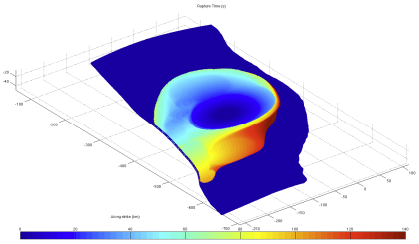
A Conceptual Model for the Mw9.0 2011 Tohoku Earthquake



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Swiss Seismological Service (SED), ETH-Zurich

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QUantitative estimation of Earth's seismic sources and STructure

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- SPECFEM3D developers (Komatitsch et al, 2004; Komatitsch and Tromp, 1999; Komatitsch and Vilotte,1998)
- Geoff Ely, for providing the Support Operator Rupture Dynamics Code (SORD)
- Swiss National Supercomputing Center (CSCS)

Introduction

- The 2011 Mw 9.0 Tohoku earthquake, that induced large tsunami at the east cost of the main island of Japan causing severe damage in cities,
- Kinematic source models inverted from seismological, geodetic and tsunami observations, including source images from back-projection, indicate that the earthquake featured complex rupture patterns, with multiple rupture fronts and rupture styles.
- The compilation of these studies reveals fundamentally three main feature:

  -1) Spectacular slip, larger than 50m,

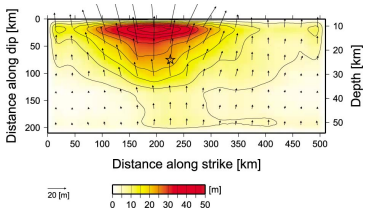
  -2) The possibility of the existence of slip reactivation

  -3) Distinct regions of low and high frequency radiation

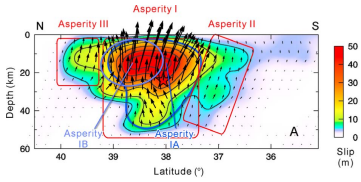
Some kinematic slip models

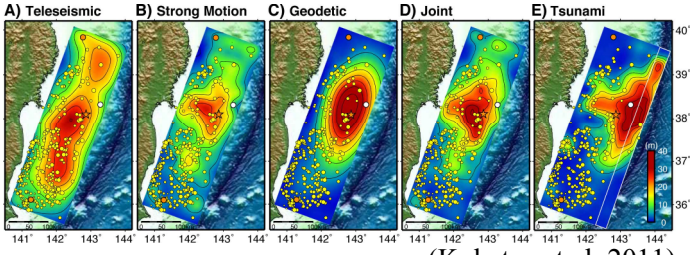
(Spectacular slip, larger than 50m)

(Suzuki et al, 2011)



(Lee et al, 2011)

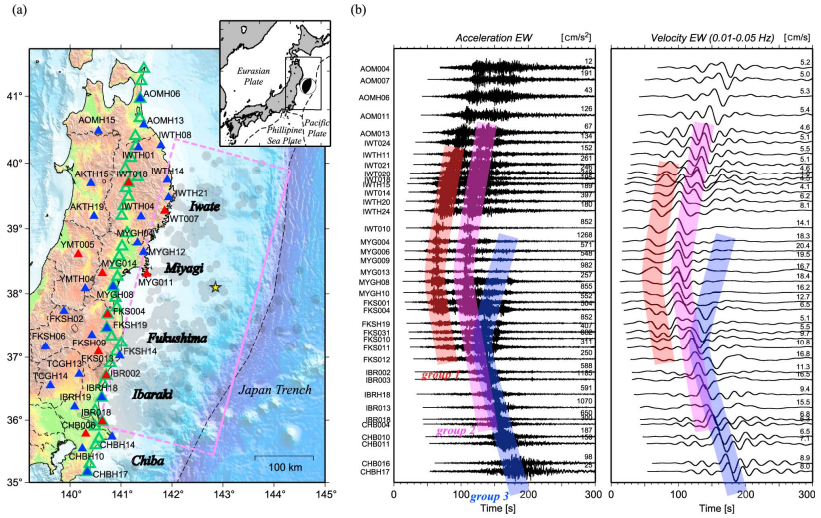




(Koketsu et al, 2011)

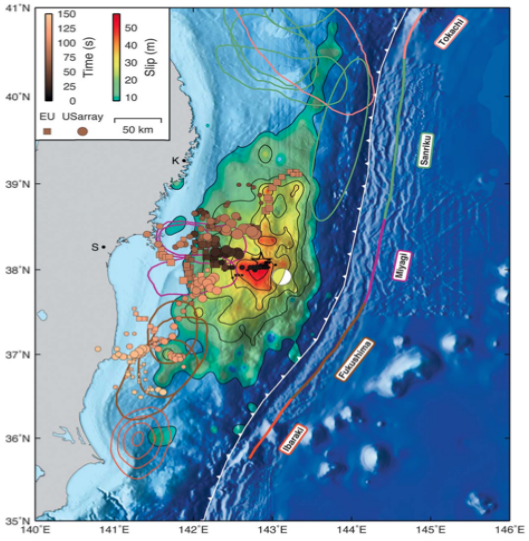
Observed strong ground motion pattern

It suggest multi rupture patterns (with possible slip reactivation, e.g. Lee et al, 2011)



(After Suziki et al,2011, GRL)

Kinematic source models (e.g. Suzuki et al, 2011, Koketzu, et al 2011,) inverted from seismological, geodetic and tsunami observations, including source images from back-projection (e.g. Cheng et al, 2011, Roten et al, 2012) indicates distinct regions of low and high frequency radiation: the regions of large slip in the shallower part of the fault dominates the low frequency radiation and the bottom part dominates the high frequency radiation.



(Simons et al, 2011, Science)

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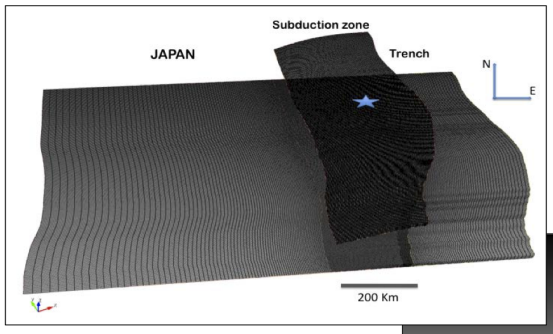
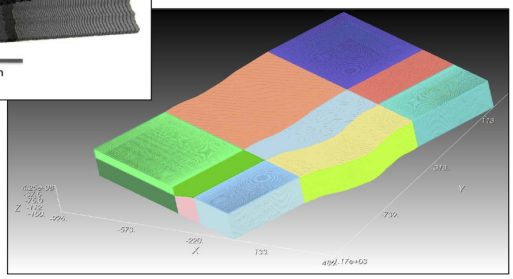
Spectral element mesh for a dynamic simulation of the 2011 Tohoku earthquake



View of the fault mesh and bottom surface mesh

Global view of the mesh generated with CUBIT



Density (kg/m^3)	V_s (m/s)	V_p (m/s)
2700	3420	5800

Dt (s)	Average grid size. "H" (m)	Poly order (NGLL)	TOTAL CPU TIME (h)	Number of Processors
0.007	800	5	1024	128

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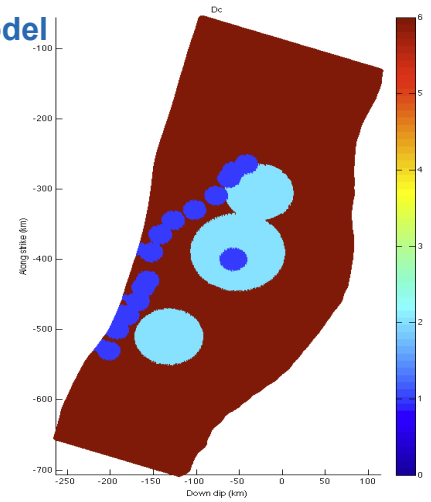
Asperity model



Normal stress (σ Mpa)	Static friction coefficient (μ_s)	Dynamic Friction coefficient (μ_p)
100	0.6	0.3

	Asperity (blue)	Asperity (light blue)	Back ground (Red)
Shear Stress (Mpa)	45.5 Mpa.	36.0 Mpa.	30.5 Mpa
D c	1	2	6

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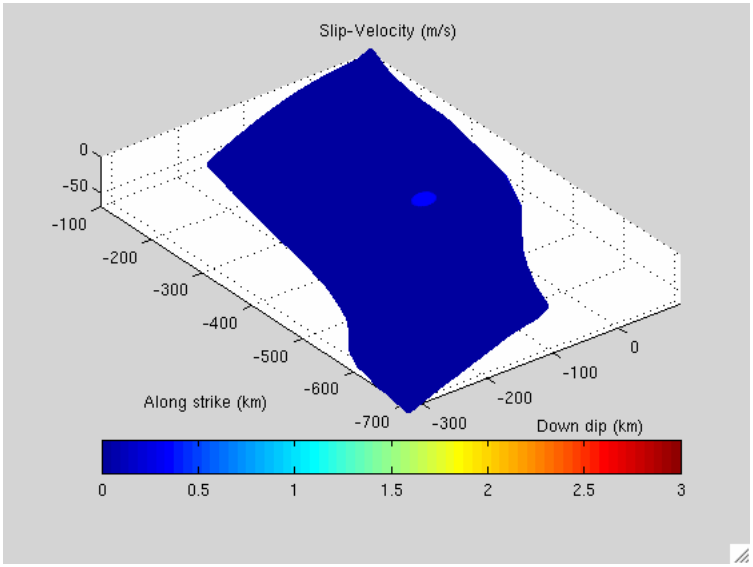
Movie of Slip rate (Model 2)



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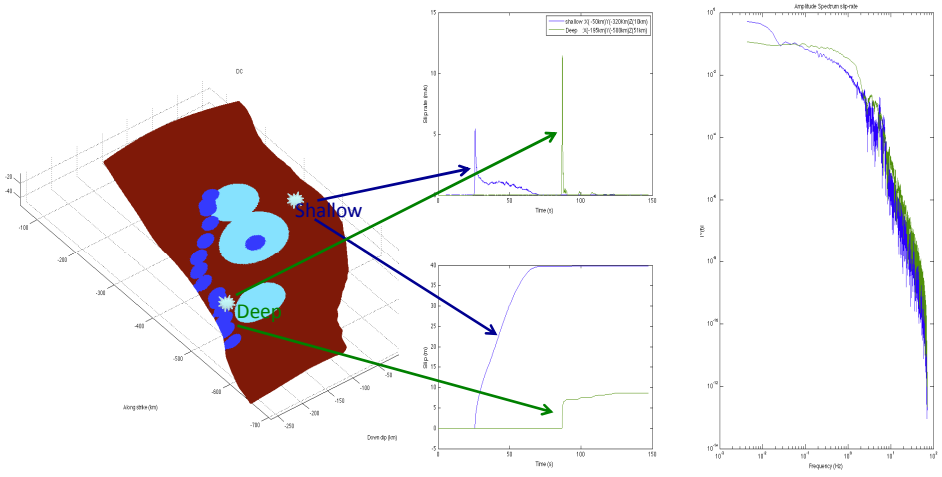
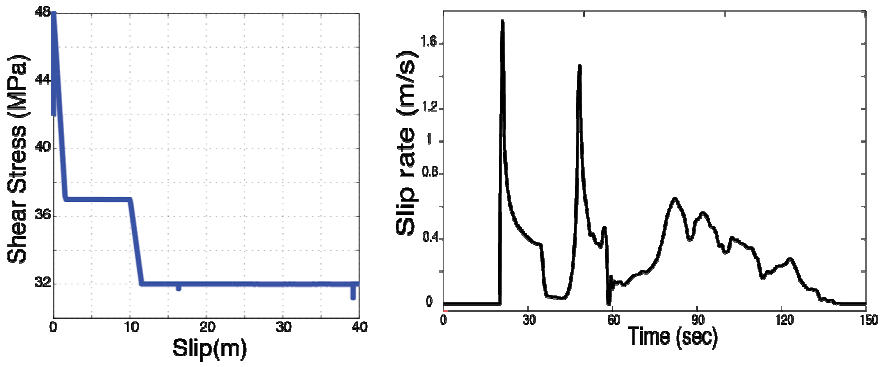
Slip and slip rate at shallow and deep



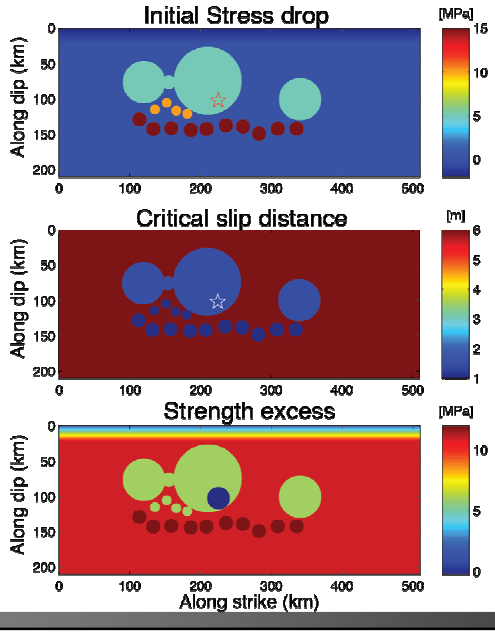
We model large slip in the shallow zone and the distinct regions of low and high frequency radiation, but what about slip reactivation?

A model for Slip Reactivation

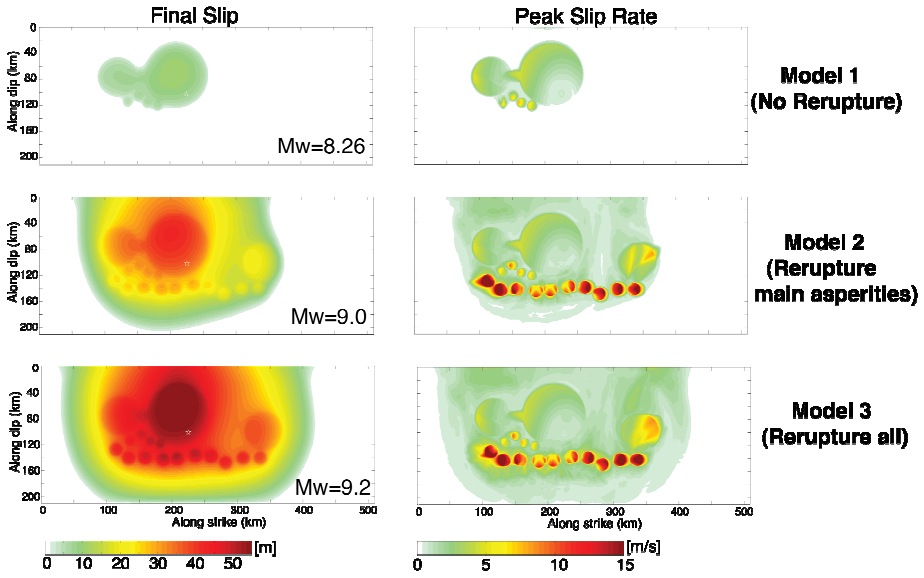


- Earthquakes with extremely high slip can result from fault melting, pressurization, lubrication or other thermal weakening mechanisms that reduces further the frictional strength to lower levels (e.g. Rice, 1996; Kanamori and Heaton, 2000)
- Kanamori and Heaton (2000) proposed a friction model in which frictional strength drops initially to certain value, but then at large slips there is a second drop in frictional strength.

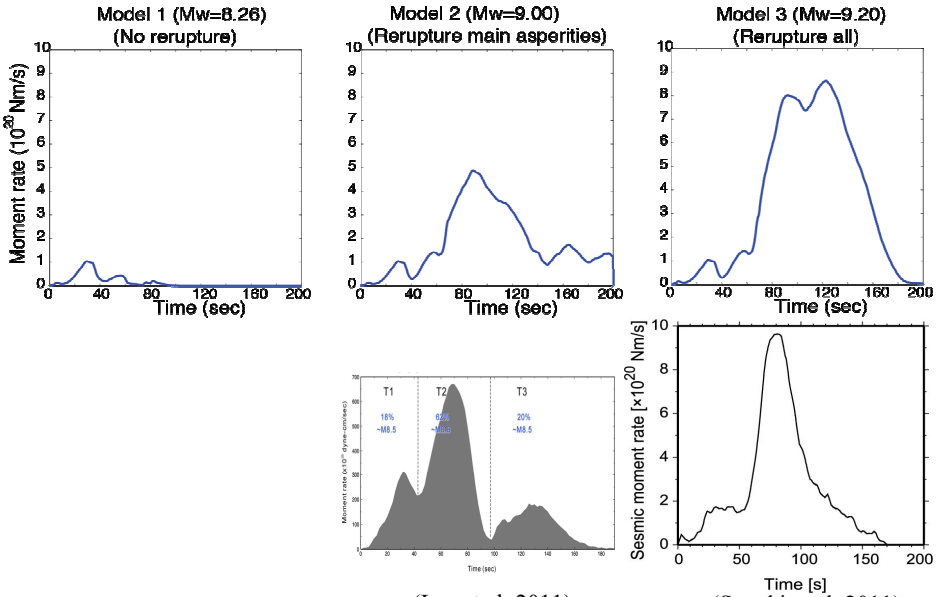
A test in a dipping planar fault, using SORD code)



Numerical solution of three rupture models



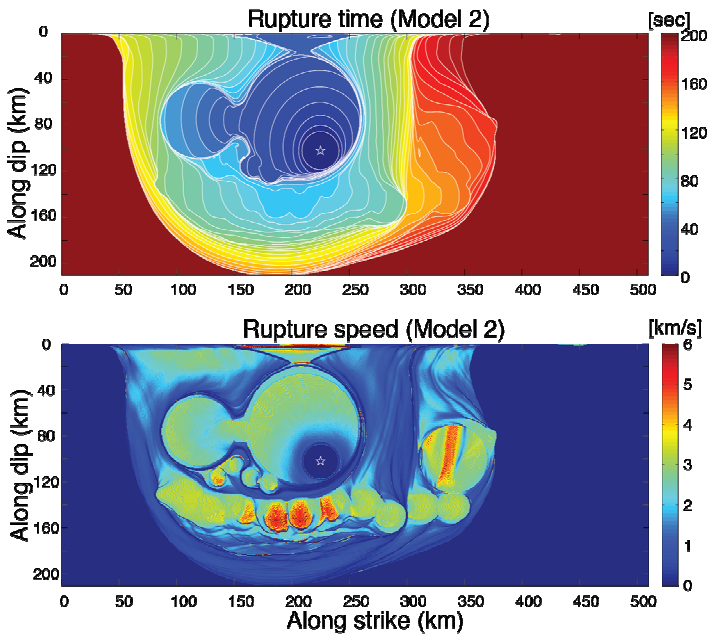
Moment rate



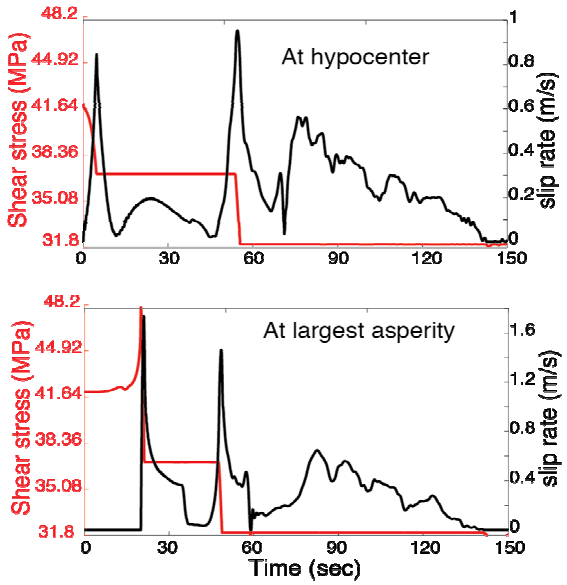
(Lee et al, 2011)

(Suzuki et al, 2011)

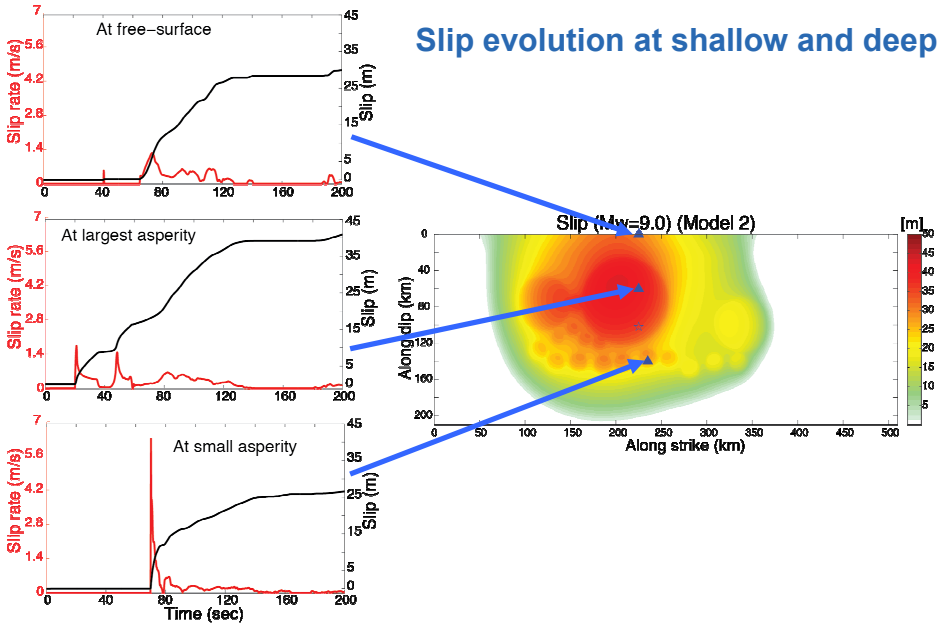
Movie of Slip rate (Model 2)



Stress and slip rate evolution with time



Slip evolution at shallow and deep



Conclusions

- With the slip weakening friction model that accounts for slip reactivation we reproduce the main features of the 2011 Tohoku earthquake
- After around 40 sec of rupture initiation, the second drop of the frictional strength in the main asperity produces strong slip reactivation capable to break the free-surface with high slip.
- This slip reactivation also excites the small asperity patches producing burst of high frequency radiation, which in turn produces a third rupture of an asperity propagating southward.
- Within the framework of our frictional model, the slip reactivation plays a fundamental role to produce multi type of ruptures, to break the free-surface and to reach a magnitude Mw9.0 or larger. Without this ingredient, the earthquake is inhibited to a magnitude Mw8.2.

Future work

- Evaluate ground motion
- Investigate the role of realistic geometrical complexity of the thrust fault (work in progress)