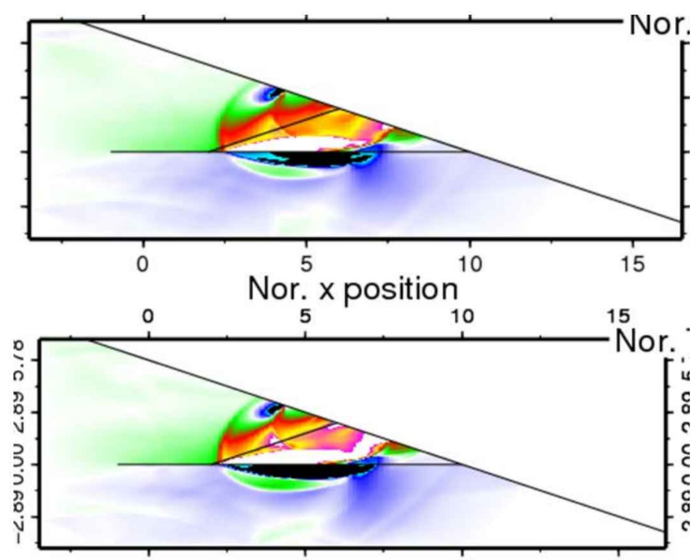


Without a branching fault



・Plastic deformation（Drucker-Prager）reduce total deformation near the trench

With plastic deformation



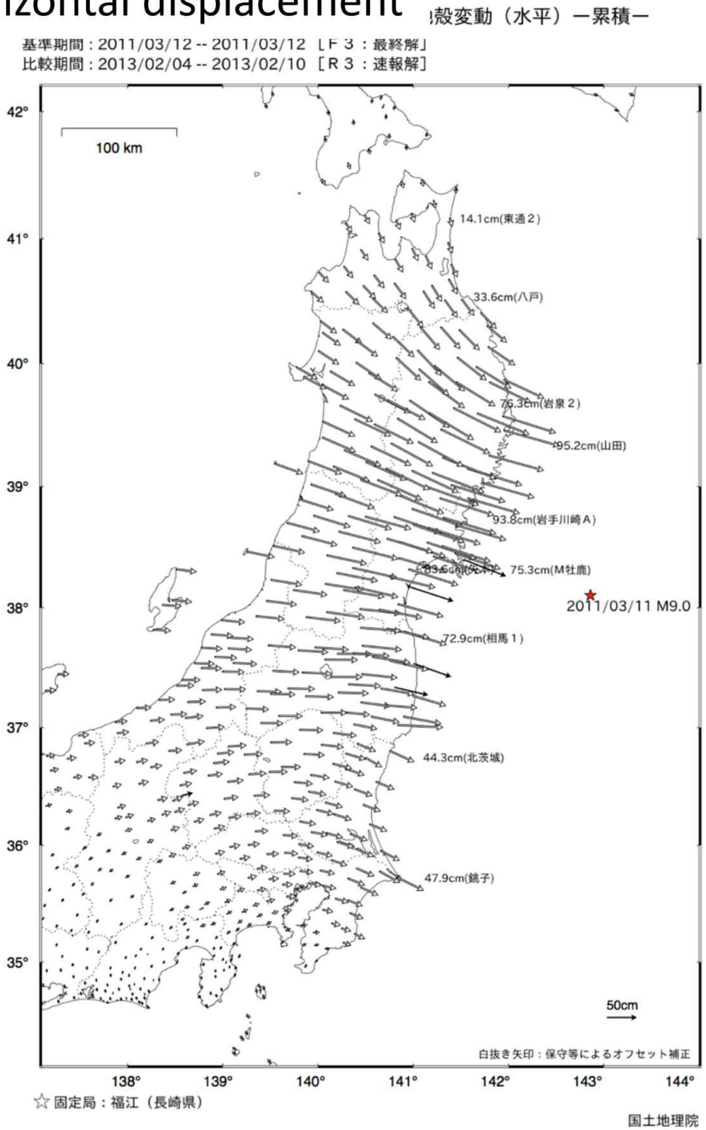
Without plastic deformation

Fracture dynamics of shallow plate interface

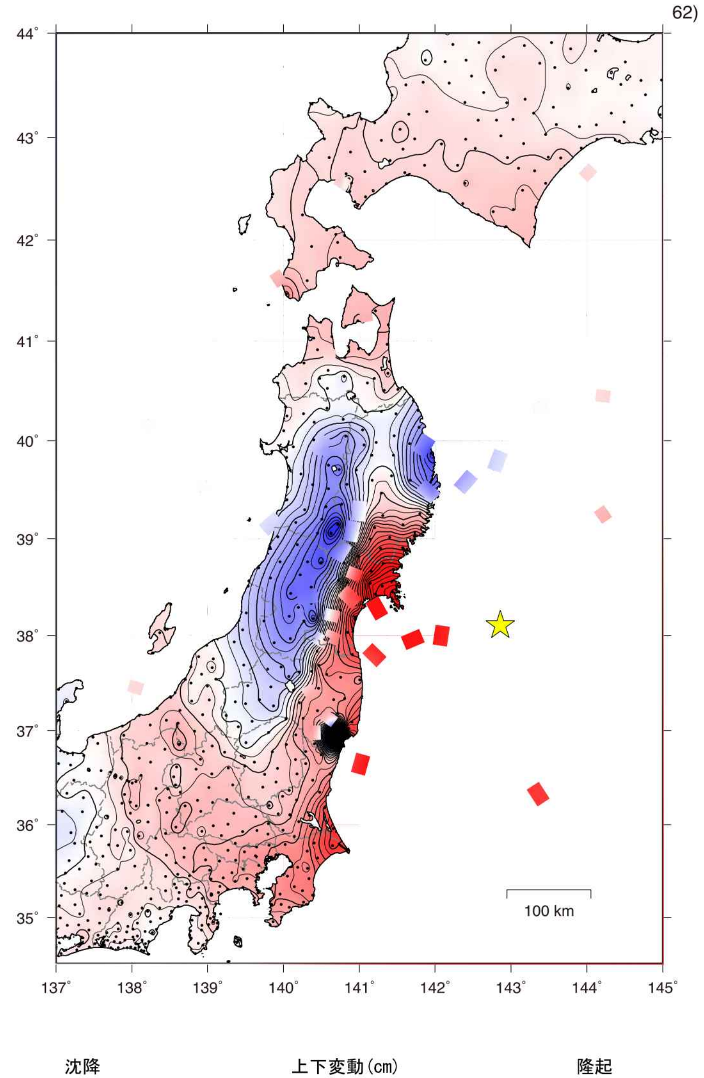
- Multiscale patch model
  - Explains switch-back rupture process
  - Constructed based on seismicity catalog
- Dynamic rupture model with more realistic conditions
  - 3D, Free surface, branching faults, thermal pressurization, inelastic deformation
  - Downward rupture propagation (switch-back process)
  - TP control on fault branching

Postseismic deformation for 2 years

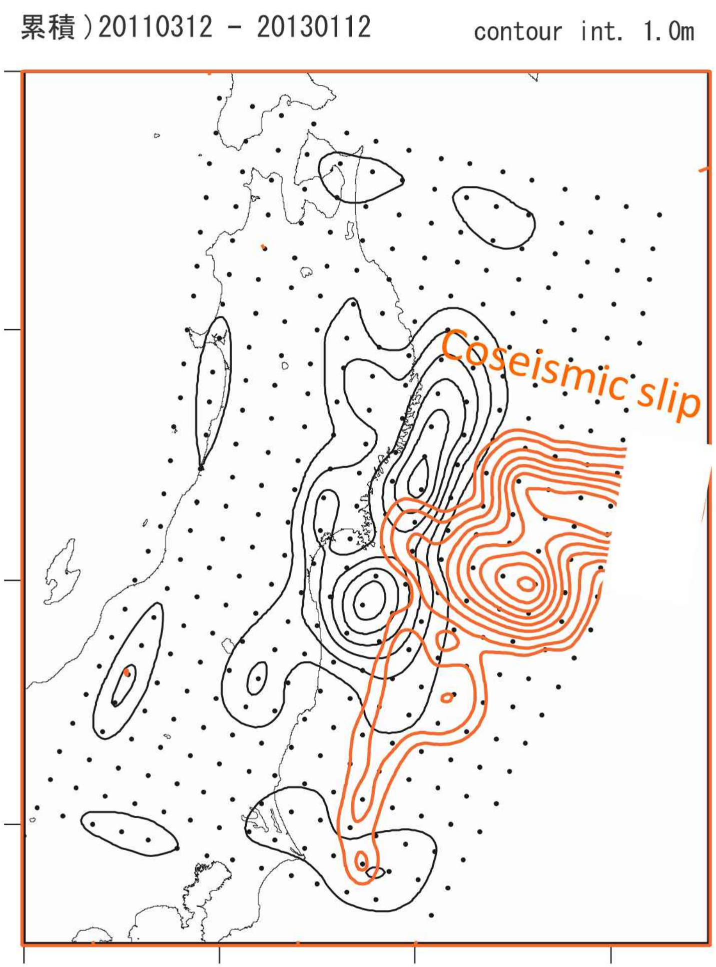
Horizontal displacement



Vertical displacement

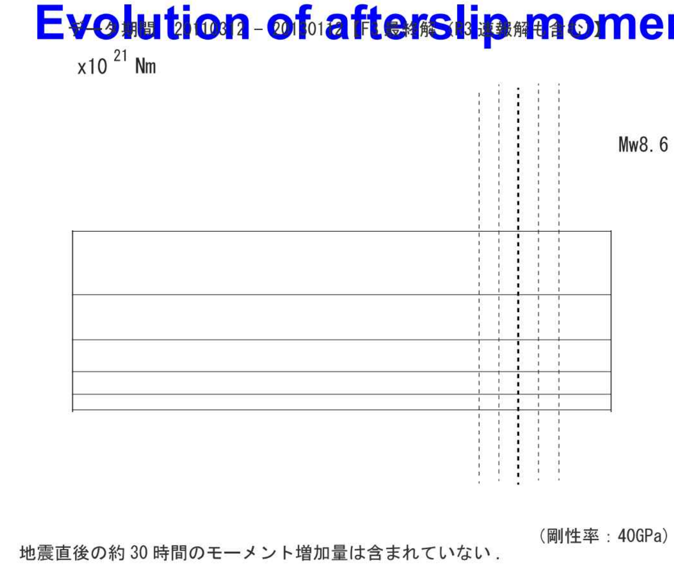


Afterslip distribution for 2 years



- We assume afterslip solely cause the postseismic deformation.
- Daily GPS coordinates are inverted to estimate spatio-temporal evolution of afterslip.
- Characteristics of estimated afterslip distribution
  - Slip along the Pacific coast up to 6 m
  - Little overlapping coseismic slip
  - Propagation and movement of afterslip area is not significant.

Evolution of afterslip moment



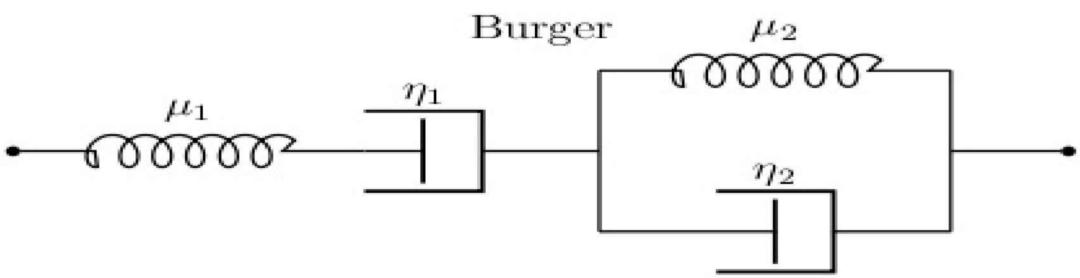
(Ozawa et al., 2012 and update)

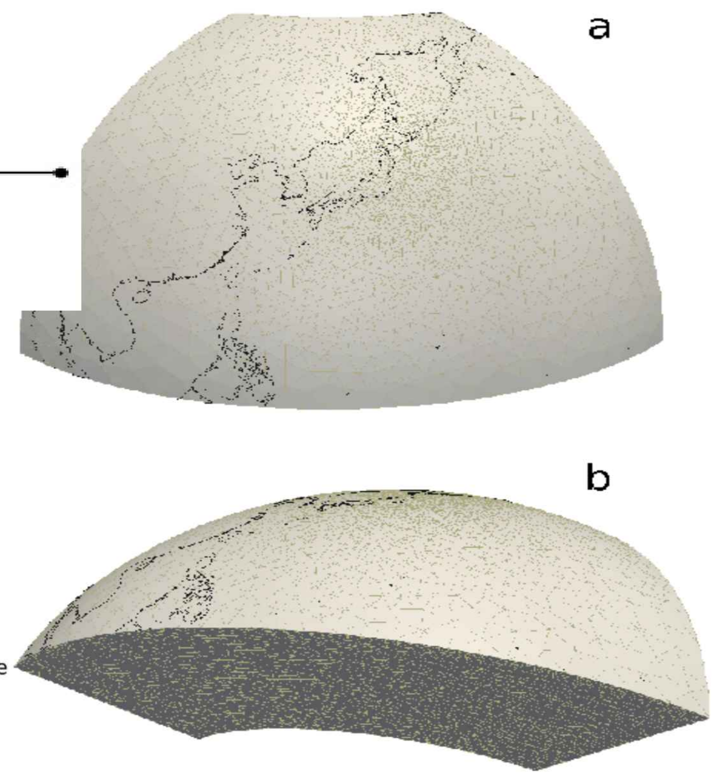
A finite element model to model deformation

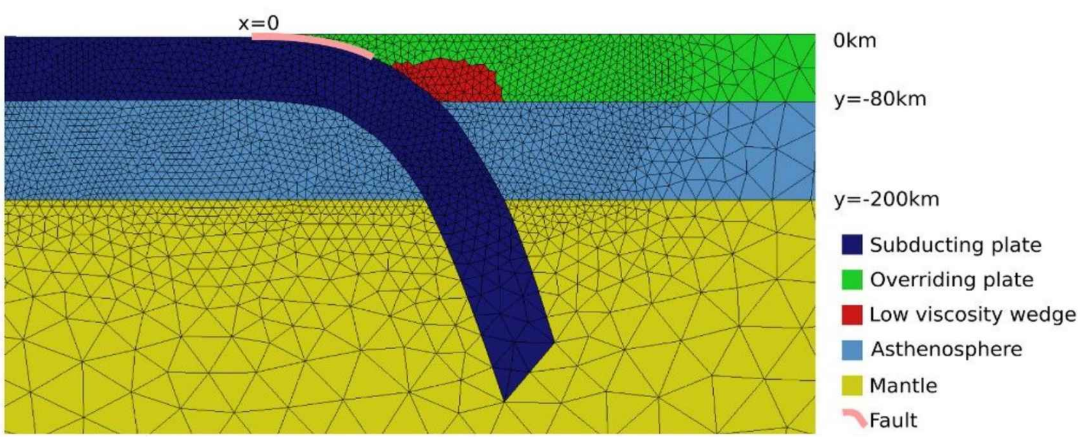
The 3D mesh includes an elastic slab. Viscoelastic relaxation occurs in a low viscosity layer from 80 and 200km depth.
The viscoelastic rheology is of Burger type with transient viscosity of 2. 10^{18} Pas

We consider a portion of spherical shell from the core-mantle boundary to the

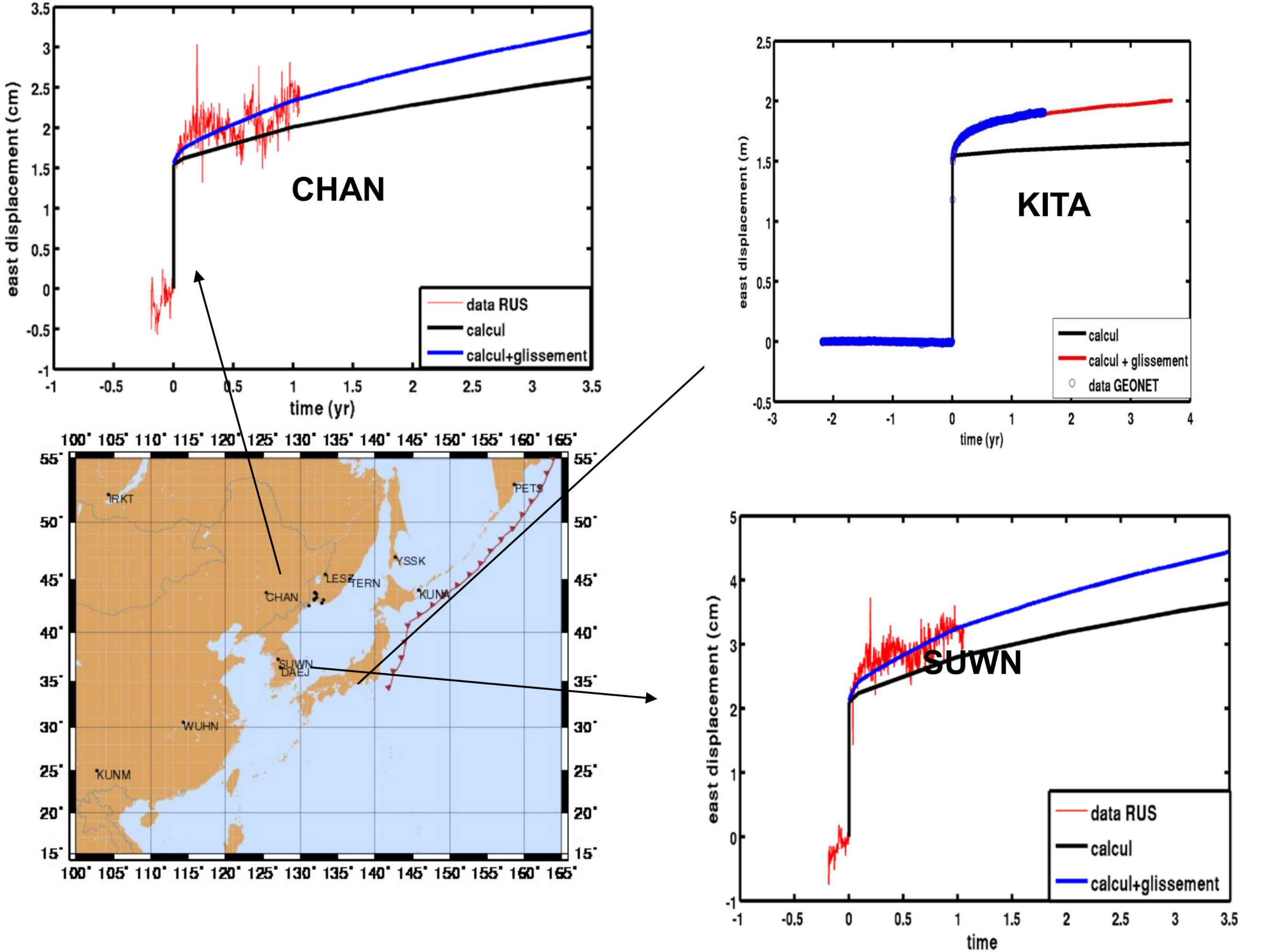
Earth's surface, ■







Preliminary fit for some near-field and far-field stations



Long-term deformation

- Large & long postseismic deformation
  - More than Mw 8.6, and still increasing
  - Afterslip near the bottom edge of coseismic slip region
- Deformation in wide area
  - In Korea and eastern China
  - Viscous deformation in asthenosphere is important