A Dynamic Rupture Model with Slip Reactivation for the 2011 Mw9.0 Tohoku Earthquake

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ECGS Workshop 2012 "Earthquake Source Physics on Various Scales"

Luxembourg, October 3-5, 2012

Acknowledgement

- Jean-Paul Ampuero (California Institute of Technology, USA)
- Swiss National Supercomputing Center (CSCS)
- Geoff Ely, for providing the Support Operator Rupture Dynamics Code (SORD)

Introduction

- The 2011 Mw 9.0 Tohoku earthquake 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,

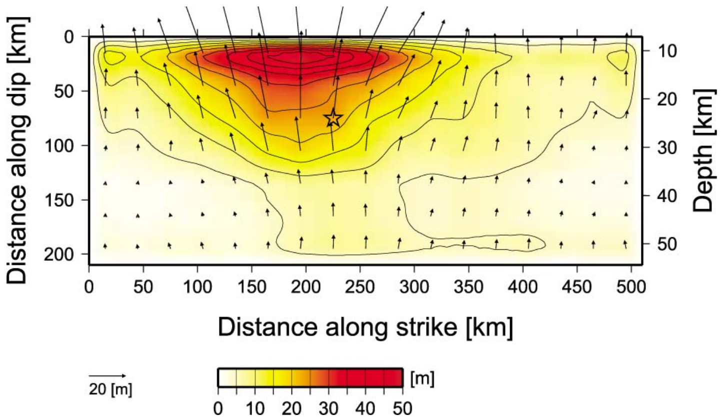
  -2) The possibility of the existence of slip reactivation

  -3) Distinct regions of low and high frequency radiation

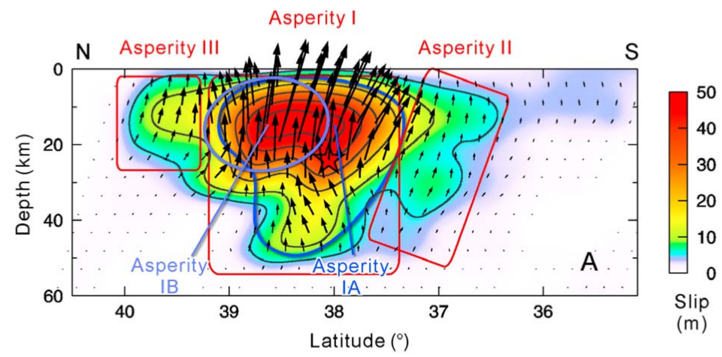
Some kinematic slip models

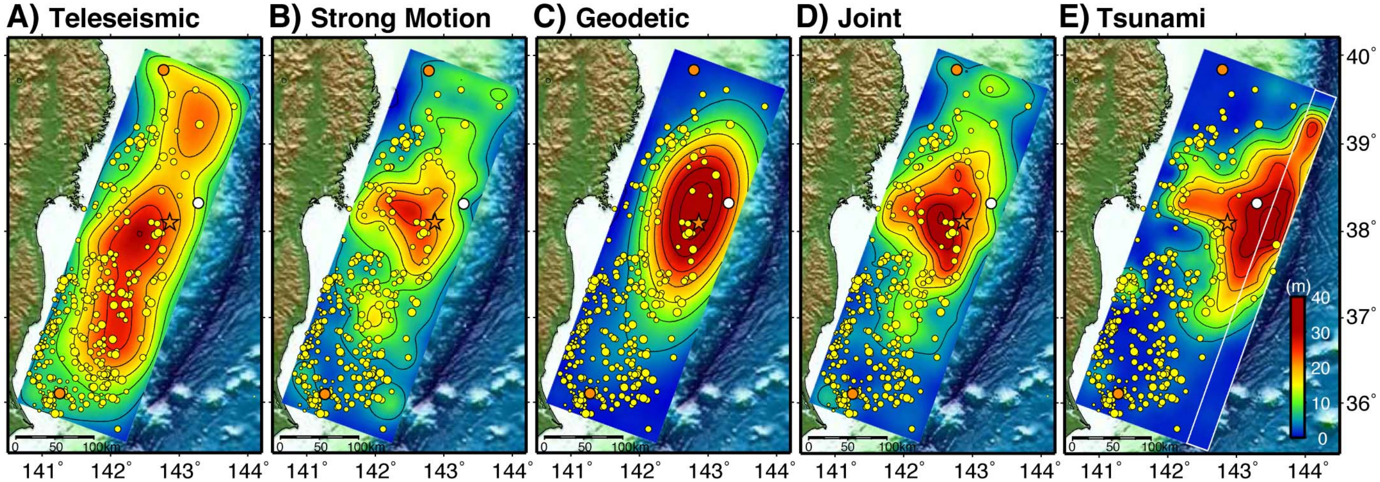
(Spectacular slip, larger than 50m)

(Suzuki et al, 2011)



(Lee et al, 2011)

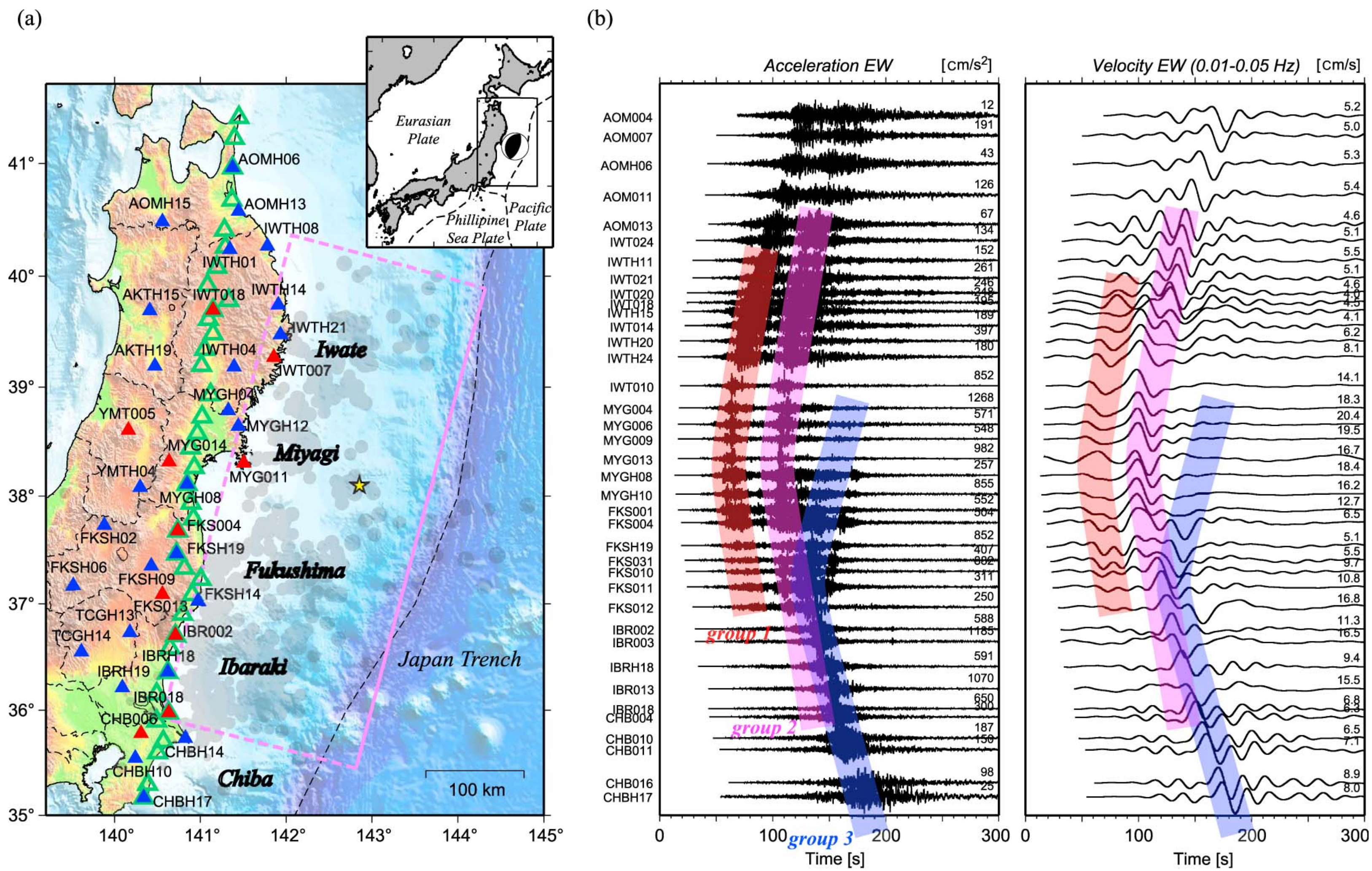




(Koketsu et al, 2011)

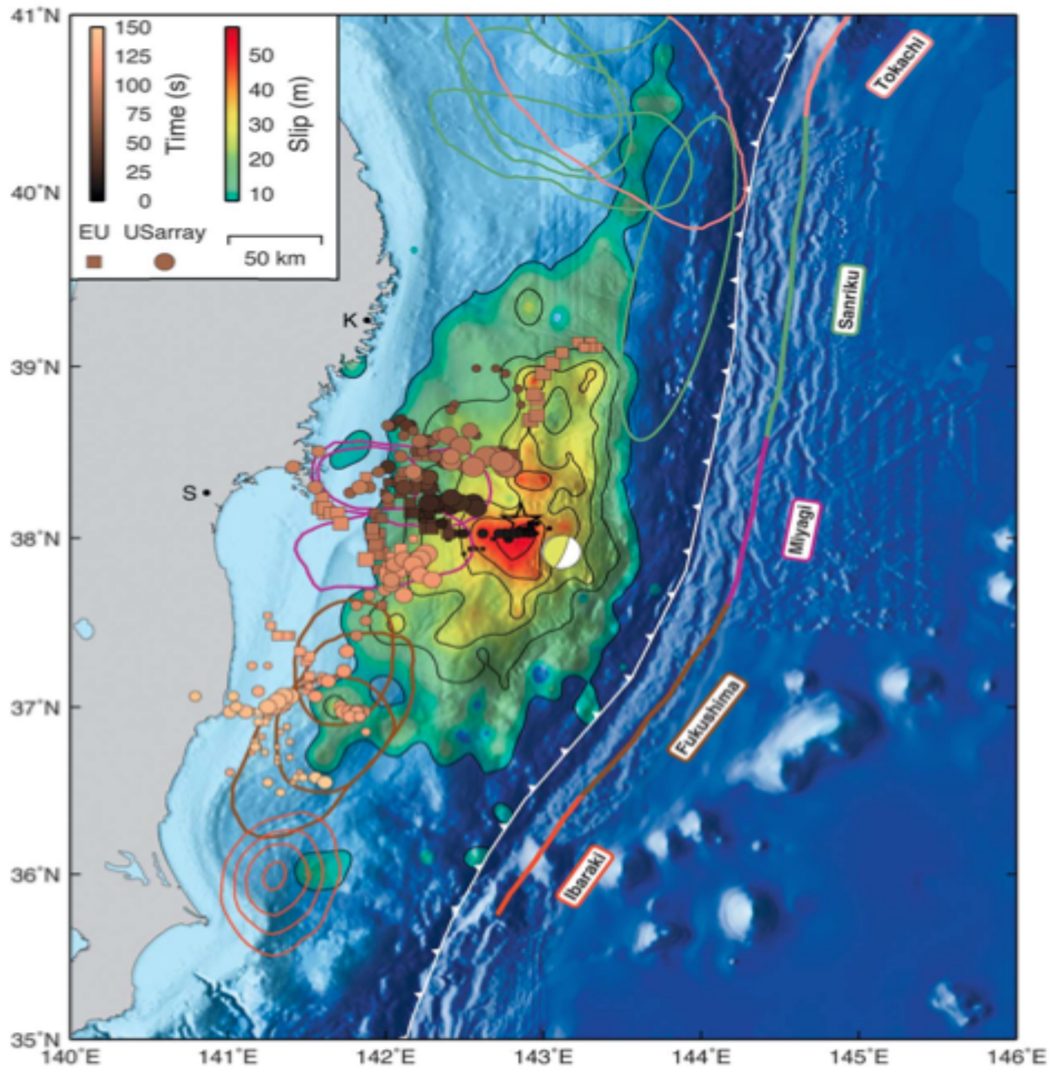
Observed strong ground motion pattern

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



(After Suziki et al,2011, GRL)

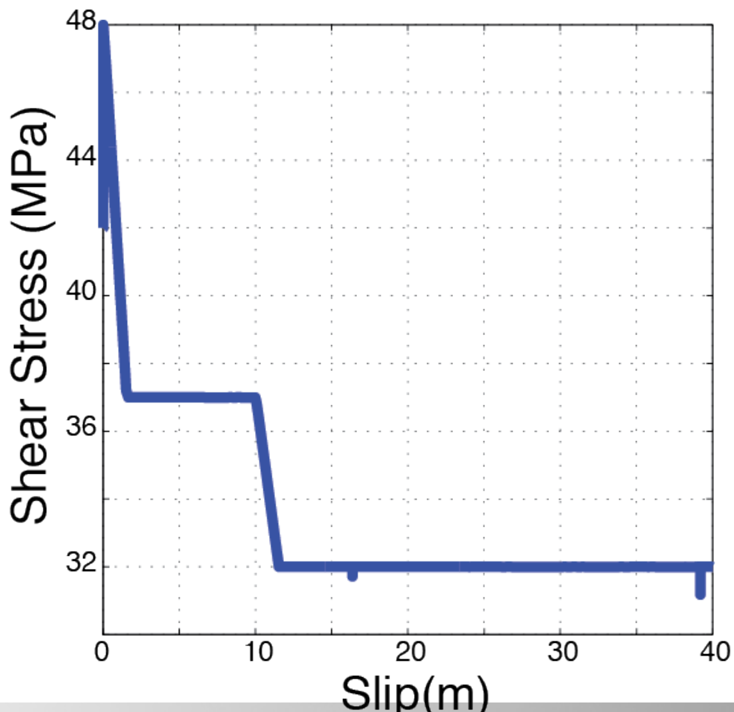
Kinematic source models (e.g. Suzuki et al, 2011, Koketzu, et al 2011,) inverted from seismological, geodetic and tsunami observations, including source images from back-projection (e.g. Cheng et al, 2011, Roten et al, 2012) indicates distinct regions of low and high frequency radiation: the regions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

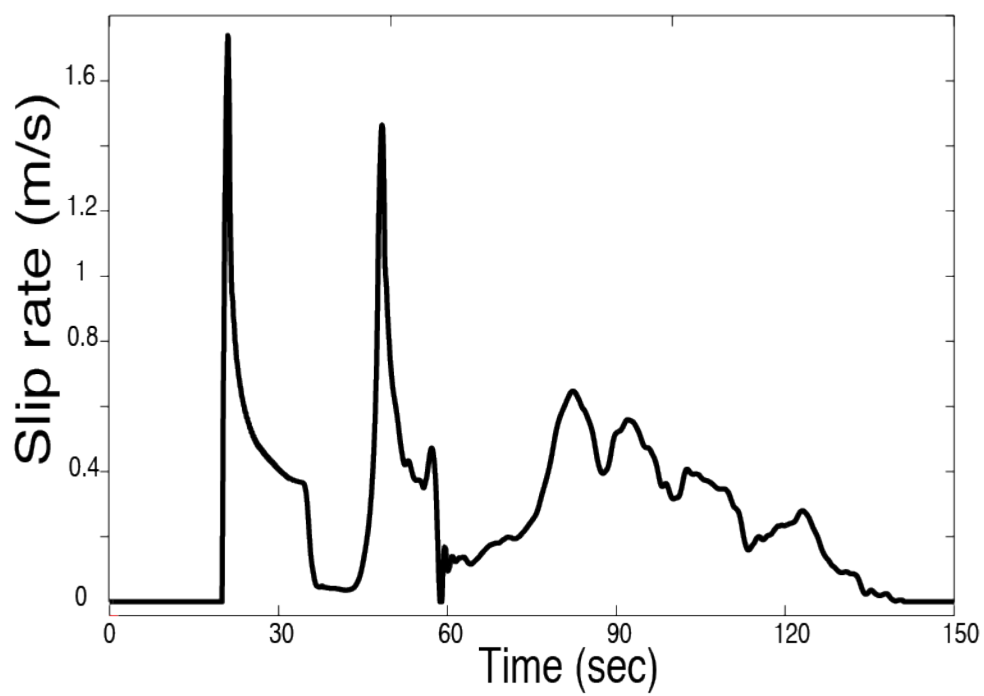


(Simons et al, 2011, Science)

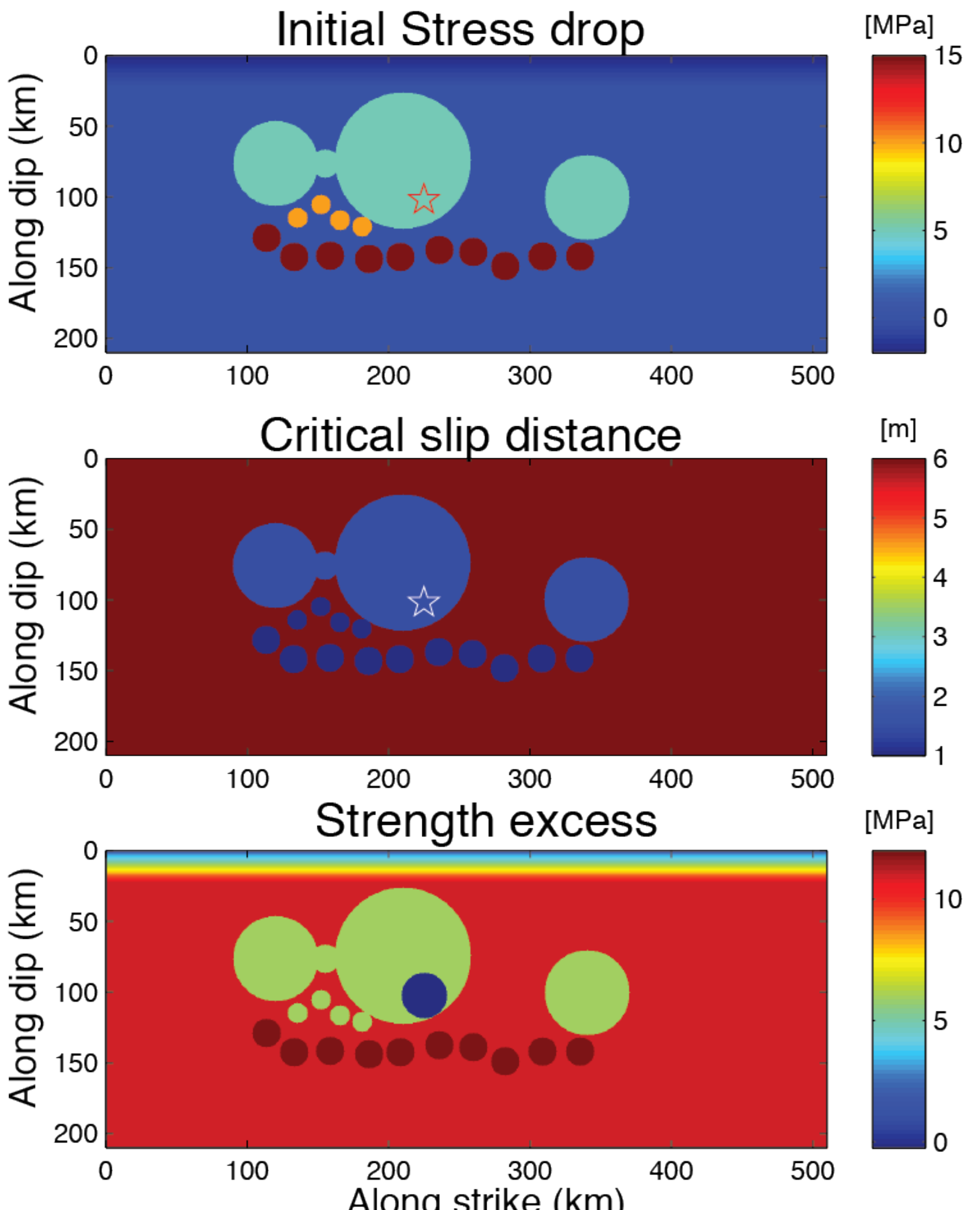
A model of Slip Reactivation

- 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.

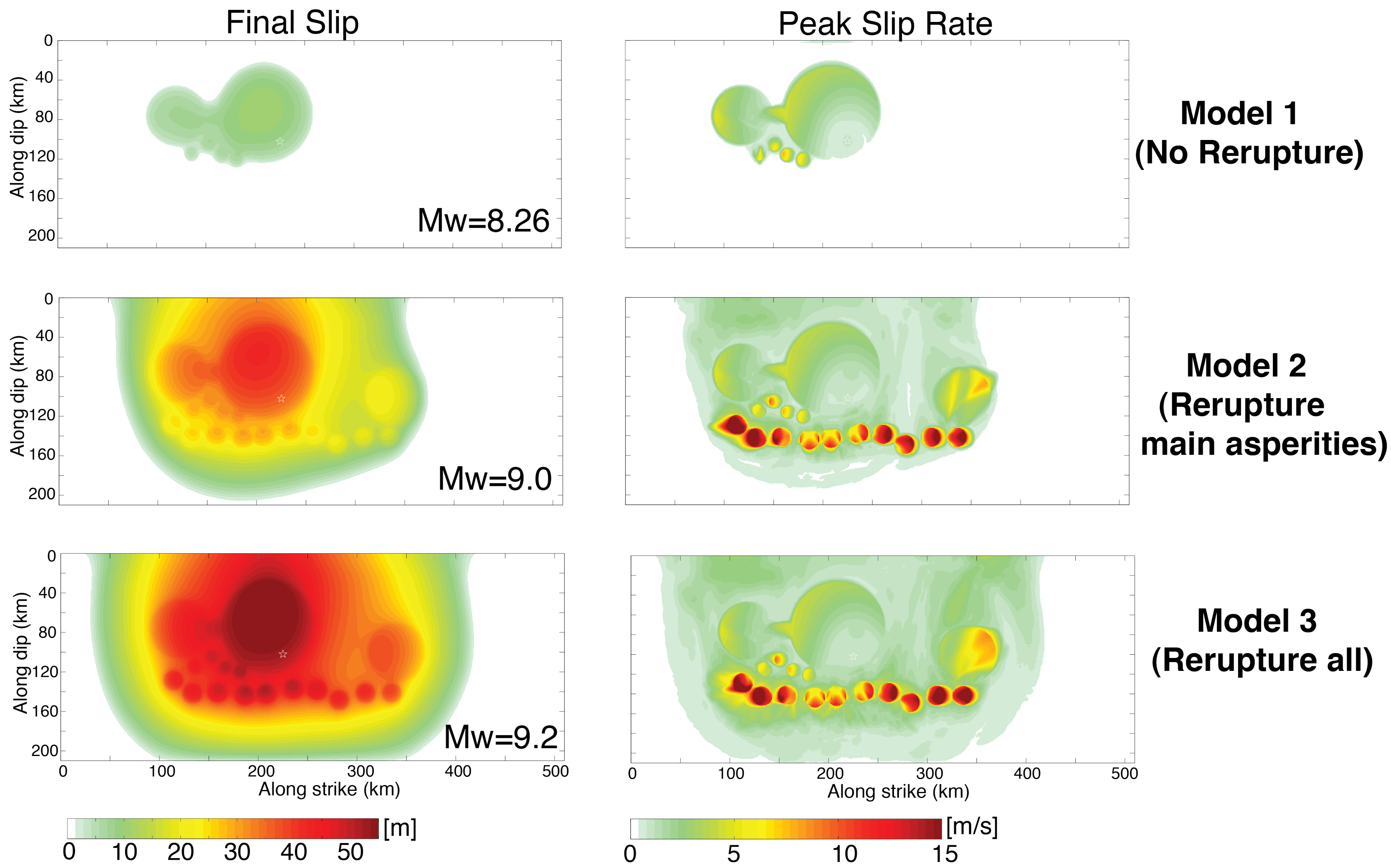




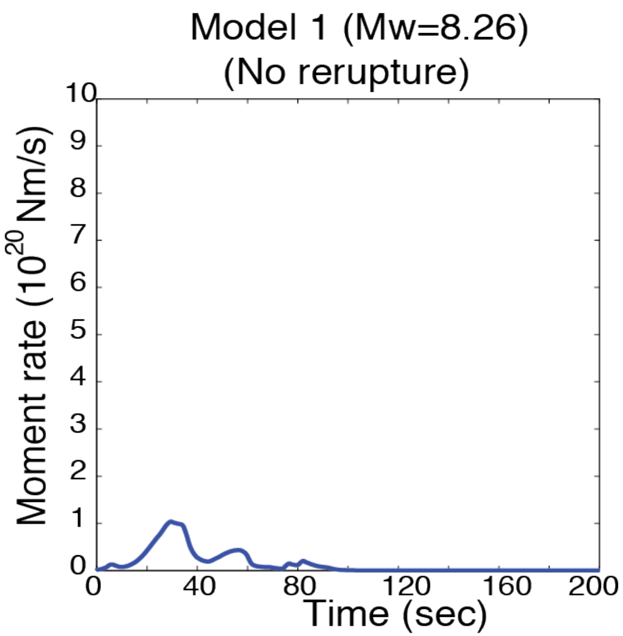
Asperity source model for dynamic rupture simulation

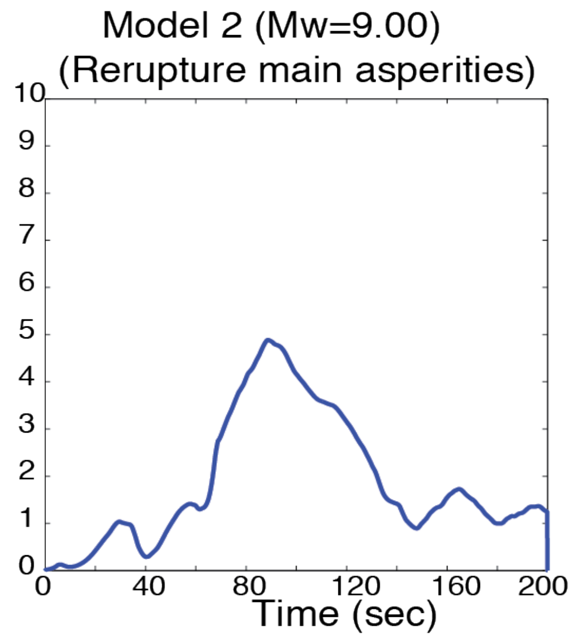


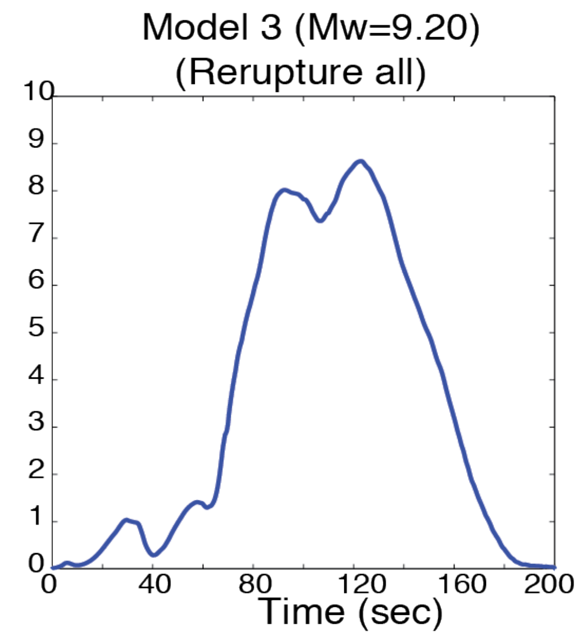
Numerical solution of three rupture models

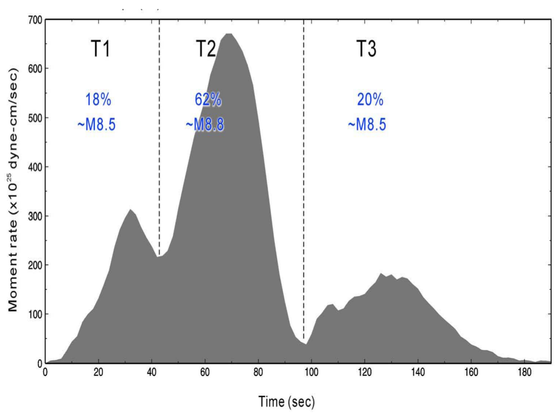


Moment rate

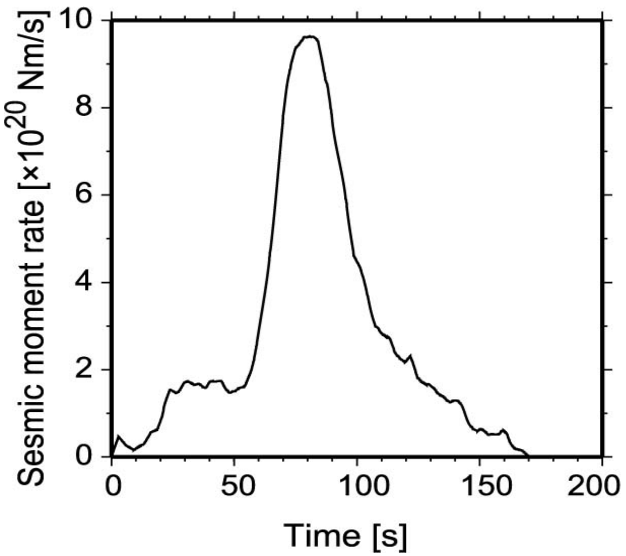






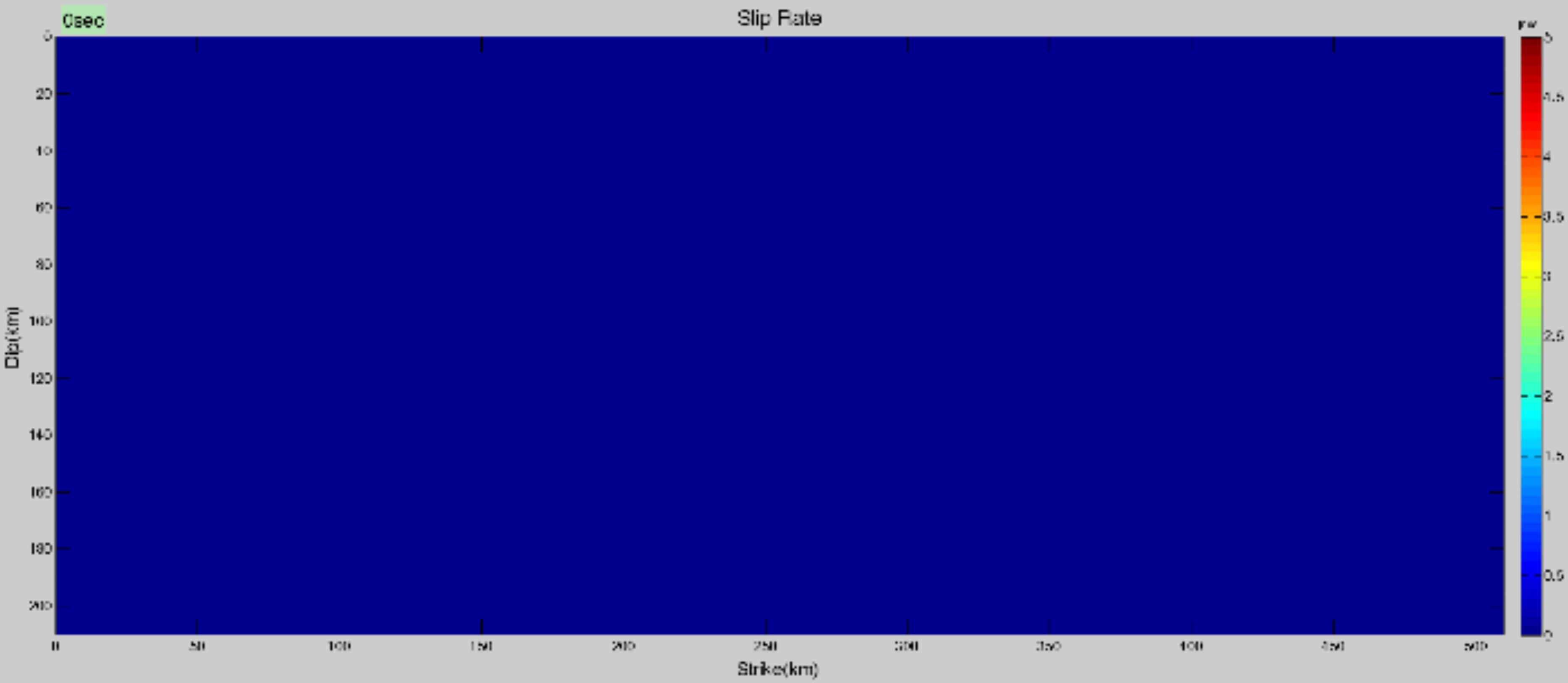


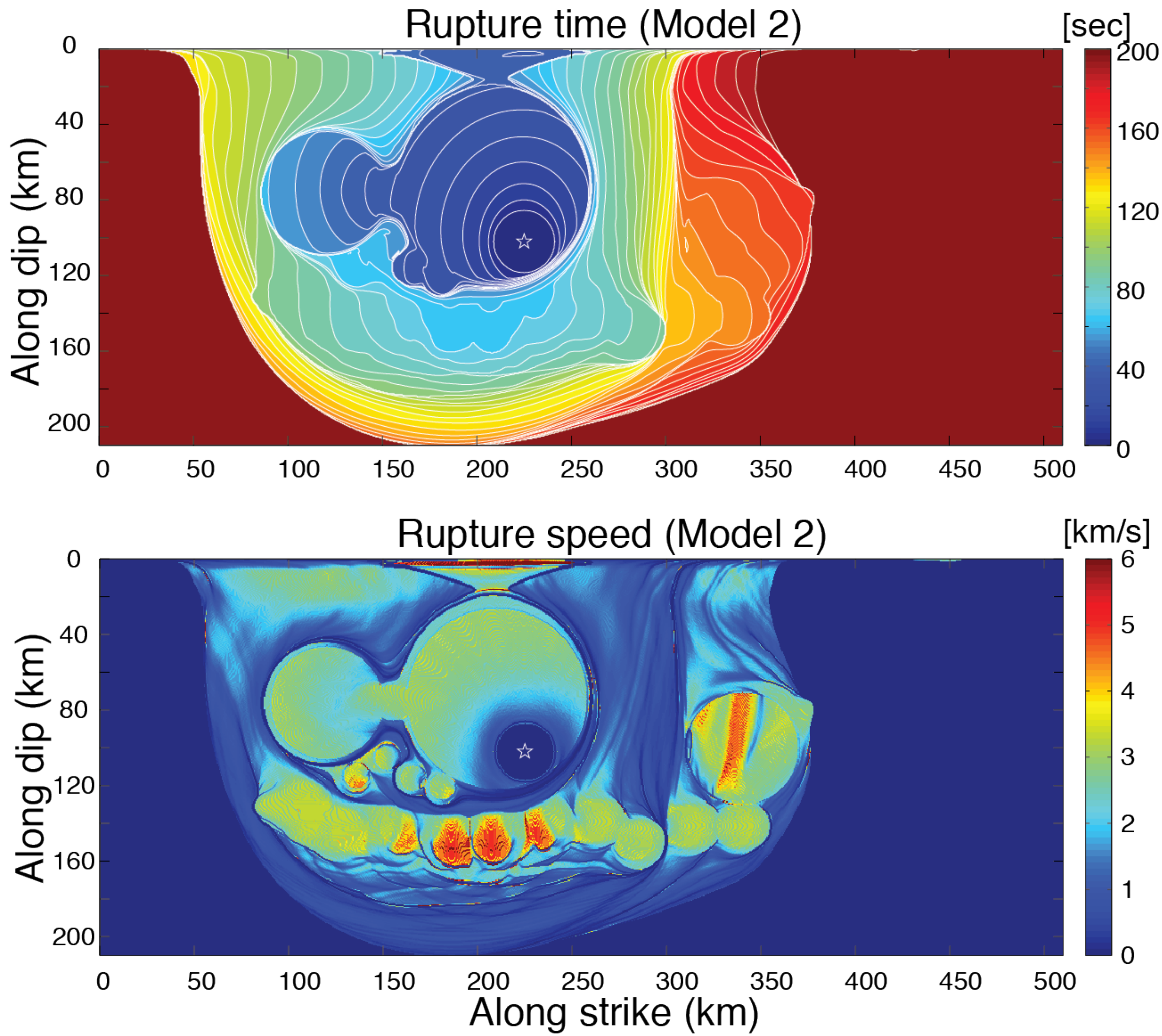
(Lee et al, 2011)



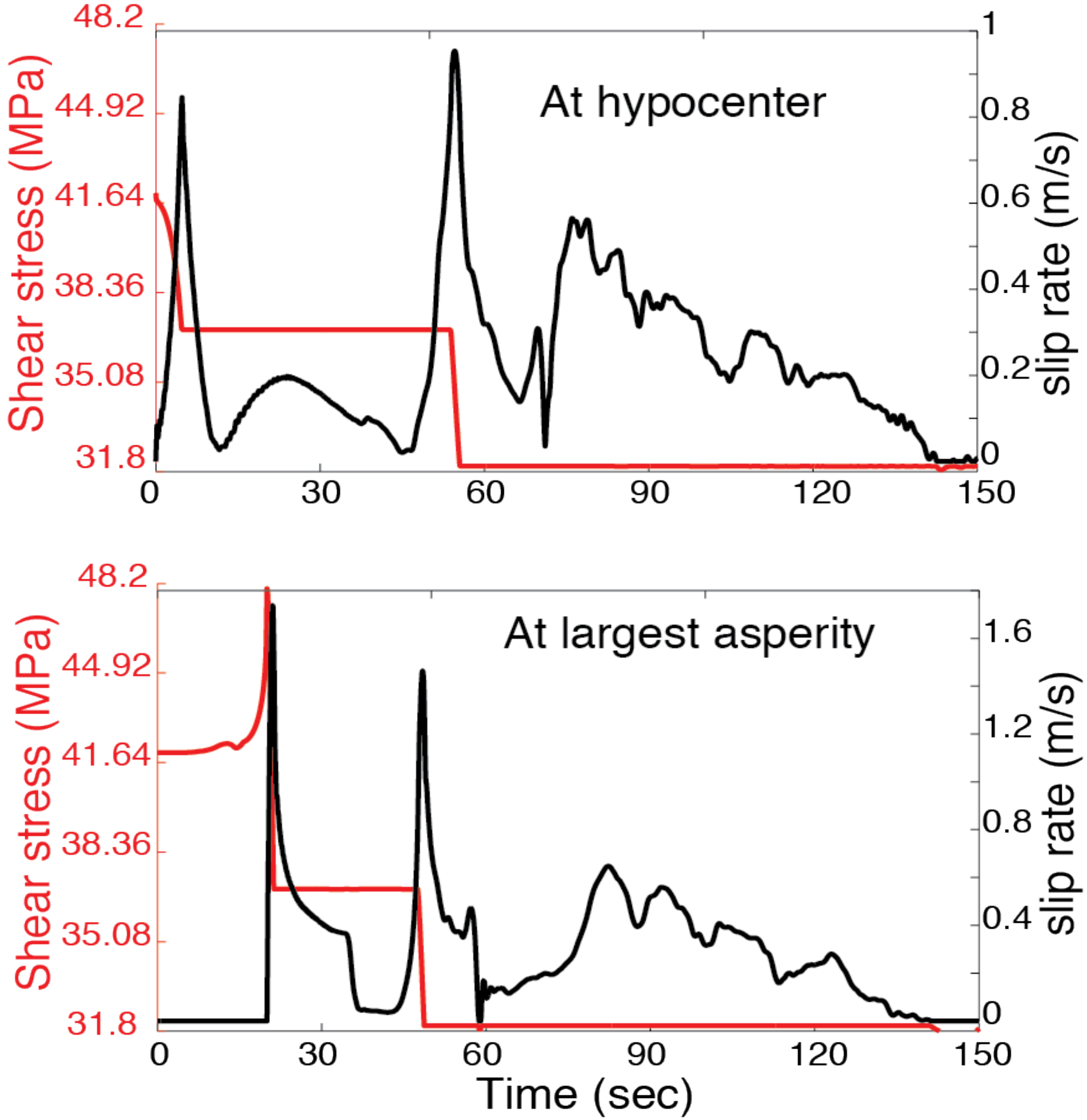
(Suzuki et al, 2011)

Movie of Slip rate (Model 2)

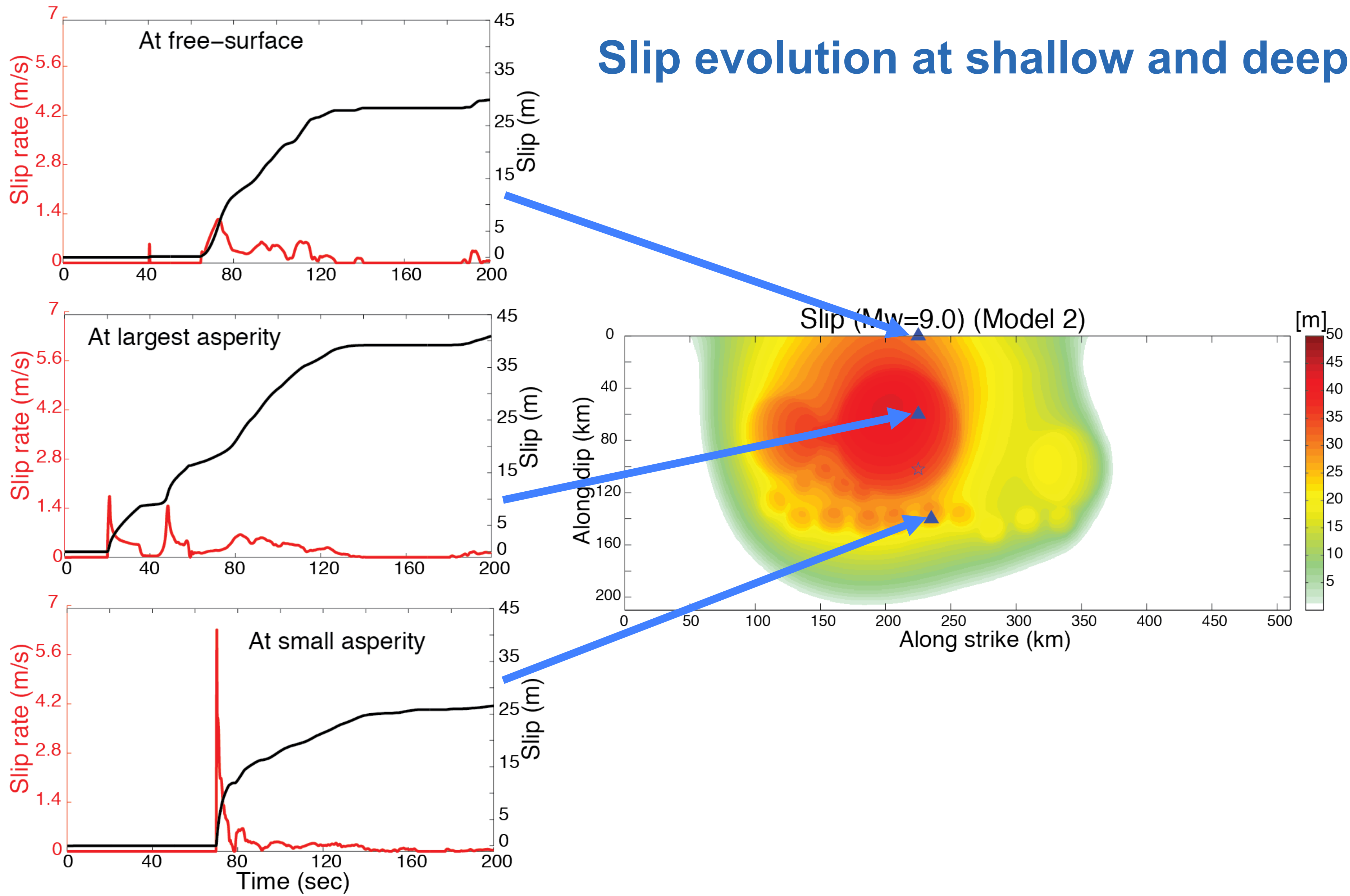



Rupture time (Model 2)
[sec]
200
160
120
80
40
0
Along dip (km)
0
40
80
120
160
200
0
50
100
150
200
250
300
350
400
450
500
Rupture speed (Model 2)
[km/s]
6
5
4
3
2
1
0
Along strike (km)

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)