SEISMOLOGY

Master Degree Programme in Physics - UNITS
Physics of the Earth and of the Environment

INTRODUCTION

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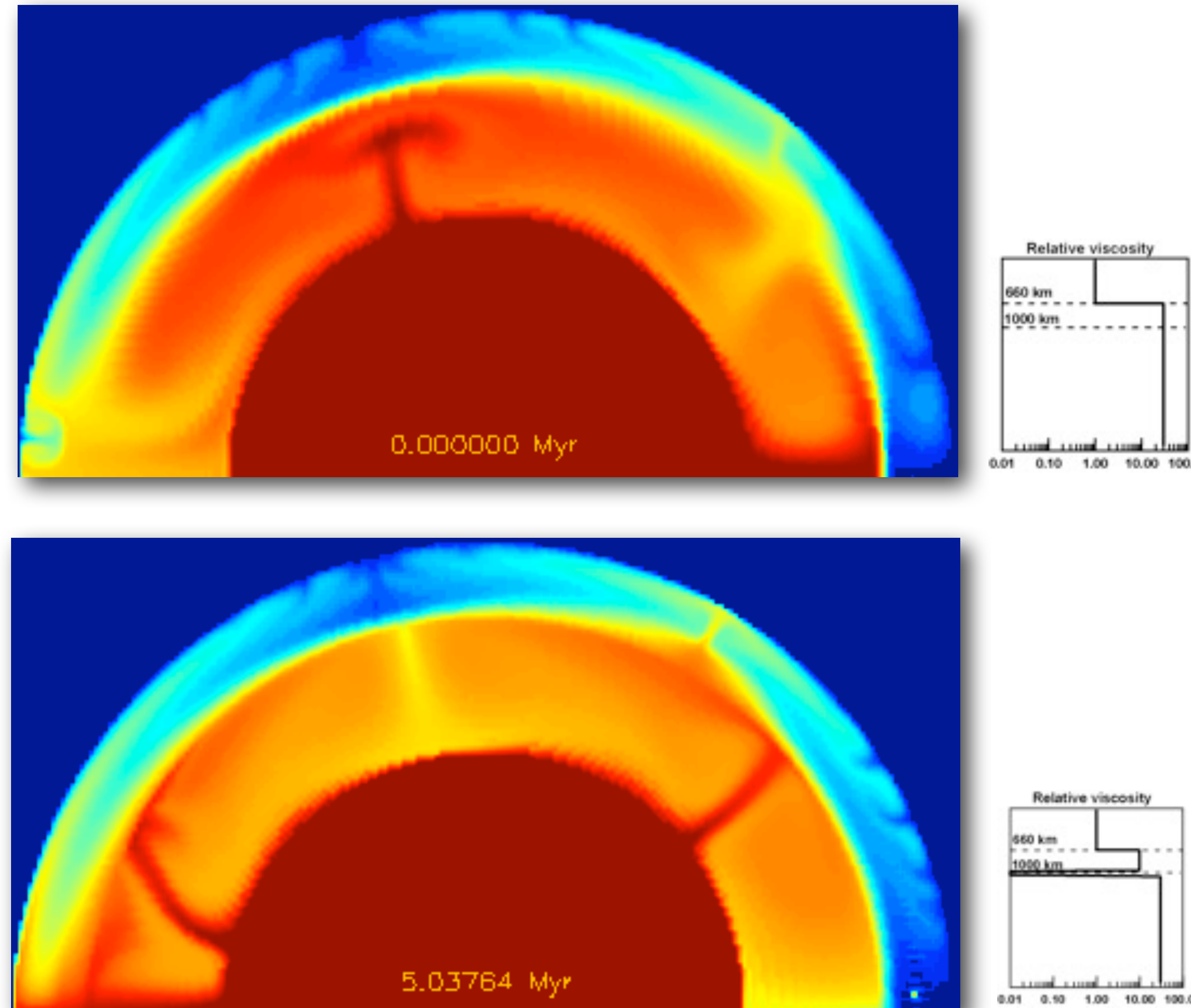
http://moodle2.units.it/course/view.php?id=362

Why do earthquakes happen?

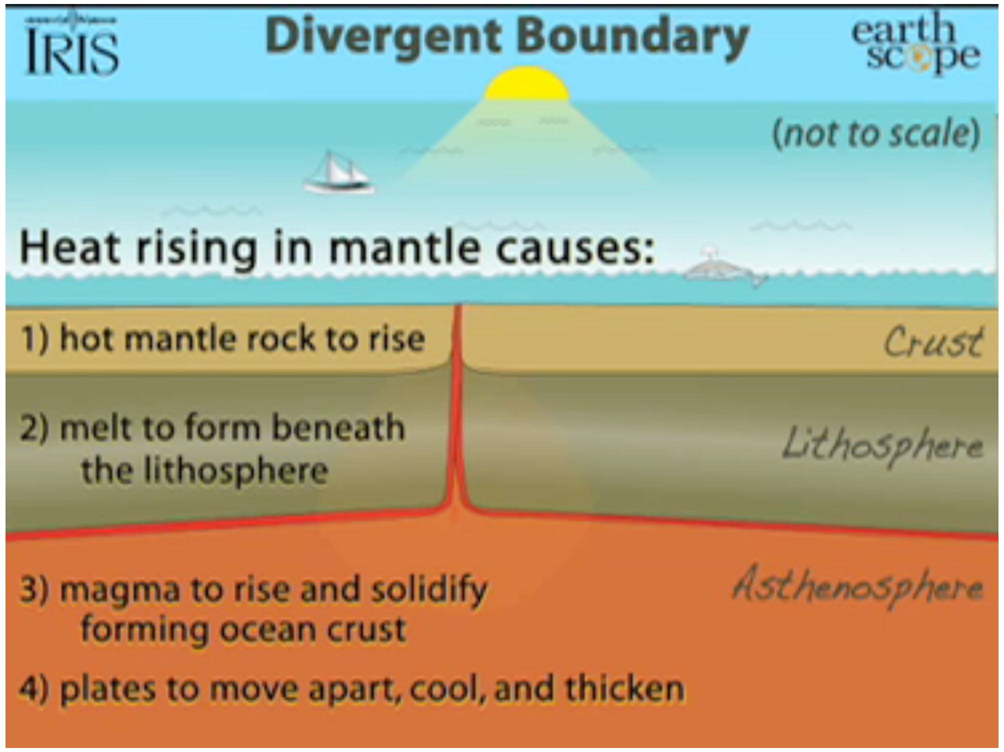
From Namazu....

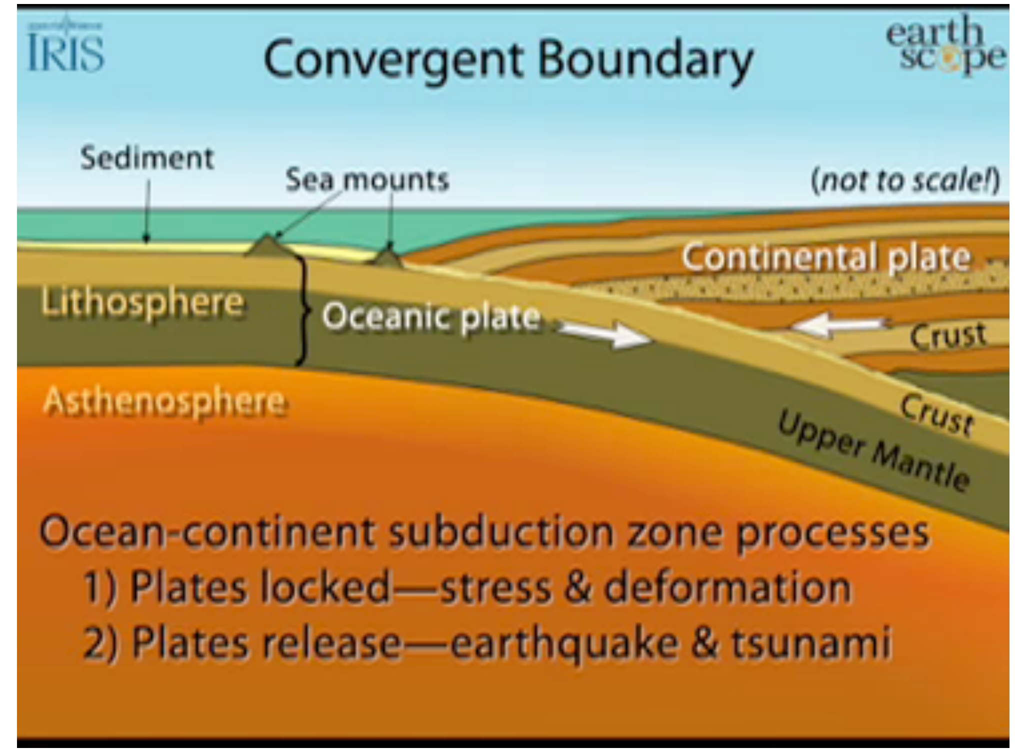


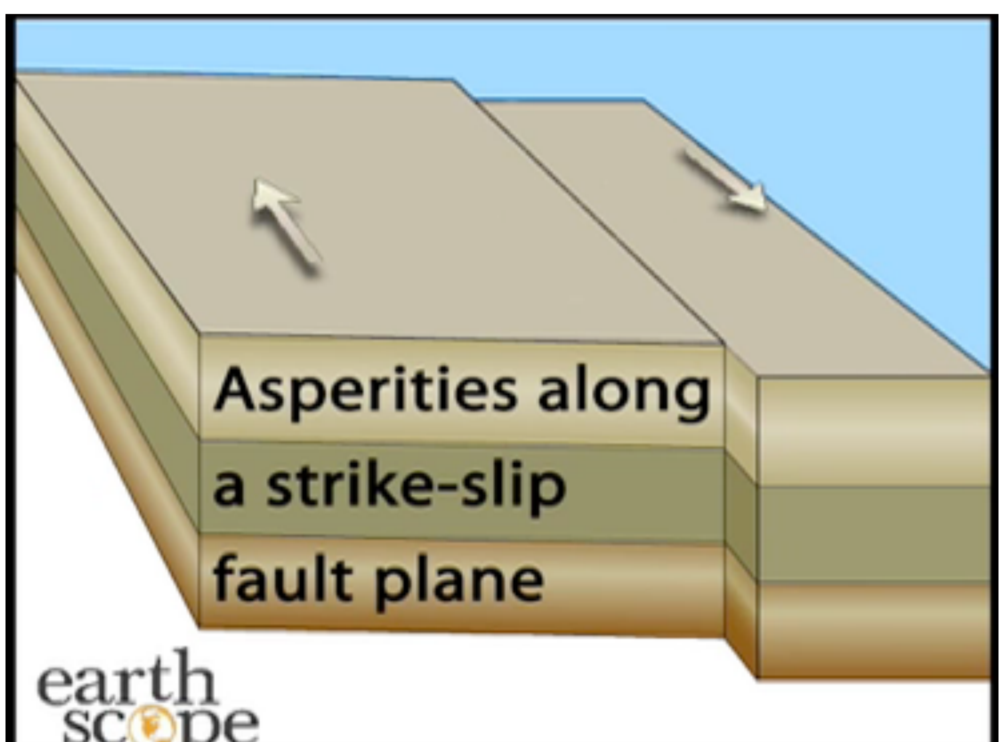
Thermo chemical convection
http://geo.mff.cuni.cz/~cizkova/Anim/animace.htm

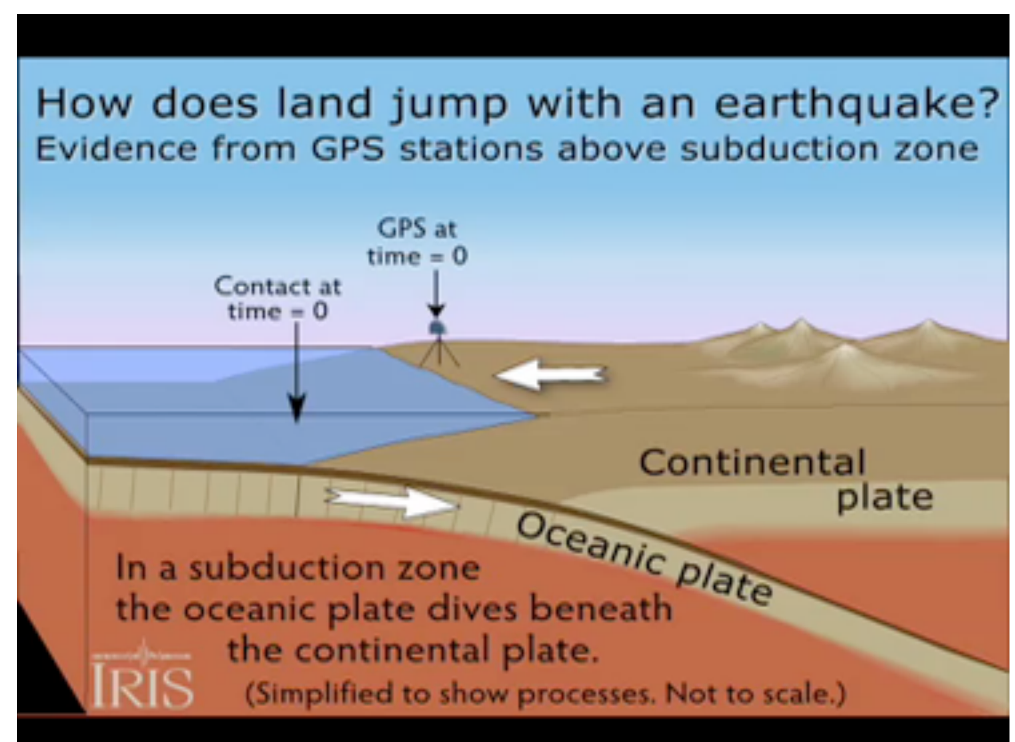
...to complex fluid dynamics

Why do earthquakes happen?

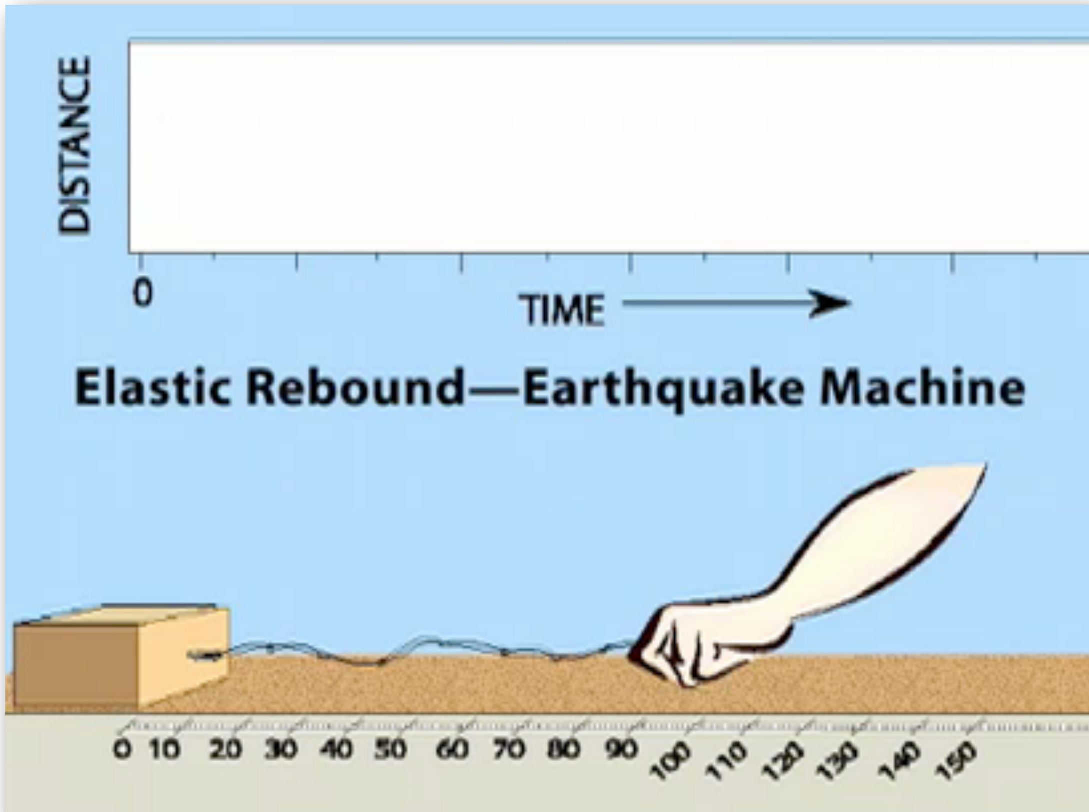


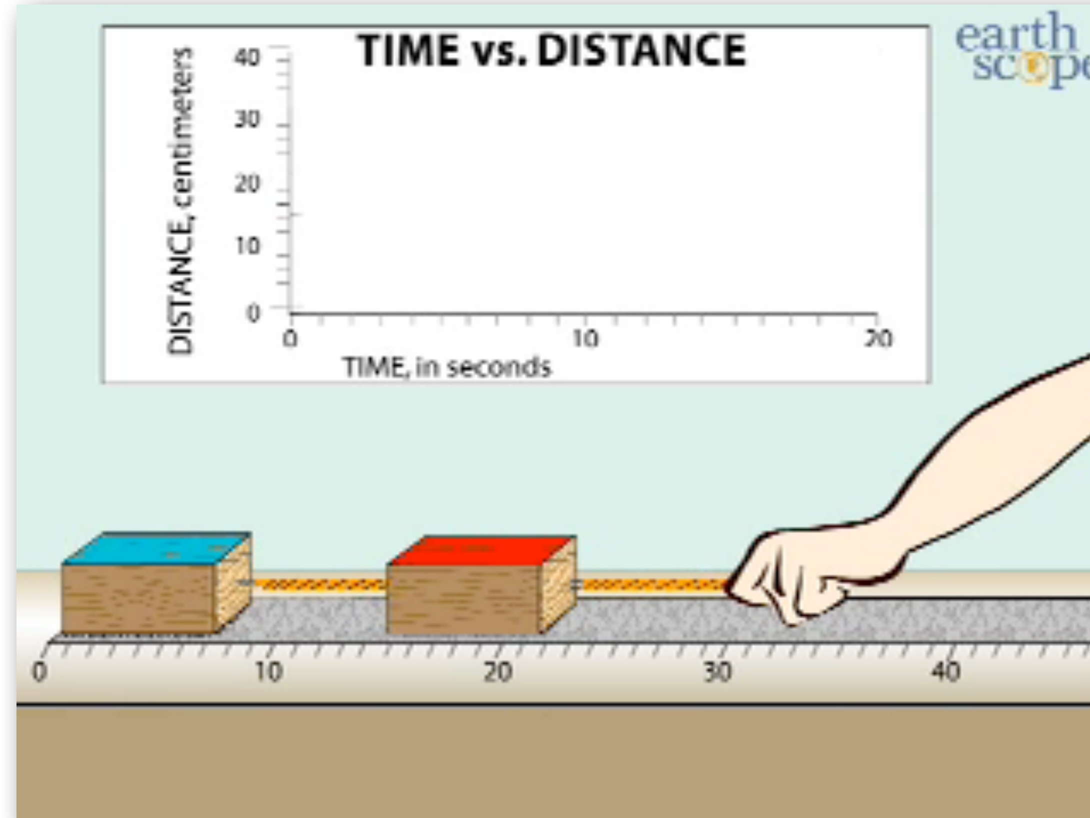


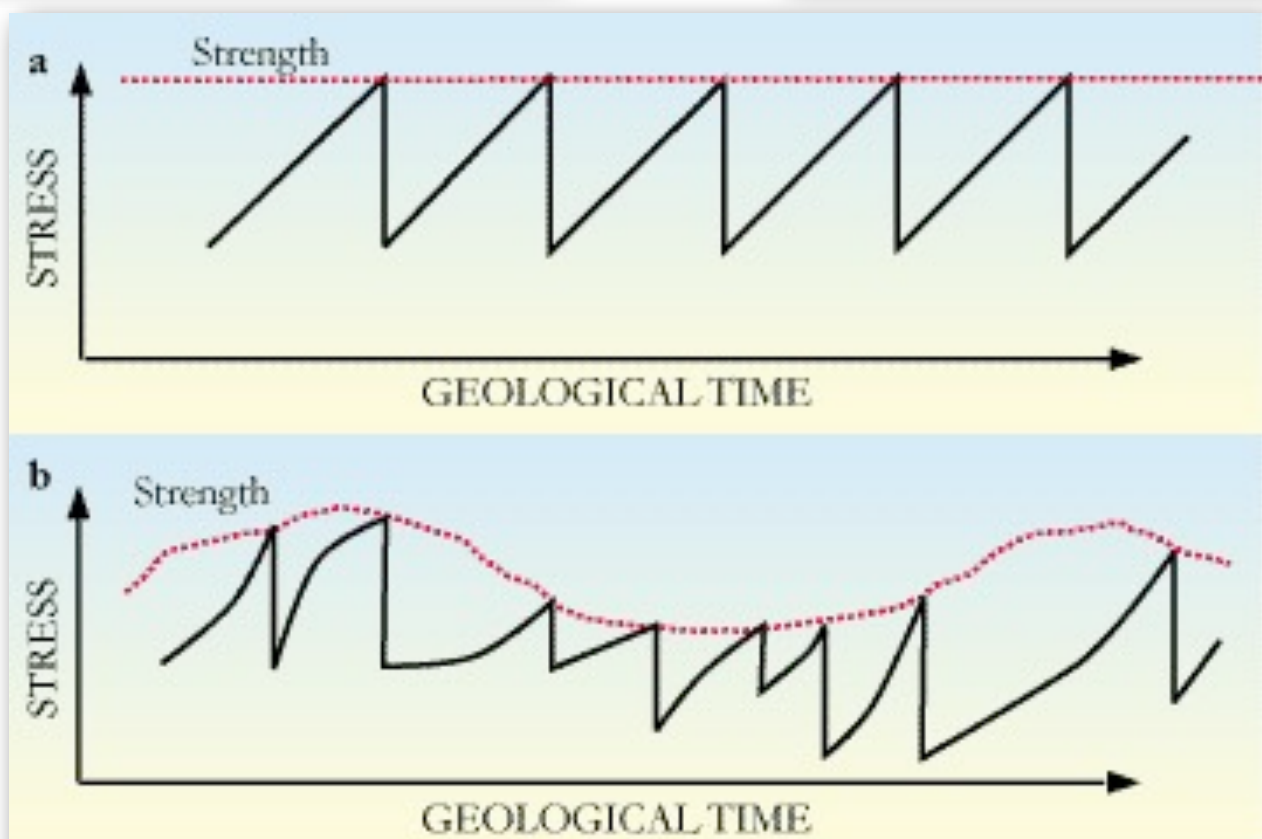




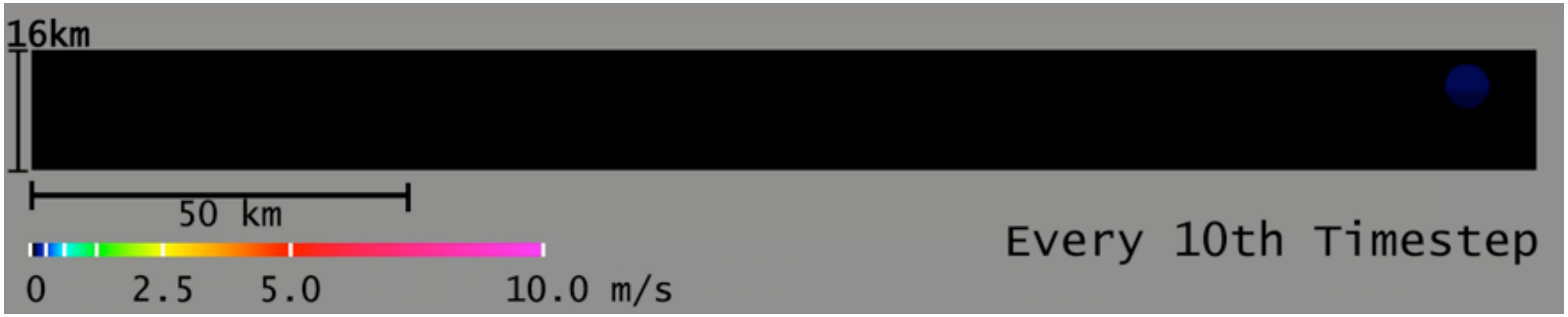
Earthquake (complex) cycle





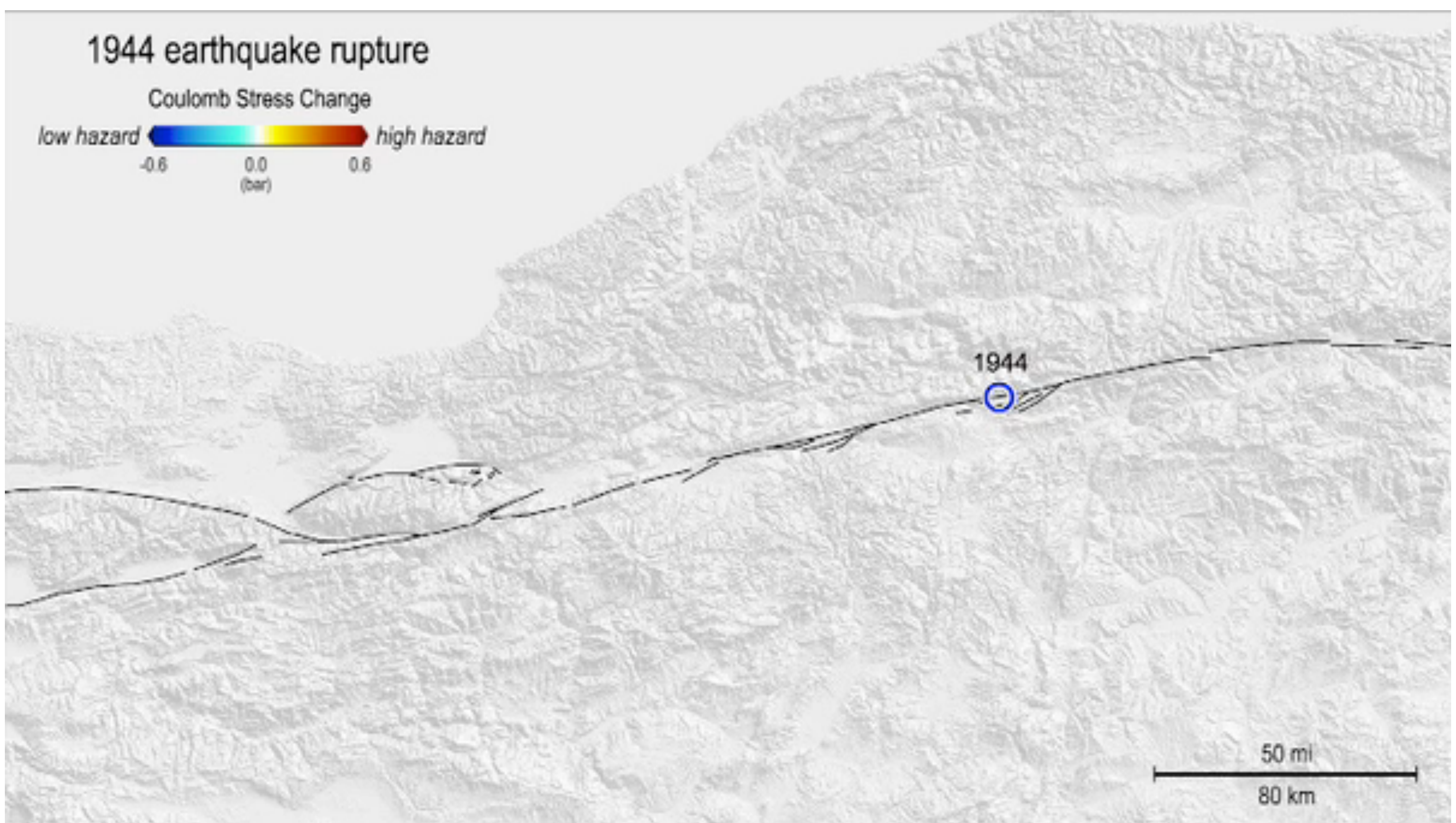


Dynamic rupture and stress transfer



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

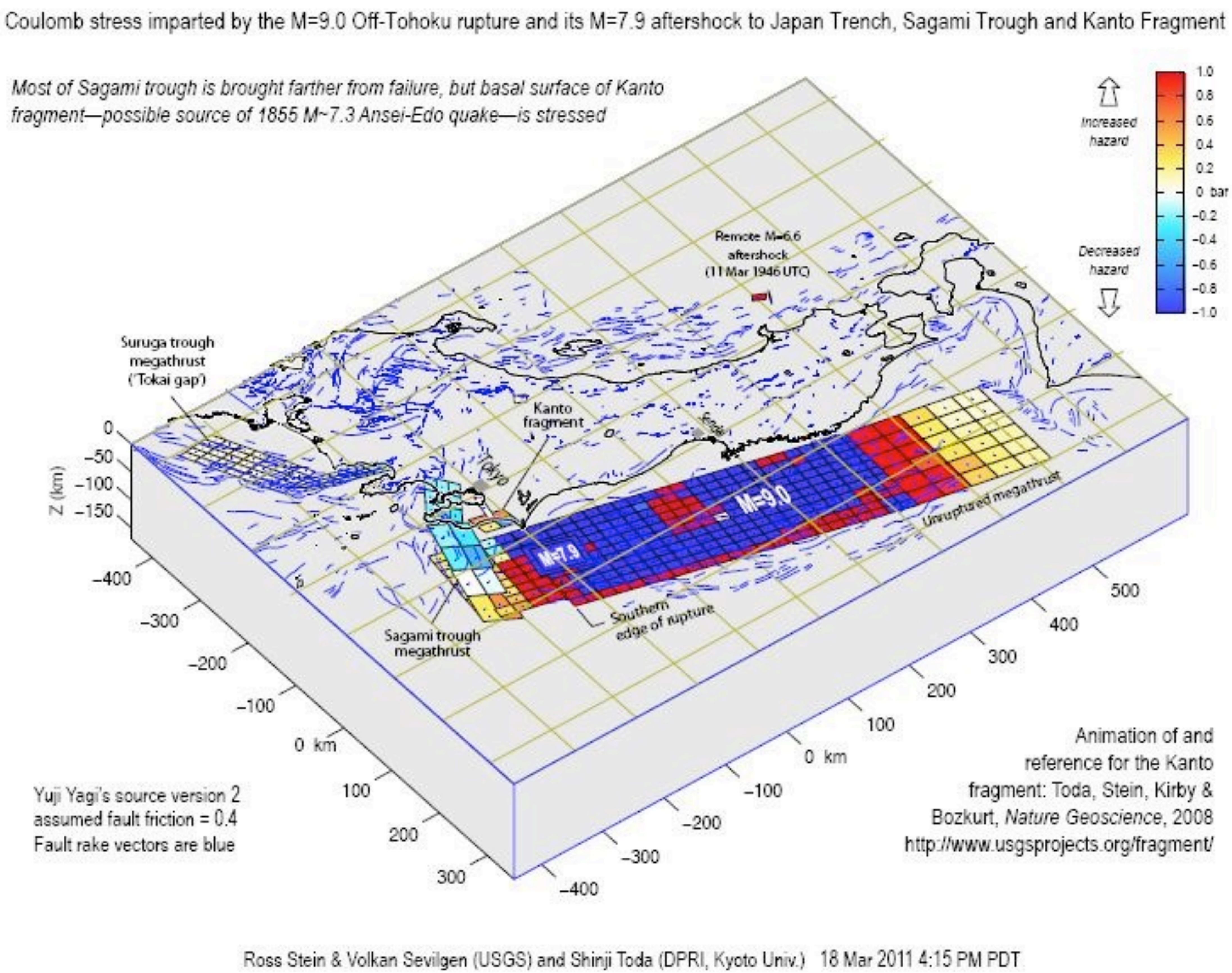
When a fault fails during an earthquake, it modifies the stress field in its surroundings. The modification of the stress pattern can give a rough idea of where the next shocks are more likely occur.



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

Courtesy of Kim B. Olsen

Dynamic rupture and stress transfer

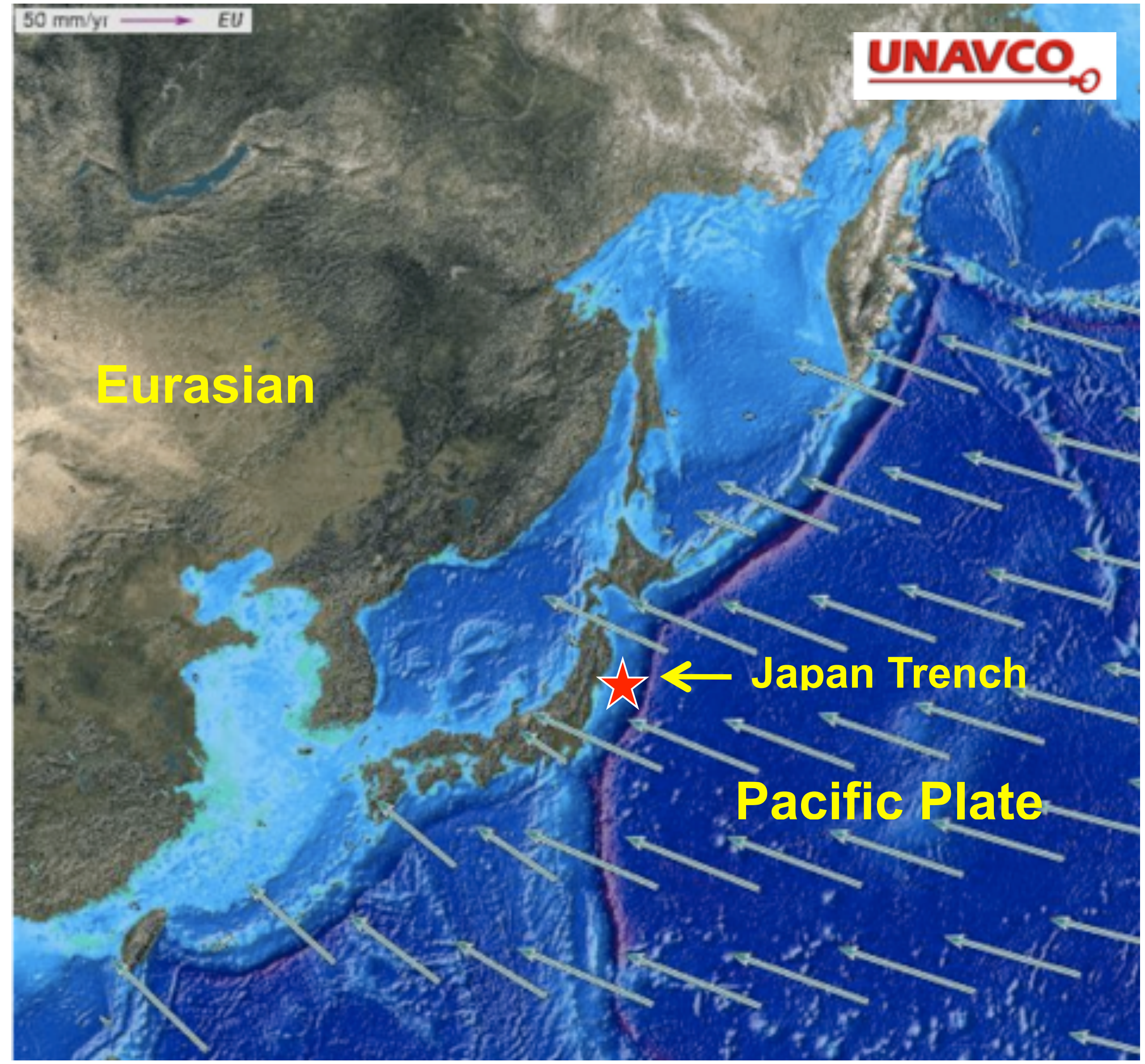


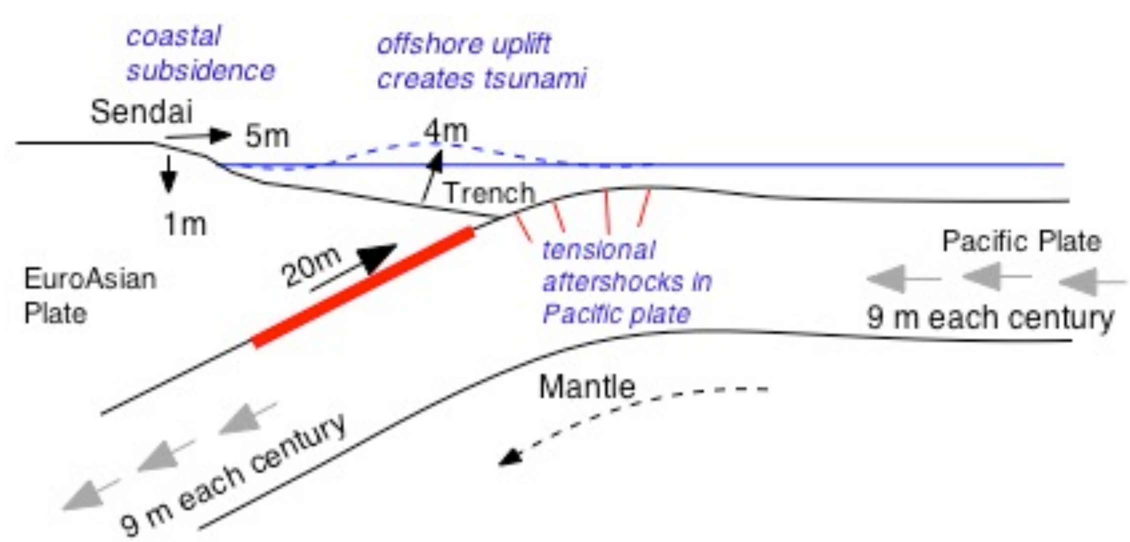
Tohoku-oki event: Tectonic setting

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

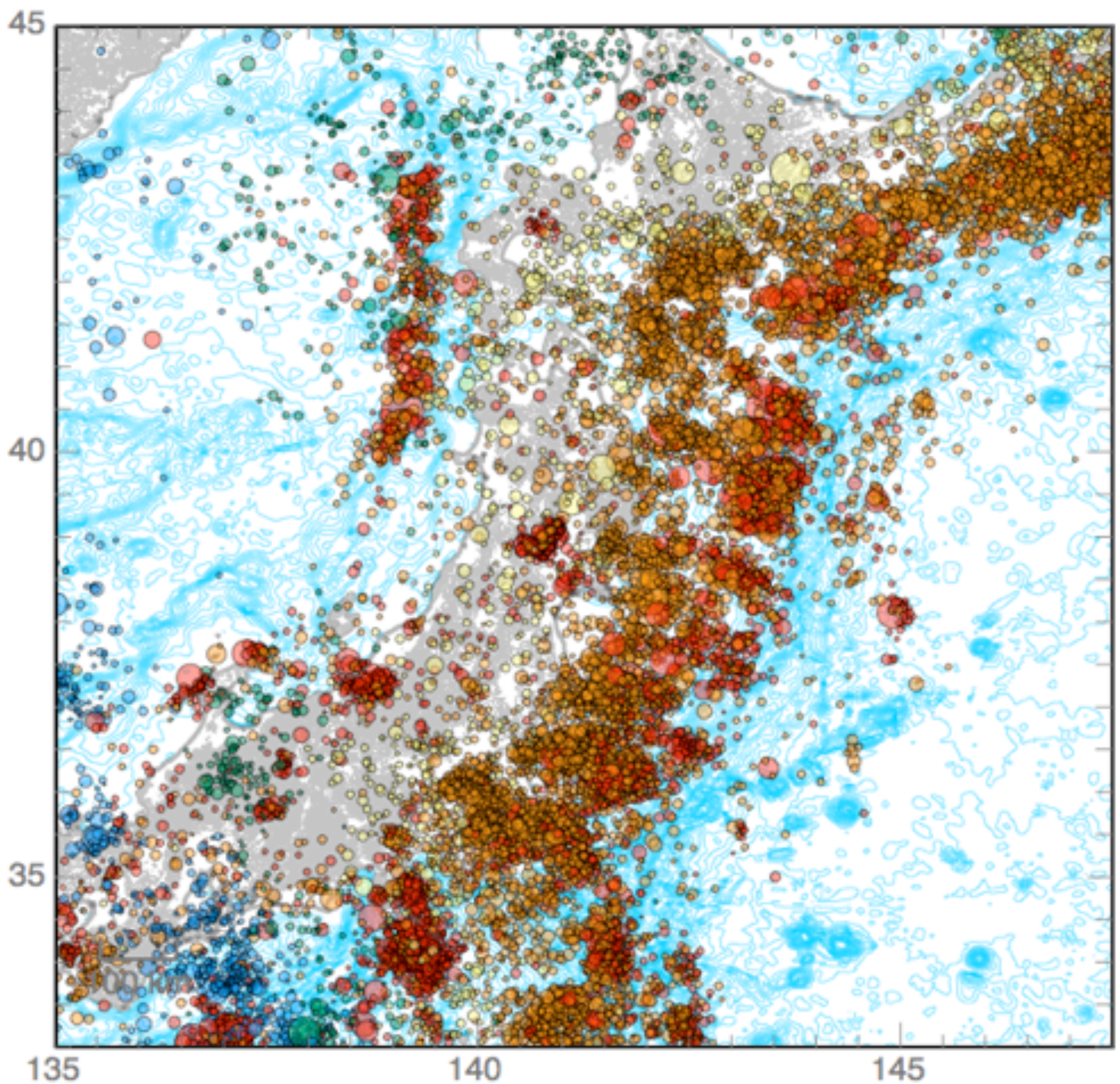
This map also shows the rate and direction of motion of the Pacific Plate with respect to the Eurasian Plate near the Japan Trench. The rate of convergence at this plate boundary is about 100 mm/yr (9 cm/year).

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





Historical seismicity and aftershocks



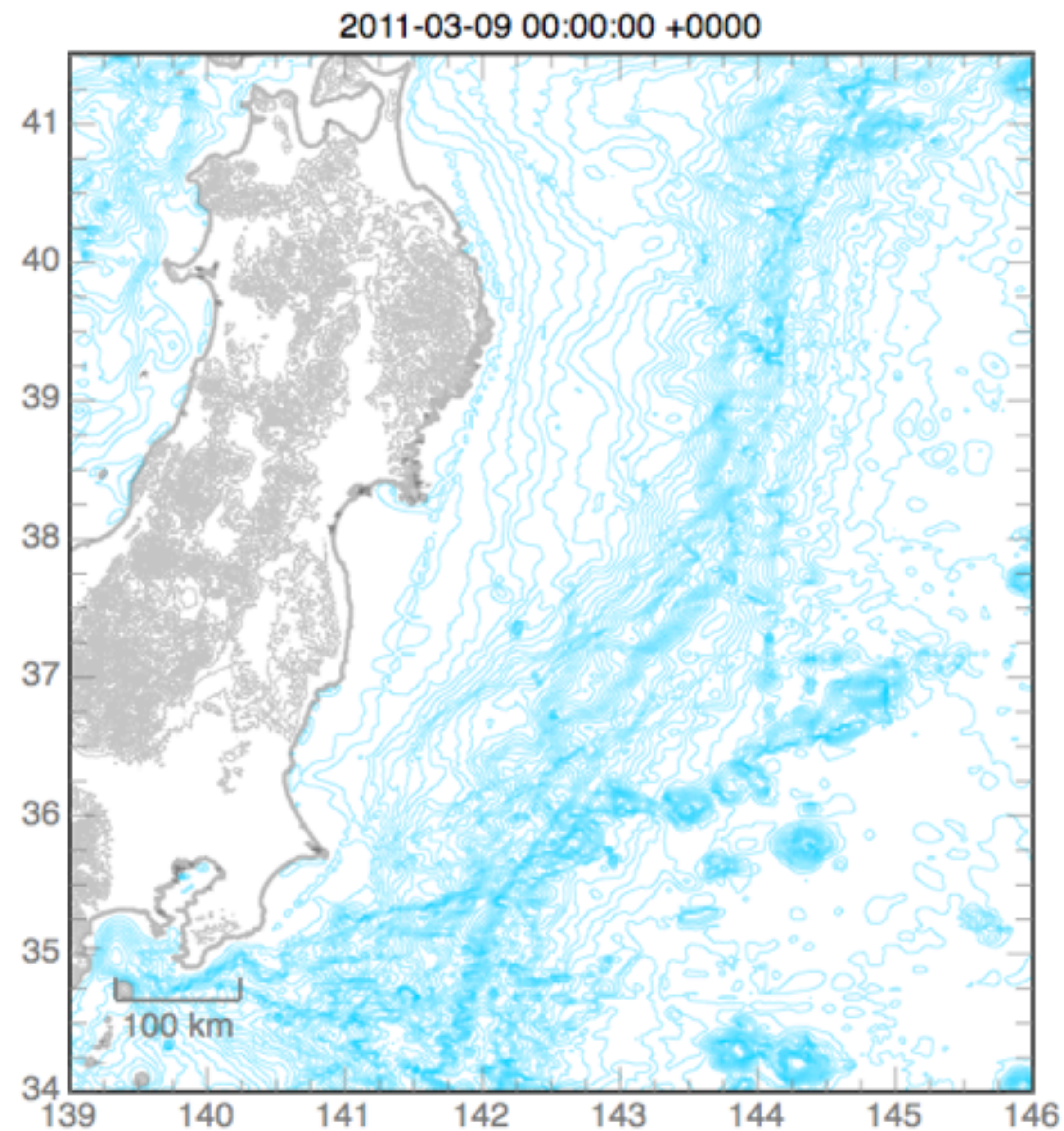


Image courtesy of Charles Ammon

USGS - CMT - Seismic Moment solution

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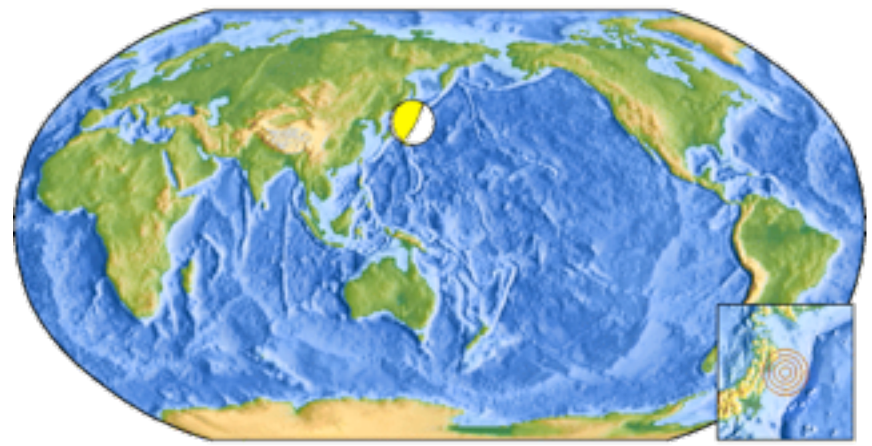
March 11, 2011, NEAR EAST COAST OF HONSHU, JAPAN, MW=9.1

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

           ---########
       --##############---
     --################-----
   --##################-------
  --##################---------
 --##################-----------
 -#######   #########-----------
--####### T ########-------------
-########   #######--------------
-#################---------------
-################--------   -----
 -##############--------- P ----
 -#############----------   ----
  -###########-----------------
   -#########-----------------
     -######----------------
       -##----------------
           -----------
```

Mw 8.9
USGS WPhase Moment Tensor Solution



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
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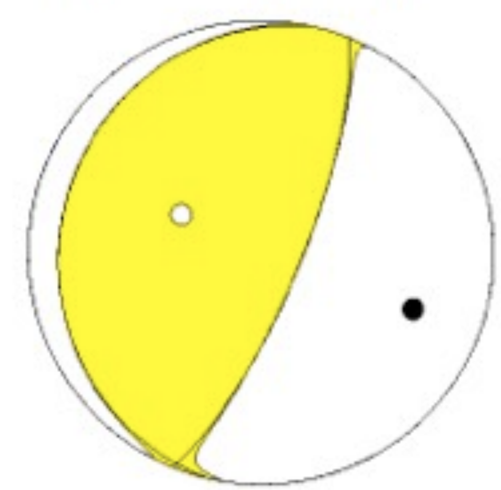
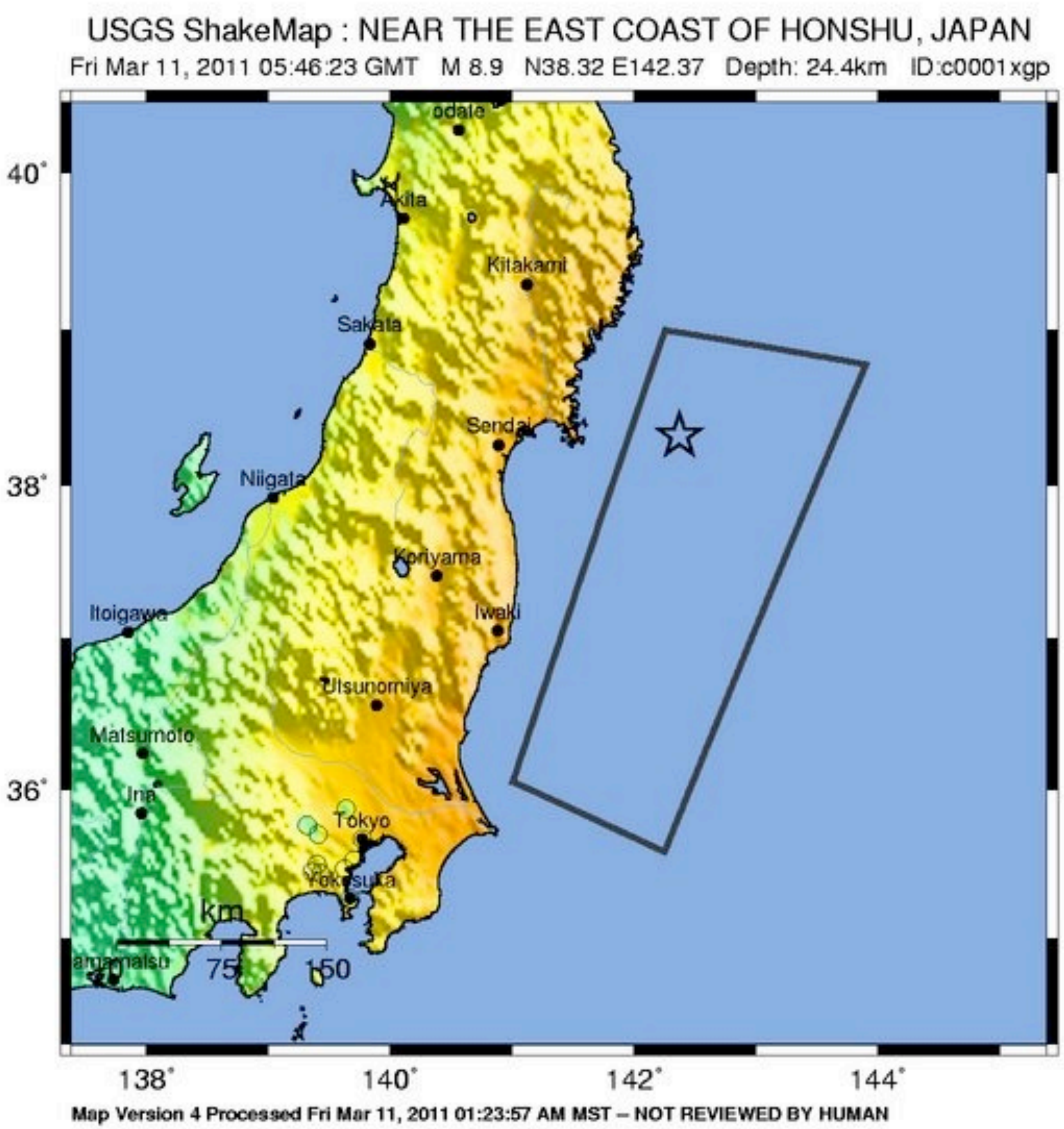


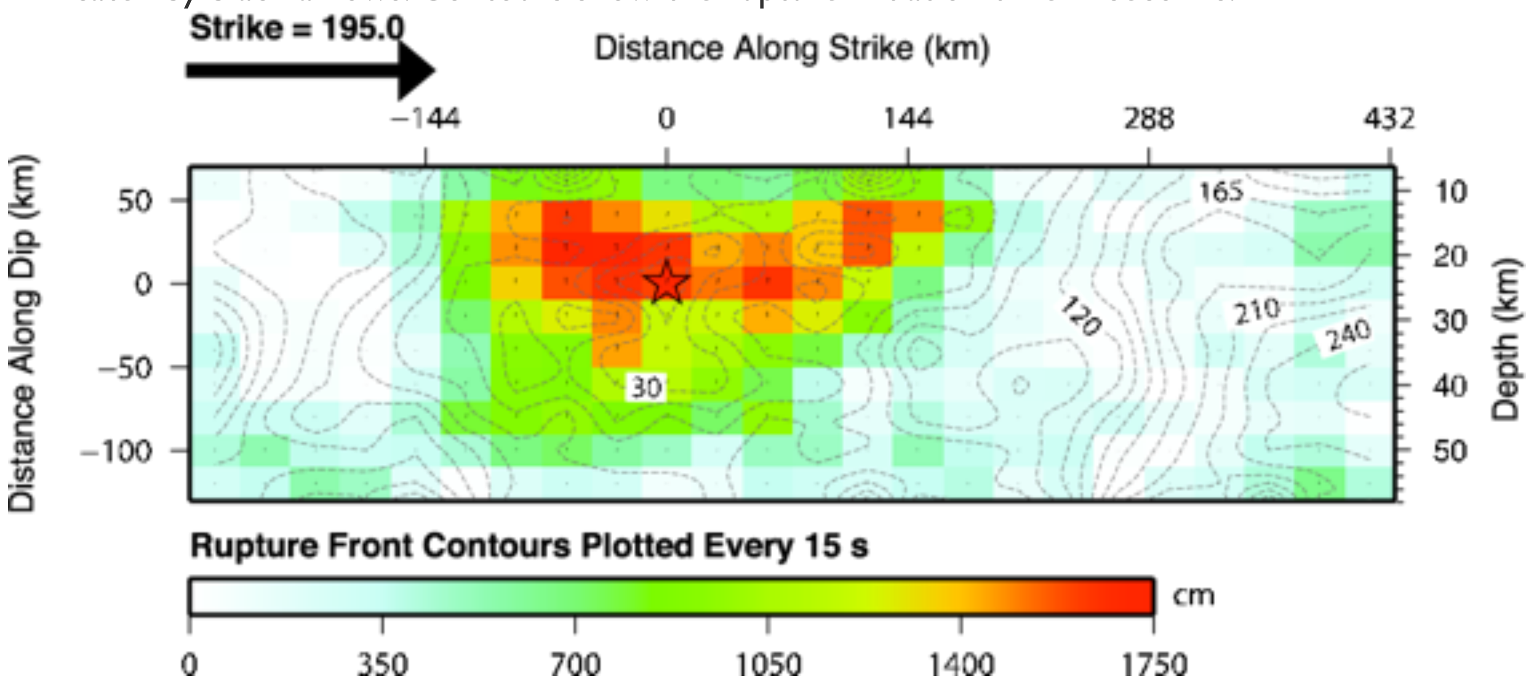
Shakemap - Instrumental Intensity

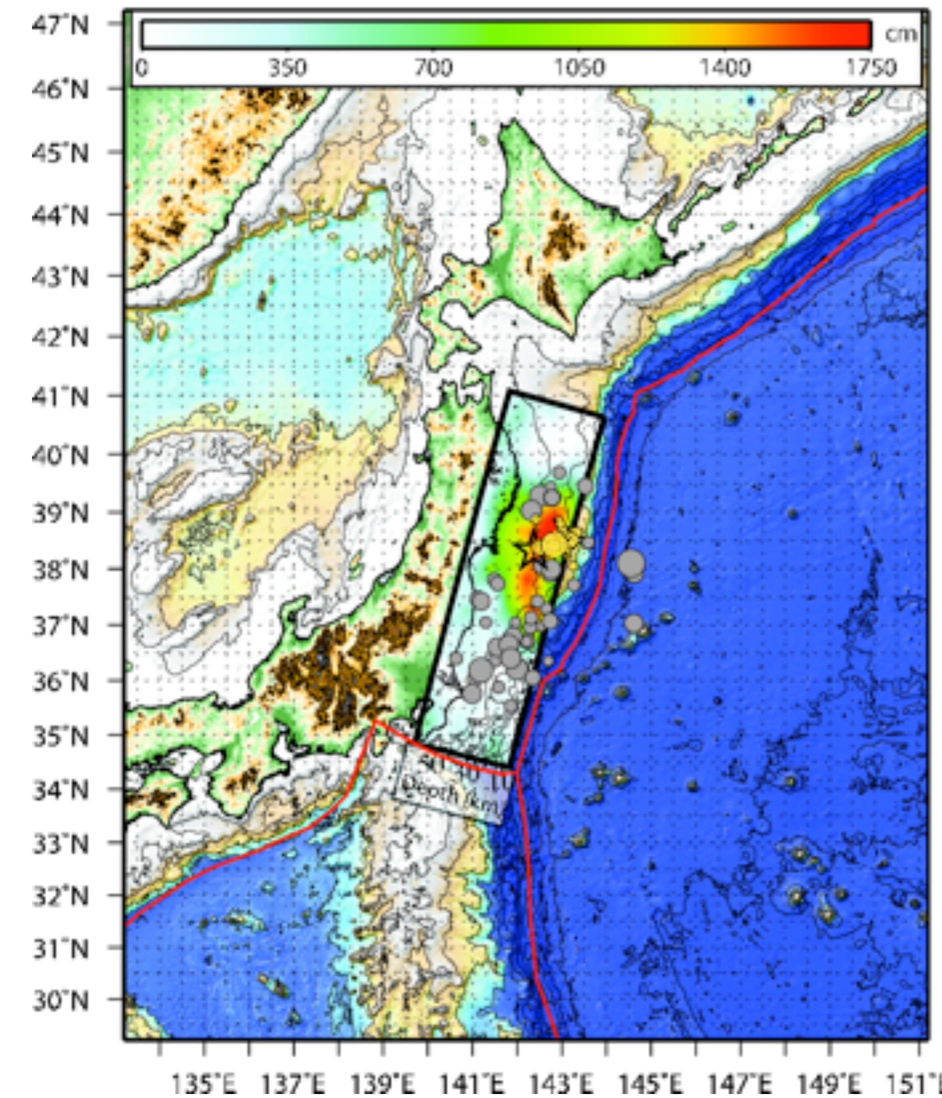


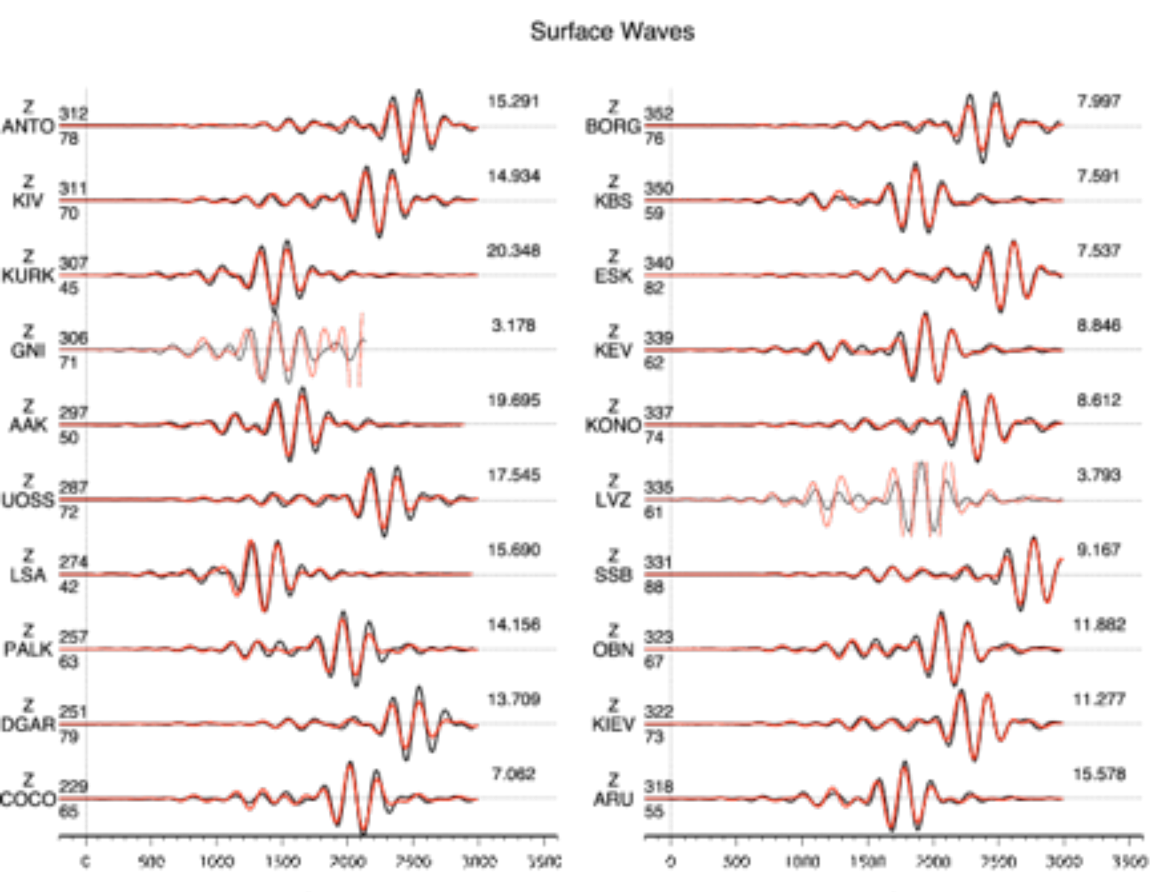
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

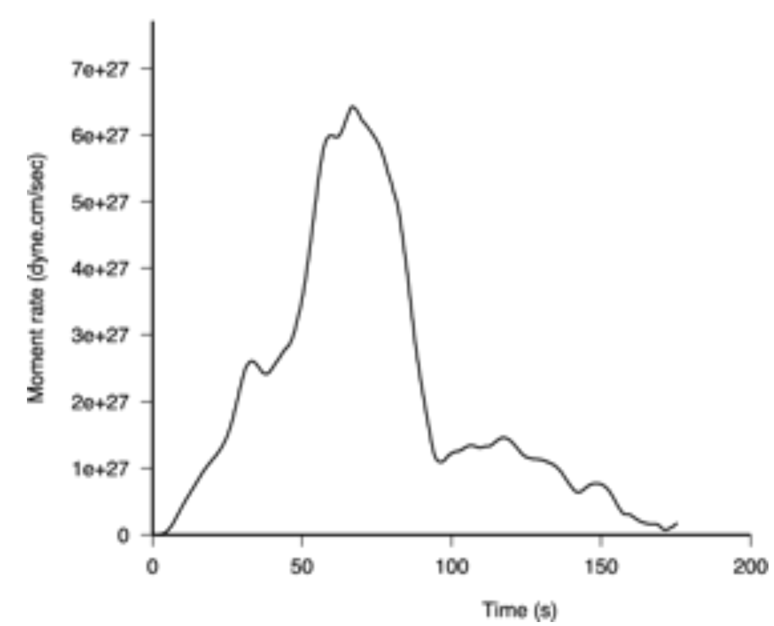
USGS - Finite fault model

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.



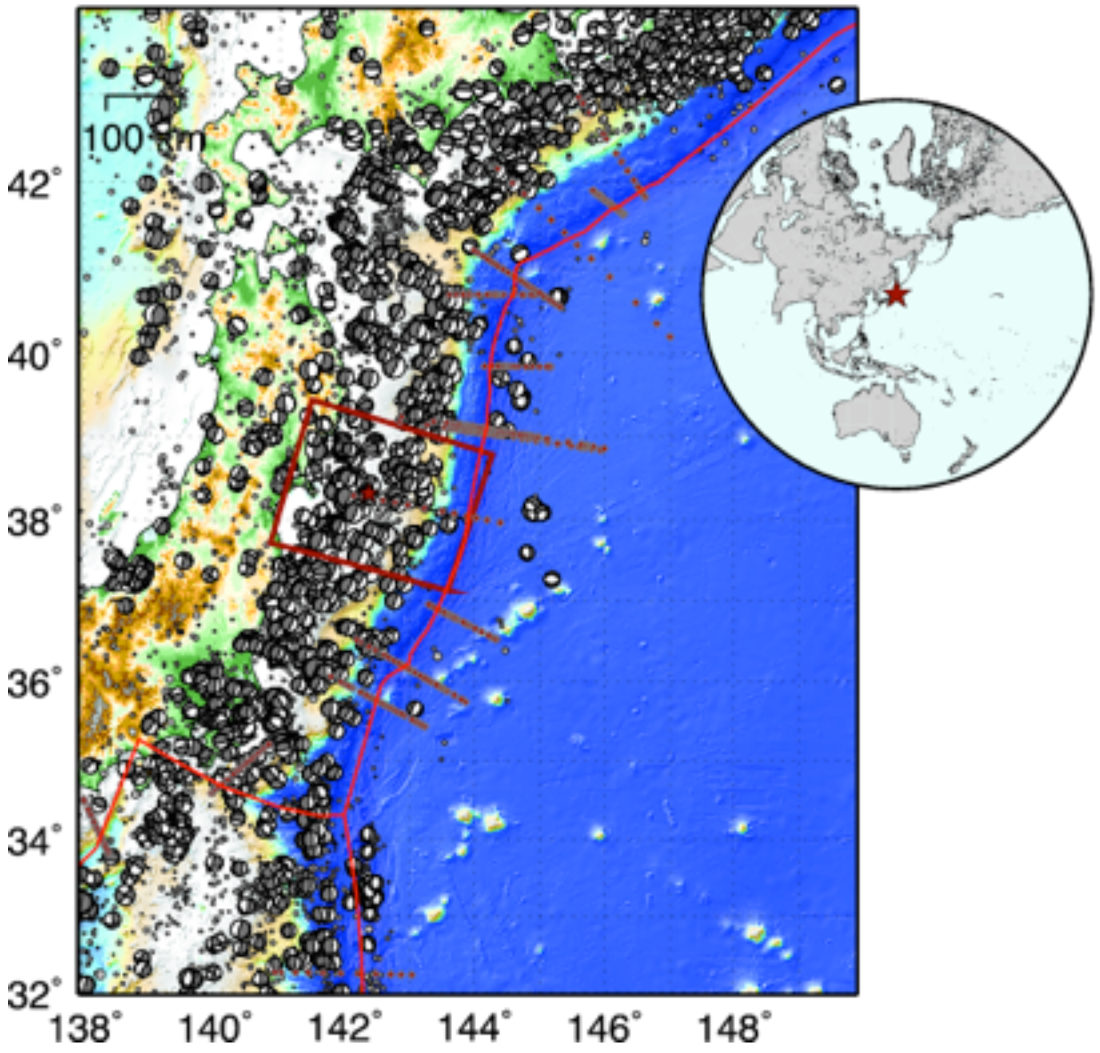




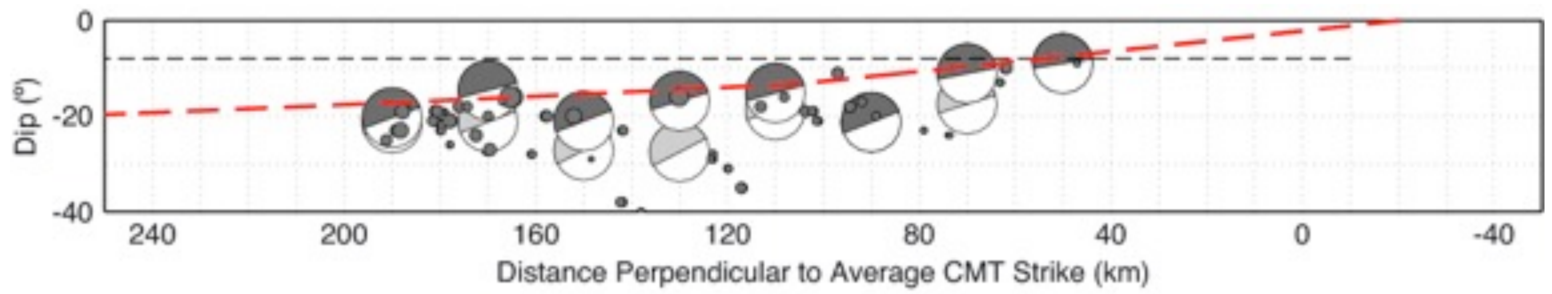


USGS - Finite fault model

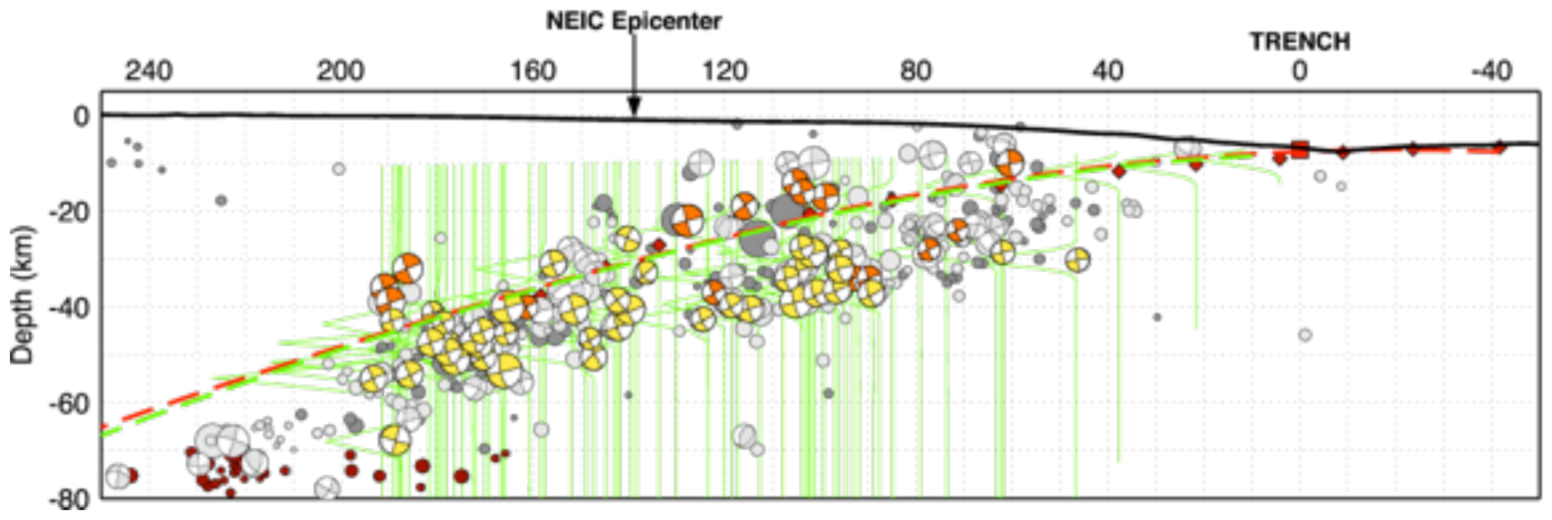
Basemap of subduction zone showing the area of the trench constrained in this example. Earthquake locations from the gCMT catalog and EHB catalog (gray circles, sized according to magnitude) are shown. Maroon rectangle indicates the area shown in cross section (c); all earthquakes within this area may be used to constrain trench geometry.



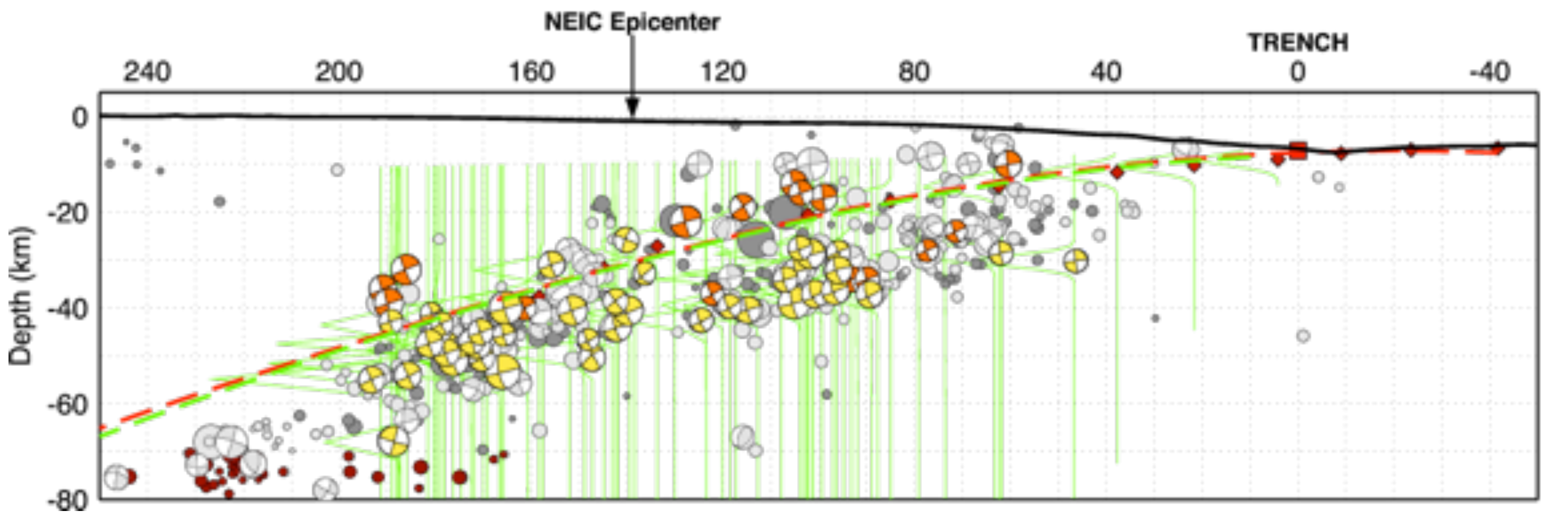
Variation in dip of best-fitting fault planes from the gCMT catalog for all events used to constrain trench geometry across the plane of the cross-section. Individual event dips are shown with small dark gray circles, sized with magnitude. Large mechanisms indicate the average dip in 20km bins across the plane of the cross-section. Light gray mechanisms represent a bulk average; dark gray represents a moment-weighted average.

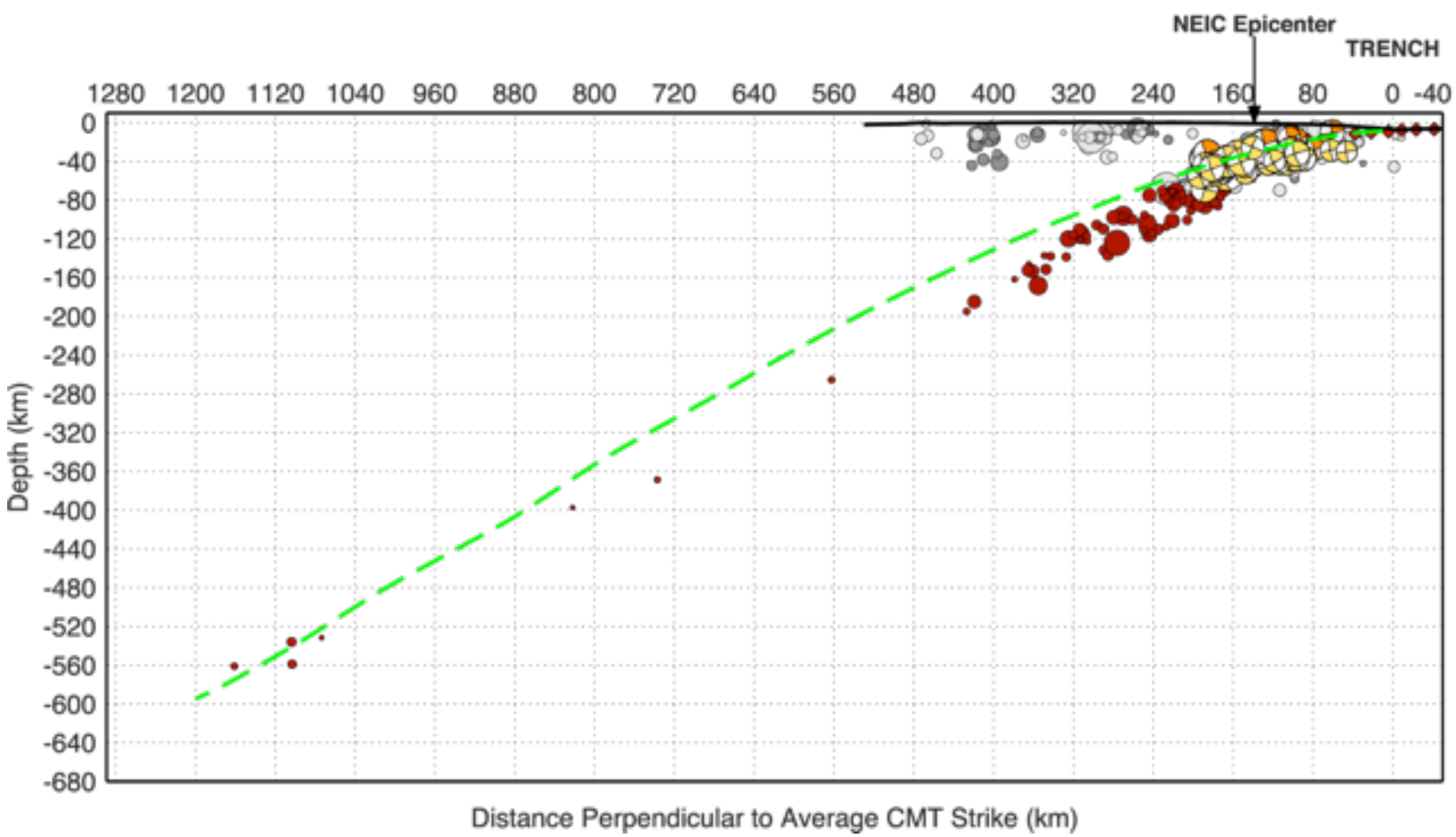


Cross-section of subduction zone taken perpendicular to the average strike of gCMTs that match selection criteria and whose equivalent EHB or NEIC locations lie within the maroon box from Figure 1.



USGS - Finite fault model

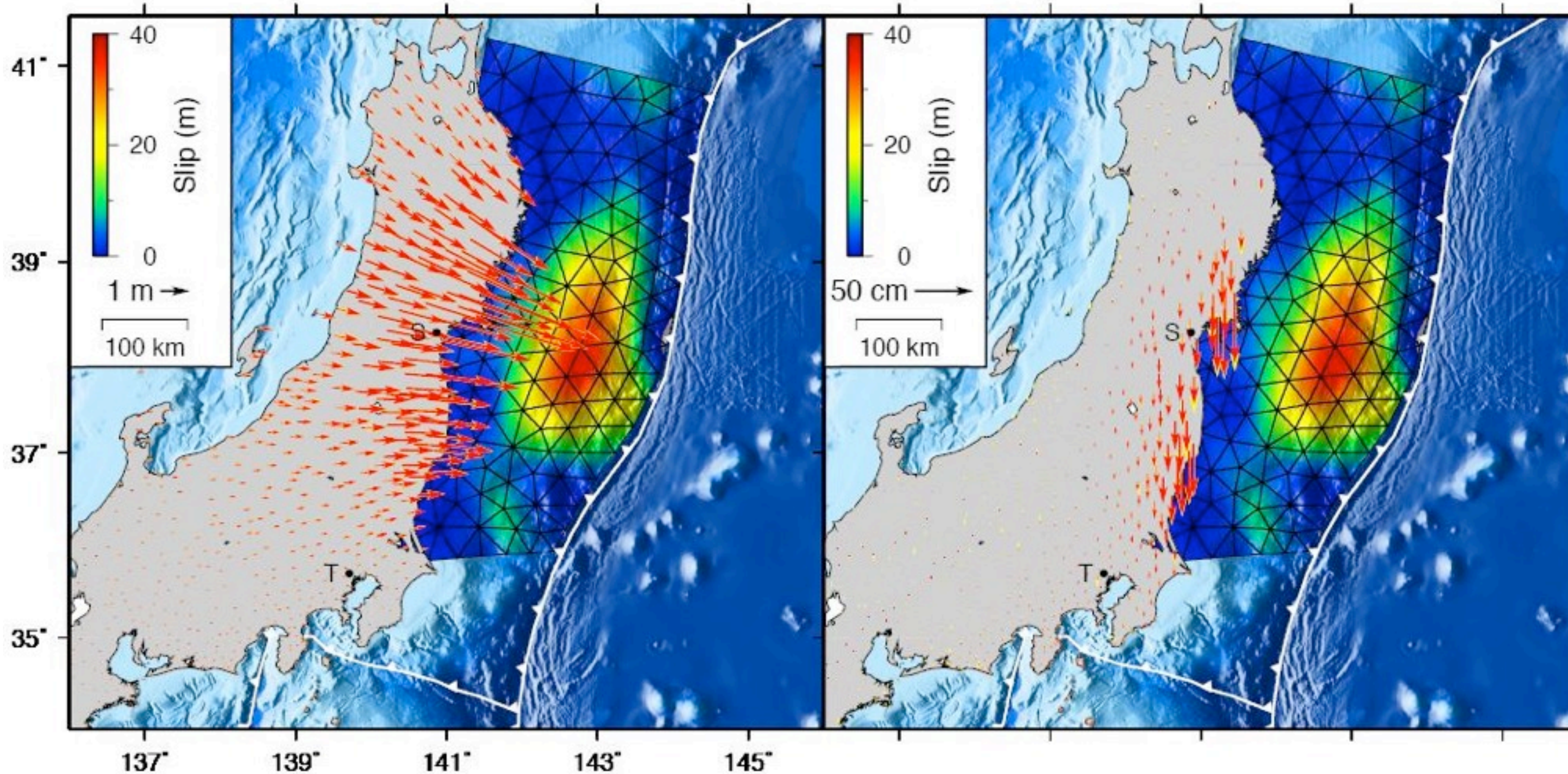




Cross-section of subduction zone taken perpendicular to the average strike of gCMTs that match selection criteria and whose equivalent EHB or NEIC locations lie within the maroon box from Figure 1. Gold CMTs are mechanisms from the gCMT catalog plotted at their equivalent EHB catalog location, used to constrain trench strike and dip. Orange CMTs are mechanisms without EHB locations, placed instead at the equivalent event location in the NEIC catalog, and also used to constrain geometry. Light and dark gray circles are events from the EHB catalog in front and behind the plane of the cross-section, respectively, but not used to constrain geometry because either (i) they did not have a corresponding mechanism in the gCMT catalog, or (ii) their mechanism in the gCMT catalog did not match selection criteria. The trench location is marked with a red square. Probability density functions for EHB and NEIC locations are shown as green lines, scaled by a factor of x20 for display purposes. The black solid line describes the best fitting planar geometry; the red dashed line the best-fitting non-planar geometry. The initial locations of the 'new event' used to help constrain geometry are shown by black circles and marked with arrows corresponding to the gCMT epicentroid and NEIC epicenter. PDFs for these locations are shown in red. The best-fitting fault plane from the gCMT catalog for the new event (if available) is shown with a black dashed line.

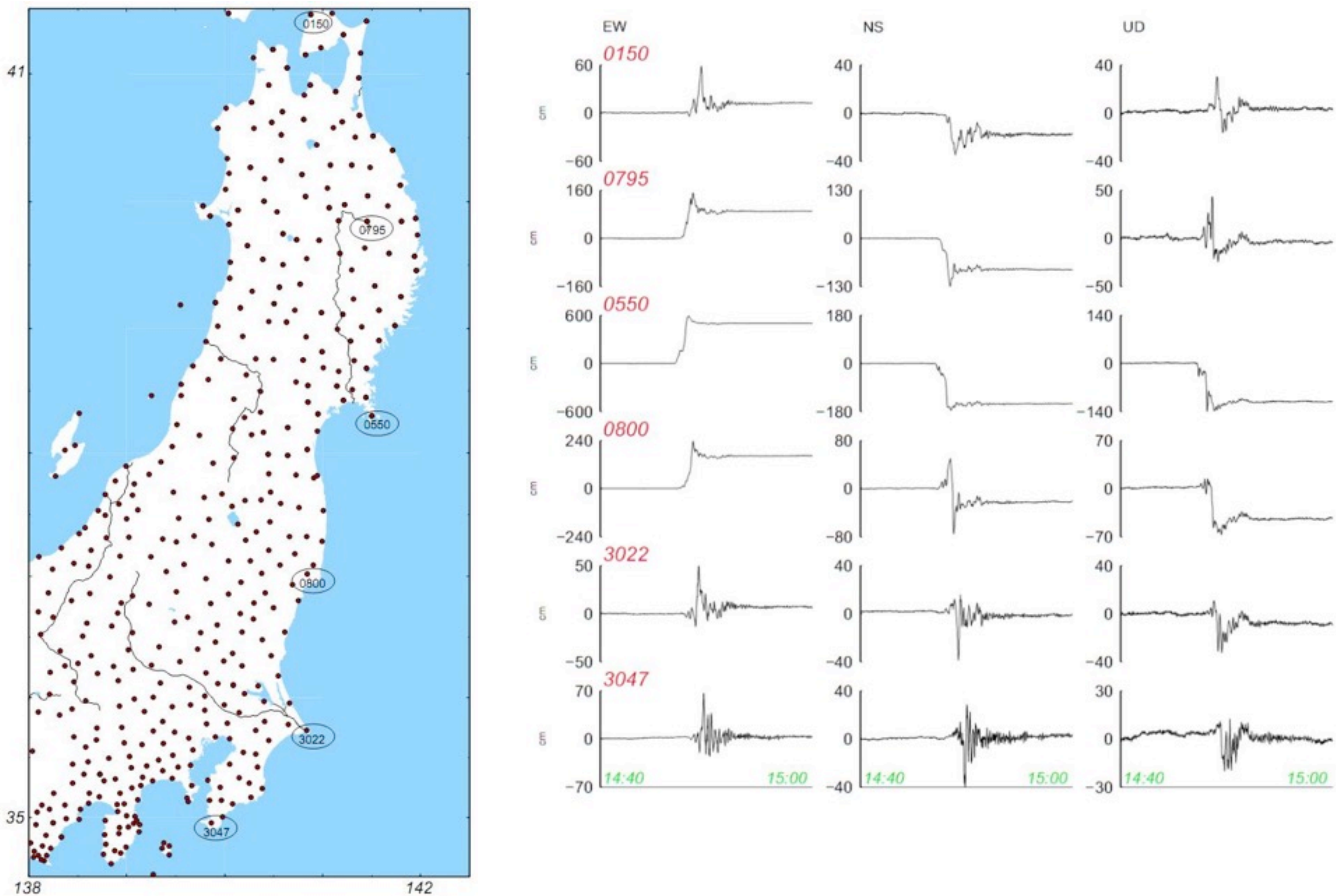
An expanded cross-section will show the fit between the non-planar geometry and deeper earthquake data (maroon circles), also used to help constrain this geometry. On this section, gray lines represent 100 bootstrapped interfaces computed with a random selection of the input data.

Co-seismic slip



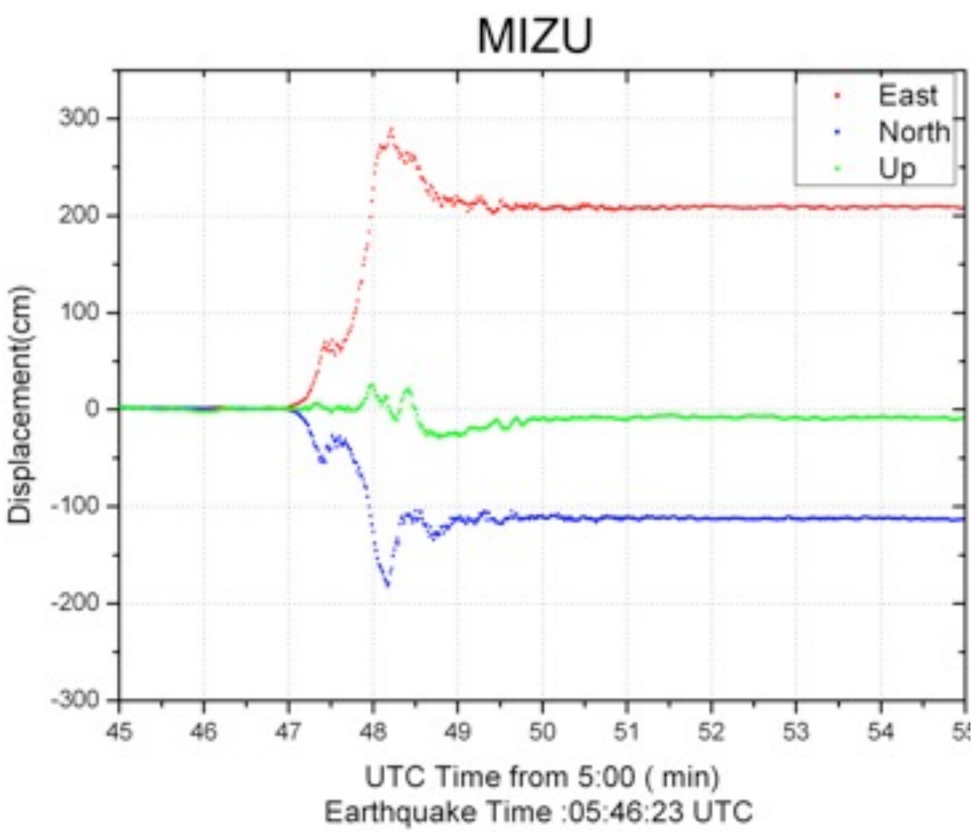
M. Simons, F. Ortega, J. Jiang, A. Sladen, and S. Minson at Caltech as part of the ARIA project.
All orginal GEONET RINEX data provided to Caltech by the Geospatial Information Authority (GSI) of Japan.

GPS waveforms



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

Co-seismic slip



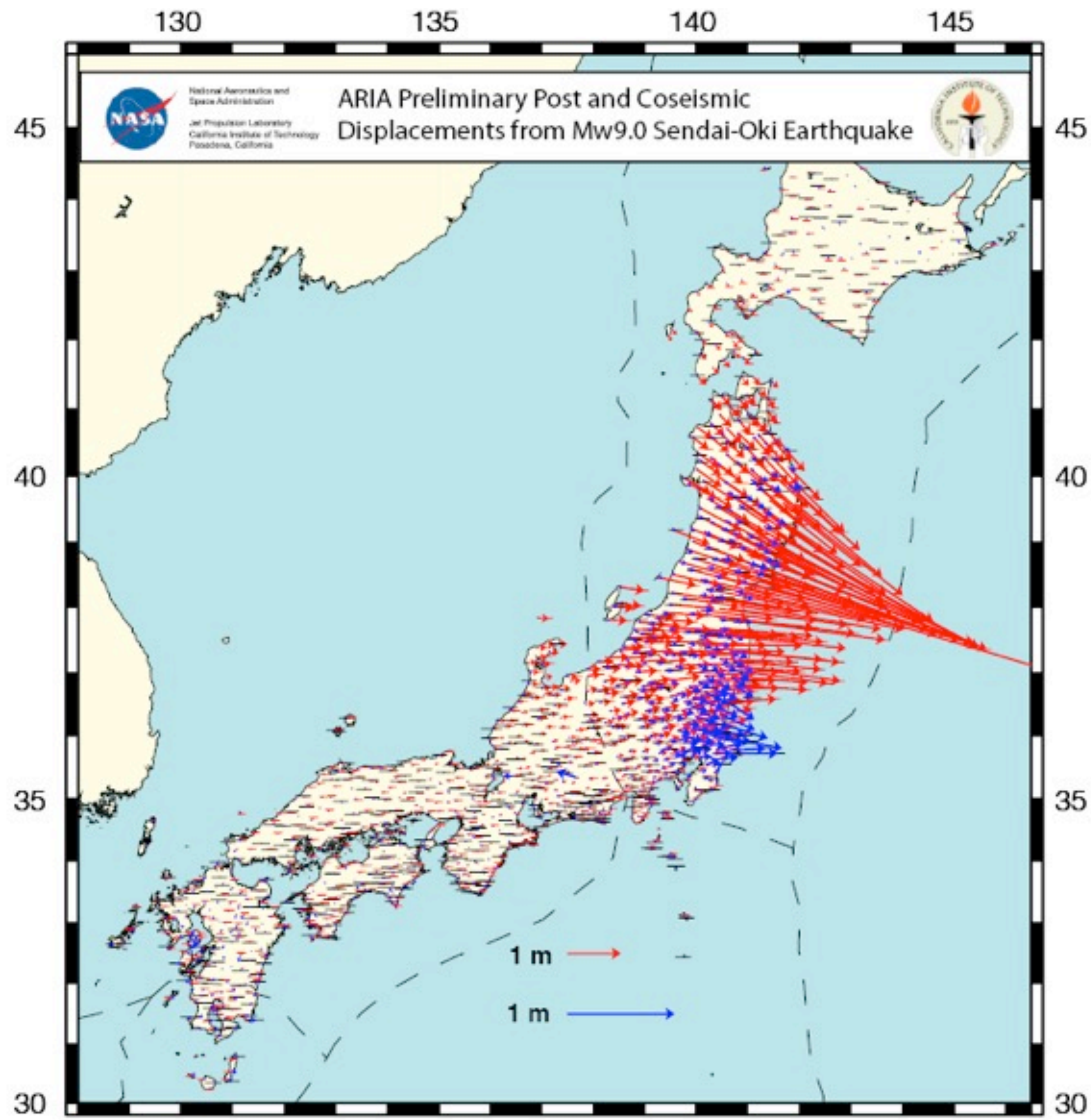
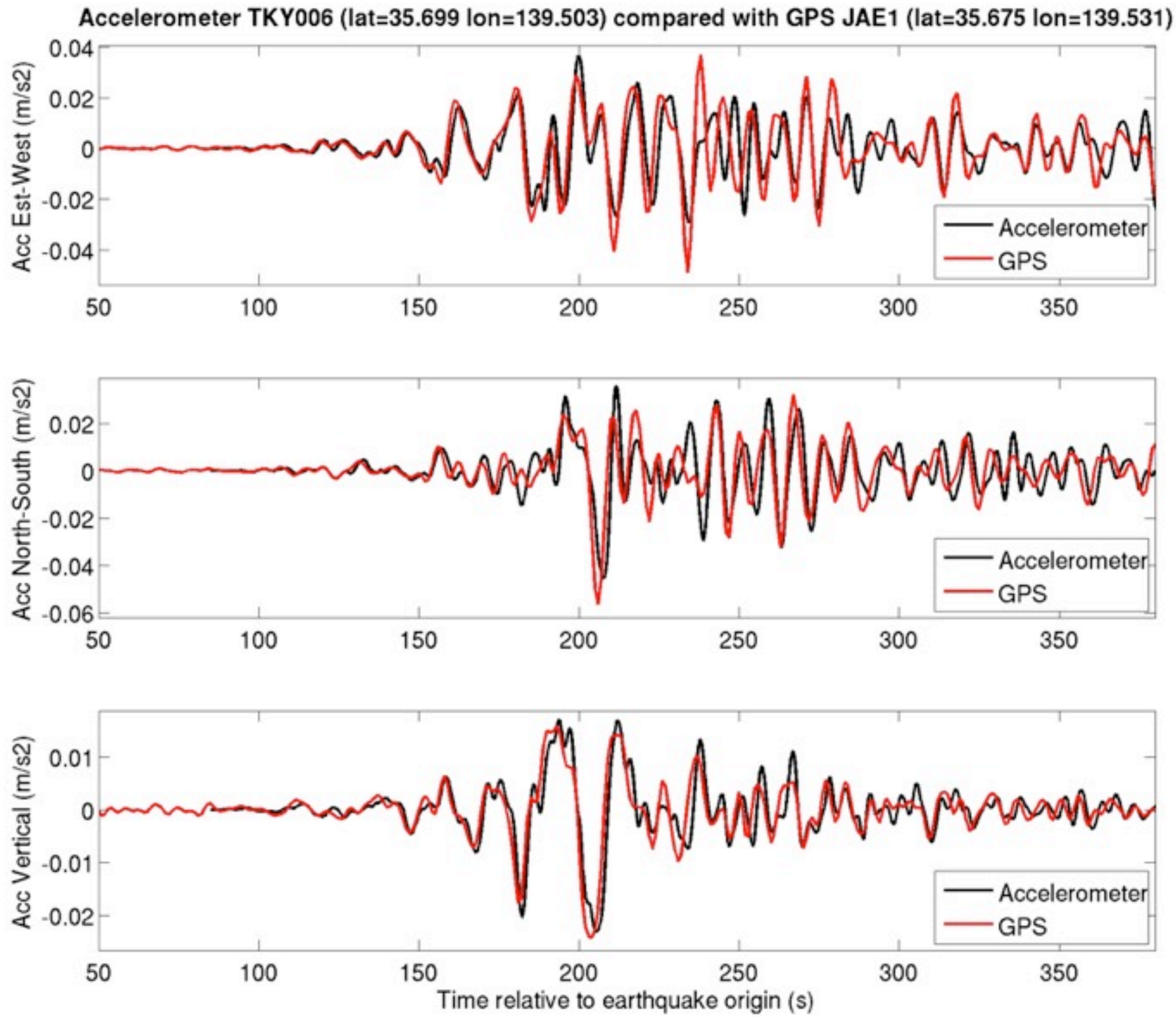


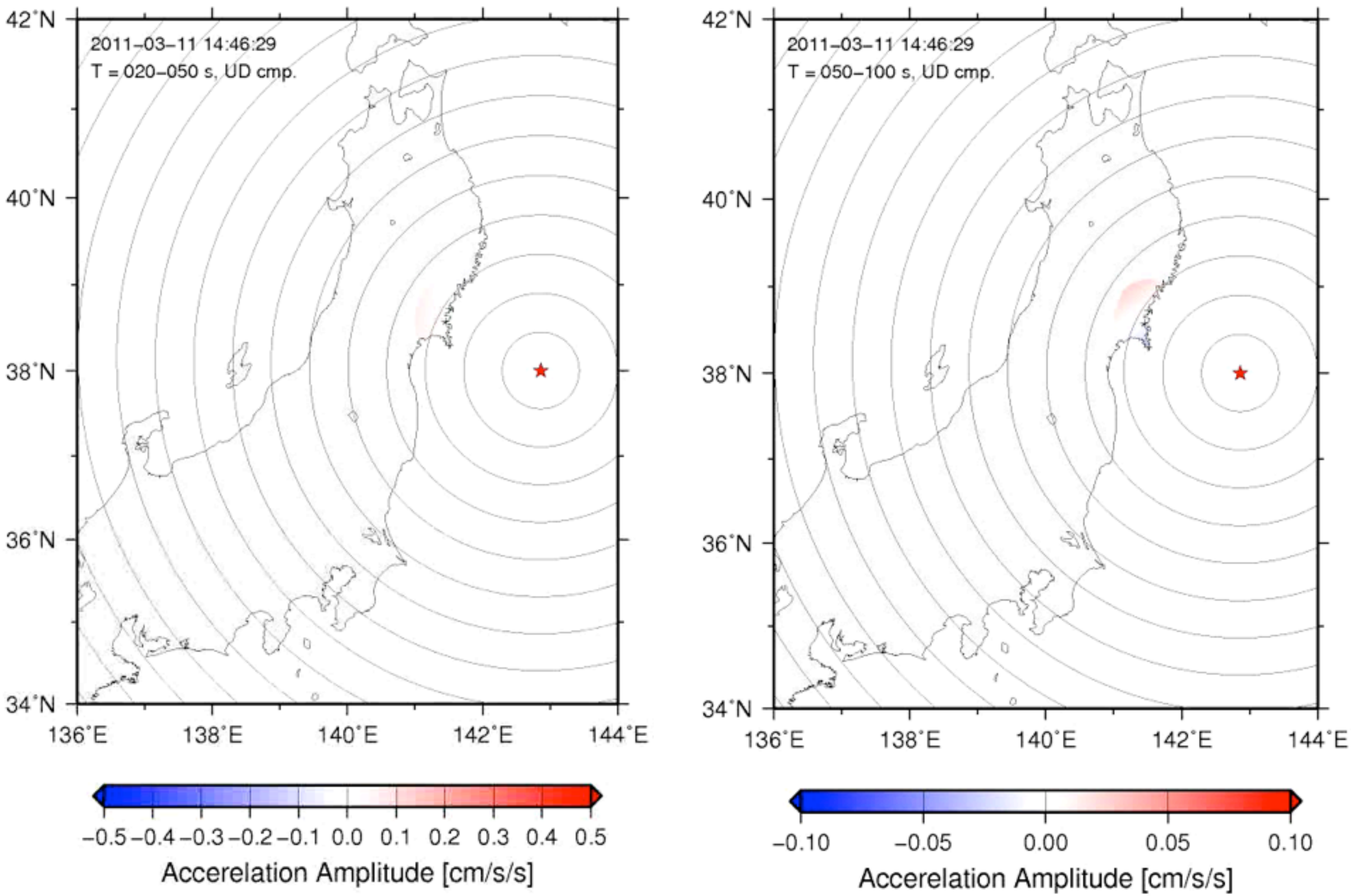
Figure shows horizontal displacements based on ARIA verion 0.3 position estimates for GEONET stations. Coseismic displacement is shown in red, and first 8 hours of postseismic motion is shown in blue, including motion caused by aftershocks. Bars at end of vector show 95% error estimate. Solutions courtesy 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



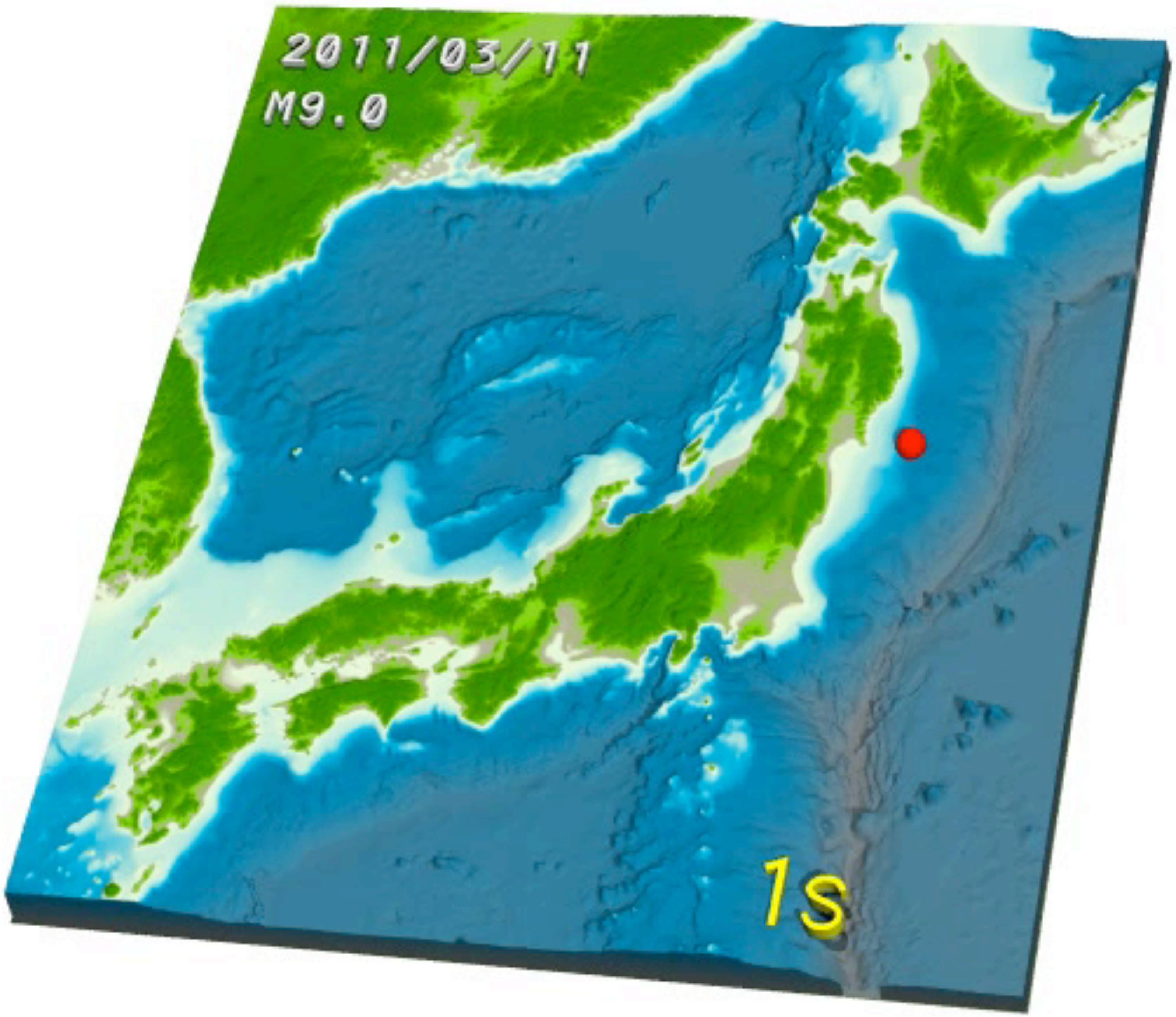
The figure shows the comparison between this GPS signal - twice differentiated - and the accelerometric signal, in the [0.005Hz - 0.125Hz] range.

Long period GM



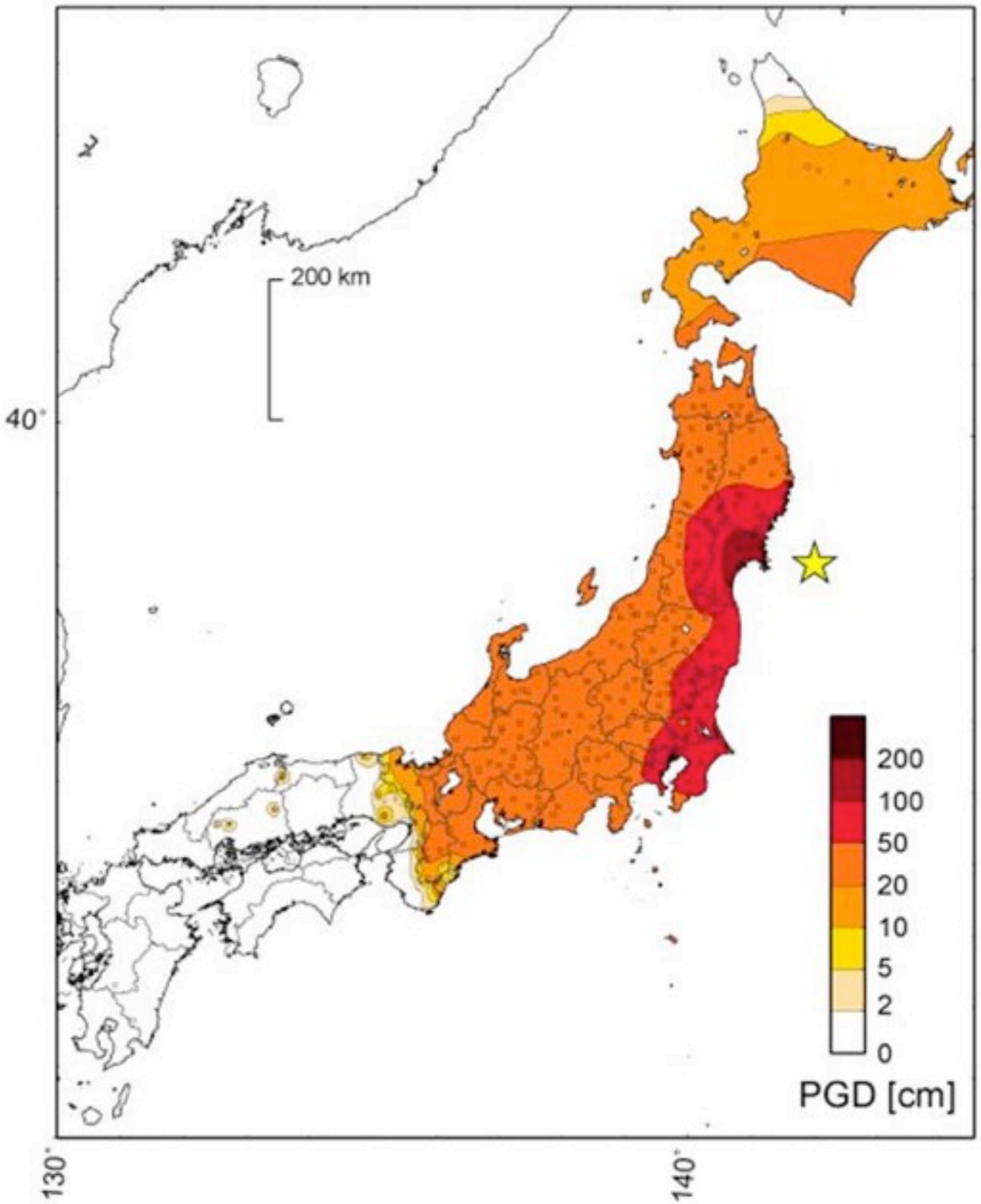
“Earthquake Research Institute, University of Tokyo: Dr. Furumura and Project Researcher Maeda

Ground motion animation: time scales...



Courtesy of Takashi Furumura

PGD



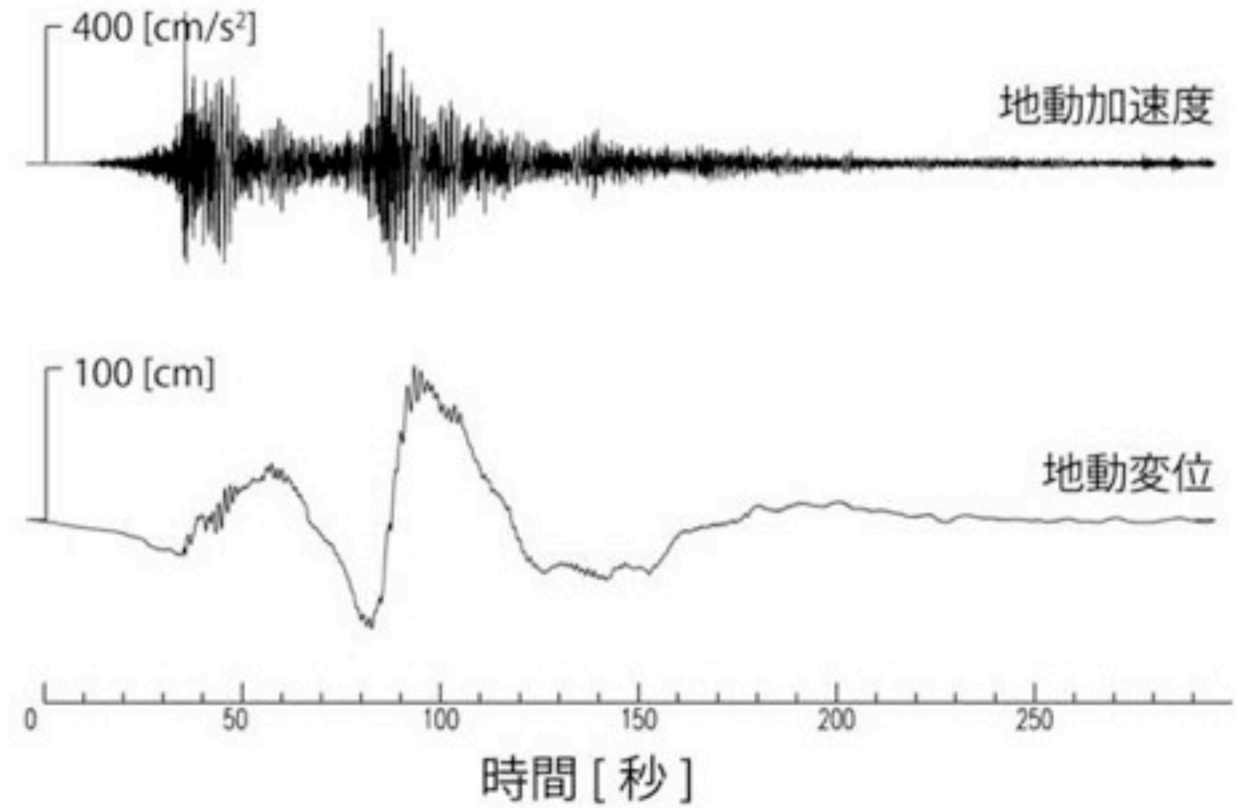
- A strong ground acceleration of over 2933 cm/s/s was observed in K-NET Tsukidate observation station (Miyagi pref.) near the hypocenter, and a strong ground acceleration propagated in broad area from Ibaraki to southern Iwate. The distribution of strong ground acceleration is extending to three areas: 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

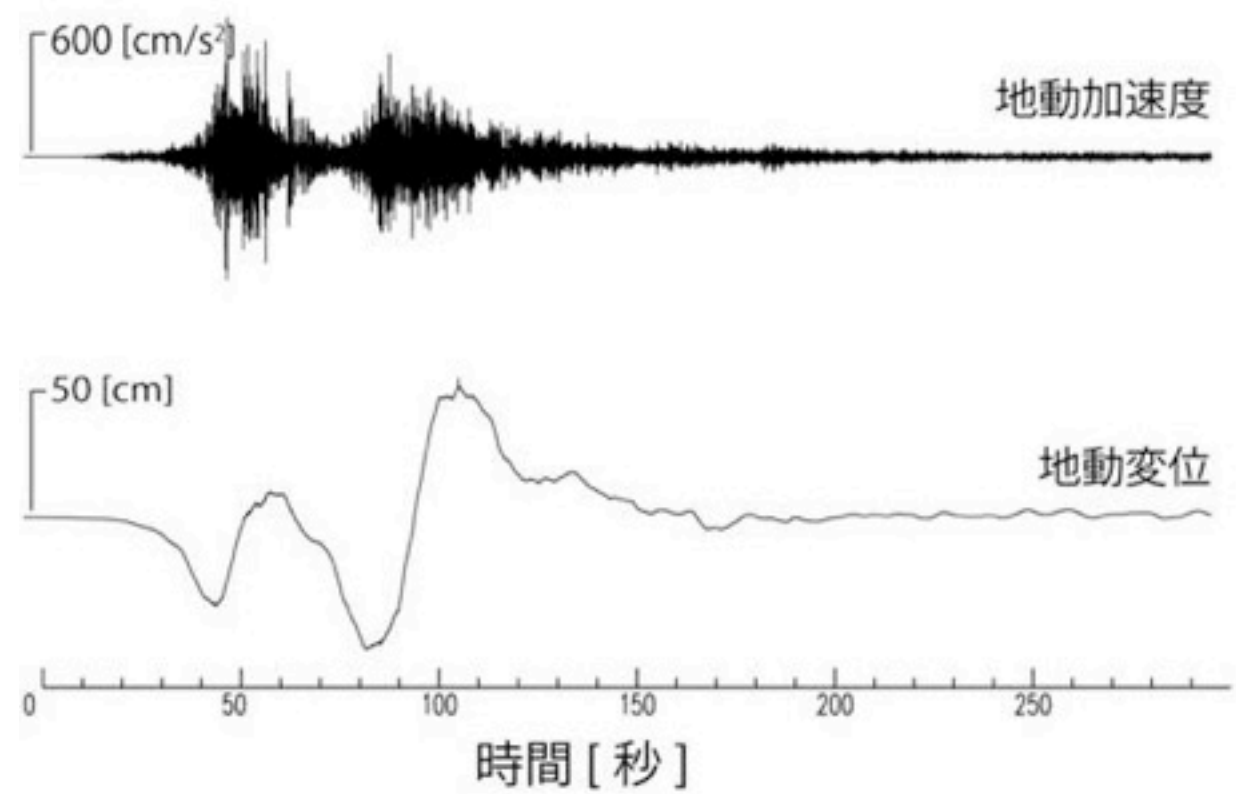
- Maximum acceleration and maximum displacement of ground motion in Ishinomaki and Rikuzentakata where ground motion was strong. The arrival of 2 strong seismic wave groups is seen after about 50 seconds. They suggest that a strong seismic wave was radiated from the 2 major asperities of the Miyagi coast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

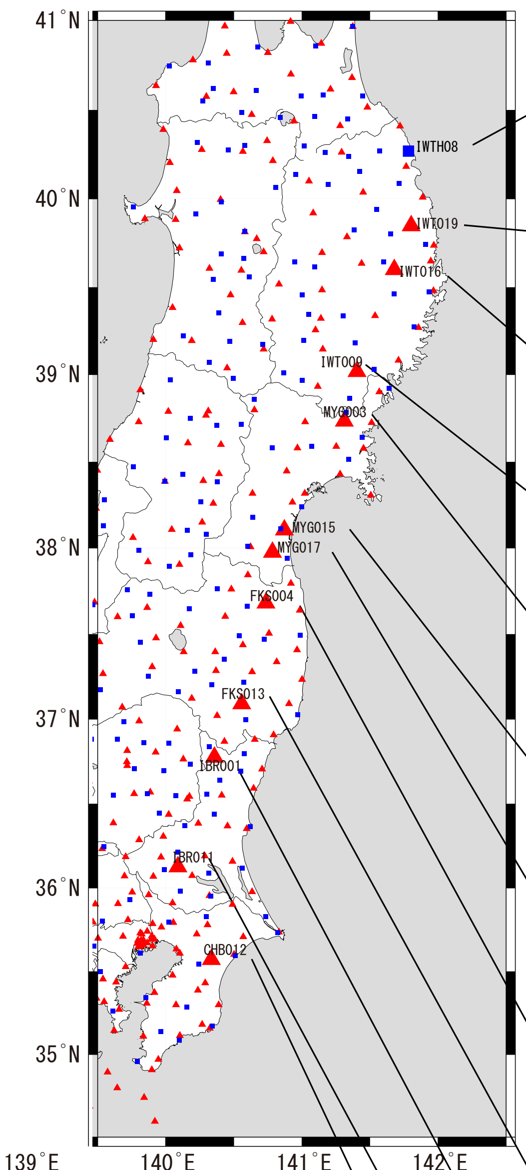
K-NET 石巻（MYG010）南北成分

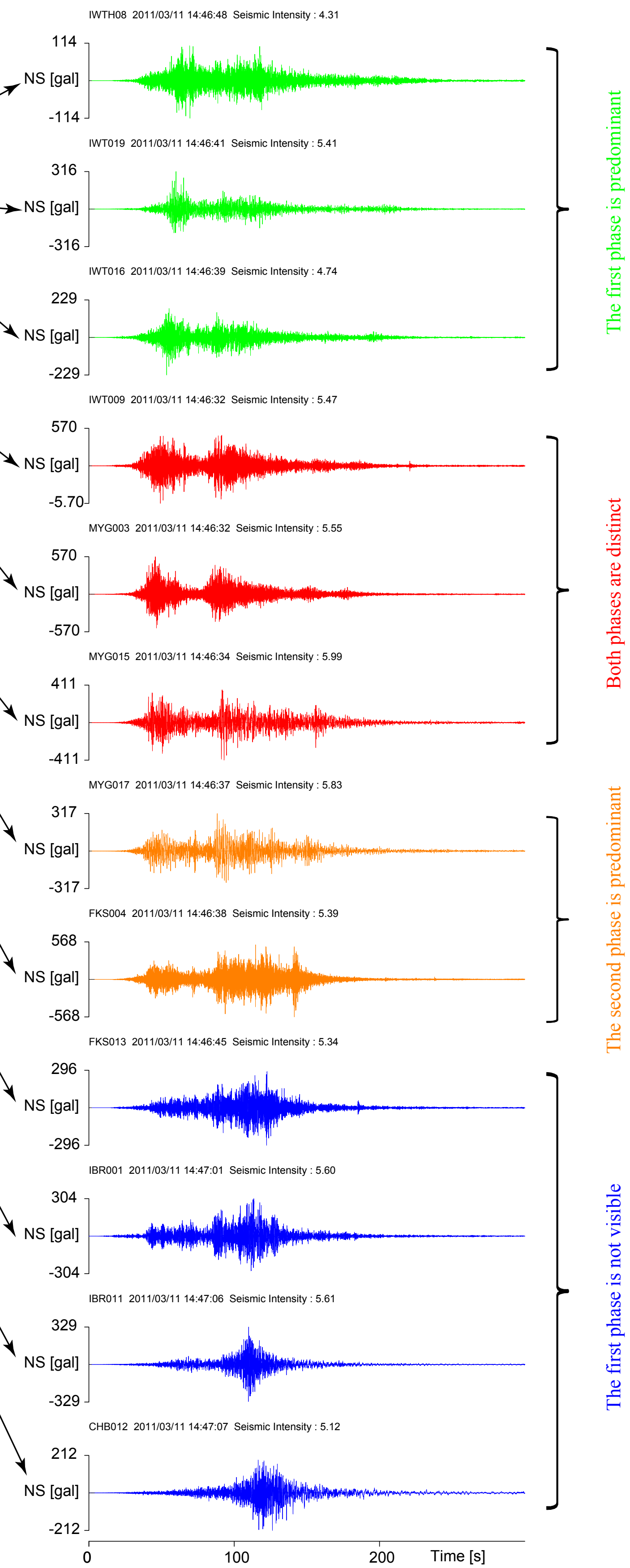


KiK-net 陸前高田（IWTH27）南北成分



Rupture from ground motion





Near-source acceleration waveforms display two remarkable phases of ground motion which suggest the existence of a least two areas of large slip.

In the northern part of the source area the first phase is predominant while in the South this phase is not visible.

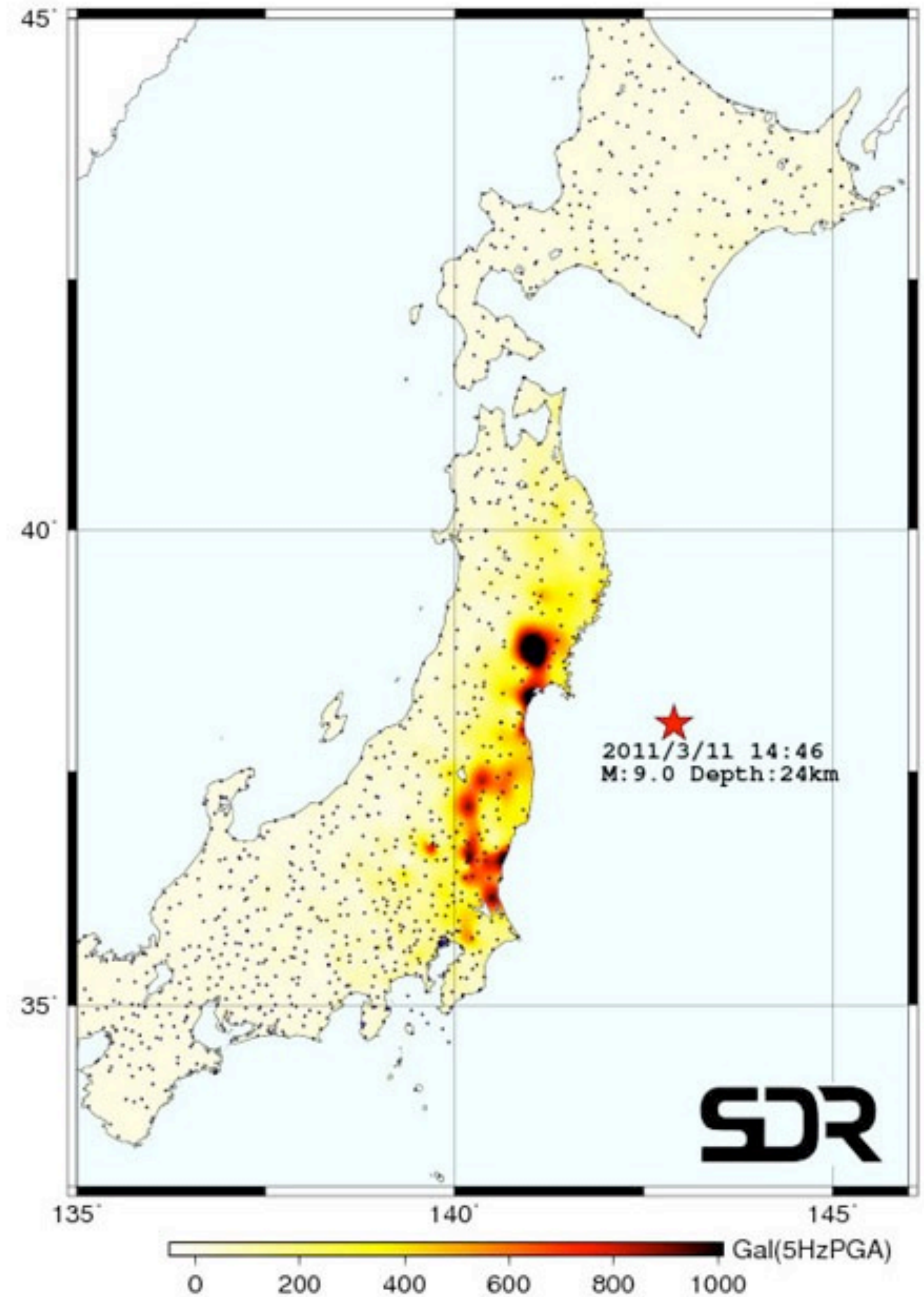
These two phases of ground motion suggest large slip areas in the North and South regions respectively.

The remarkable differences in grow characteristics of intensity values for the Miyagi and Ibaraki regions indicate they originate from different slip areas.

A small ground motion phase is observed between the two large distinct phase at some stations (FKS013, FKS004, MYG017, MYG015).

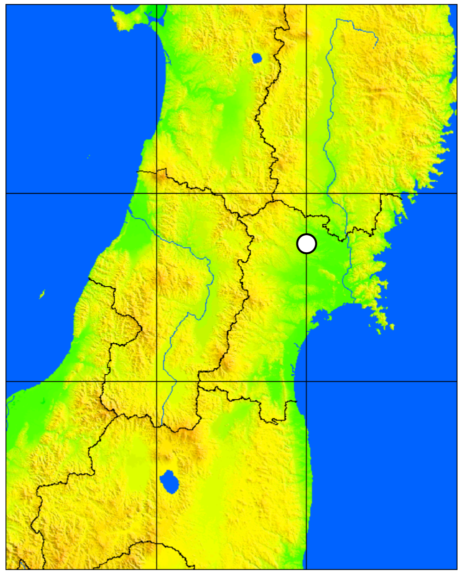
Other secondary phases are also observed suggesting a very complex source process

Source: Knet-NIED



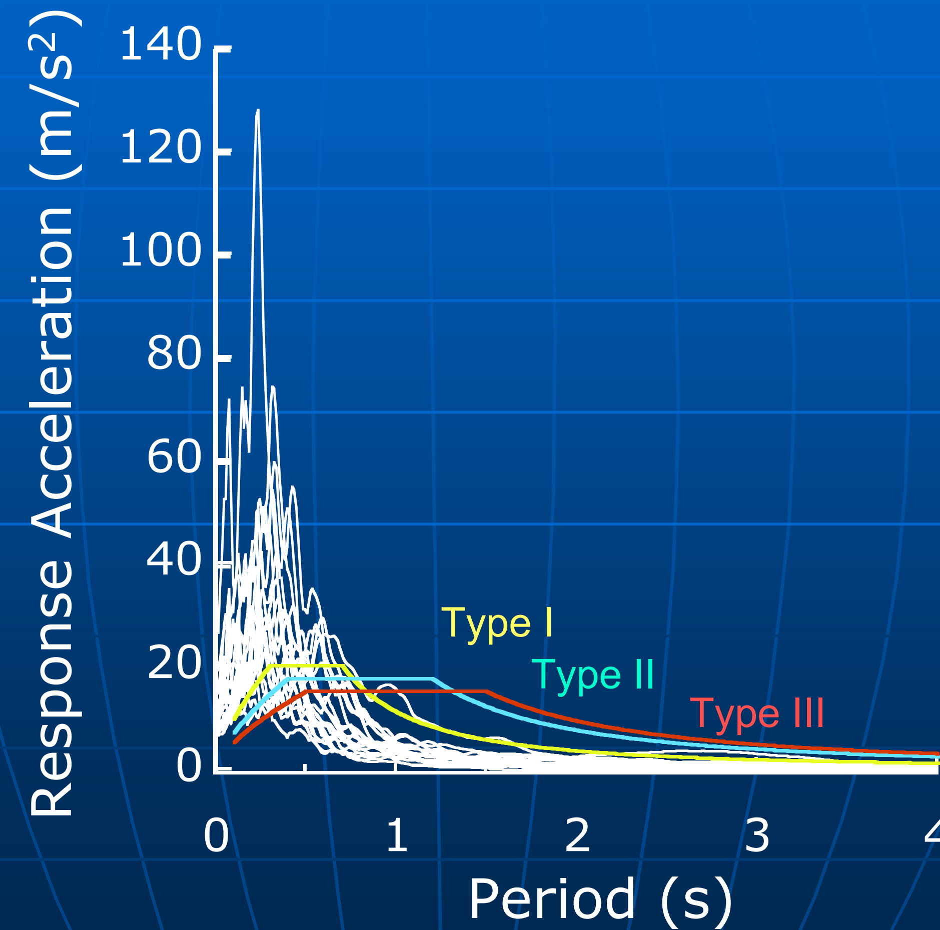
Strong motion distribution at Eastern Japan (5HzPGA)
This PGA is commonly used as an index for the alarm to stop the train operation.

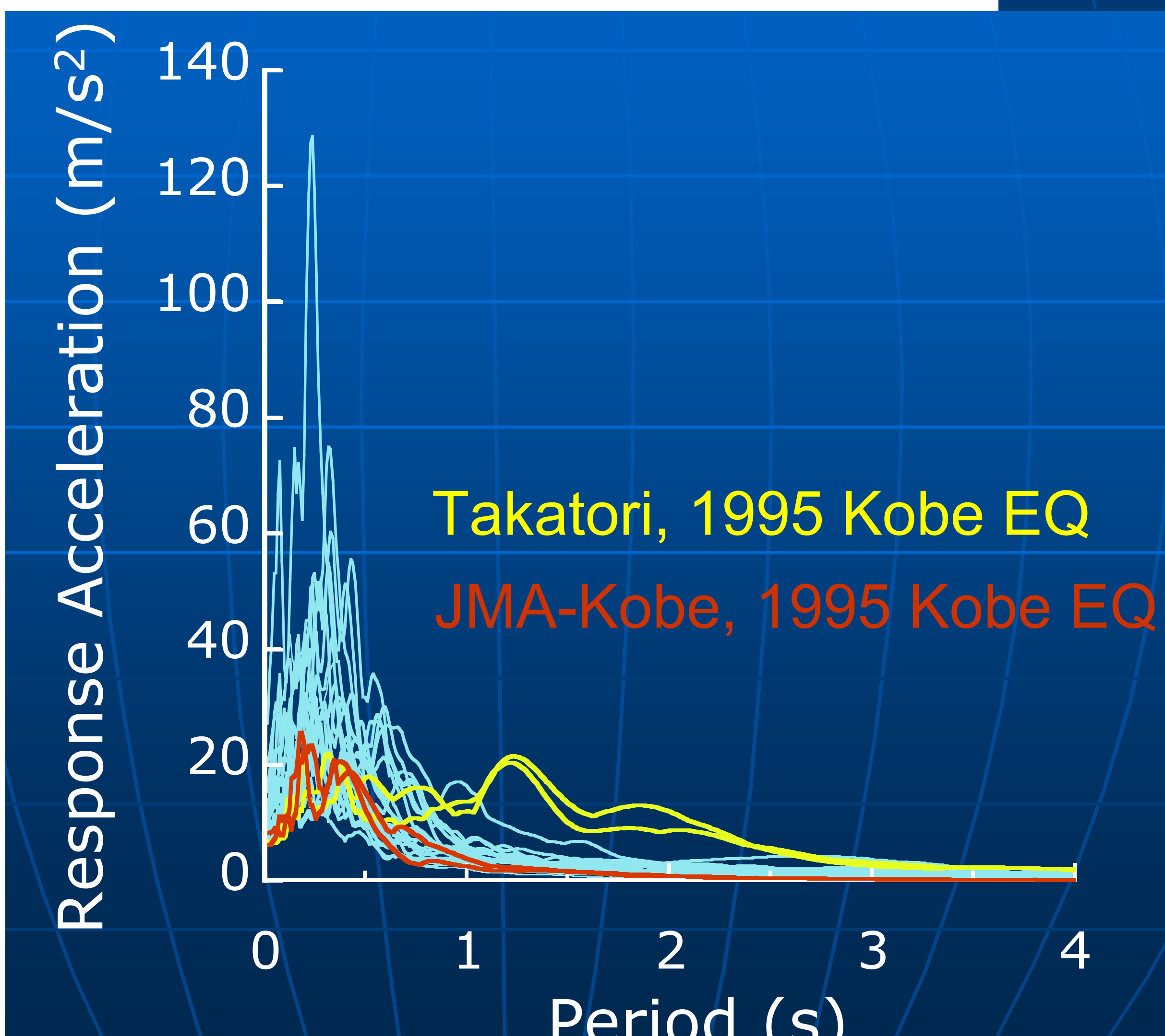
Tsukidate

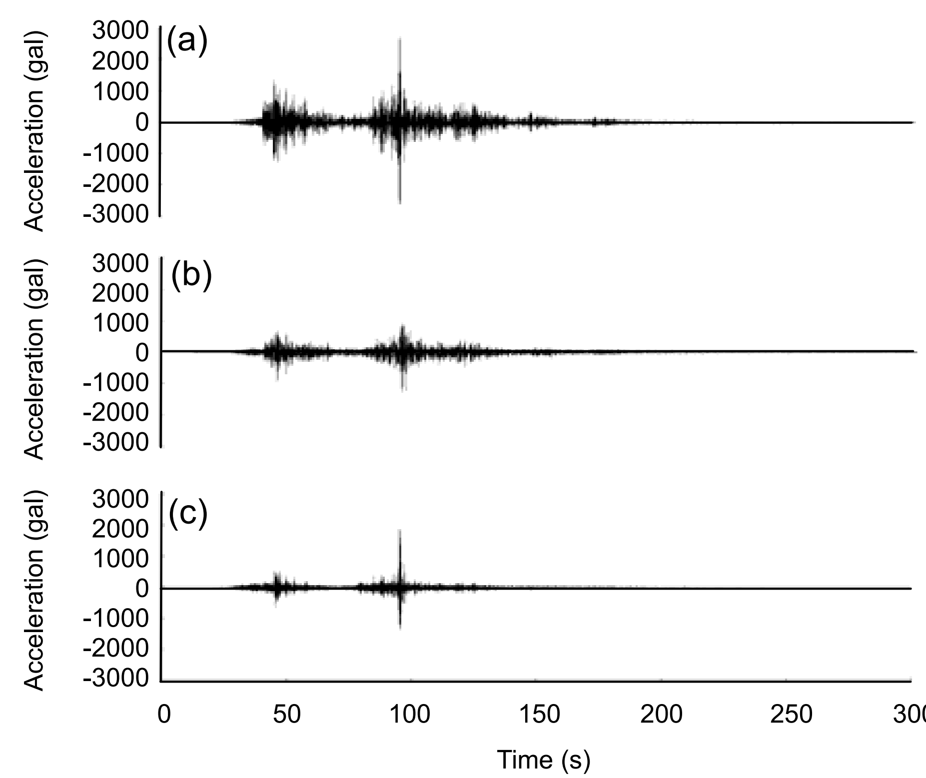


Courtesy of Kazuhiko Kawashima

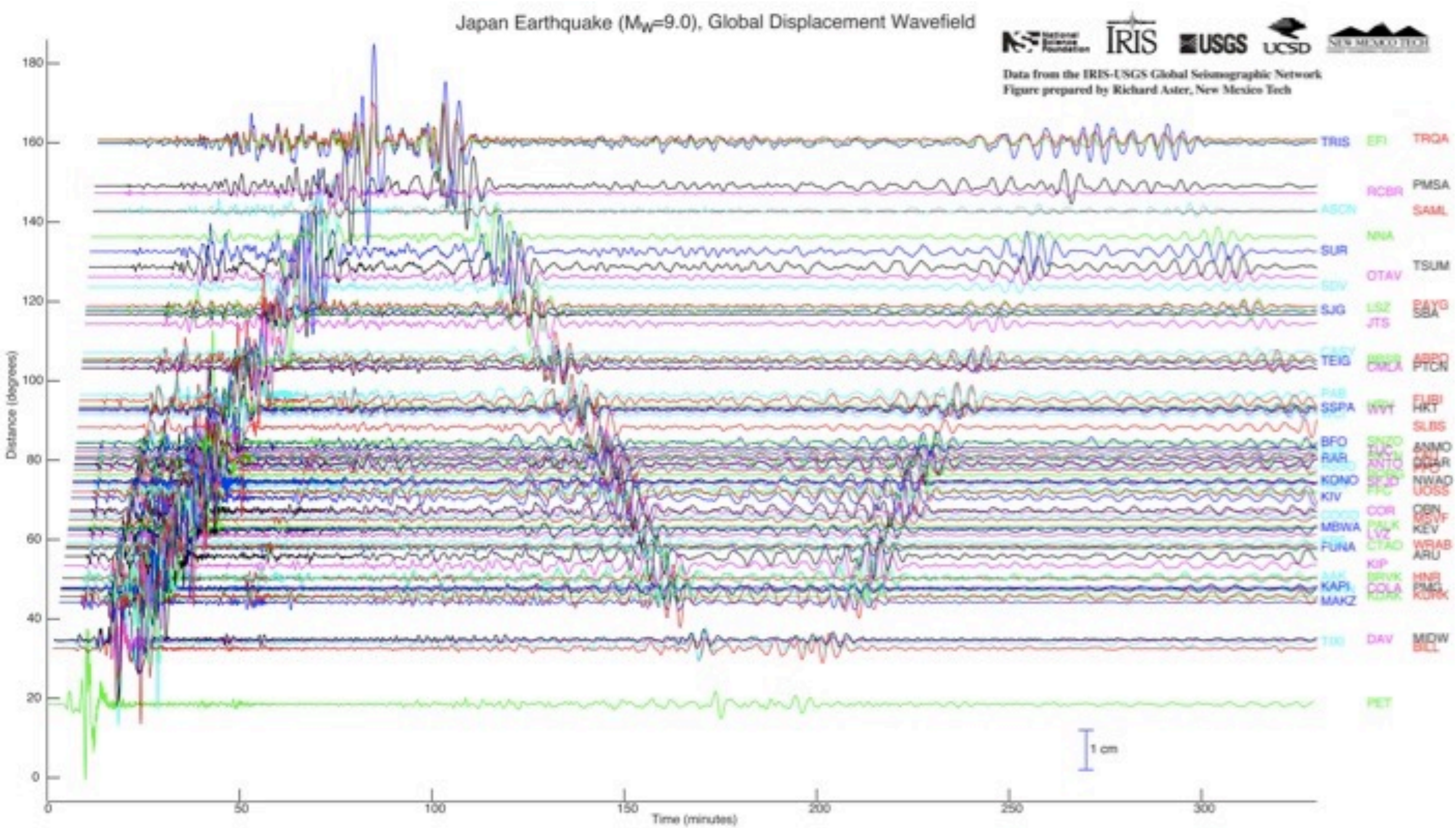
Comparison with Type II Design Spectra, JRA Design Specifications of Bridges



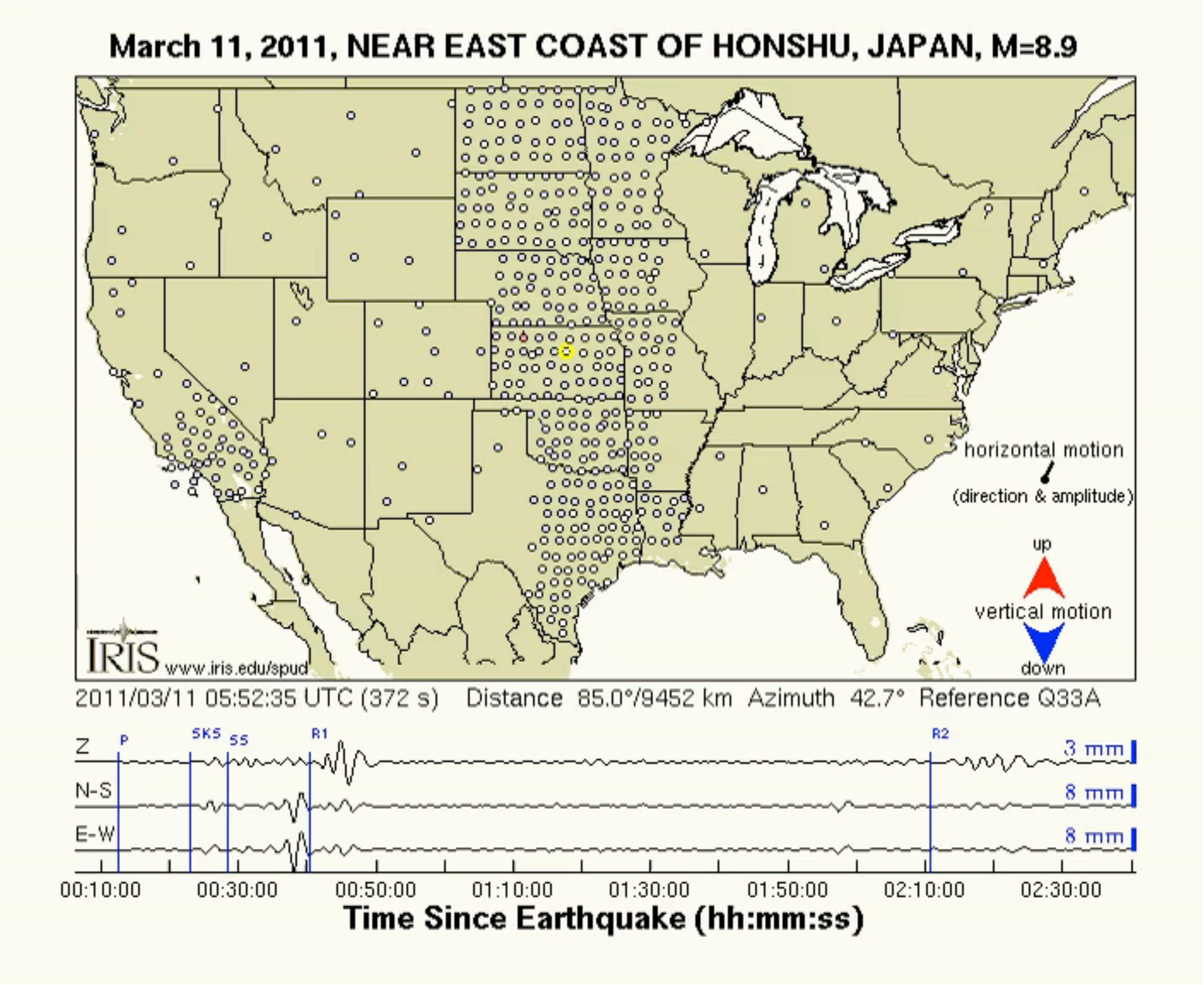




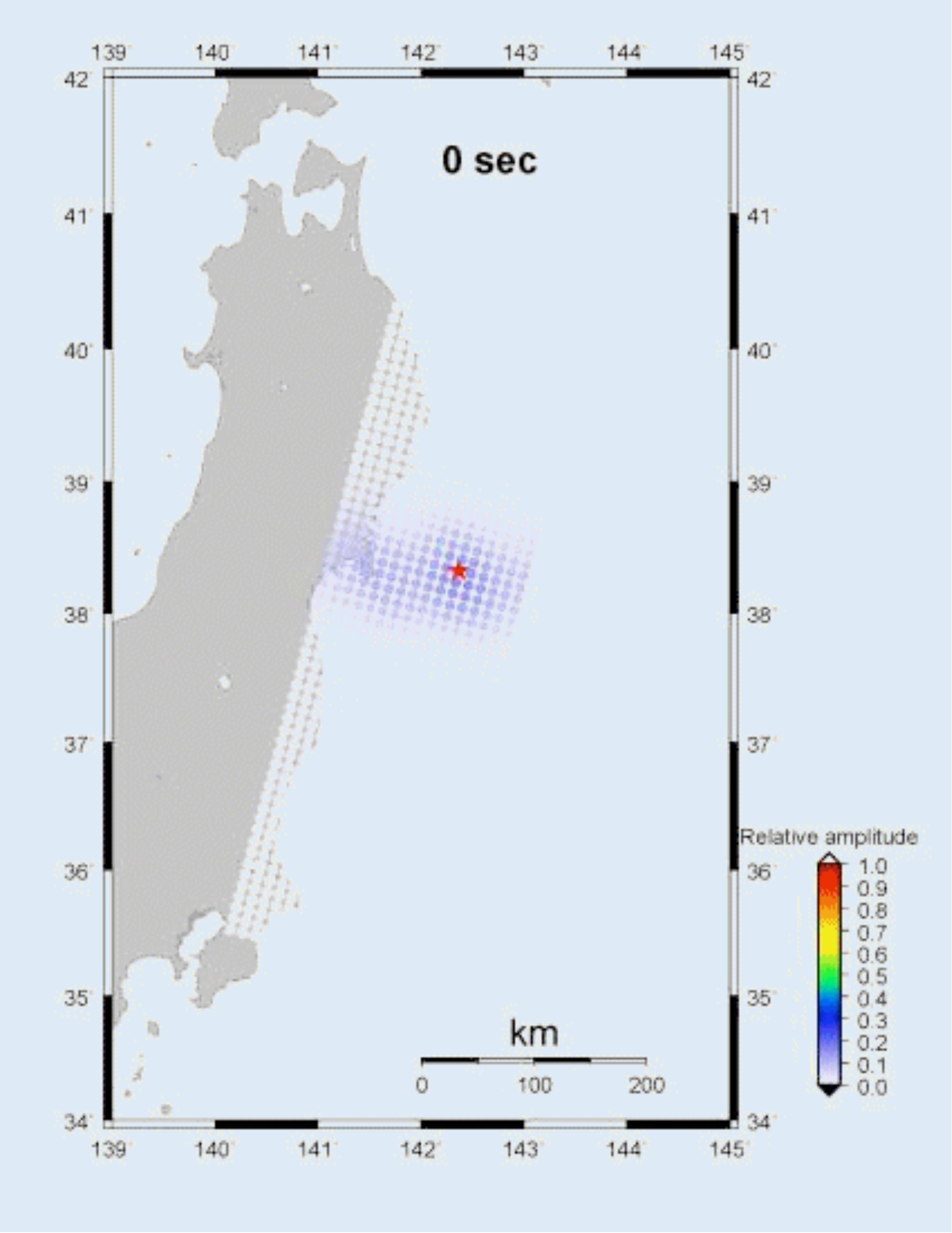
Ground motion - Worldwide



Ground motion - USA



Finite fault model from backprojection



Courtesy of Dun Wang and Jim Mori

Ocean bottom data

The observation record of the ocean bottom pressure gauge. At around 14:46, the ground motion of the earthquake (M9) reaches the pressure gauge and at TM1 (coast-side), the sea level is gradually rising from that point.

The sea level rose 2 m, and after 11 minutes, the level went drastically up to 3m, which makes 5 m of elevation in total. At TM2: located 30km toward the land, a same elevation of sea level was recorded with 4 minutes delay from TM1.

釜石沖海底ケーブル式地震計システムで観測された海面変動

東京大学地震研究所

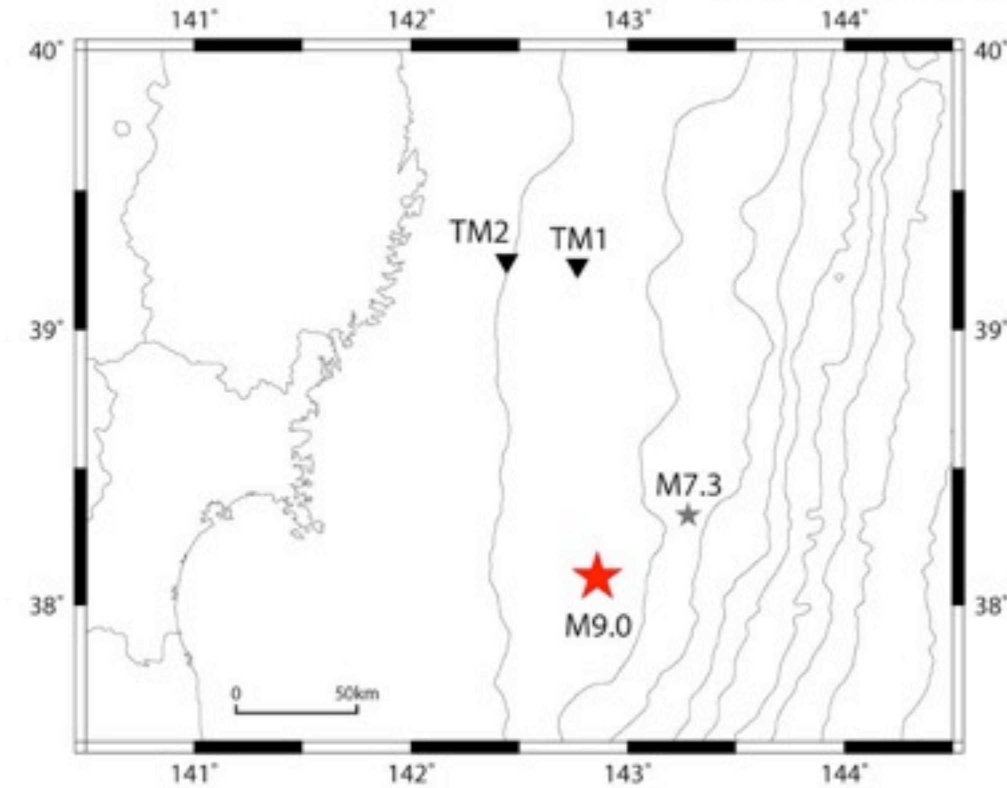


図 1　釜石沖ケーブル式海底水圧計の位置

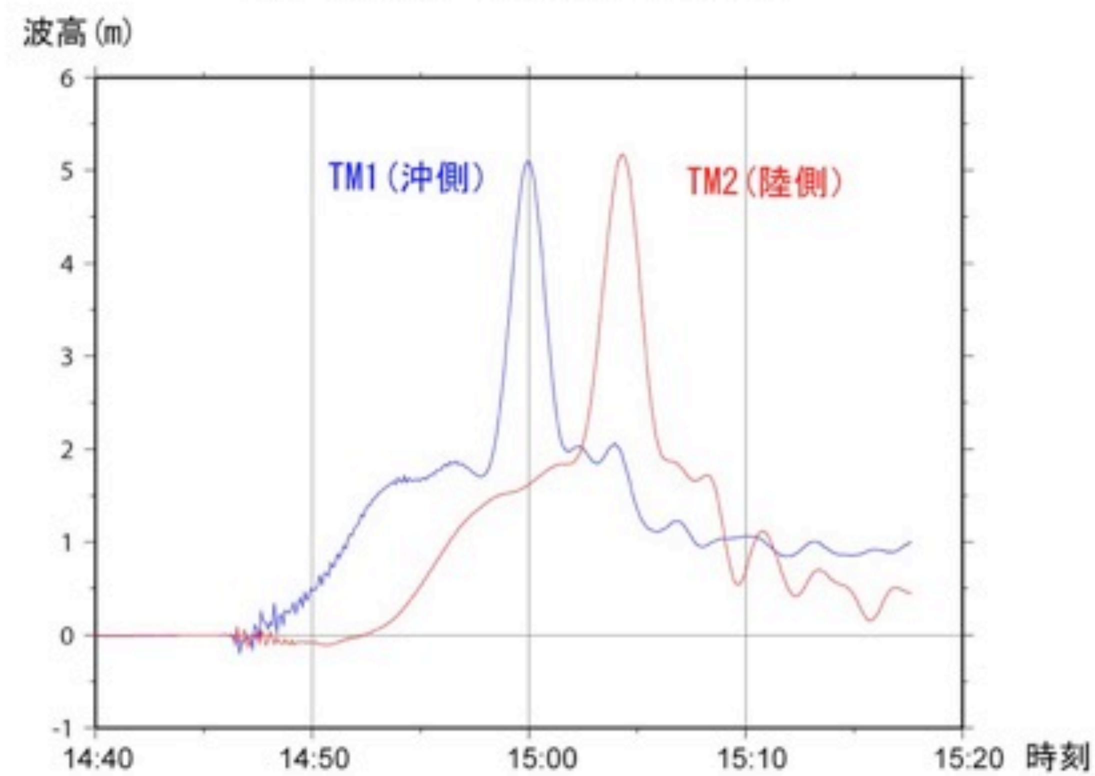


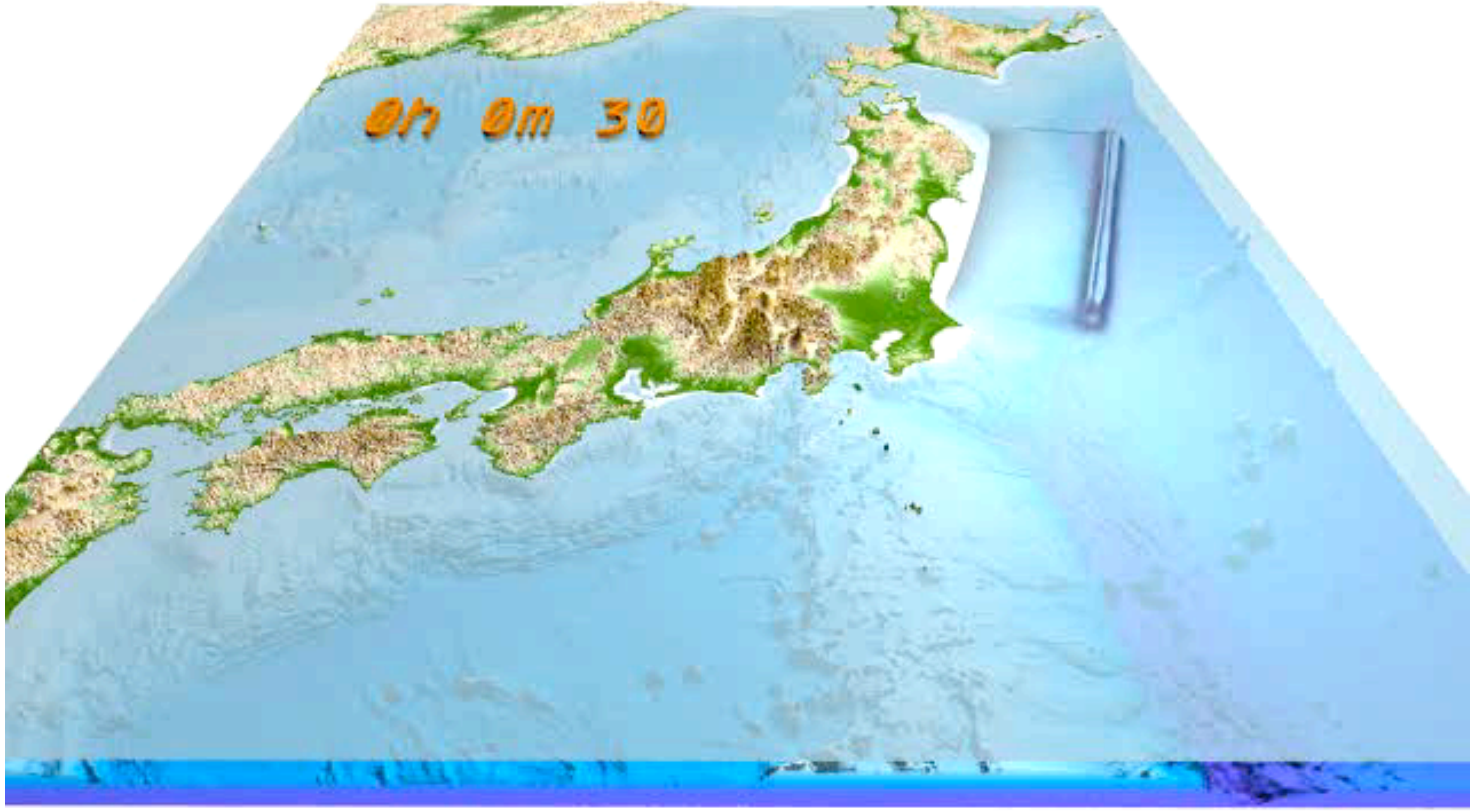
図２　海底水圧計の観測記録。14時46分頃、本震(M9.0)の振動が水圧計に伝わり、TM1(海寄り)では、その時から徐々に海面が上昇している。約２ｍ上昇し、約11分後にはさらに約3m急激に上昇し、合計約5m海面が上昇した。約30km陸寄りに設置されているTM2では、TM1から約4分遅れて同様の海面上昇を記録した。

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/



"Earthquake Research Institute, University of Tokyo, Prof. Takashi Furumura and Project Researcher Takuto Maeda"

Any strategy for seismic risk reduction should be outlined trying to answer two basic questions:

- When, where and how big we have to expect a strong earthquake to strike a region?
- What should we expect when it occurs?

The answer to the first question is matter for earthquake prediction,

while the second one is matter for sound seismic & tsunami hazard assessment...

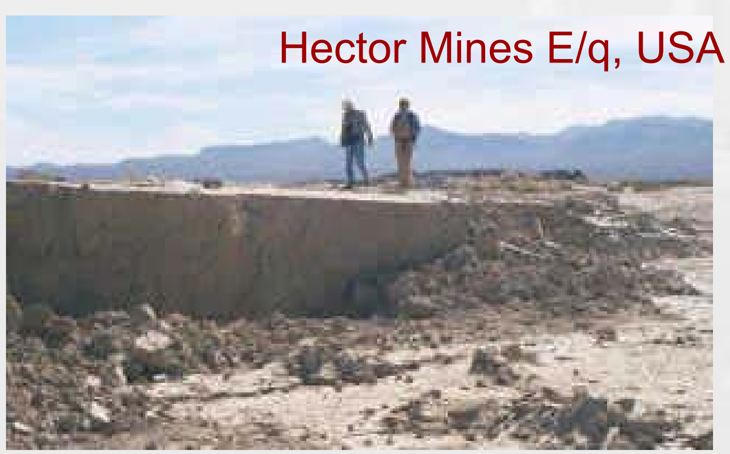
Earthquake effects

ground shaking

liquefaction

surface rupture

Chi Chi E/q, Taiwan



Hector Mines E/q, USA

Hazard, Risk & Vulnerability

Risk = Hazard * Vulnerability

Nature decided, and can be assessed

Man decided, and can be reduced

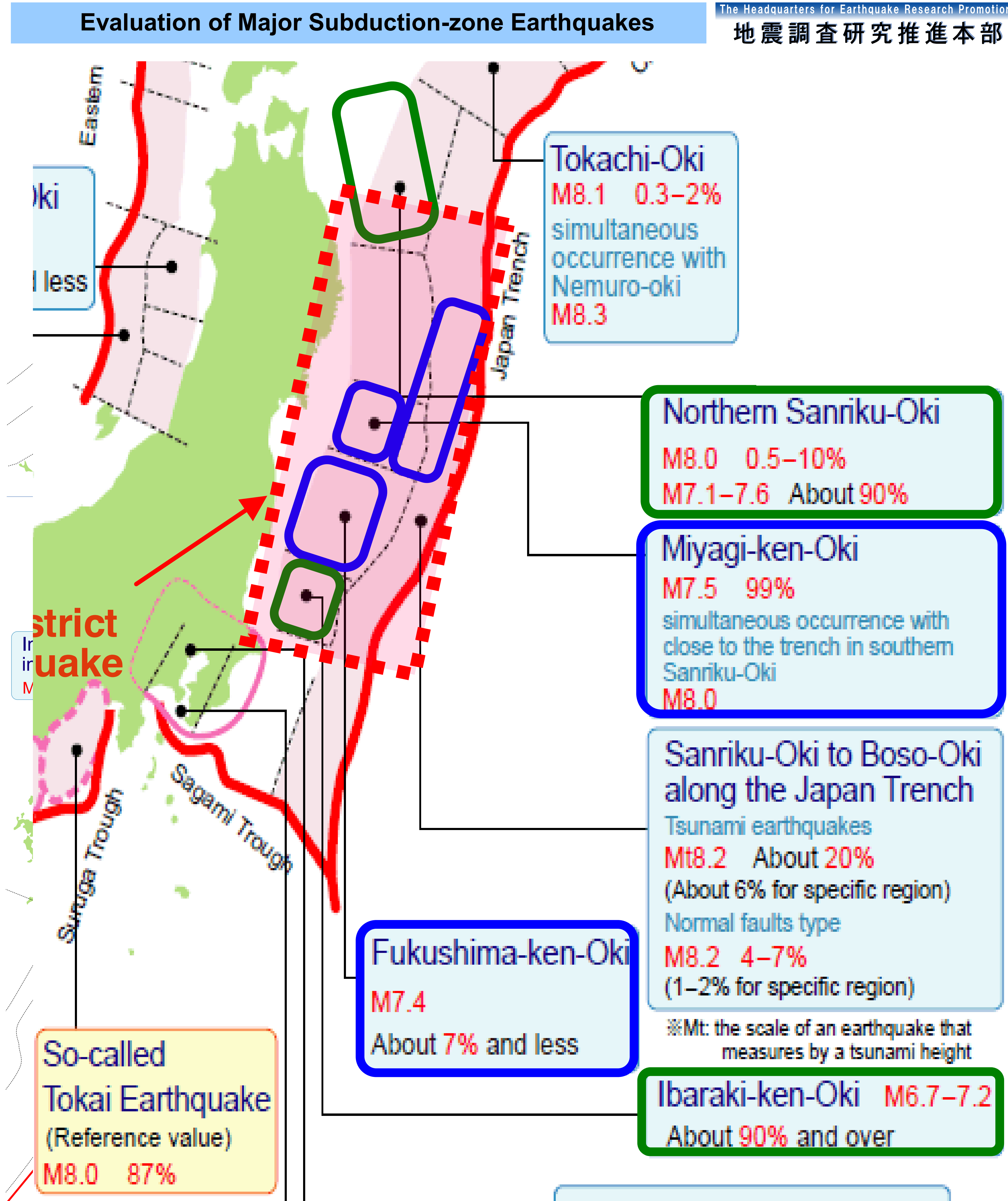
$$R = \langle H_i, P_i, C_i \rangle$$

set of i-events with possible adverse consequences

associated probabilities of their occurrence

associated intolerable consequences

Expectations...



"Estimated magnitude and long-term possibilities within 30 years of earthquakes on regions of offshore based on Jan. 1, 2011."

"Estimated magnitude and long-term possibilities within 30 years of earthquakes on regions of offshore based on Jan. 1, 2008."

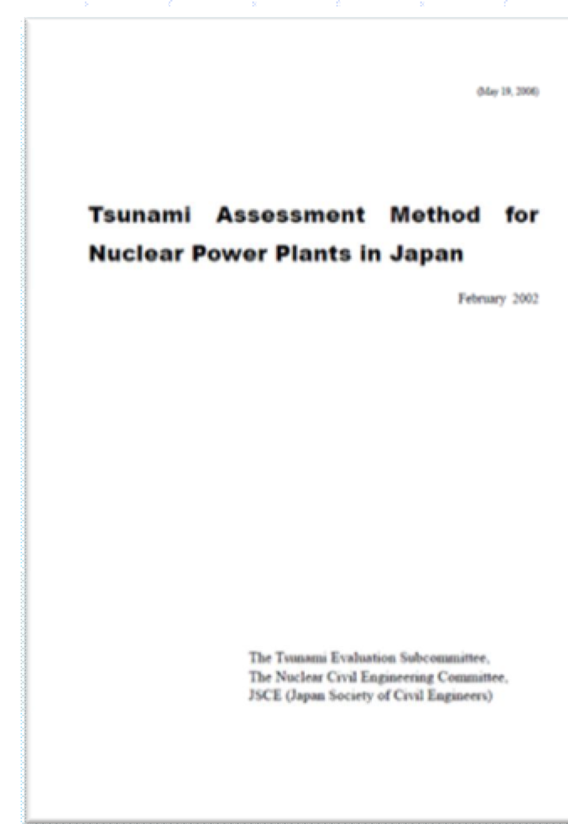
Tsunami Assessment method for NPP in JSCE, Japan

The TSUNAMI EVALUATION SUBCOMMITTEE,
Nuclear Civil Engineering Committee, JSCE

Masafumi Matsuyama (CRIEPI)

History of TES

- Phase I 1999-2000
  The maximum and minimum water levels by deterministic method
  → "Tsunami assessment method for NPP in Japan」 (2002)"
- Phase II 2003-2005
  Probabilistic Tsunami Hazard Analysis for the max. and min. water levels
  Numerical simulation of nonlinear dispersion wave theory with soliton fission and split wave-breaking
  Tsunami wave force on breakwater
- Phase III 2006-2008
  Topography change due to tsunami
  Development of probabilistic Tsunami Hazard Analysis
- Now → Phase IV 2009-2011
  Revising of 「Tsunami assessment method for NPP in Japan」


Tsunami Assessment Method for Nuclear Power Plants in Japan

February 2002

The Tsunami Evaluation Subcommittee,
The Nuclear Civil Engineering Committee,
JSCE (Japan Society of Civil Engineers)

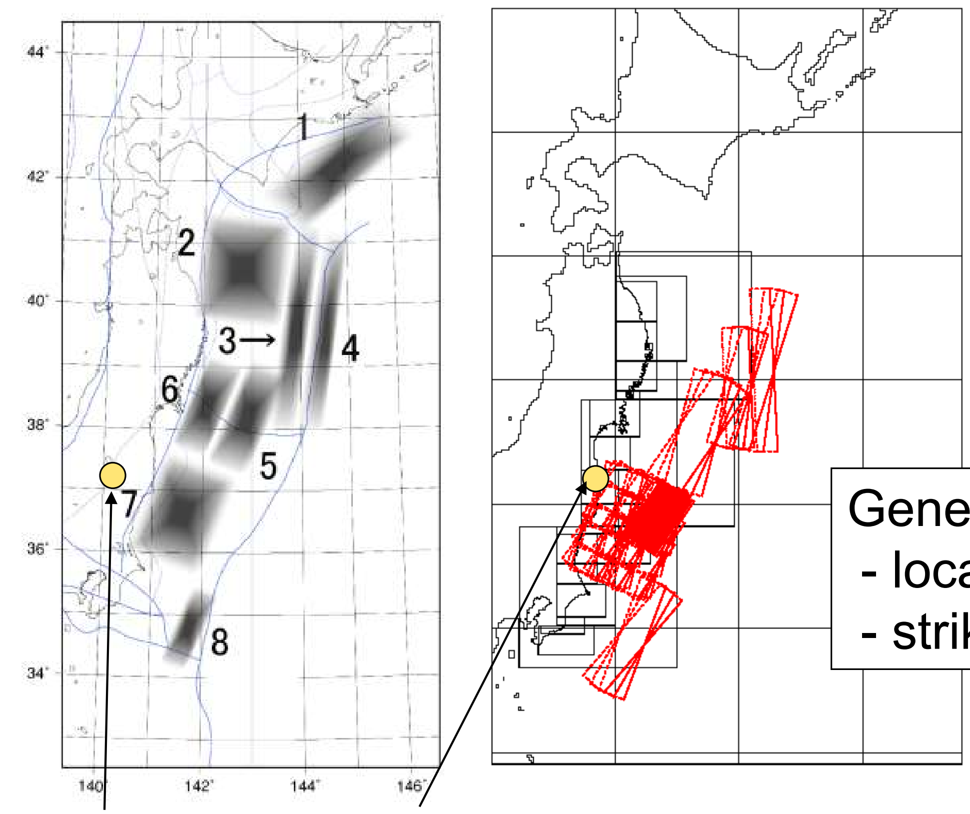
Niigata meeting, November 2010
http://www.jnes.go.jp/seismic-symposium10/presentationdata/3_sessionB.html

Tsunami Assessment method for NPP in JSCE, Japan

The TSUNAMI EVALUATION SUBCOMMITTEE,
Nuclear Civil Engineering Committee, JSCE

Masafumi Matsuyama (CRIEPI)

General parametric study in the near field



General parametric study
- location
- strike

Deterministic method (2002)
Main flow chart

Sub flow 1

Verification of fault model(s) and numerical calculation system on the basis of historical tsunami(s)

↓

Sub flow 2

Estimation of the design water levels on the basis of **parametric study** in terms of basis tsunamis

↓

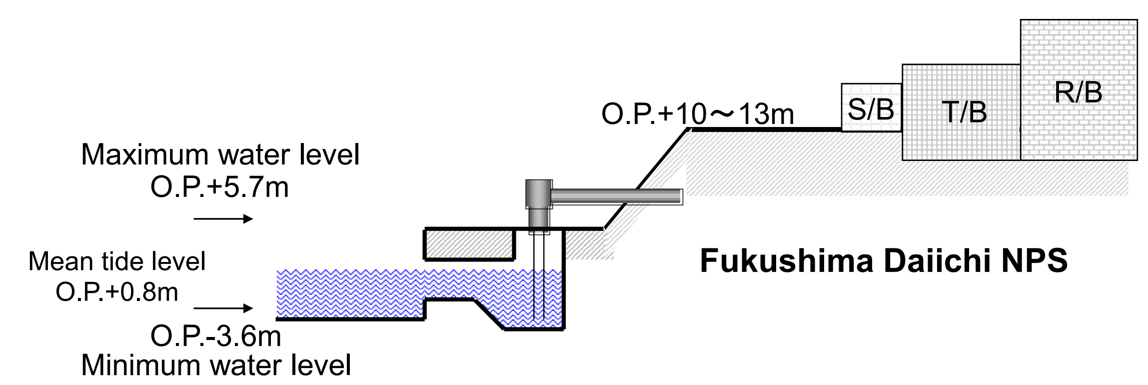
tide → Design high water level / Design low water level

↓

End

Summary of Evaluation

Maximum water level = 4.4m + O.P.＋1.3m = O.P.+5.7m
Minimum water level = -3.6m – O.P.±0.0m = O.P.-3.6m



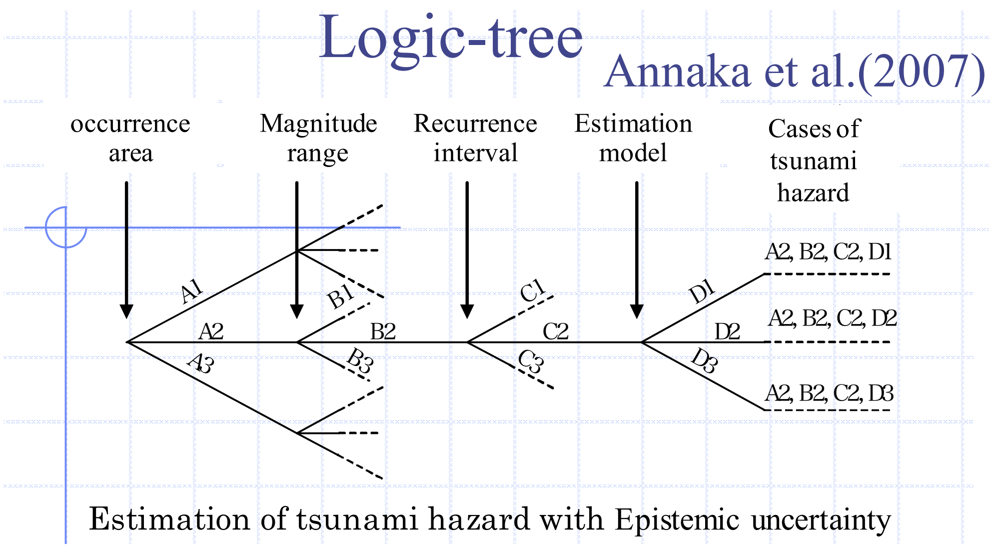
We assessed and confirmed the safety of the nuclear plants based on the JSCE method which was published in 2002.

Niigata meeting, November 2010
http://www.jnes.go.jp/seismic-symposium10/presentationdata/3_sessionB.html

Tsunami Assessment method for NPP in JSCE, Japan

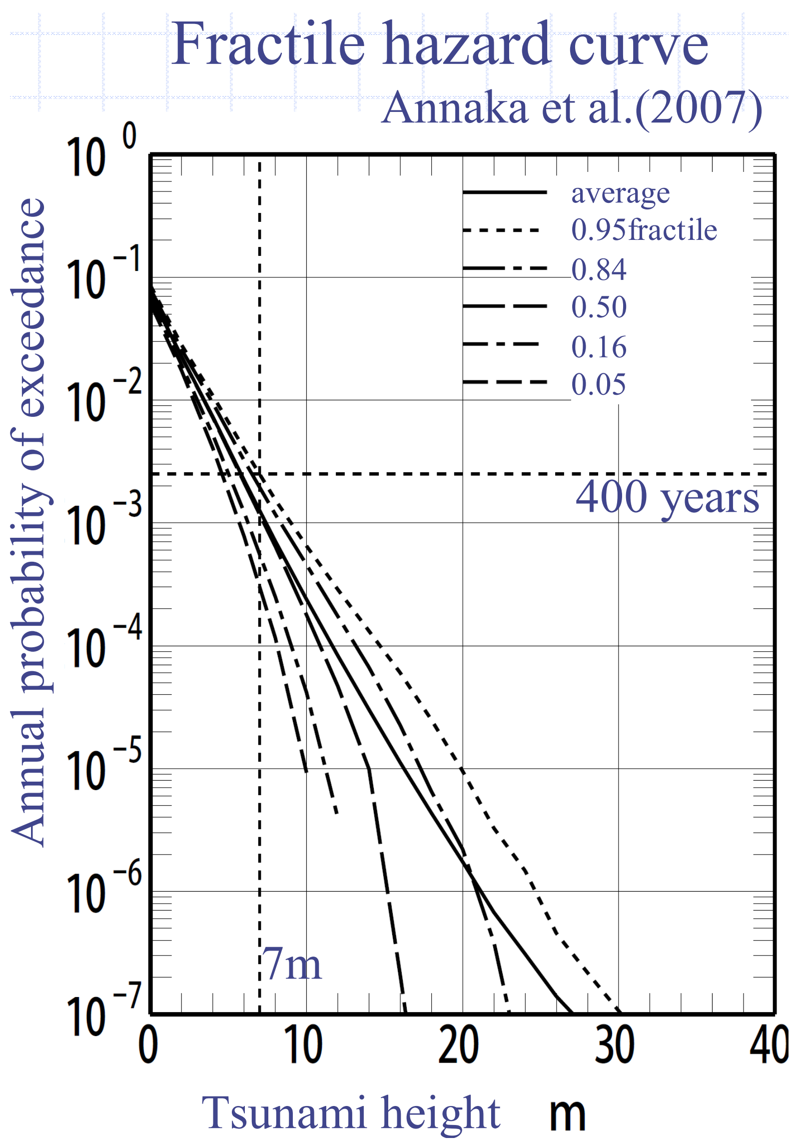
The TSUNAMI EVALUATION SUBCOMMITTEE, Nuclear Civil Engineering Committee, JSCE

Masafumi Matsuyama (CRIEPI)



Probabilistic Tsunami Hazard Analysis (PTHA)

- Probabilistic estimation of tsunami risk
  - Estimation of the deterministic design tsunamis
- Considering uncertainties in estimation
  - Errors in fault parameters
  - Errors in the numerical calculation system (numerical simulation, topography data)
  - Incomplete knowledge and data about the earthquake process



Niigata meeting, November 2010
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Tsunami Assessment method for NPP in JSCE, Japan

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Nuclear Civil Engineering Committee, JSCE

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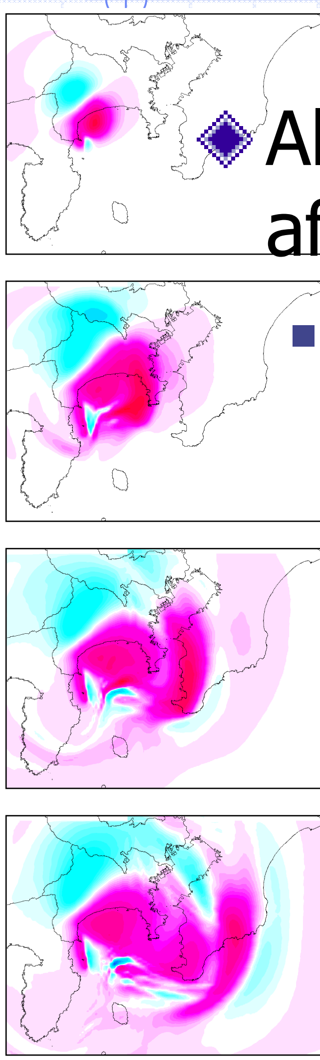
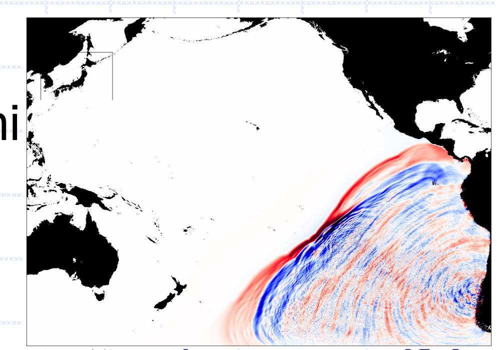
A brief review of recent activities



- Almost ten years have passed after tsunami manual released.
  - Recent advances and new knowledge
    - Tsunami source model (fault model)
      - Re-evaluation of historical tsunami faults
      - Spatial inhomogeneity in terms of slip
    - Numerical simulation
      - New simulation method of crustal motion (GMS, Grand Motion Simulator by NIED*)
      - New simulation method of far field tsunami
        - Nonlinear dispersion theory



*National Research Institute for Earth Science and Disaster Prevention, Japan

Niigata meeting, November 2010
http://www.jnes.go.jp/seismic-symposium10/presentationdata/3_sessionB.html