The Abdus Salam International Centre for Theoretical Physics

ICTP Diploma Programme

Earth System Physics

Theoretical Seismology

Seismic sources
Introduction

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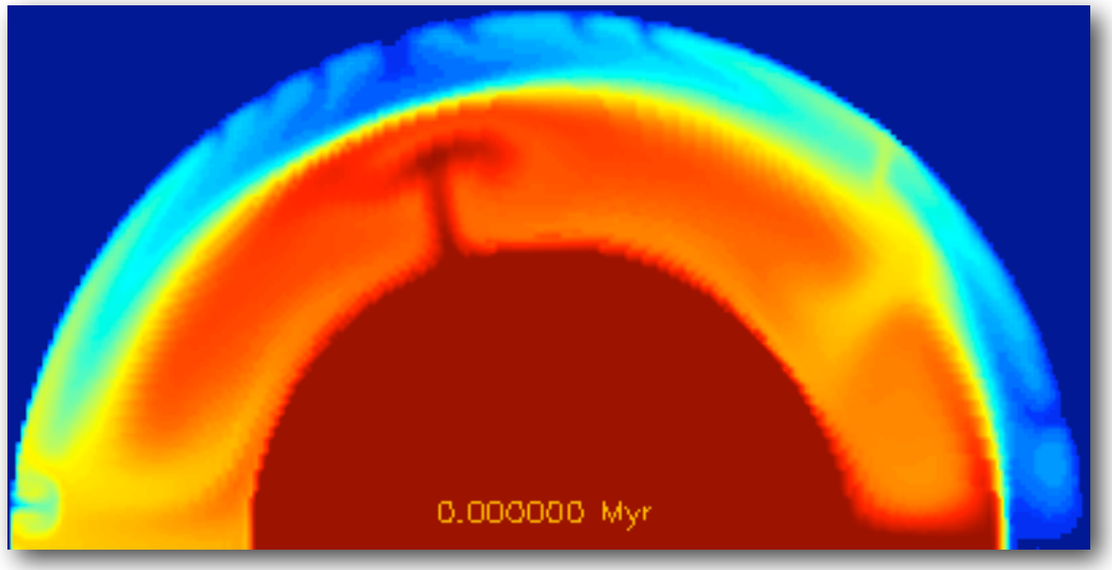
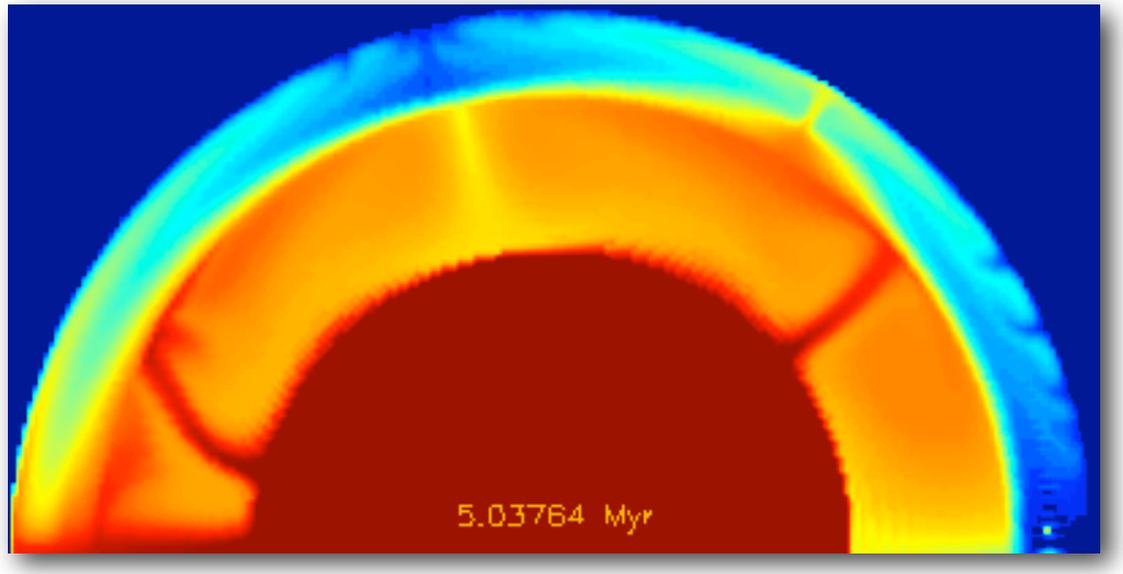
Why do earthquakes happen?

From Namazu....

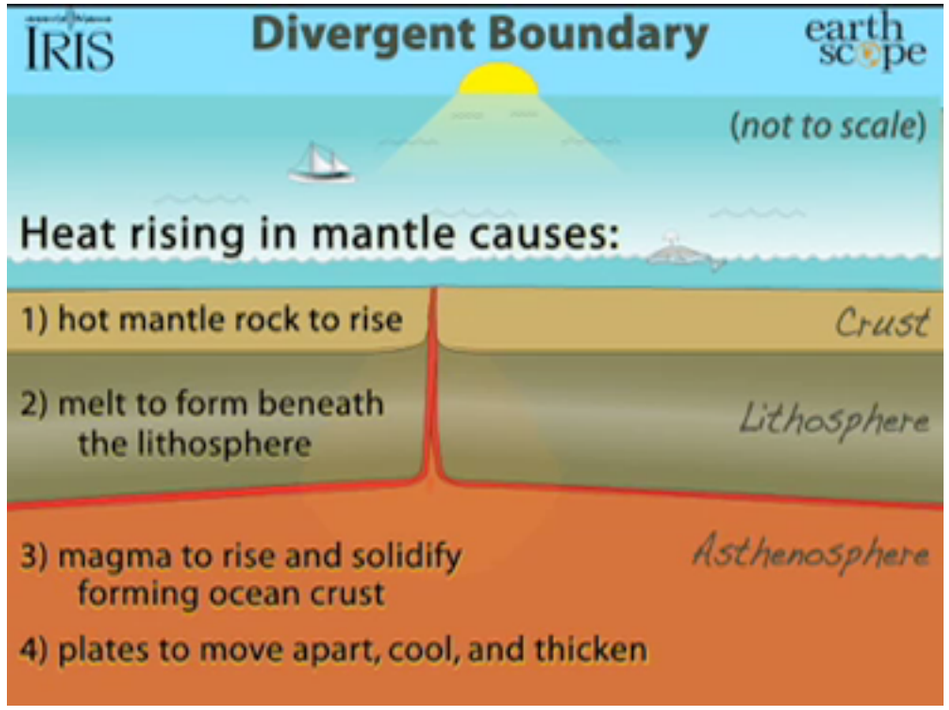


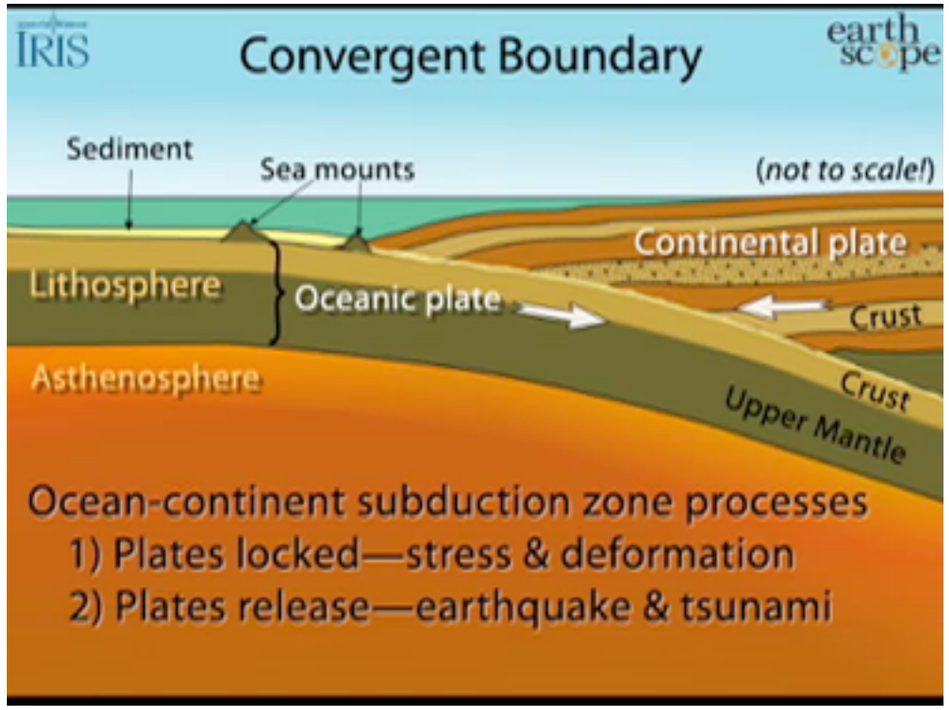


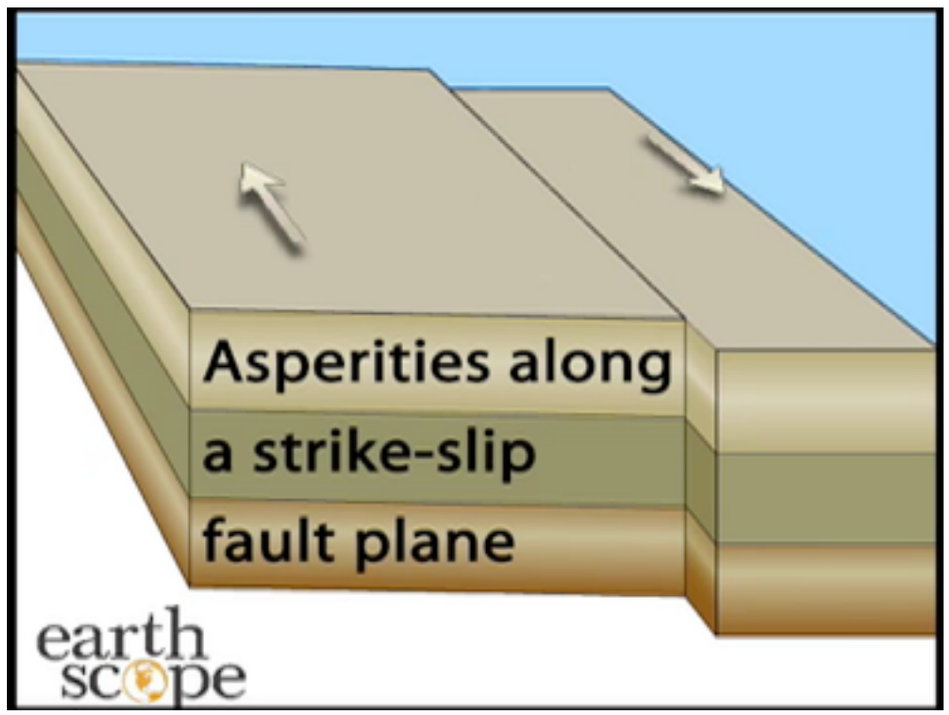
Thermo chemical convection
http://geo.mff.cuni.cz/~cizkova/Anim/animace.htm

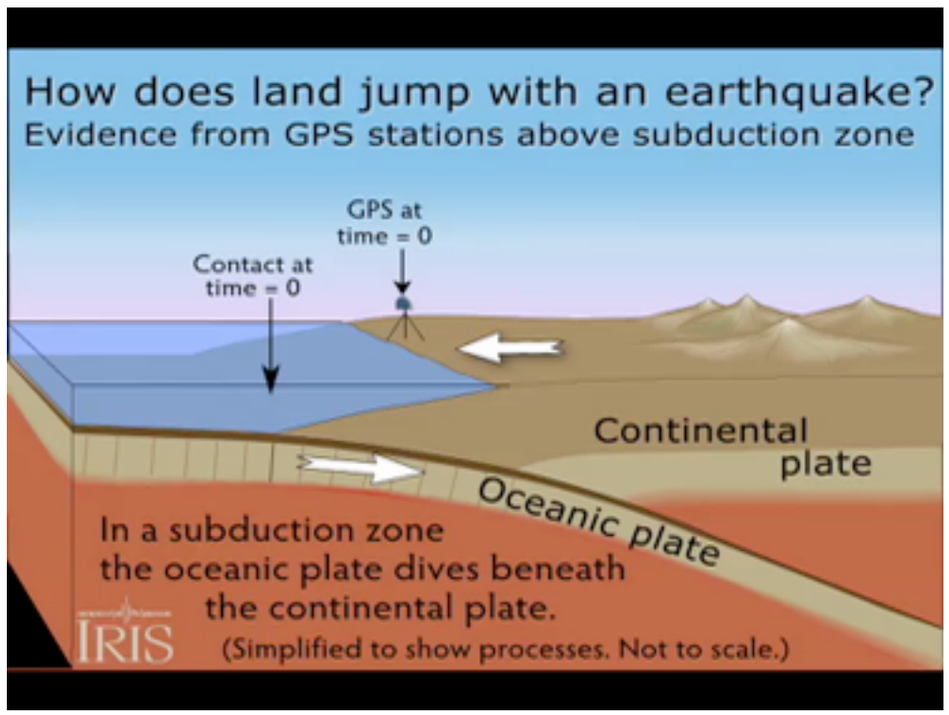
...to complex fluid dynamics

Why do earthquakes happen?

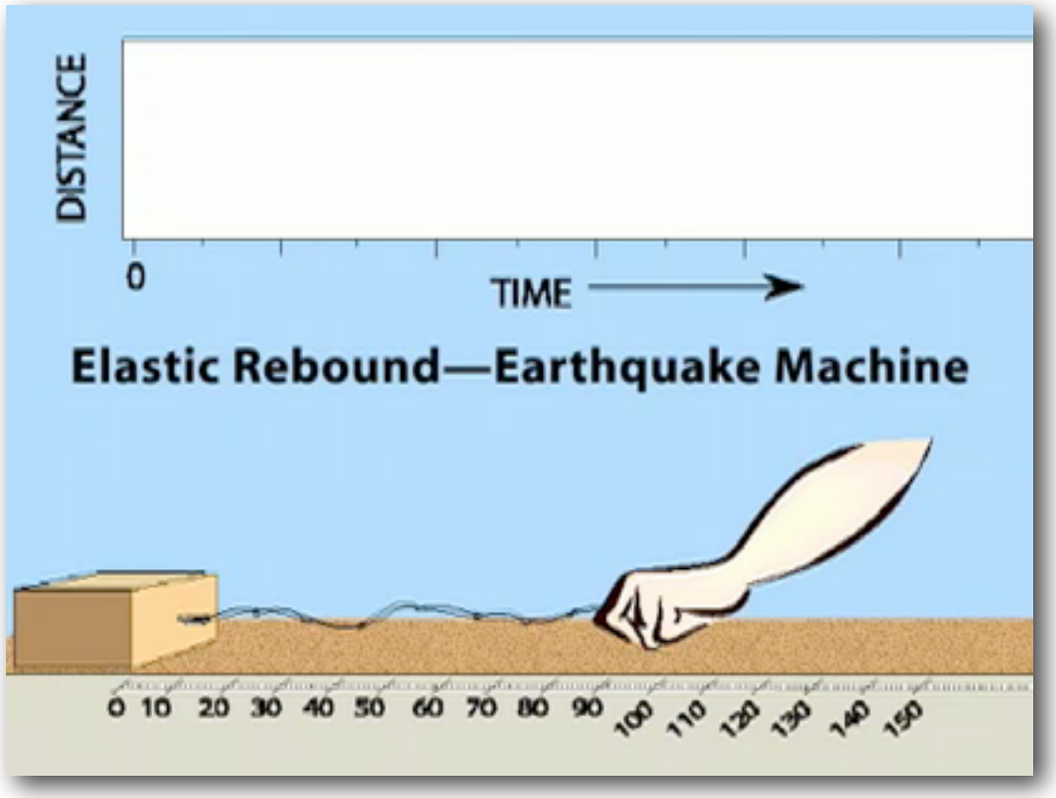


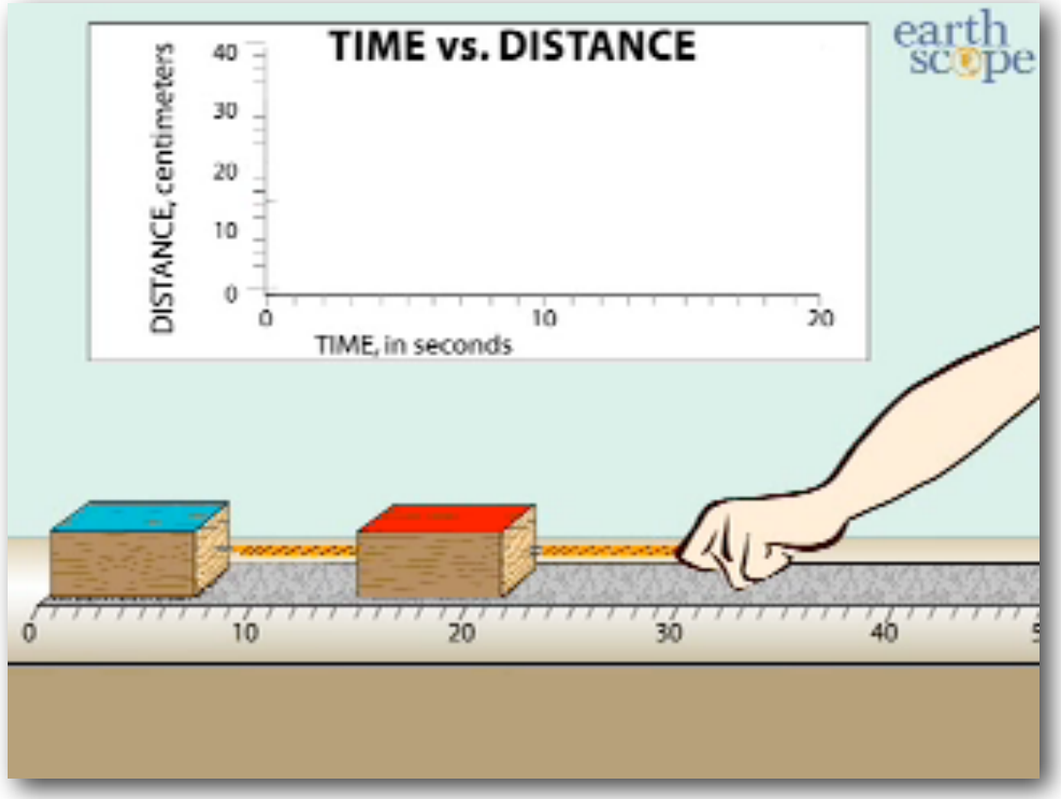


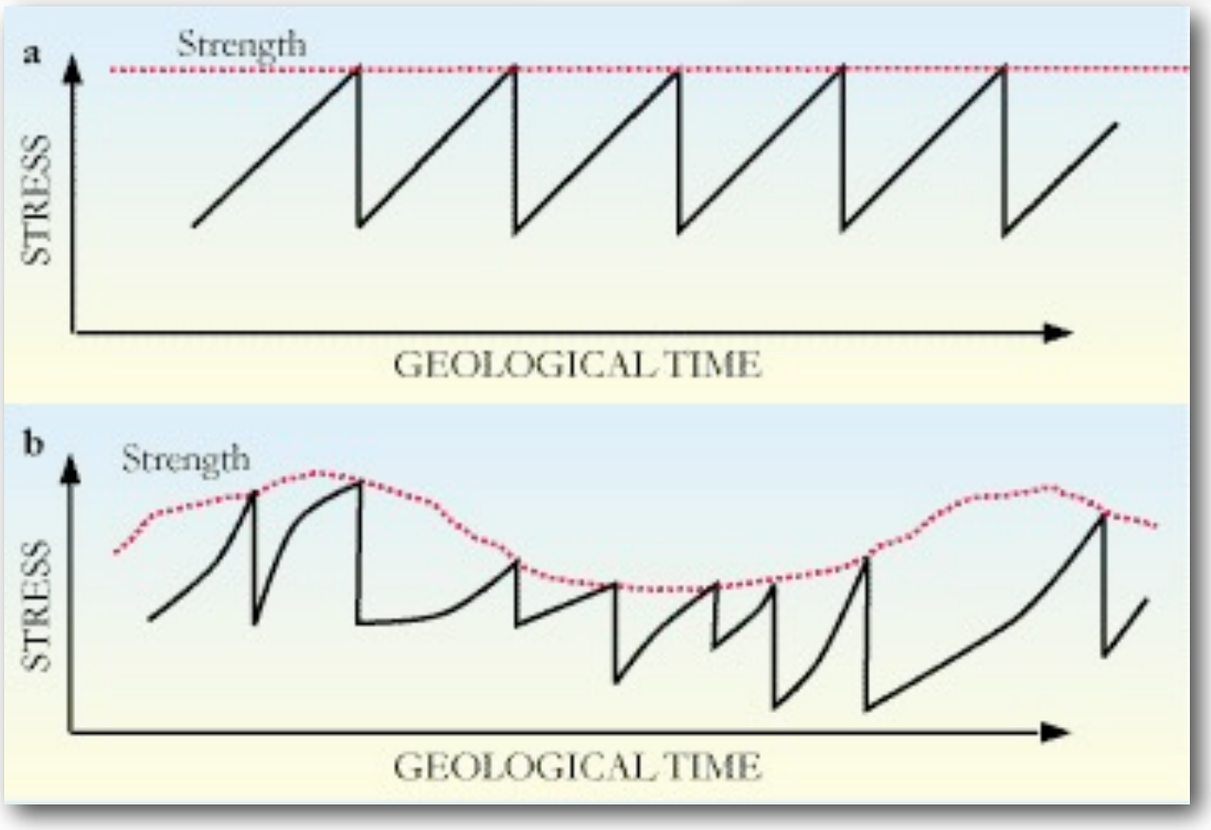




Earthquake (complex) cycle







Rate (v) and State (θ) Friction Constitutive Laws

reference value of base friction

state variable, characterizes physical state of surface or shearing region

$$\mu(\theta, V) = \mu_o + a\, ln\left(\frac{V}{V_o}\right) + b\, ln\left(\frac{V_o\theta}{D_c}\right)$$

reference velocity

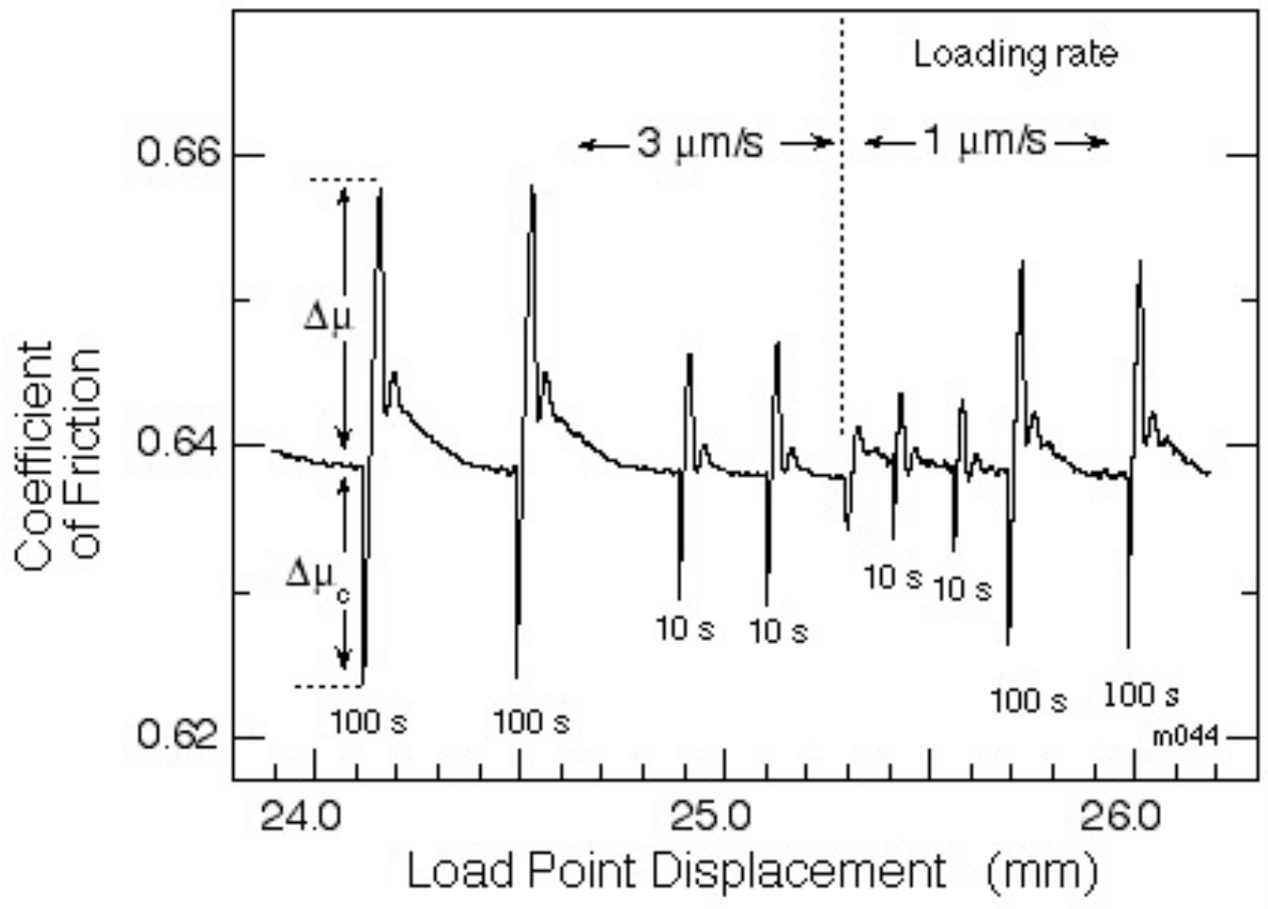
critical slip distance

$$\frac{d\theta}{dt} = 1 - \frac{V\theta}{D_c}$$

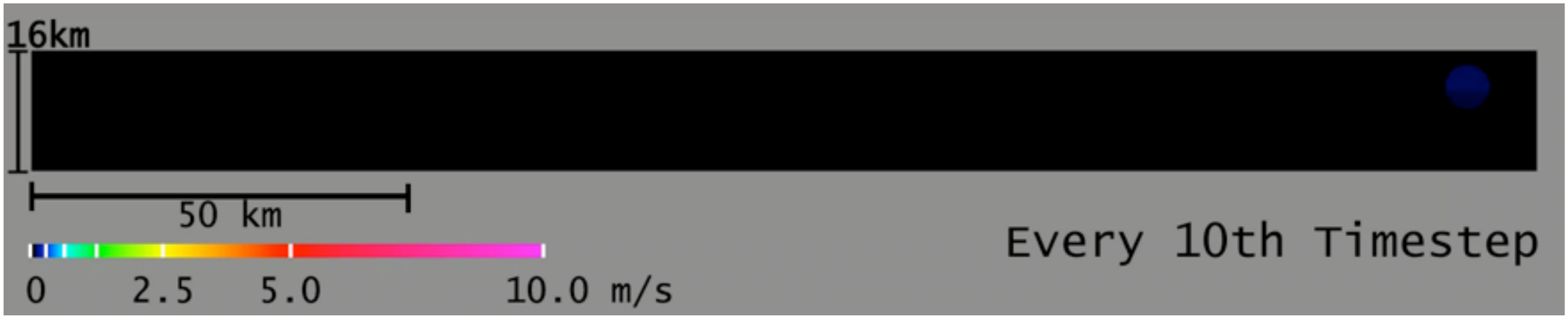
Dieterich, aging law

$$\frac{d\theta}{dt} = -\frac{V\theta}{D_c} ln(\frac{V\theta}{D_c})$$

Ruina, slip law

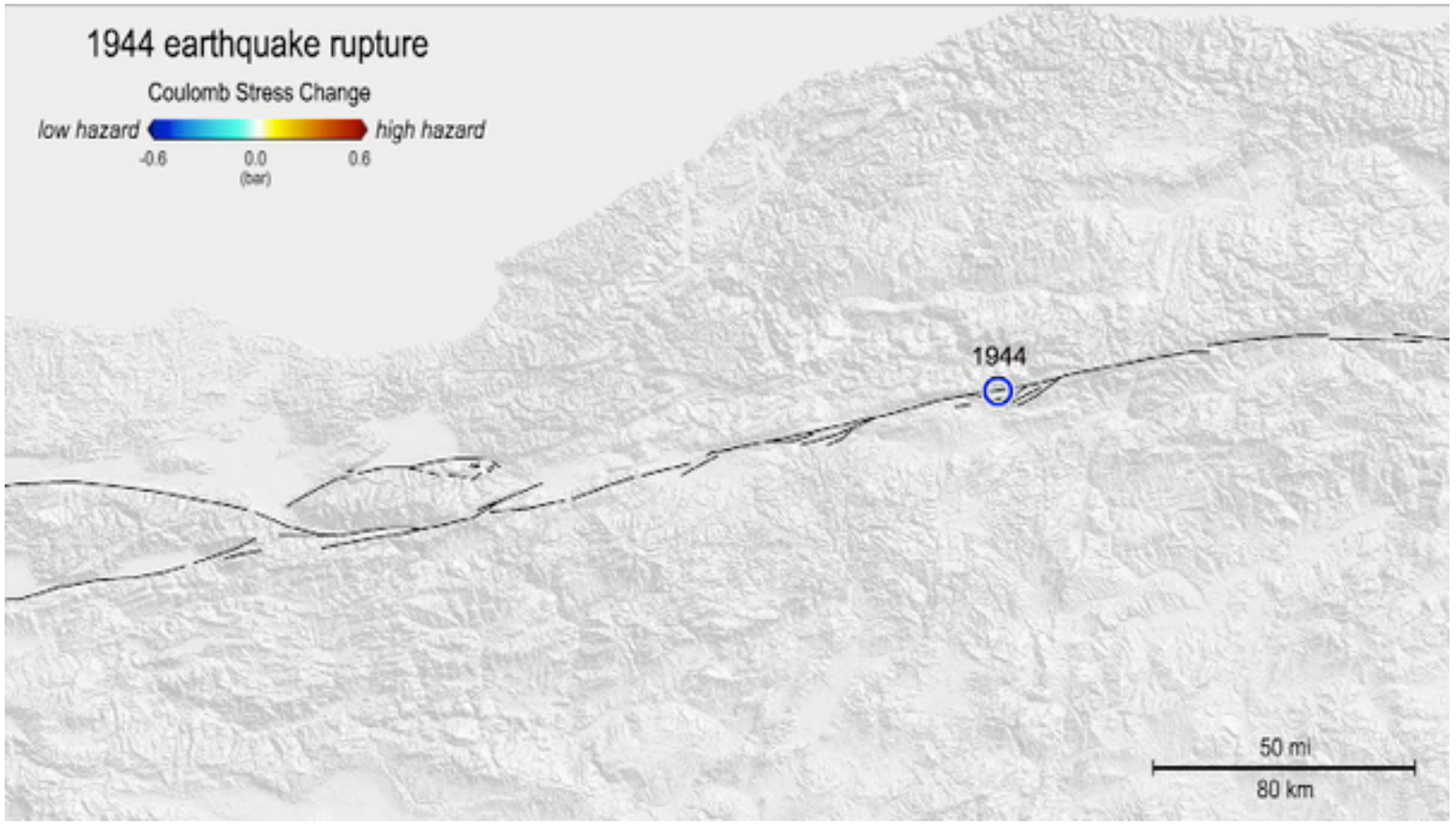


Dynamic rupture and stress transfer



rupture velocities of a dynamic rupture model of a magnitude 7.7 on the southernmost San Andreas fault www.scec.org

When a fault fails during an earthquake, it modifies the stress field in its surroundings. The modification of the stress pattern can give a rough idea of where the next shocks are more likely occur.



Coulomb stresses transmitted by seismic wave propagation for the M=7.2 1944 earthquake on the North Anatolian fault.

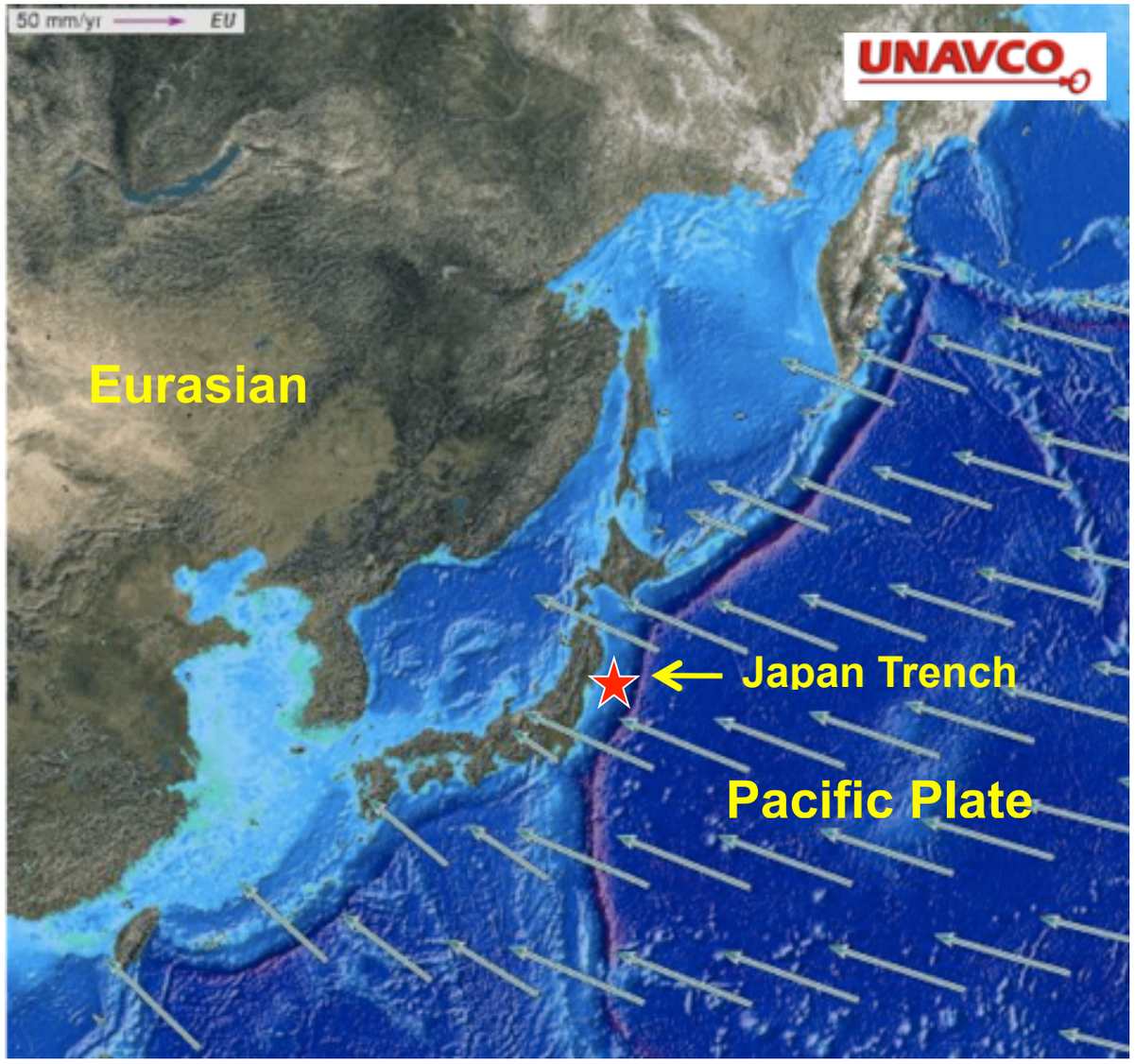
Courtesy of Kim B. Olsen

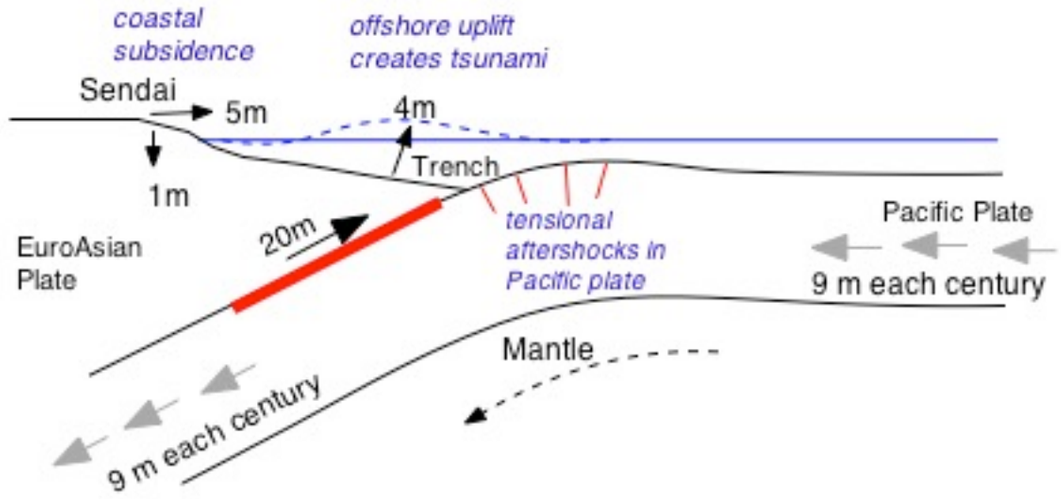
Tohoku-oki event: Tectonic setting

This earthquake was the result of thrust faulting along or near the convergent plate boundary where the Pacific Plate subducts beneath Japan.

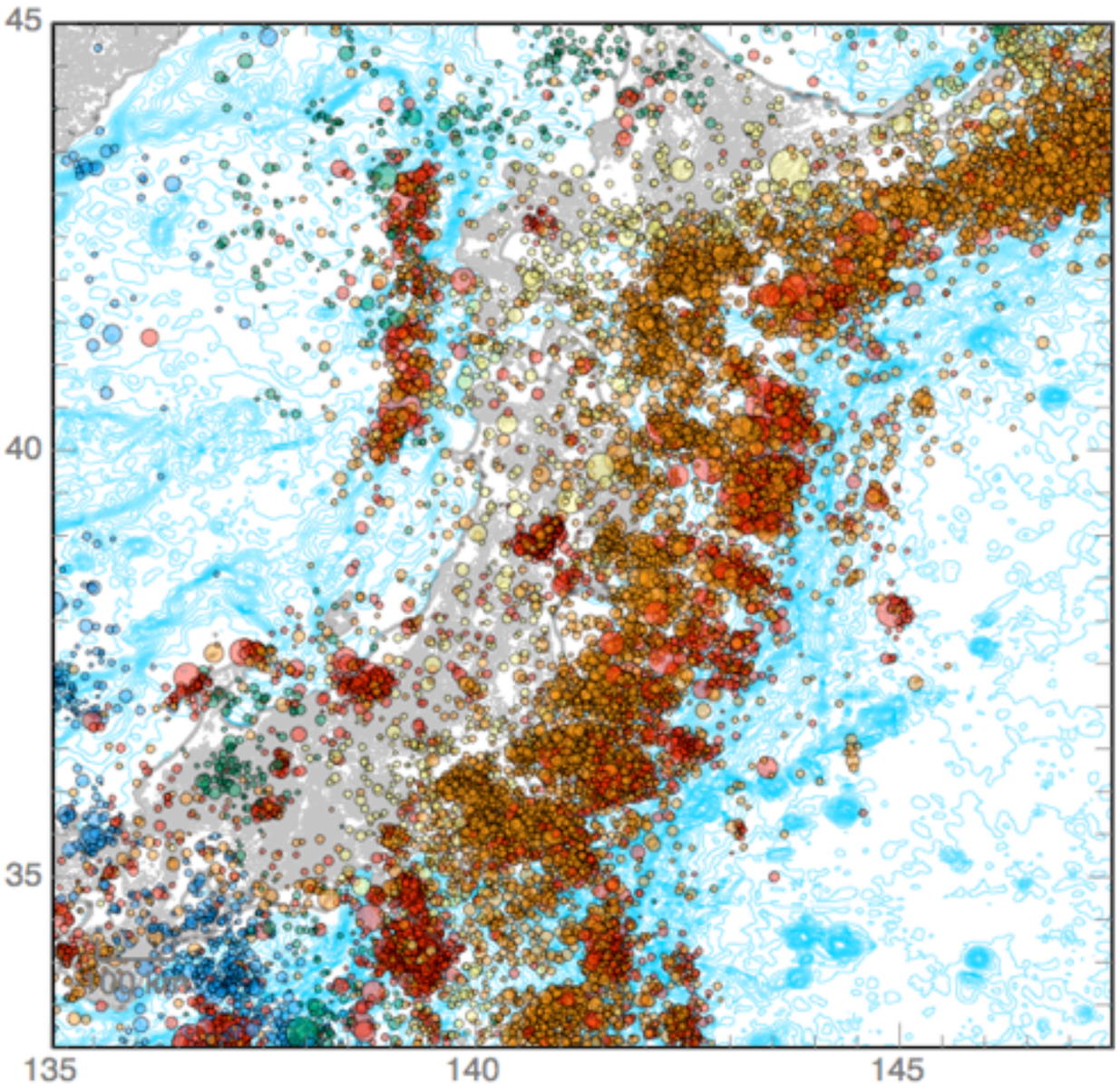
This map also shows the rate and direction of motion of the Pacific Plate with respect to the Eurasian Plate near the Japan Trench. The rate of convergence at this plate boundary is about 100 mm/yr (9 cm/year).

This is a fairly high convergence rate and this subduction zone is very seismically active.





Historical seismicity and aftershocks



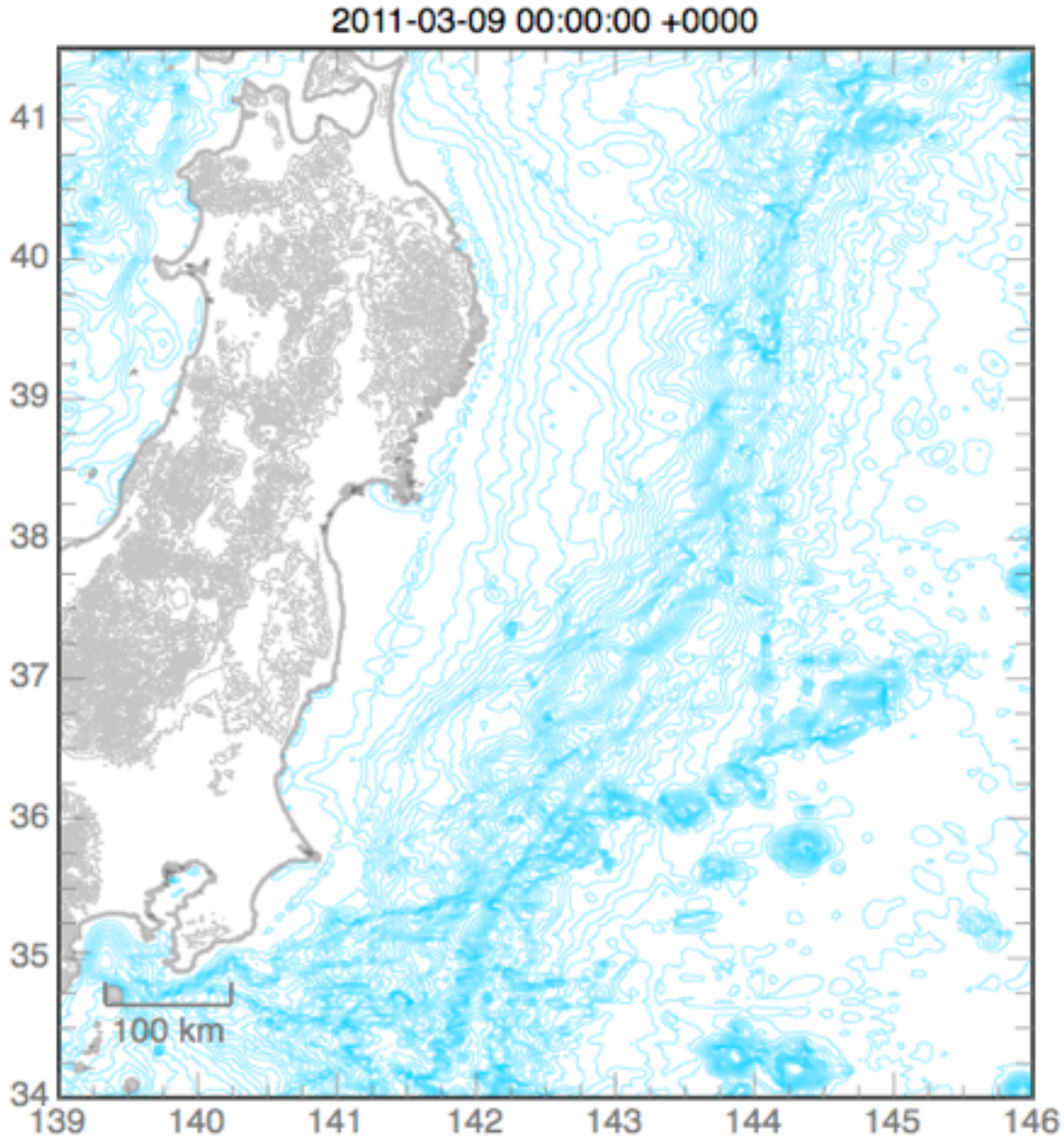


Image courtesy of Charles Ammon

USGS - CMT - Seismic Moment solution

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March 11, 2011, NEAR EAST COAST OF HONSHU, JAPAN, MW=9.1

Meredith Nettles
Goran Ekstrom

CENTROID-MOMENT-TENSOR  SOLUTION
GCMT EVENT:     M201103110546A
DATA: II IU CU G  GE IC
MANTLE WAVES:   95S, 250C, T=300
TIMESTAMP:      Q-20110311075913
CENTROID LOCATION:
ORIGIN TIME:       05:47:33.8 0.2
LAT:37.68N 0.02;LON:143.03E 0.02
DEP: 20.0  FIX;TRIANG HDUR: 89.3
MOMENT TENSOR: SCALE 10**29 D-CM
RR= 1.870 0.009; TT=-0.267 0.006
PP=-1.600 0.007; RT= 2.490 0.089
RP= 5.160 0.086; TP=-0.698 0.005
PRINCIPAL AXES:
1.(T) VAL=  6.019;PLG=54;AZM=297
2.(N)       0.028;     1;     206
3.(P)      -6.044;    36;     115
BEST DBLE.COUPLE:M0= 6.03*10**29
NP1: STRIKE=201;DIP= 9;SLIP=  85
NP2: STRIKE= 26;DIP=81;SLIP=  91
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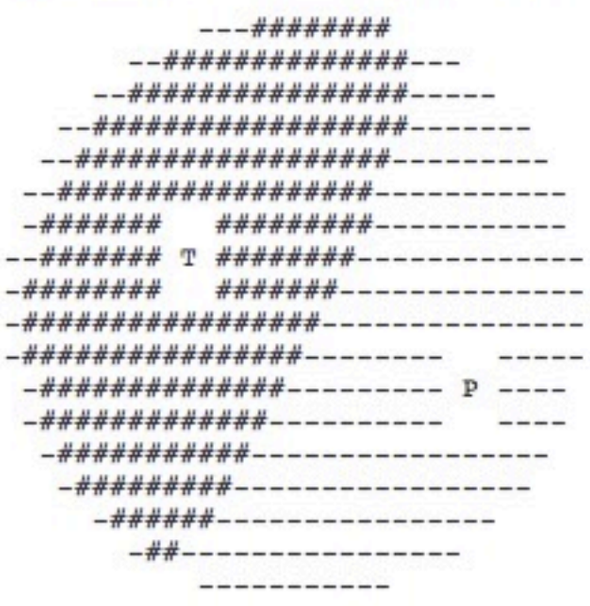
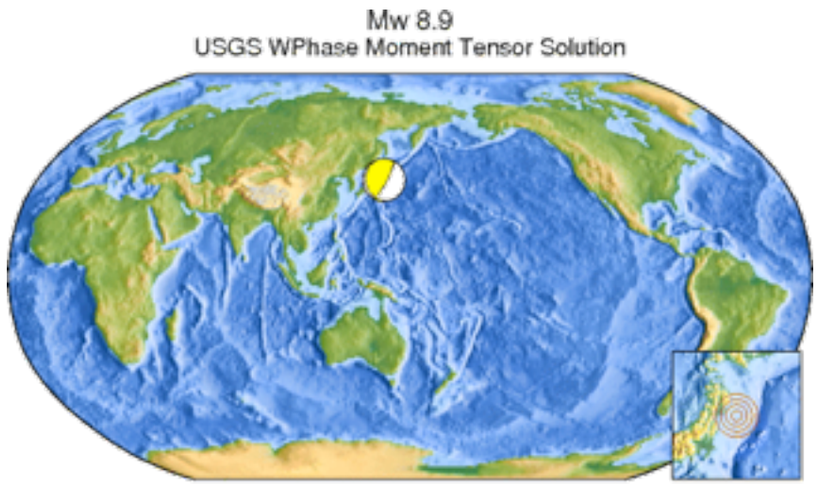


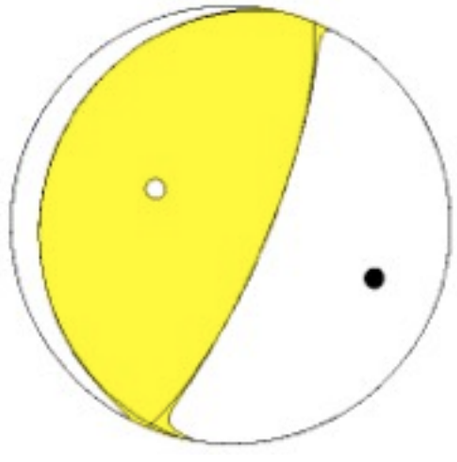


Date: 11 MAR 2011
Time: 5:46:23
Epicenter: 38.321 142.369
Depth: 24 km

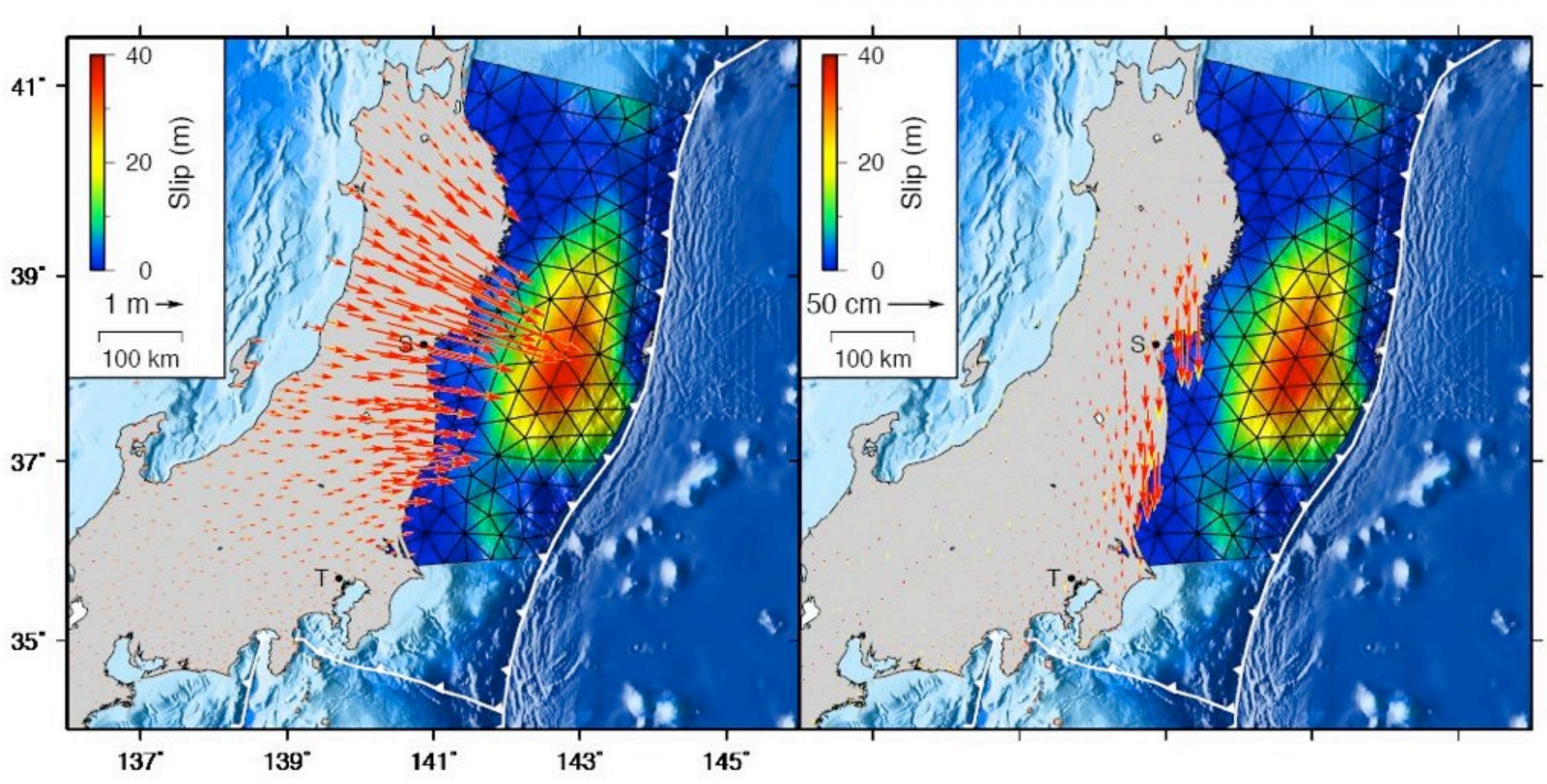
USGS WPhase Moment Solution

NEAR EAST COAST OF HONSHU, JAPAN

```
11/03/11  5:46:23

Epicenter:  38.321  142.369
MW 9.0

USGS/WPHASE CENTROID MOMENT TENSOR
11/03/11 05:46:23.00
Centroid:   38.321  142.969
Depth  24          No. of sta:256
Moment Tensor;   Scale 10**22 Nm
  Mrr= 1.82        Mtt=-0.13
  Mpp=-1.69        Mrt= 1.34
  Mrp= 3.17        Mtp=-0.56
 Principal axes:
  T  Val=  3.88  Plg=59  Azm=295
  N      =  0.03      2       201
  P      = -3.92     30       110

Best Double Couple:Mo=3.9*10**22
 NP1:Strike=193 Dip=14 Slip=  81
 NP2:        22     76        92
```

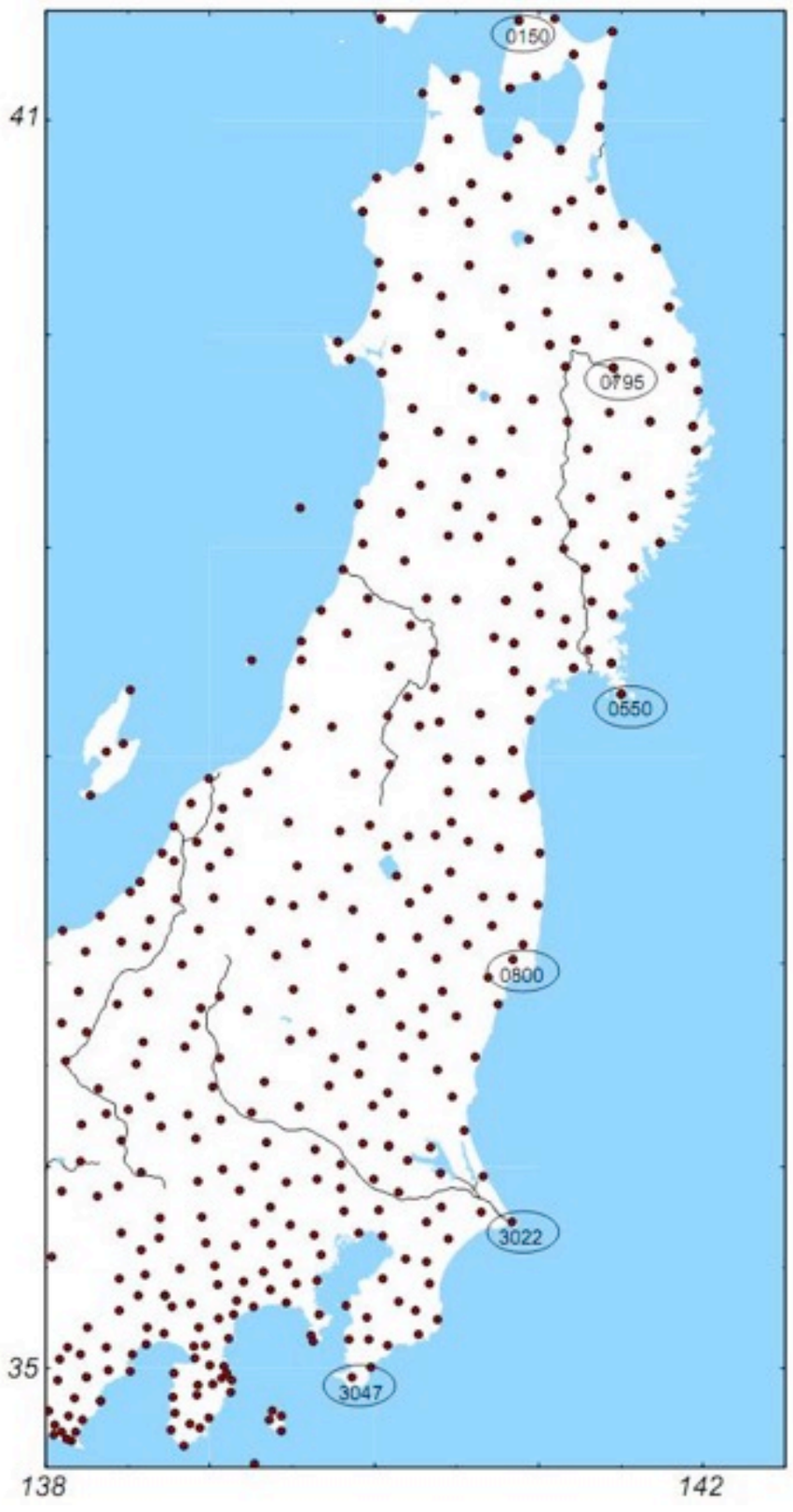


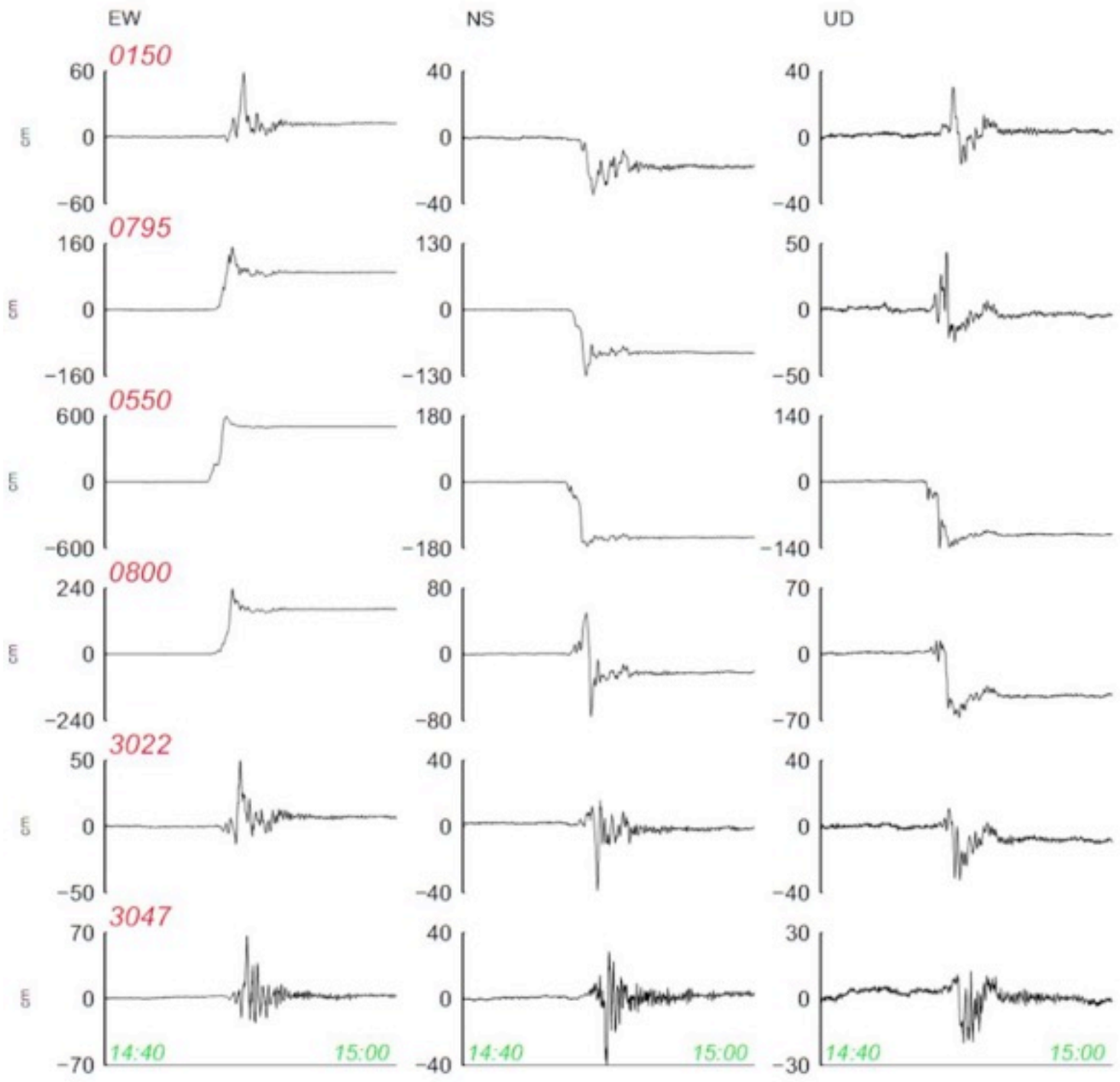
Co-seismic slip



M. Simons, F. Ortega, J. Jiang, A. Sladen, and S. Minson at Caltech as part of the ARIA project.
All orginal GEONET RINEX data provided to Caltech by the Geospatial Information Authority (GSI) of Japan.

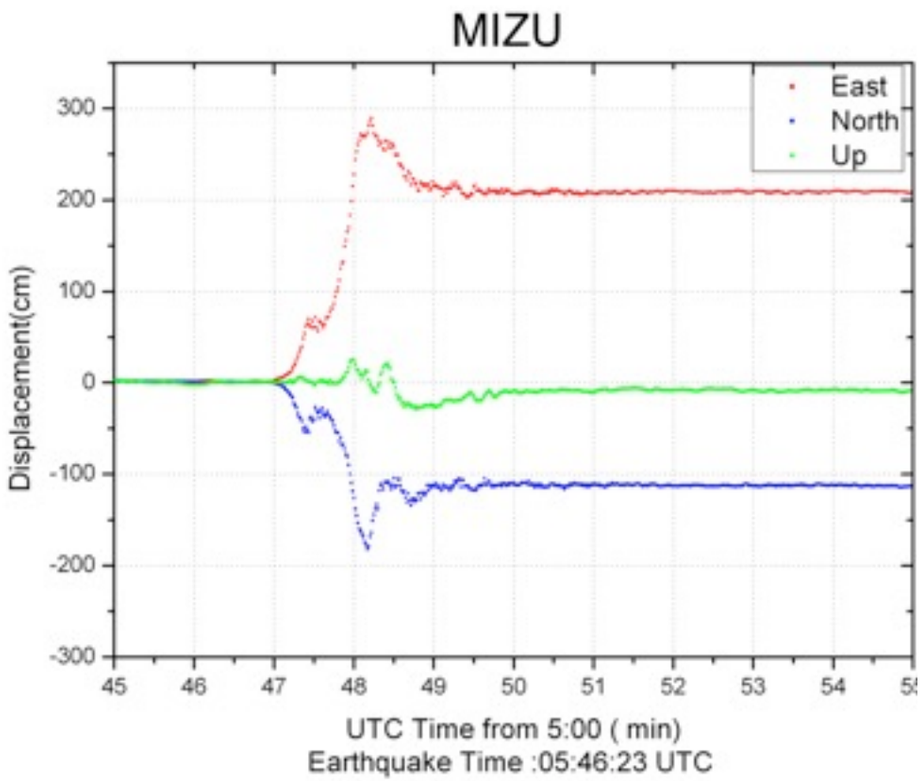
GPS waveforms





Analysis by Dr. Yokota using the GEONET data of Geographical Survey Institute

Co-seismic slip



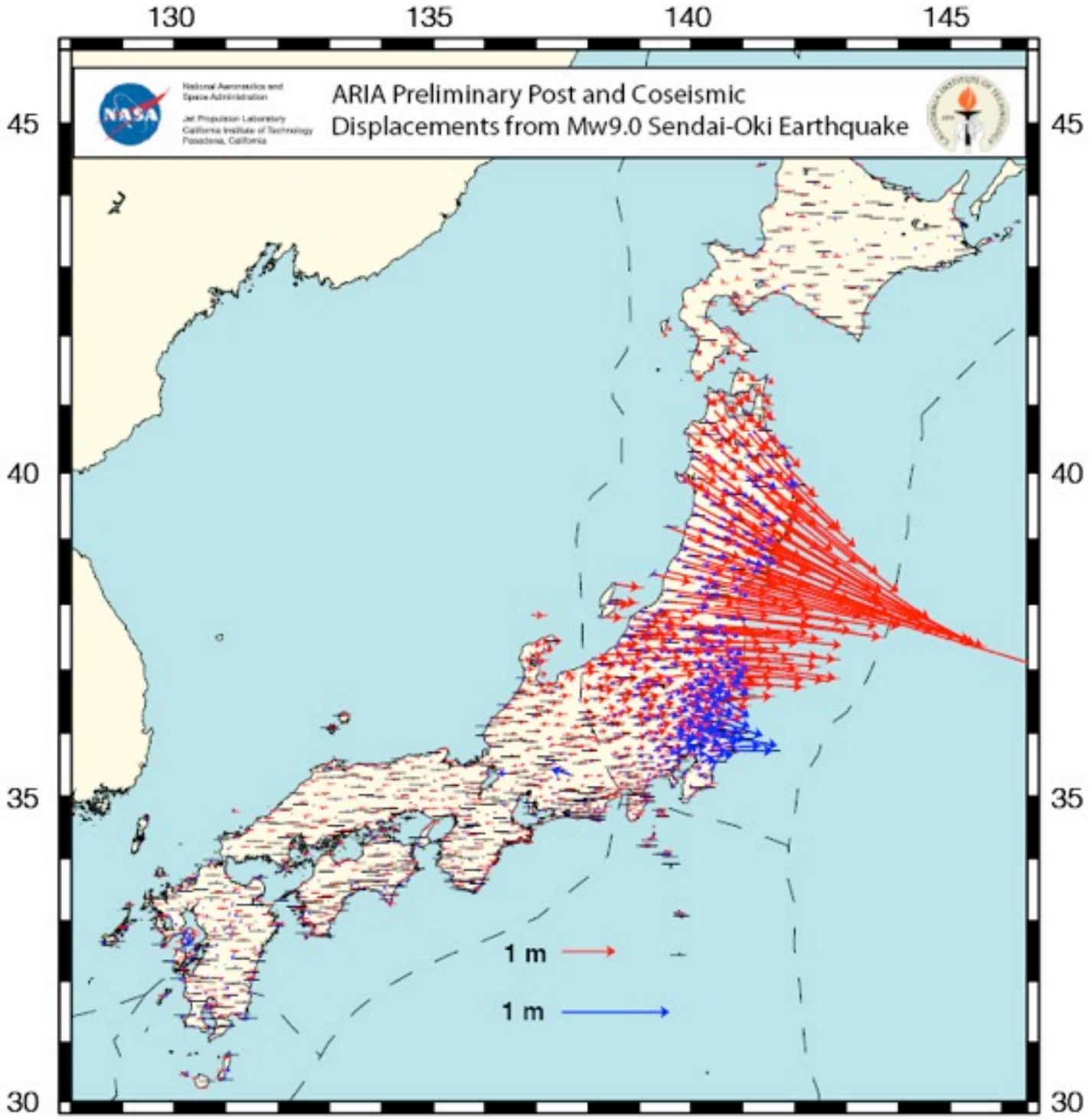
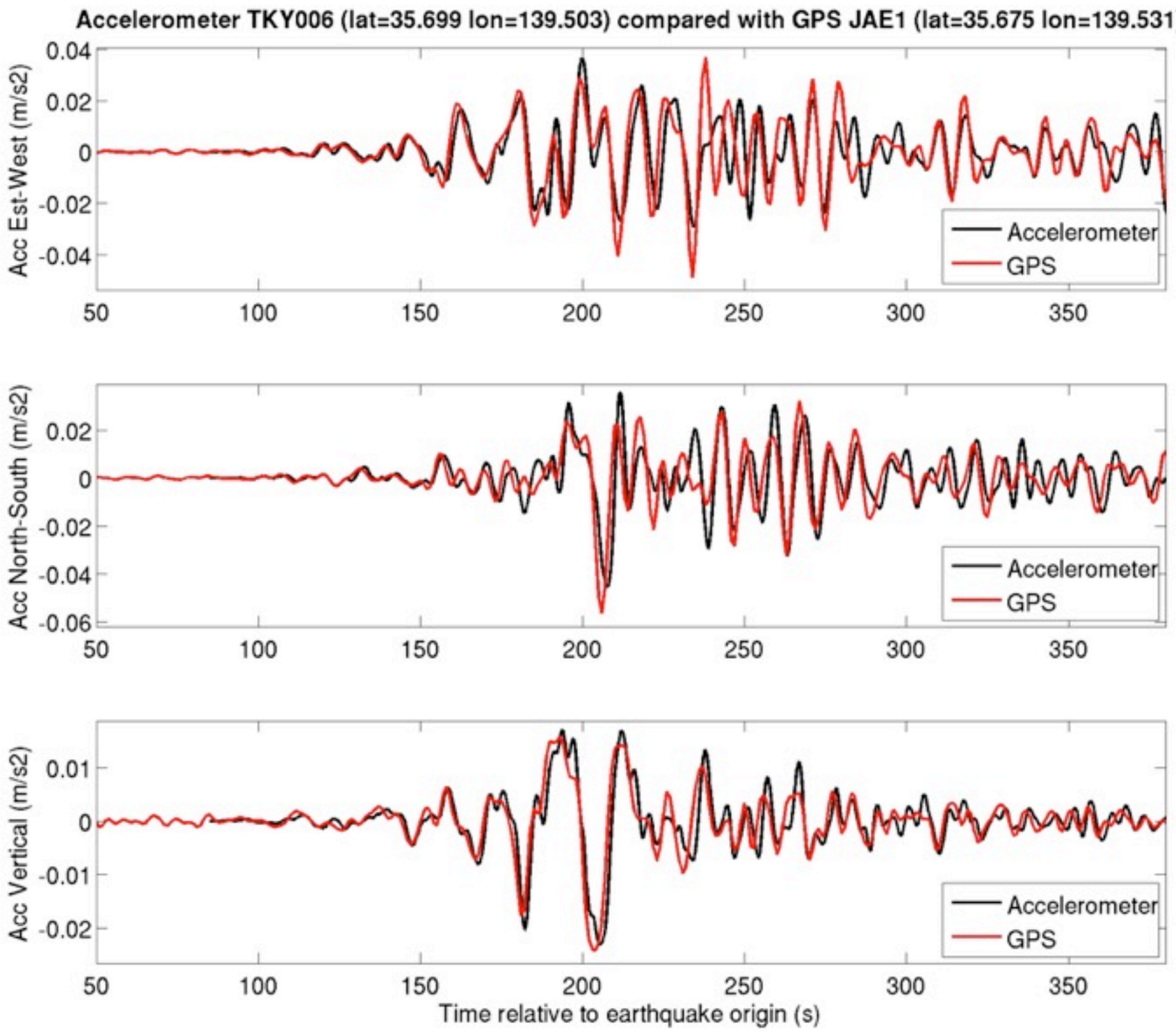


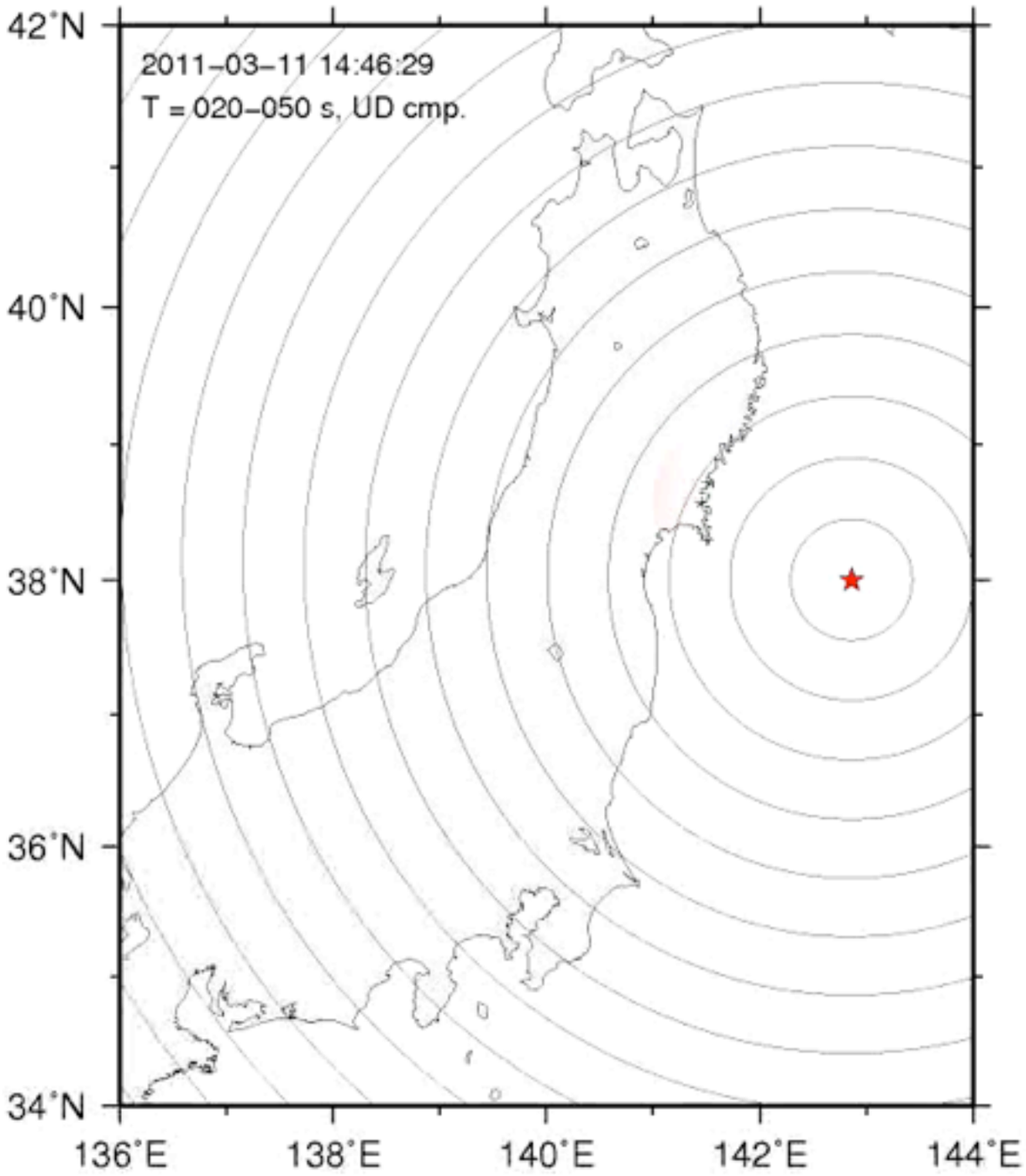
Figure shows horizontal displacements based on ARIA verion 0.3 position estimates for GEONET stations. Coseismic displacement is shown in red, and first 8 hours of postseismic motion is shown in blue, including motion caused by aftershocks. Bars at end of vector show 95% error estimate. Solutions courtesy of ARIA team at JPL and Caltech (email aria@jpl.nasa.gov or aria@caltech.edu). All original GEONET RINEX data provided to Caltech by the Geospatial Information Authority (GSI) of Japan.

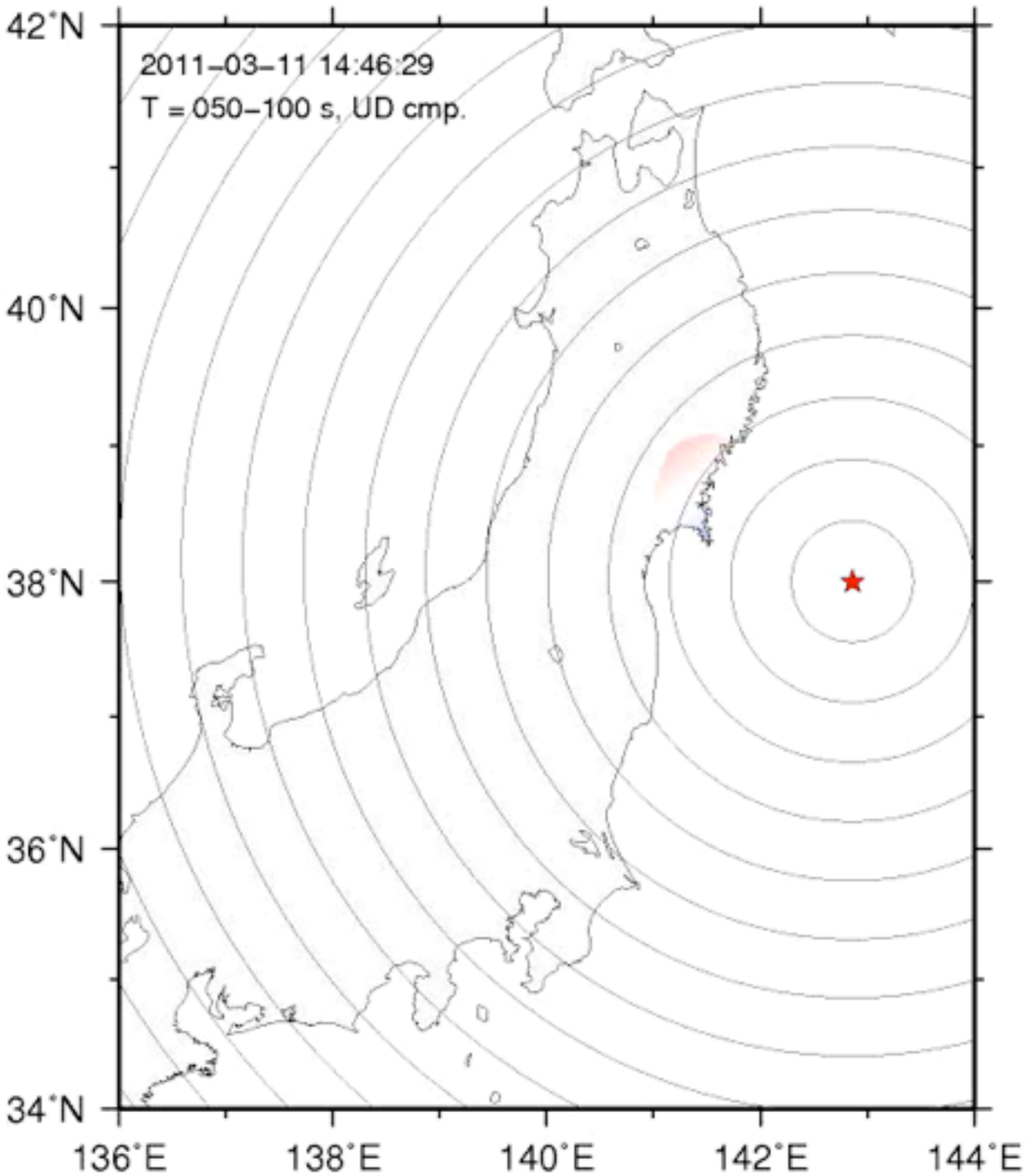
GPS and GM signals

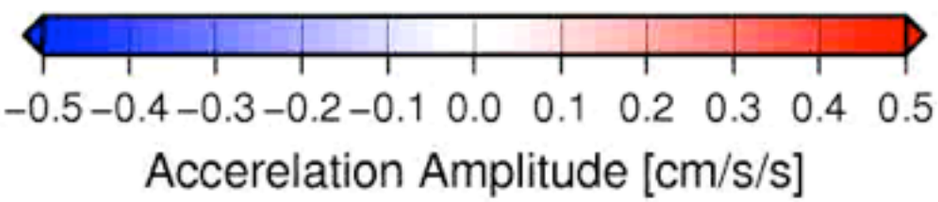


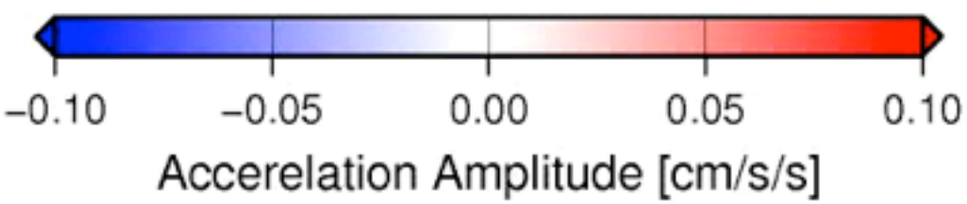
The figure shows the comparison between this GPS signal - twice differentiated - and the accelerometric signal, in the [0.005Hz - 0.125Hz] range.

Long period GM



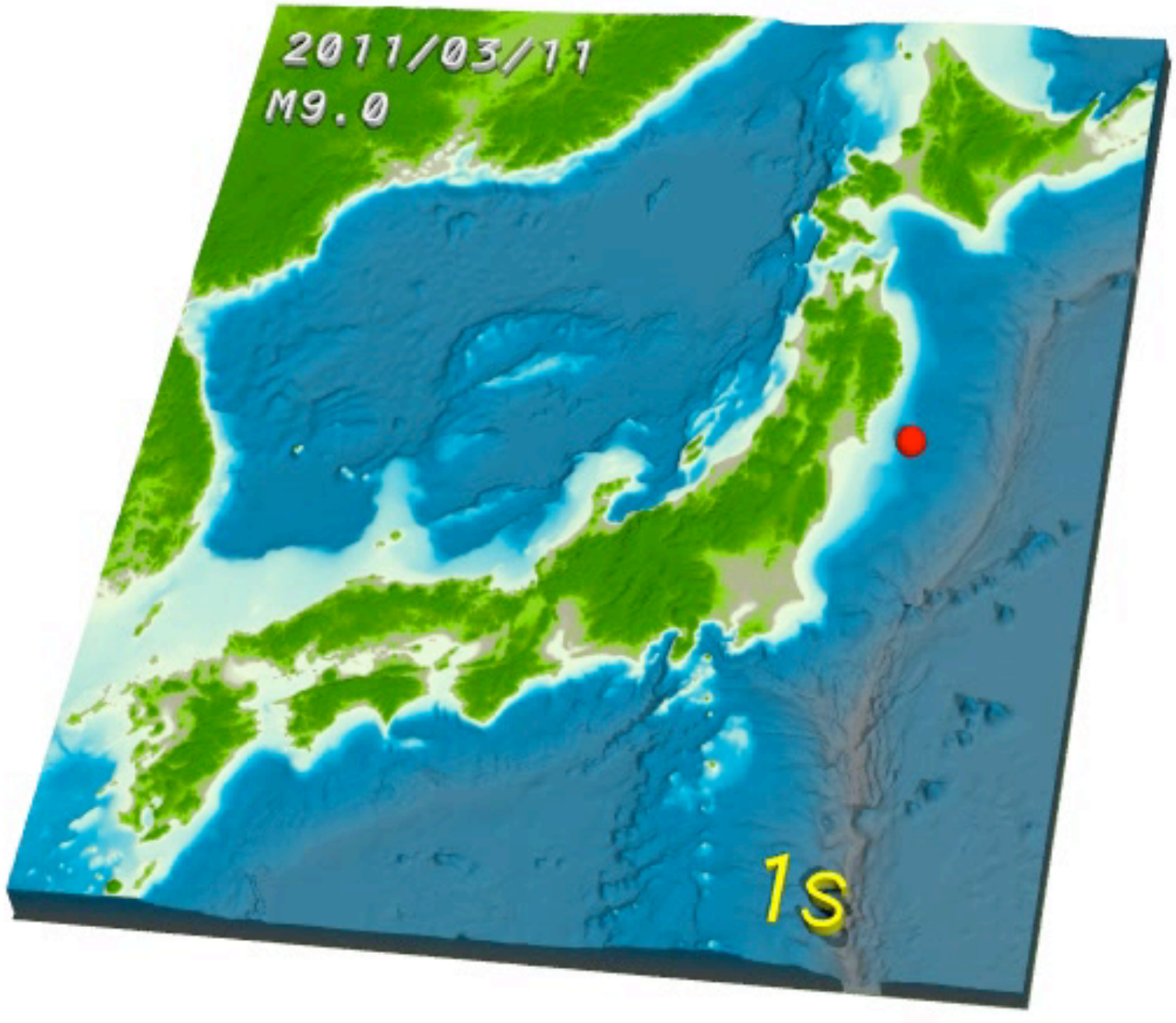






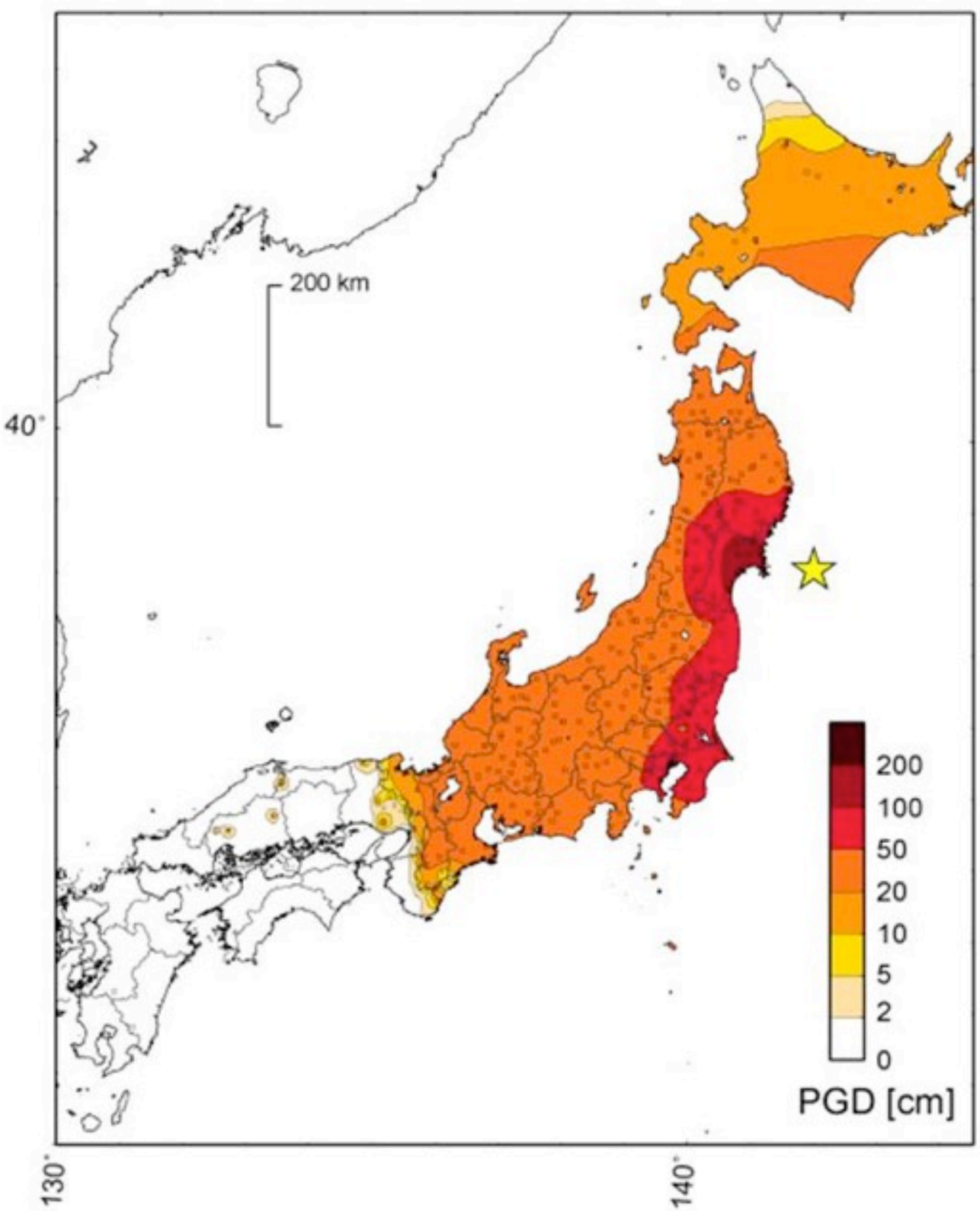
"Earthquake Research Institute, University of Tokyo: Dr. Furumura and Project Researcher Maeda

Ground motion animation: time scales...



Courtesy of Takashi Furumura

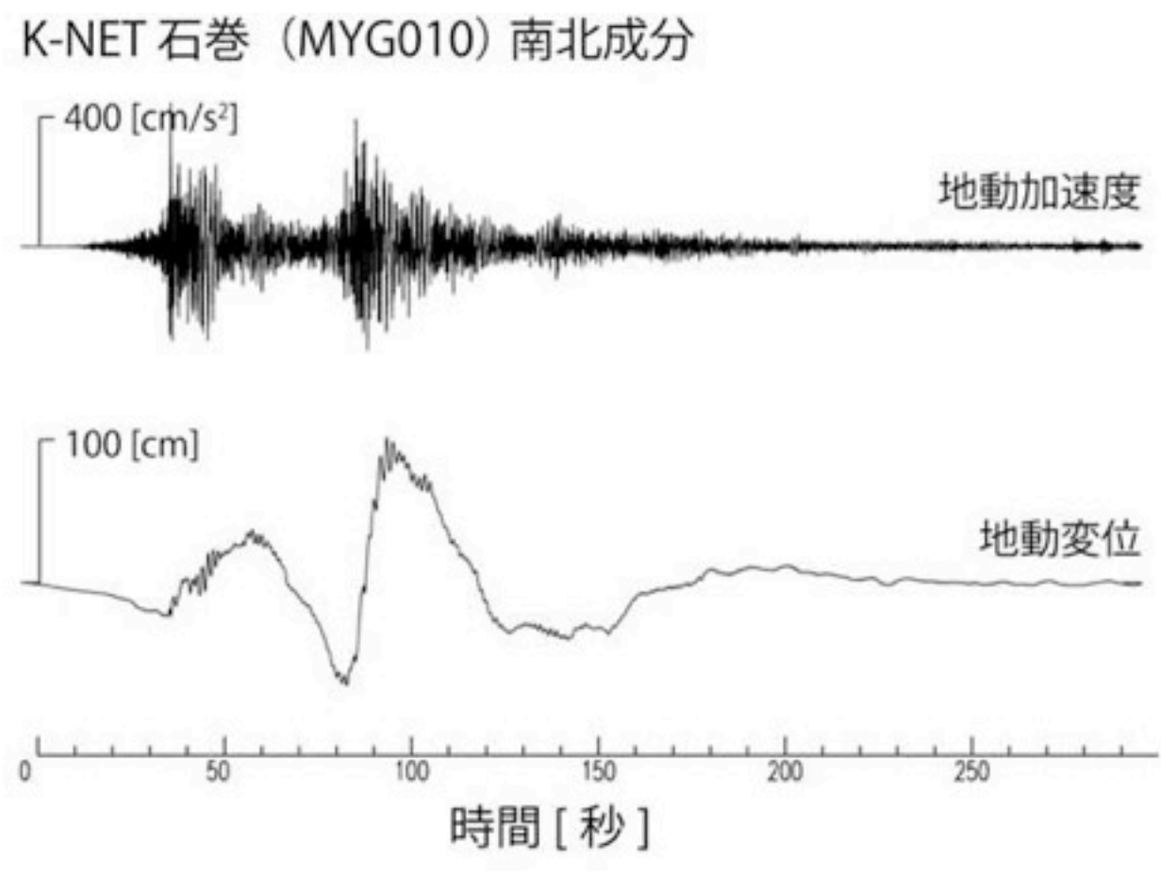
PGD



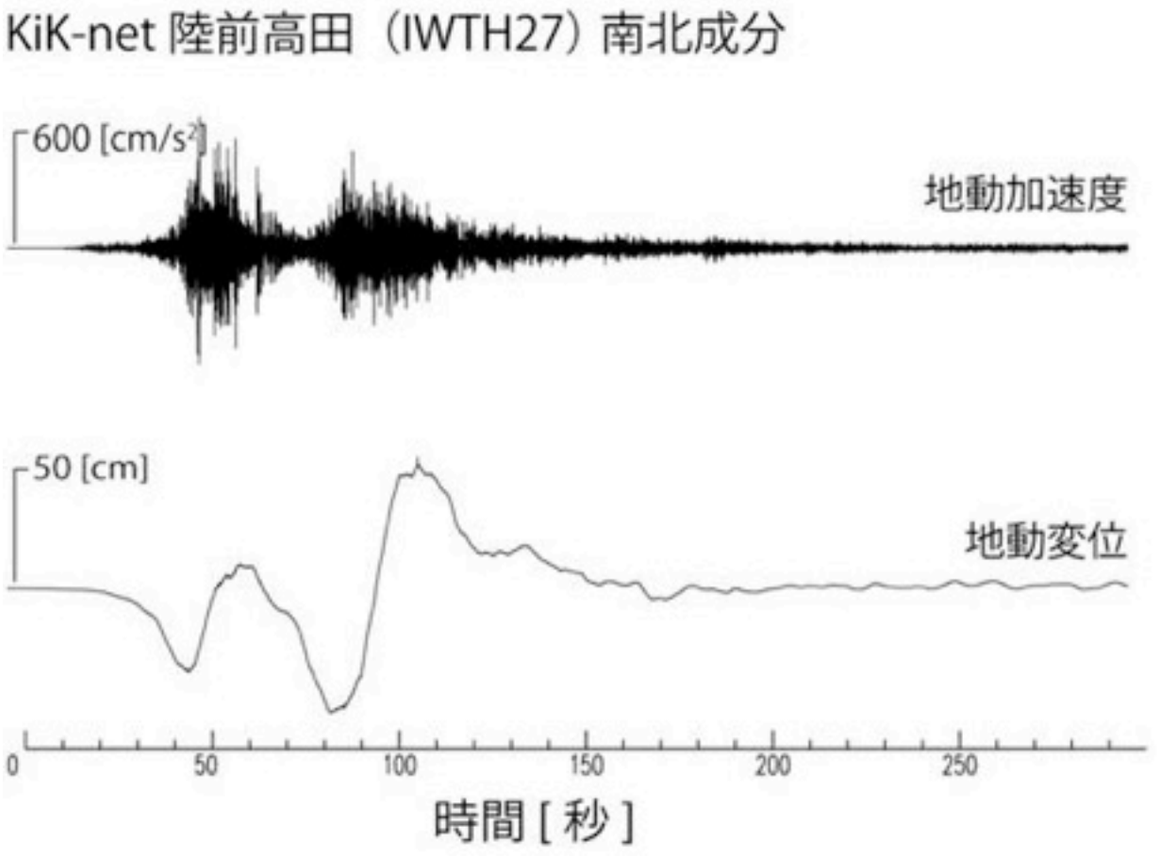
- A strong ground acceleration of over 2933 cm/s/s was observed in K-NET Tsukidate observation station (Miyagi pref.) near the hypocenter, and a strong ground acceleration propagated in broad area from Ibaraki to southern Iwate. The distribution of strong ground acceleration is extending to three areas: between Iwate and Miyagi prefecture, Fukushima pref., between Tochigi and Ibaraki pref. Therefore, it is assumed that a huge fault slip have occurred on the east of these areas. The ground acceleration is decaying drastically just after the border of Itoigawa-Shizuoka Tectonic Line, and it suggests that the wave attenuated at around this area.

Waveforms

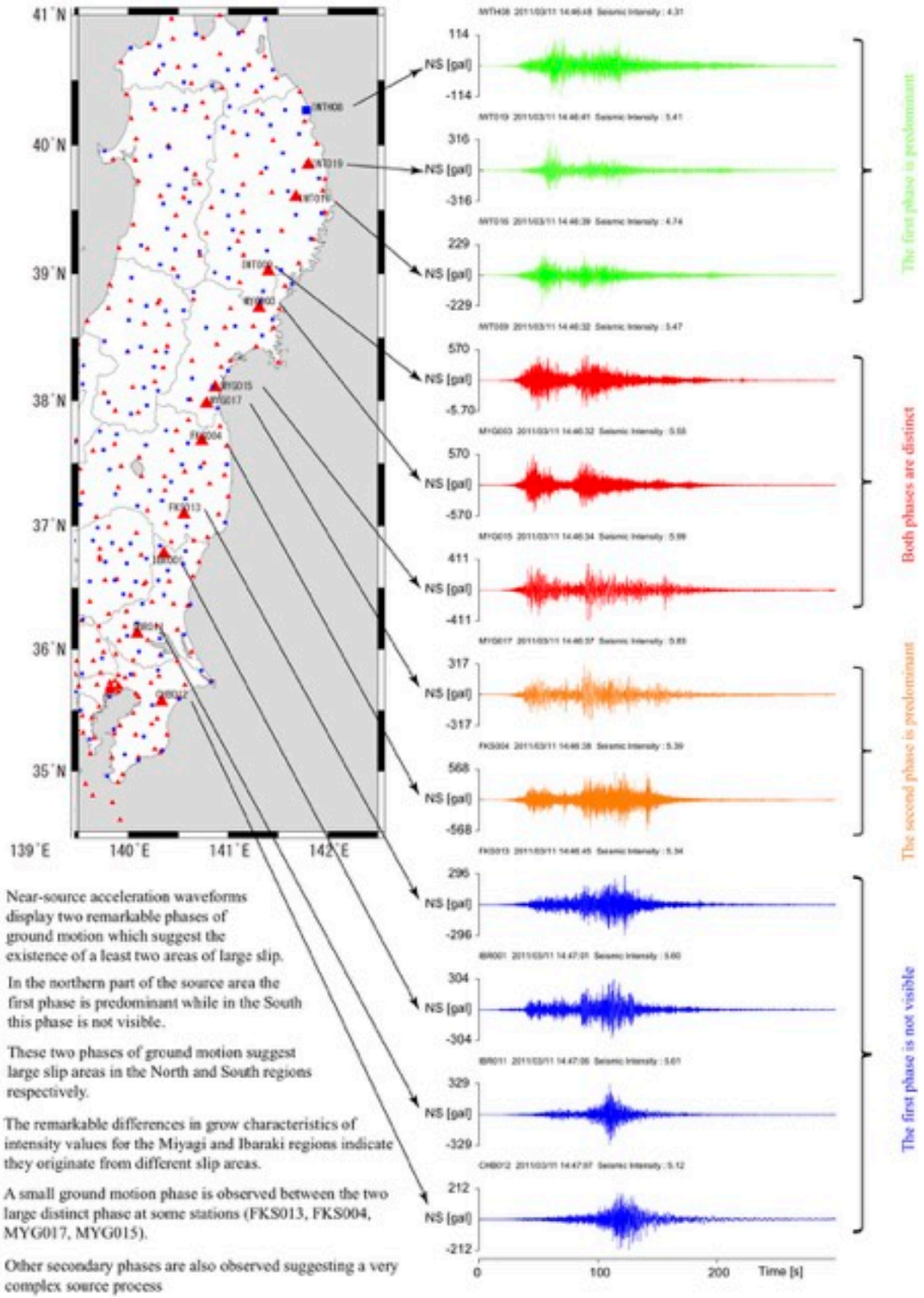
- Maximum acceleration and maximum displacement of ground motion in Ishinomaki and Rikuzentakata where ground motion was strong. The arrival of 2 strong seismic wave groups is seen after about 50 seconds. They suggest that a strong seismic wave was radiated from the 2 major asperities of the Miyagi coast and Iwate coast.



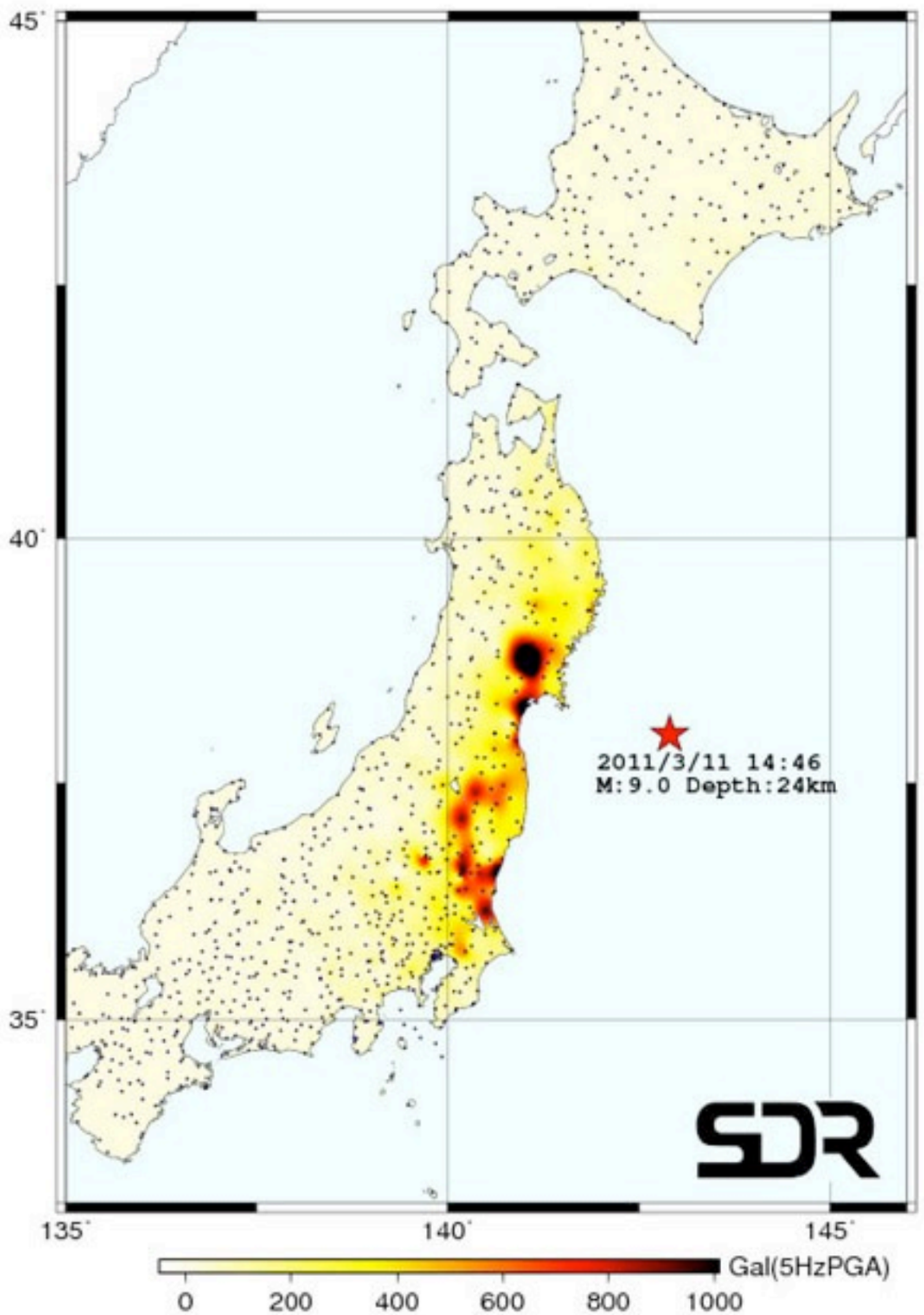
- Two long-period pulses (40-50 second) was found in ground displacement and its amplitude is more than 50 to 100cm. The long-period of ground motion that lasted for 100 and several tens of seconds, indicates the long time rupture process of the fault in this massive earthquake.



Rupture from ground motion

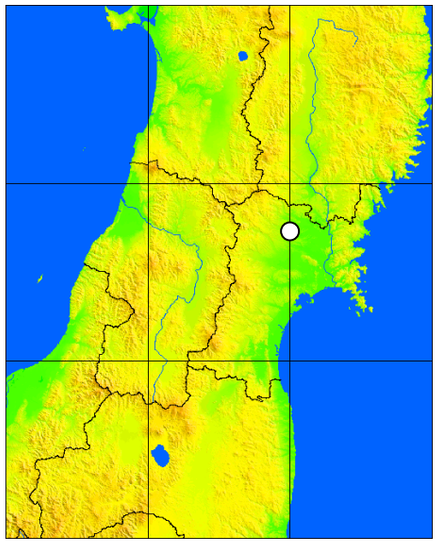


Source: Knet-NIED

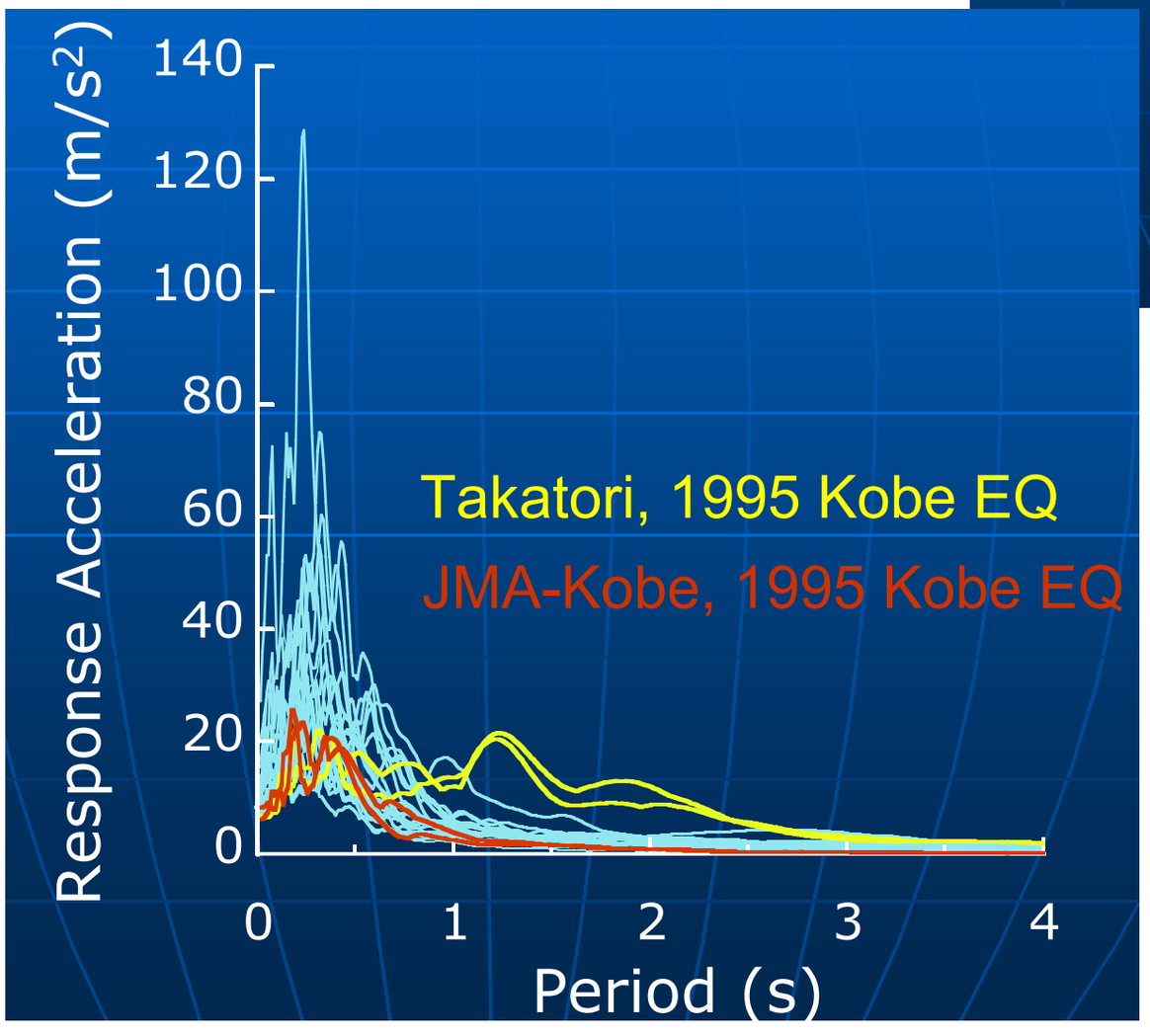


Strong motion distribution at Eastern Japan (5HzPGA)
This PGA is commonly used as an index for the alarm to stop the train operation.

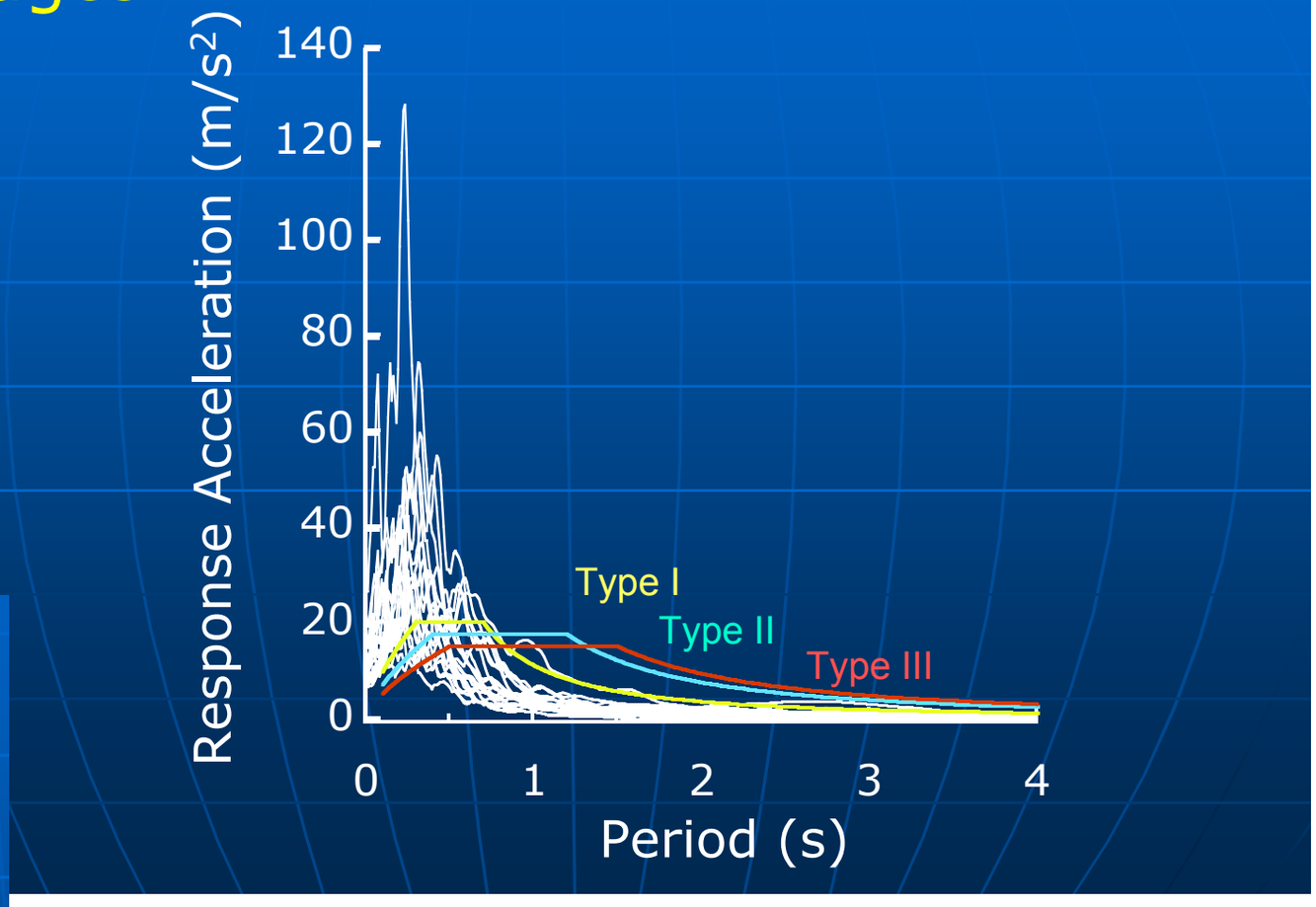
Tsukidate

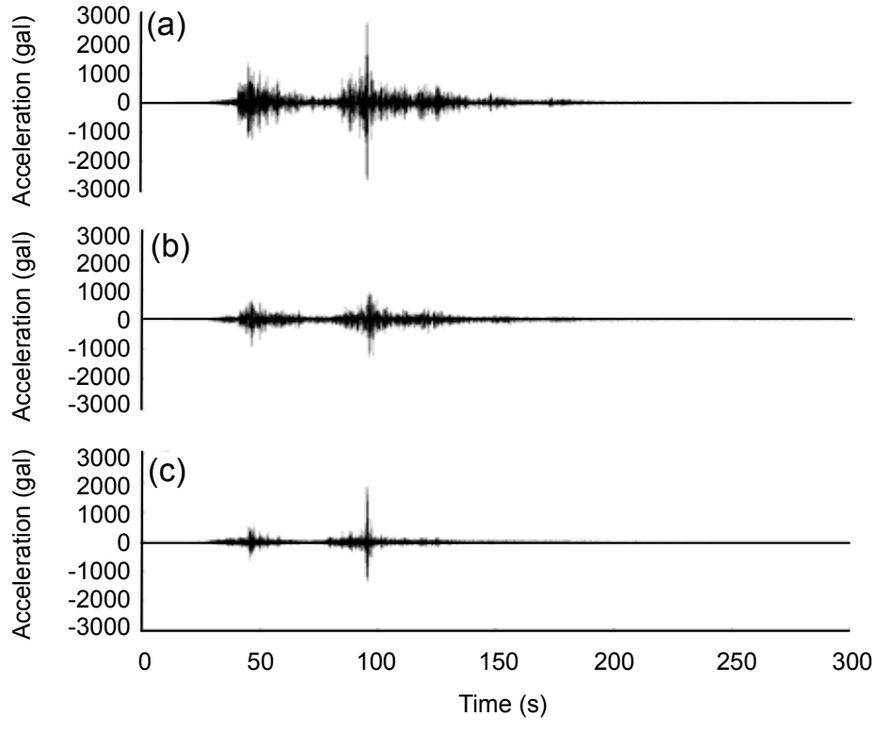


Courtesy of Kazuhiko Kawashima

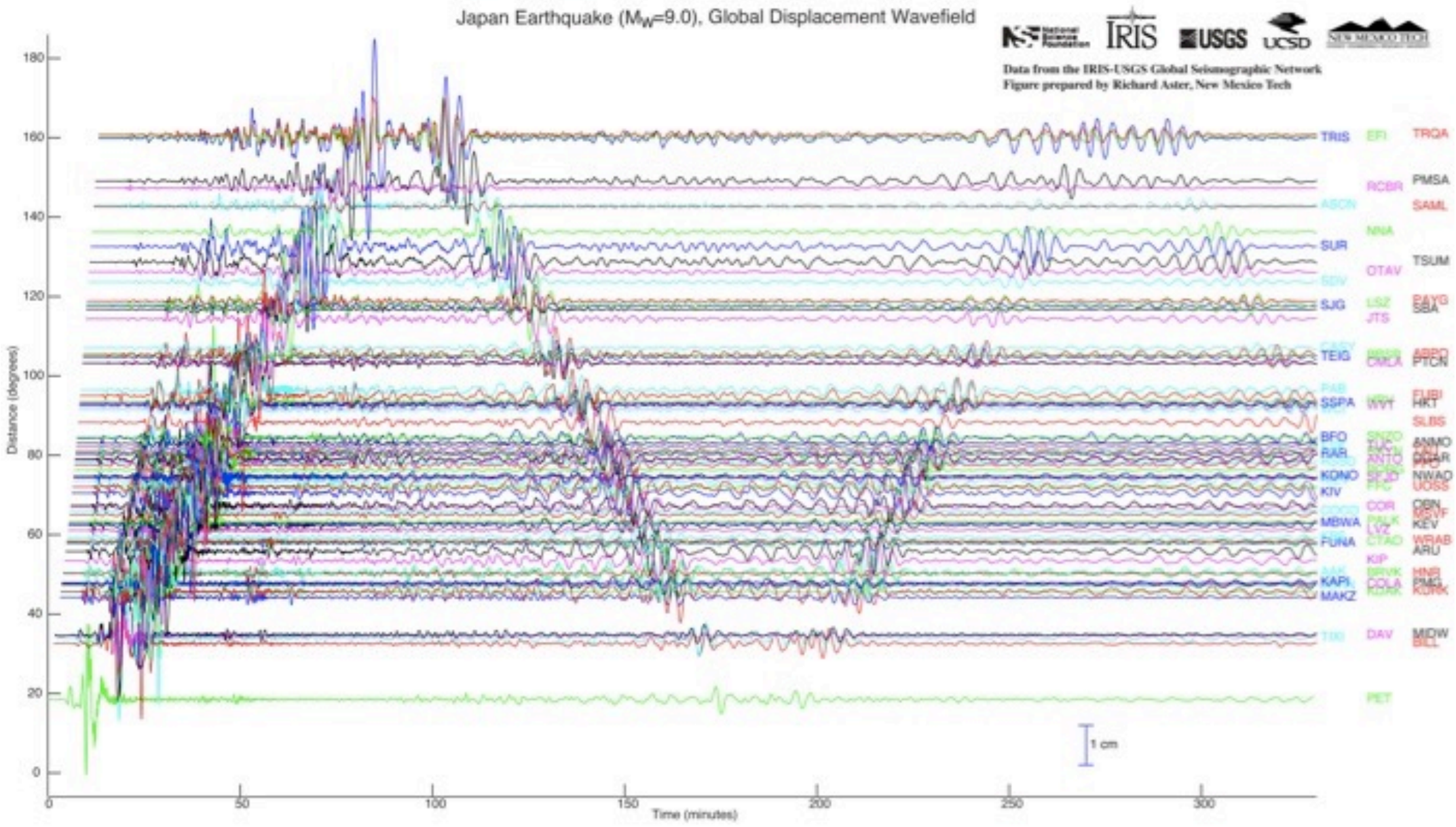


Comparison with Type II Design Spectra, JRA Design Specifications of Bridges



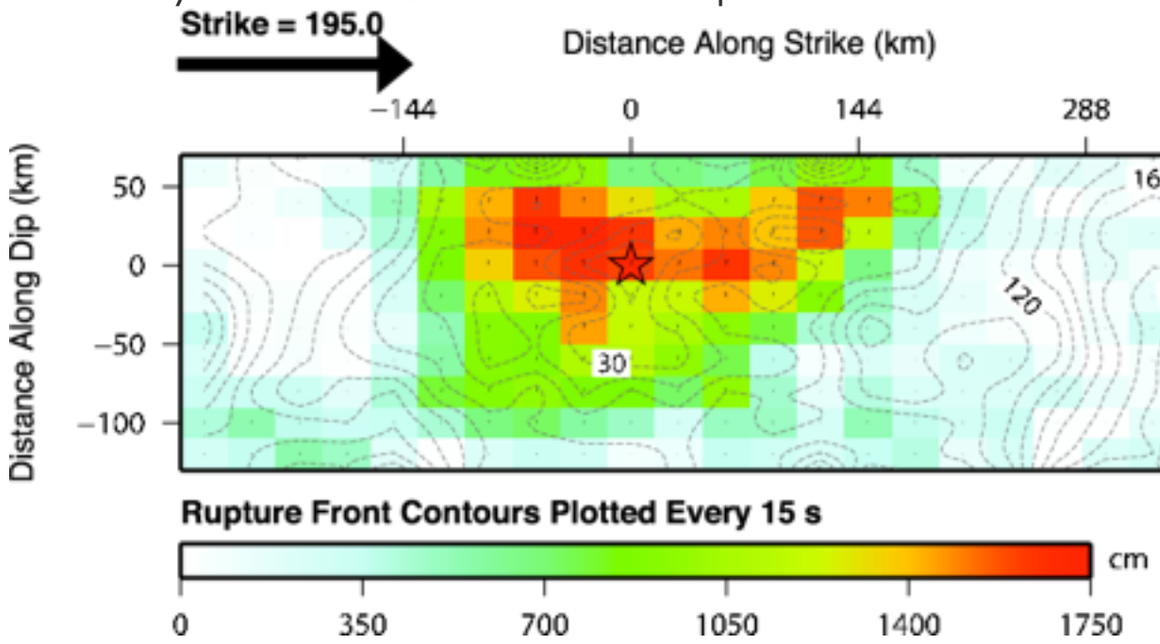


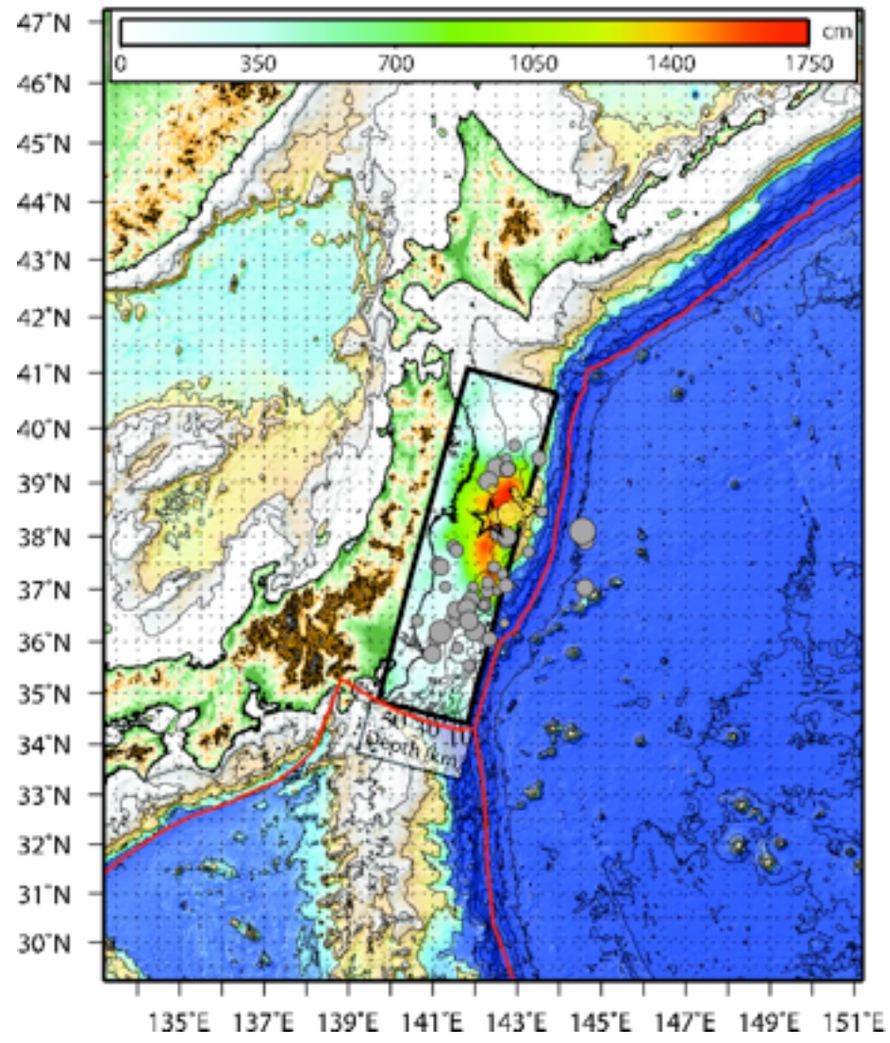
Ground motion - Worldwide

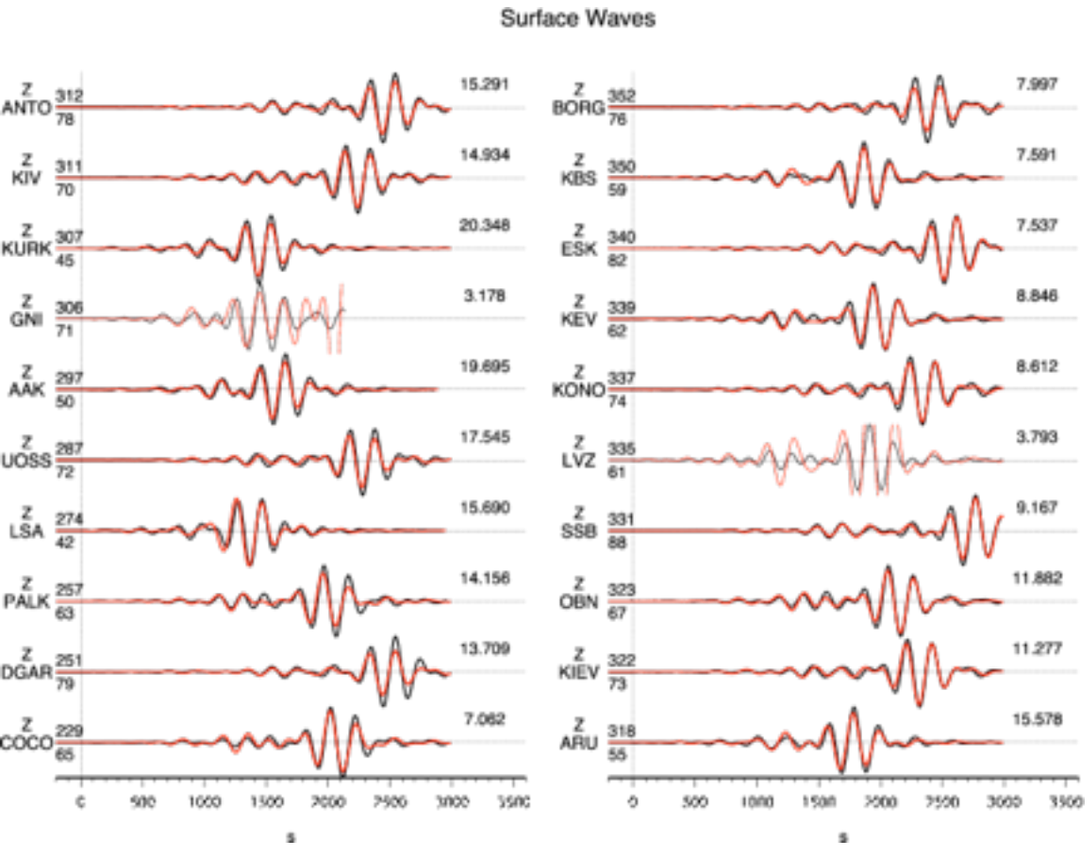


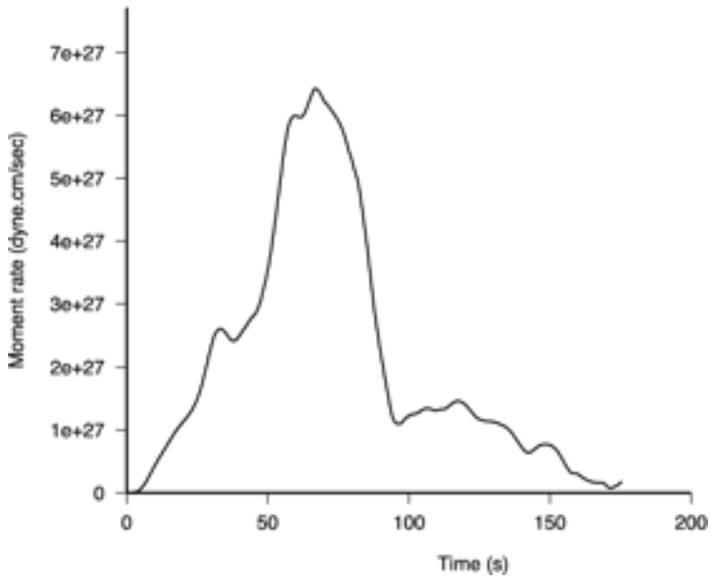
USGS - Finite fault model

Cross-section of slip distribution. The strike direction of the fault plane is indicated by the black arrow and the hypocenter location is denoted by the red star. The slip amplitude are showed in color and motion direction of the hanging wall relative to the footwall is indicated by black arrows. Contours show the rupture initiation time in seconds.

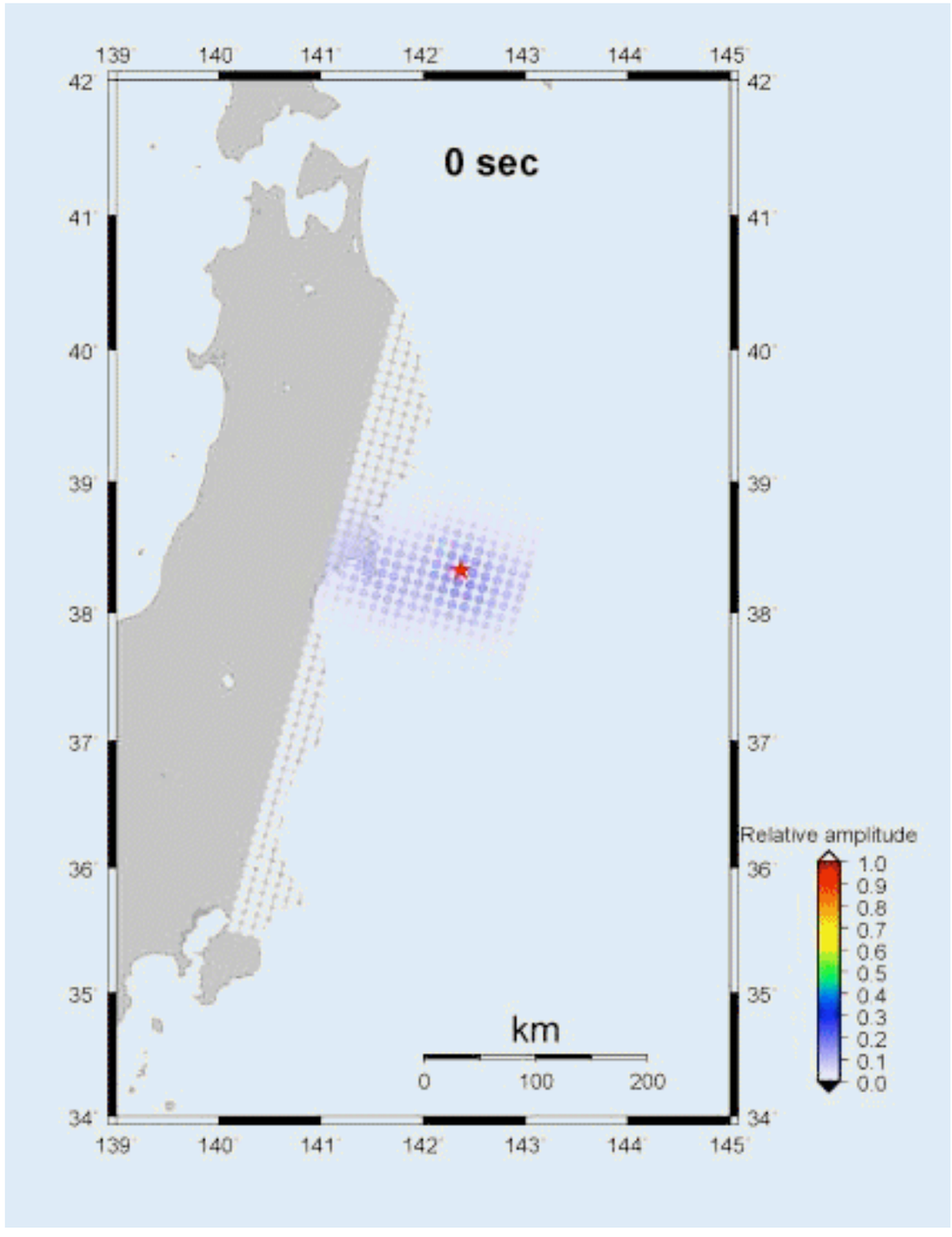






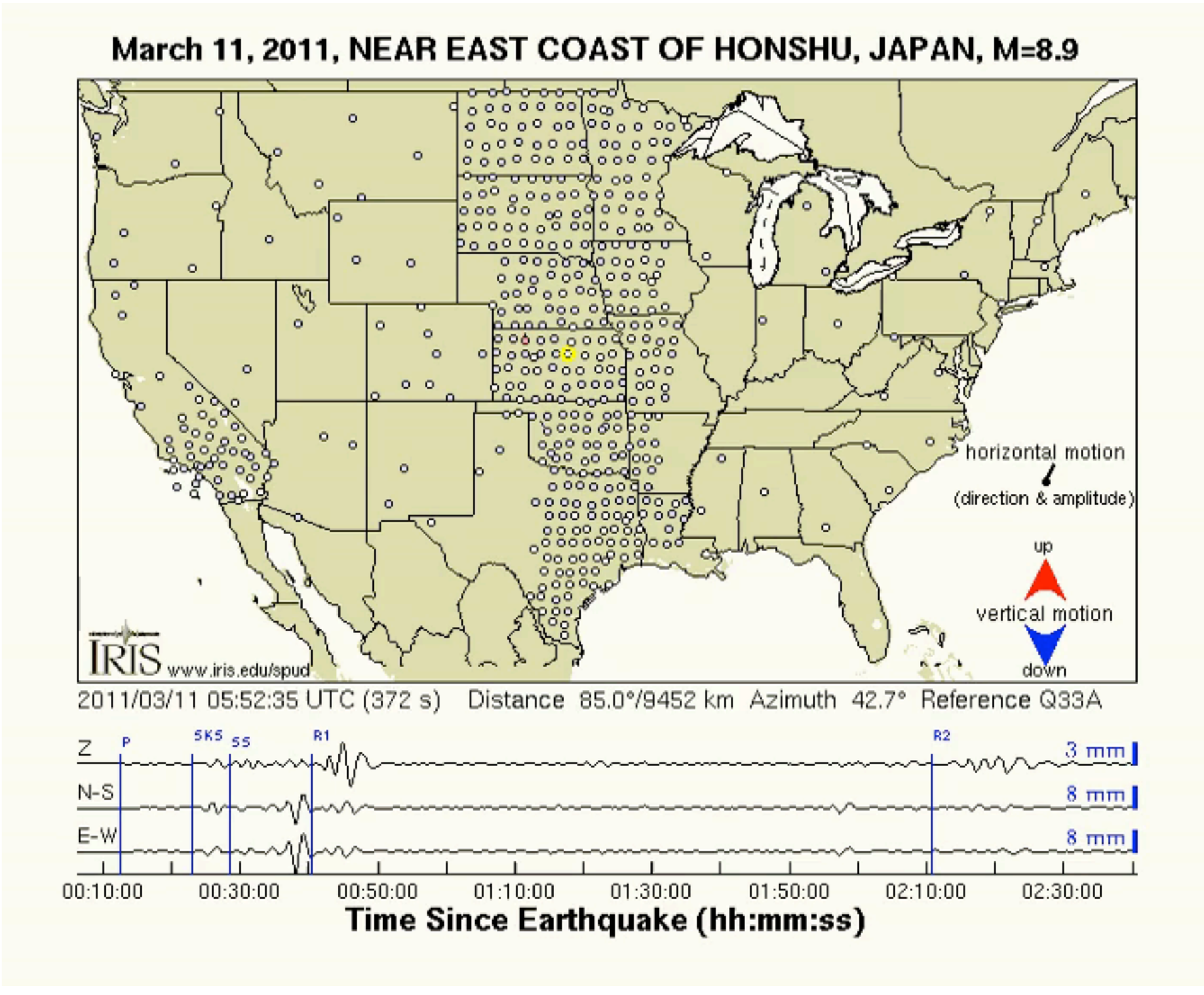


Finite fault model from backprojection



Courtesy of Dun Wang and Jim Mori

Ground motion - USA

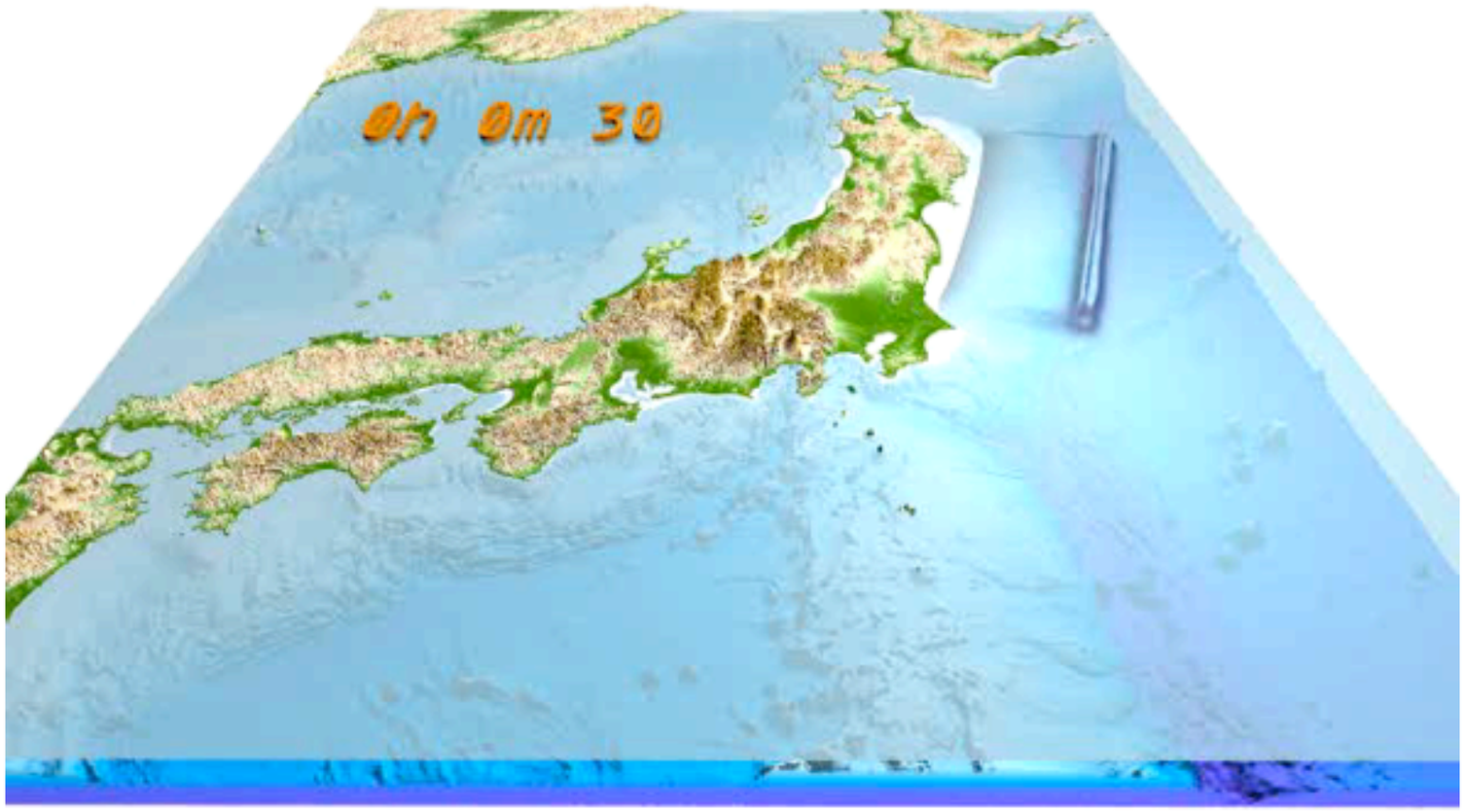


Tsunami animation: time scales...

http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/eng/

http://supersites.earthobservations.org/honshu.php

http://eqseis.geosc.psu.edu/~cammon/Japan2011EQ/



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