Dedicated to the people of Tohoku Region, who lost their lives by this earthquake

AN OVERVIEW OF THE M9.0 EARTHQUAKE OFF THE PACIFIC COAST OF TOHOKU REGION OF JAPAN ON MARCH 11, 2011 AND ITS LESSONS

Ömer AYDAN

Tokai University, Shizuoka, Japan

March 20, 2011

ATTENTION

Please note that this document is prepared with a sole purpose to provide an overview of various aspects of the earthquake for researchers, who would be involved with this earthquake.

The pictures and figures are obtained from various source available in various web-sites and they are gratefully acknowledged for the information through images of the earthquake

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1) Major characteristics of the earthquake (magnitude, casualties etc.)

2) Location and geography and Tectonics

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5) Ground Motions

6) Geotechnical Damage

7) Damage to Structures

8) Damage to Transportation Facilities

9) Damage to Industrial Facilities

10) Tsunami and Its effects on Built Environment

11) Damage to Nuclear Power Plants and Lifelines

12) Lessons

MAJOR CHARACTERISTICS OF THE EARTHQUAKE

Local time: 14:46 (2011-03-11)

Magnitude: 9.0 (Ml); 8.9-9.1 Mw

Casualties:

Faulting Mechanism: Thrust faulting (450 x 200 km)

Hypocenter depth: 24 km

Strong Motions; 3.0g

Collapse or heavy damage to timber houses due to tsunami

Most structures performed well despite very high ground motions

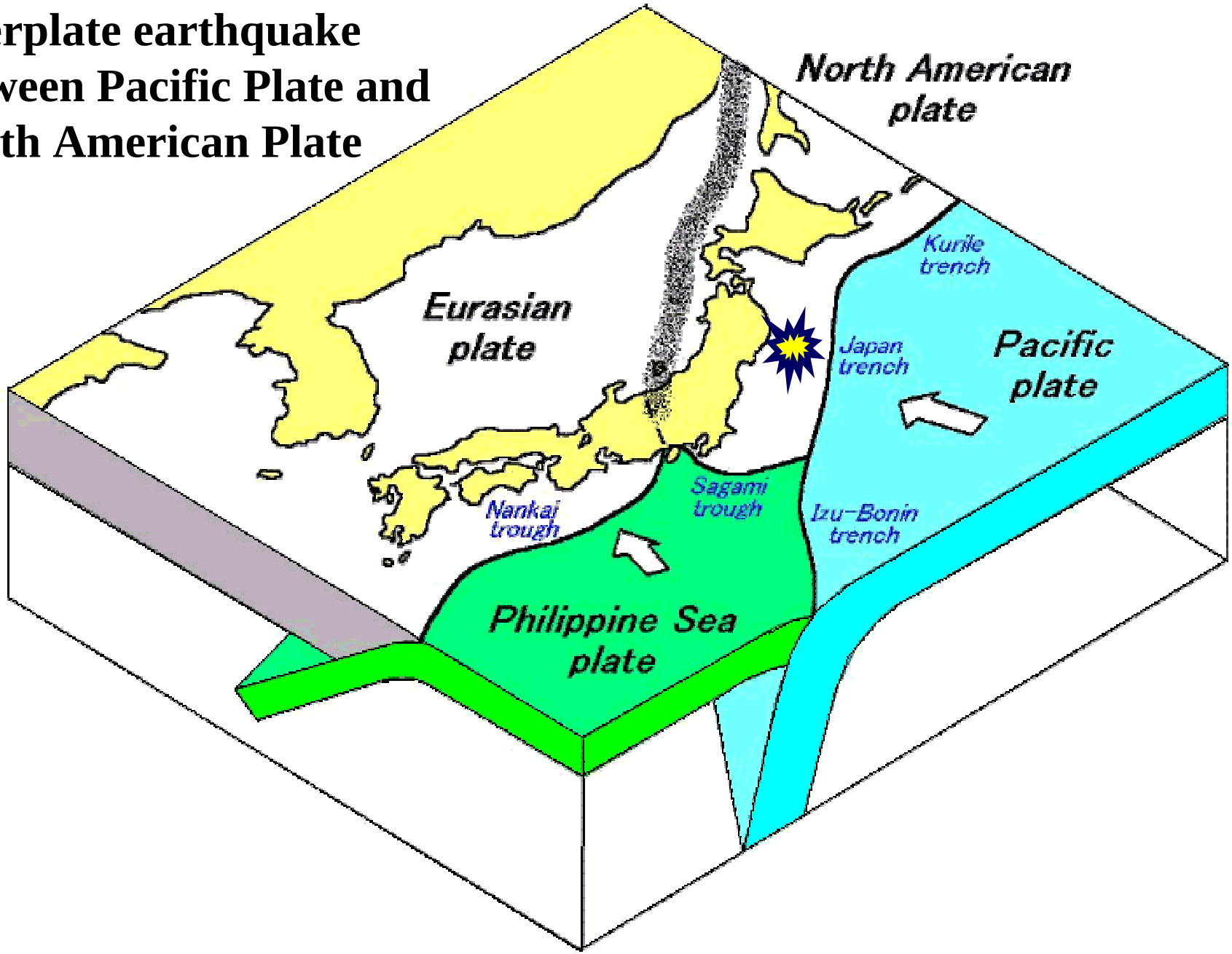
Nearest Settlements 139 km W Sendai; 177 km SE Fukushima; 373 km N Tokyo ; 260 km S Morioka

Location and Geography

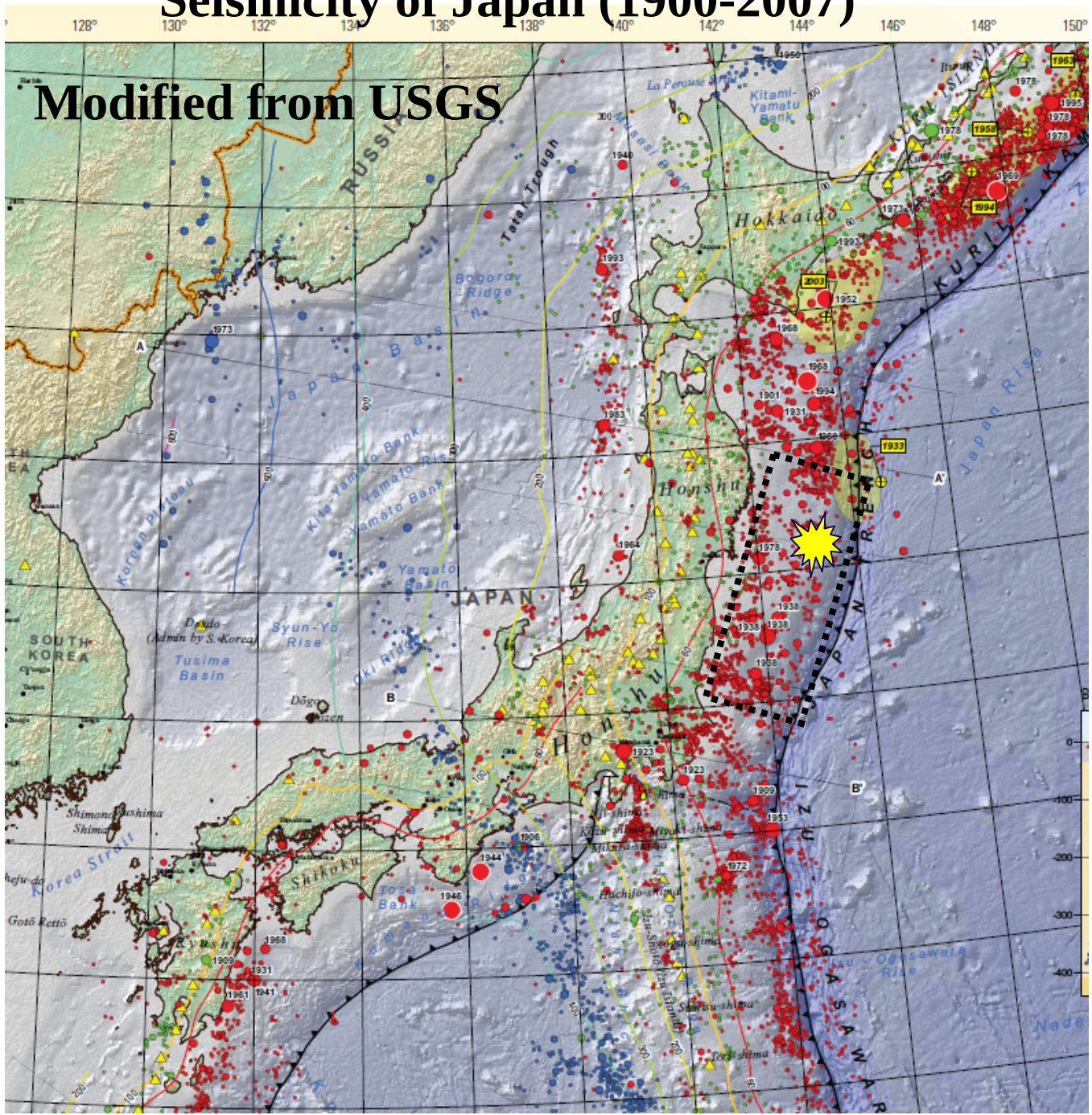
Modified from Google Map

Tectonics

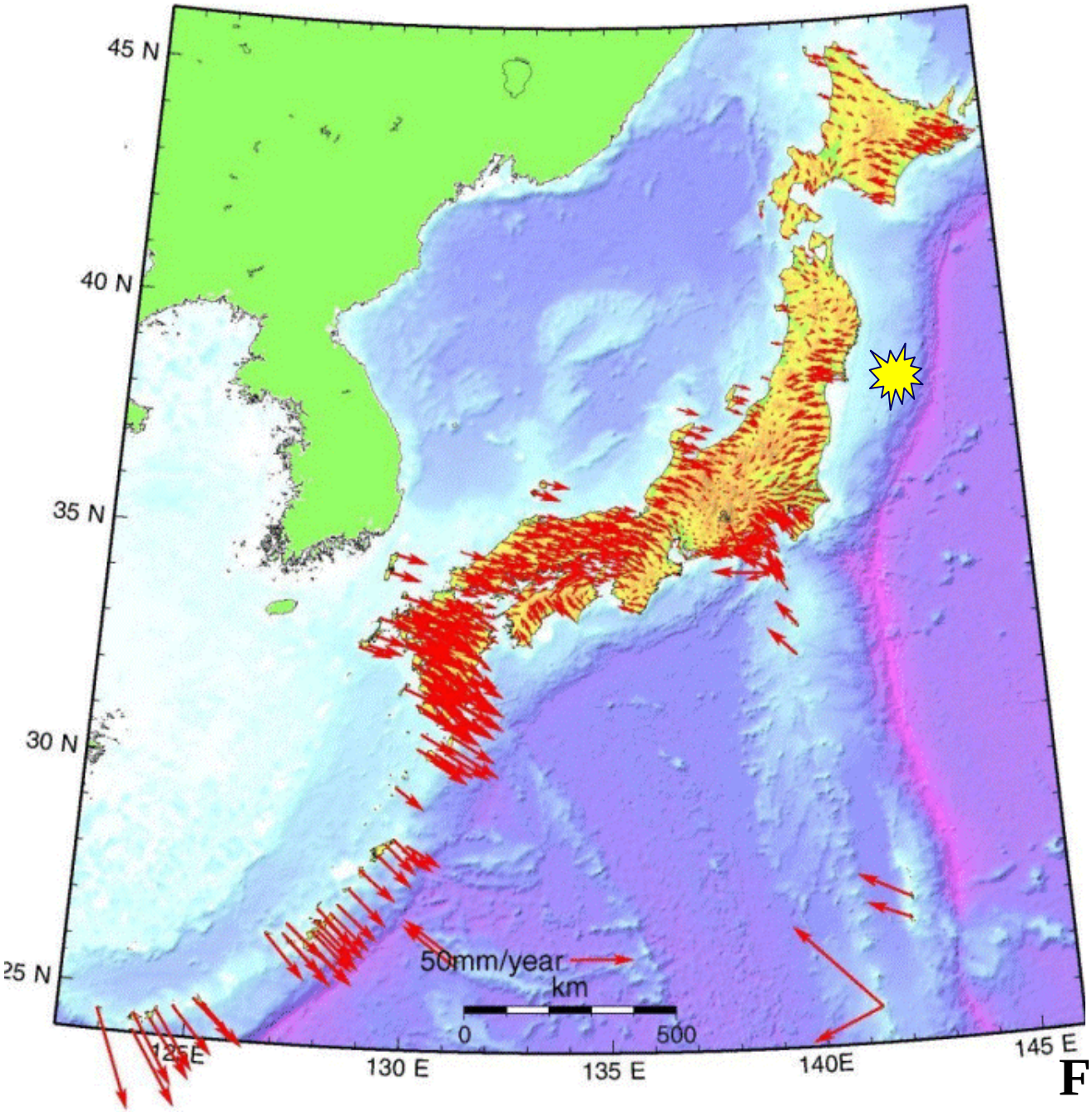
Interplate earthquake between Pacific Plate and North American Plate



Seismicity of Japan (1900-2007)

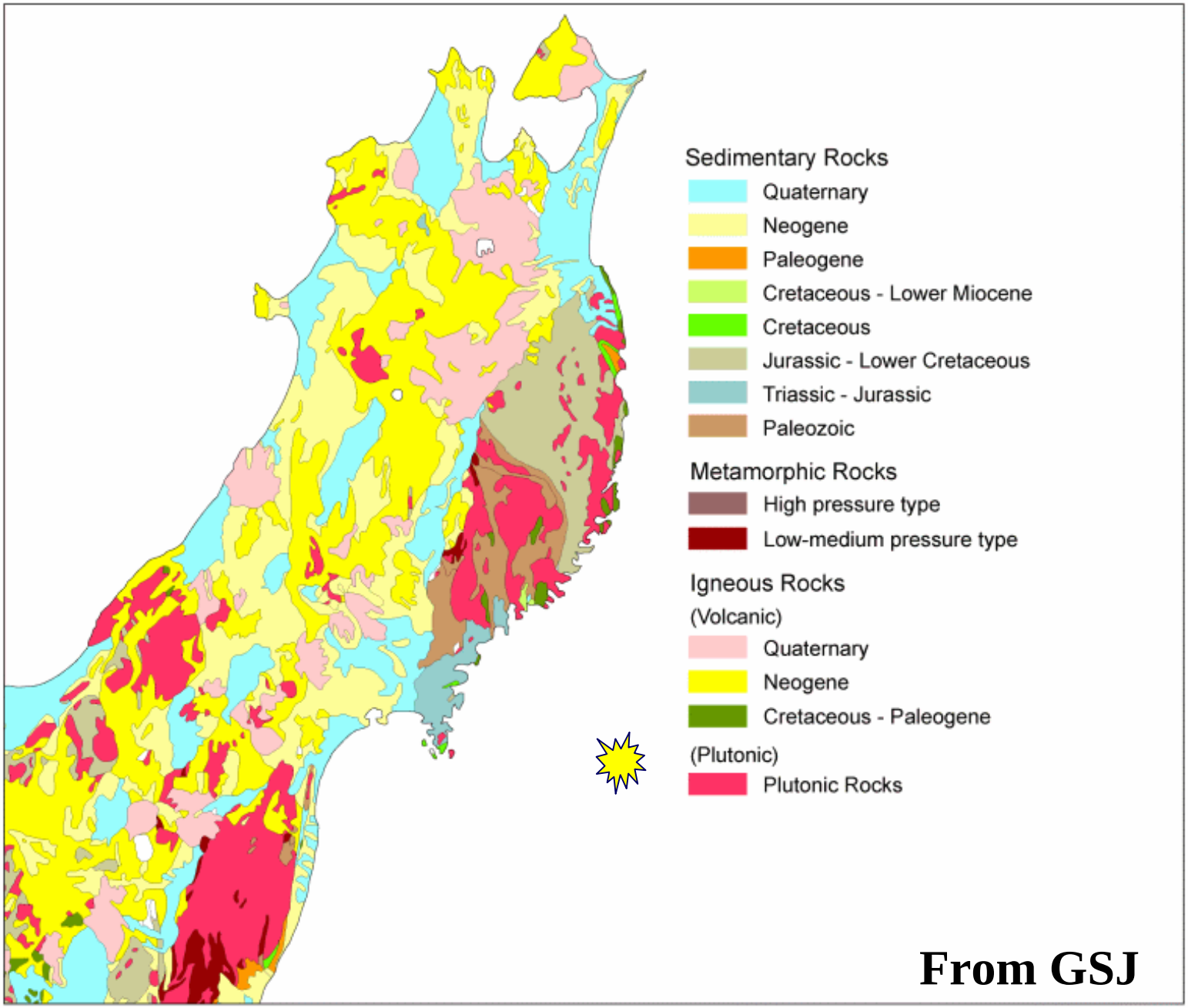


Crustal Deformations



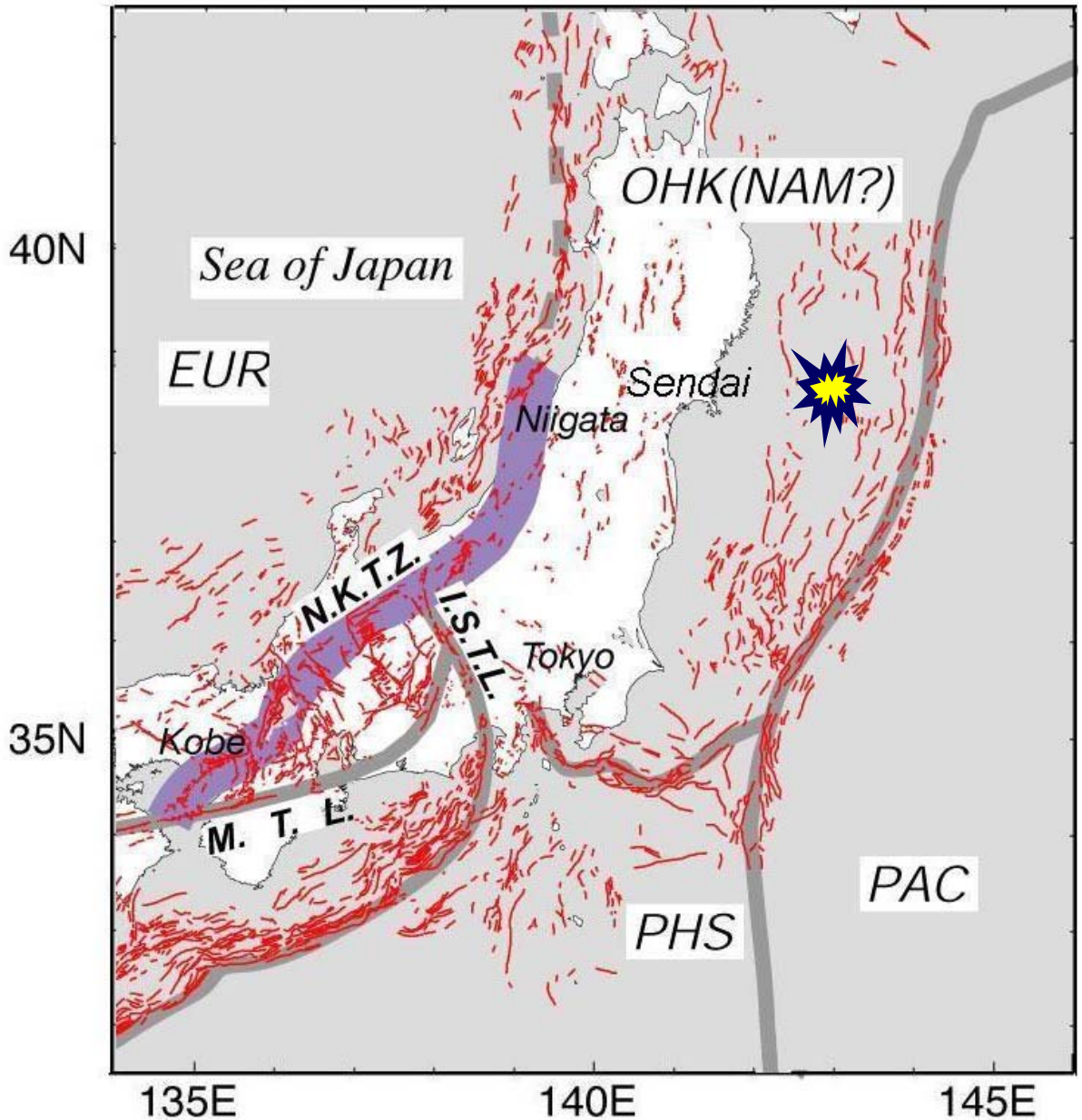
From GSI

REGIONAL GEOLOGY



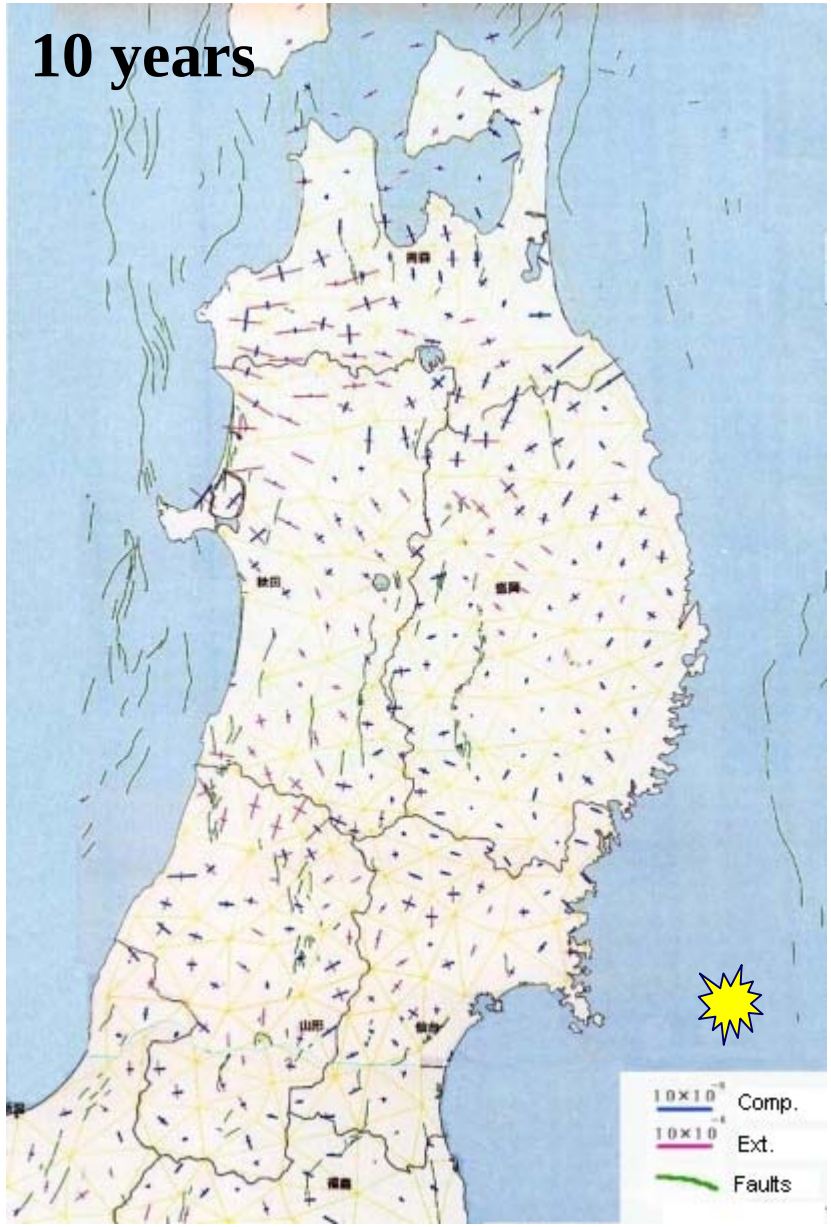
From GSJ

Regional Tectonics



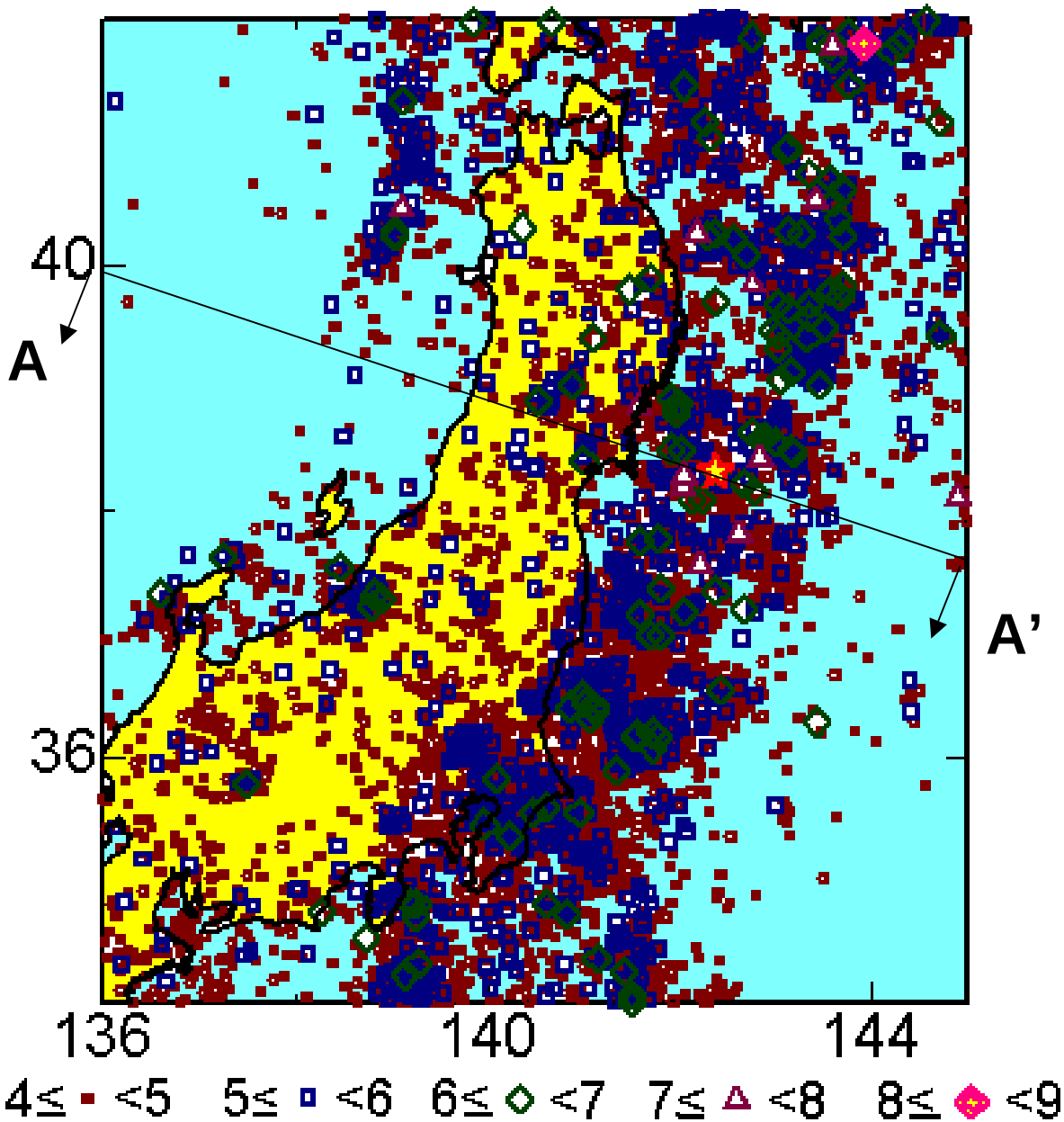
Modified from GSJ

Regional Straining

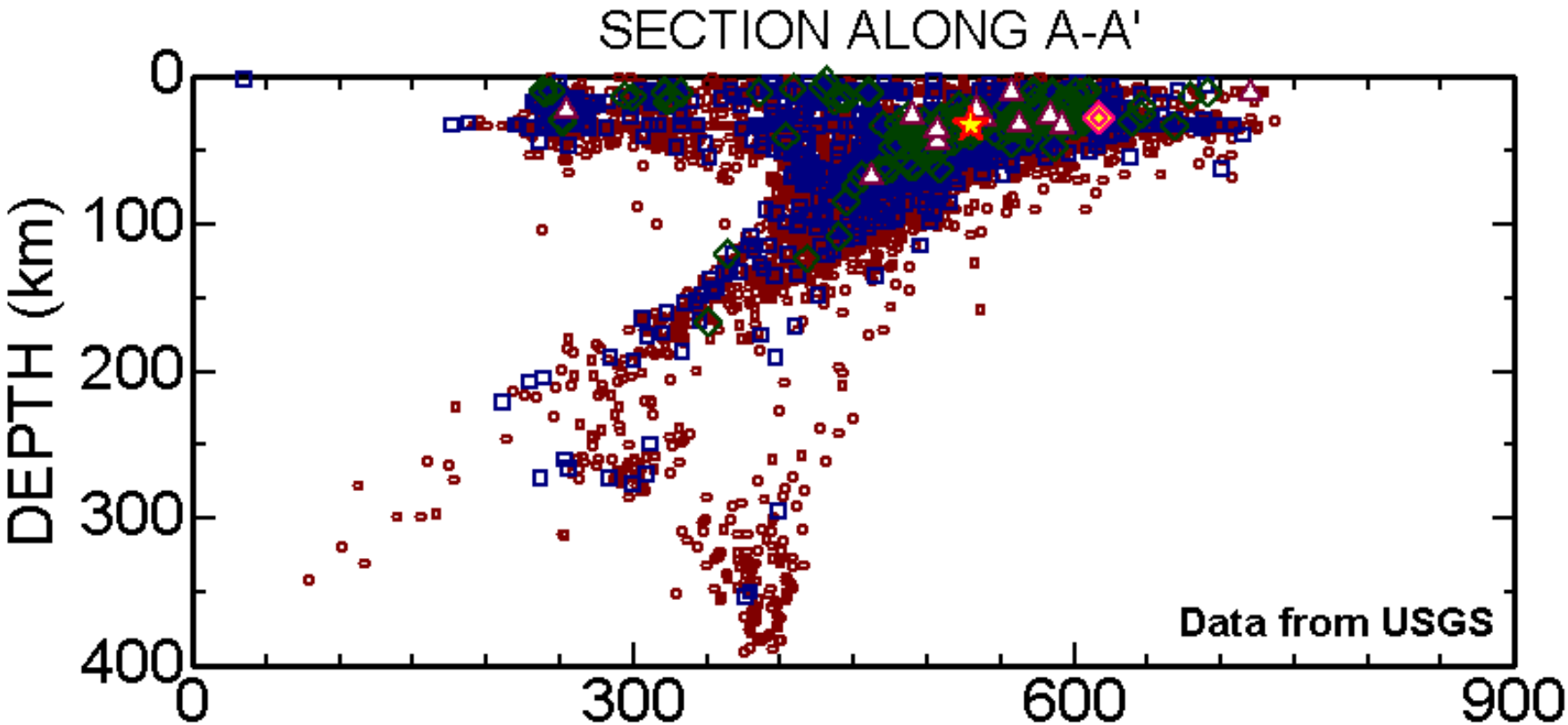


From GSI

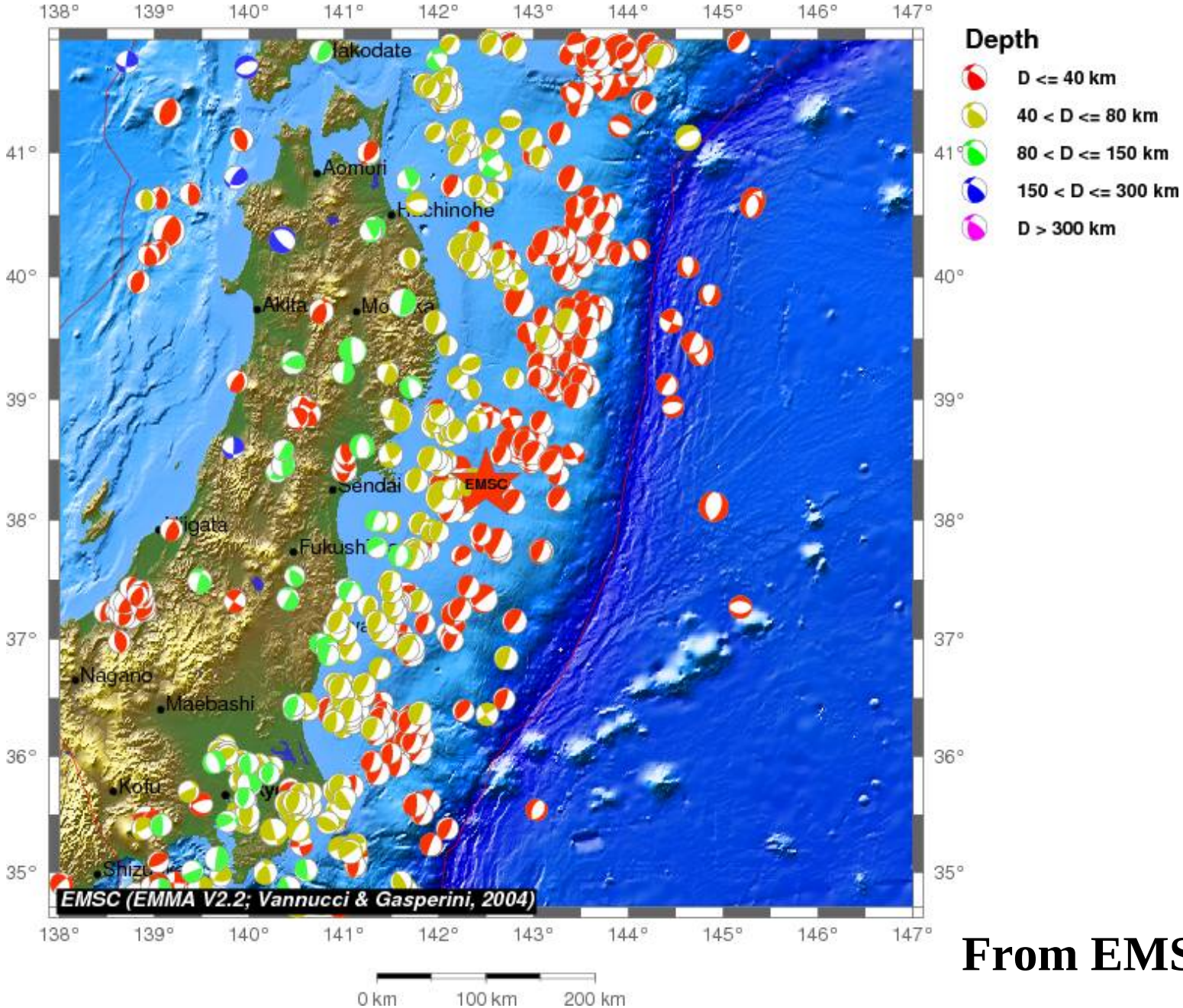
Regional Seismicity (1973-2011)



Data from USGS

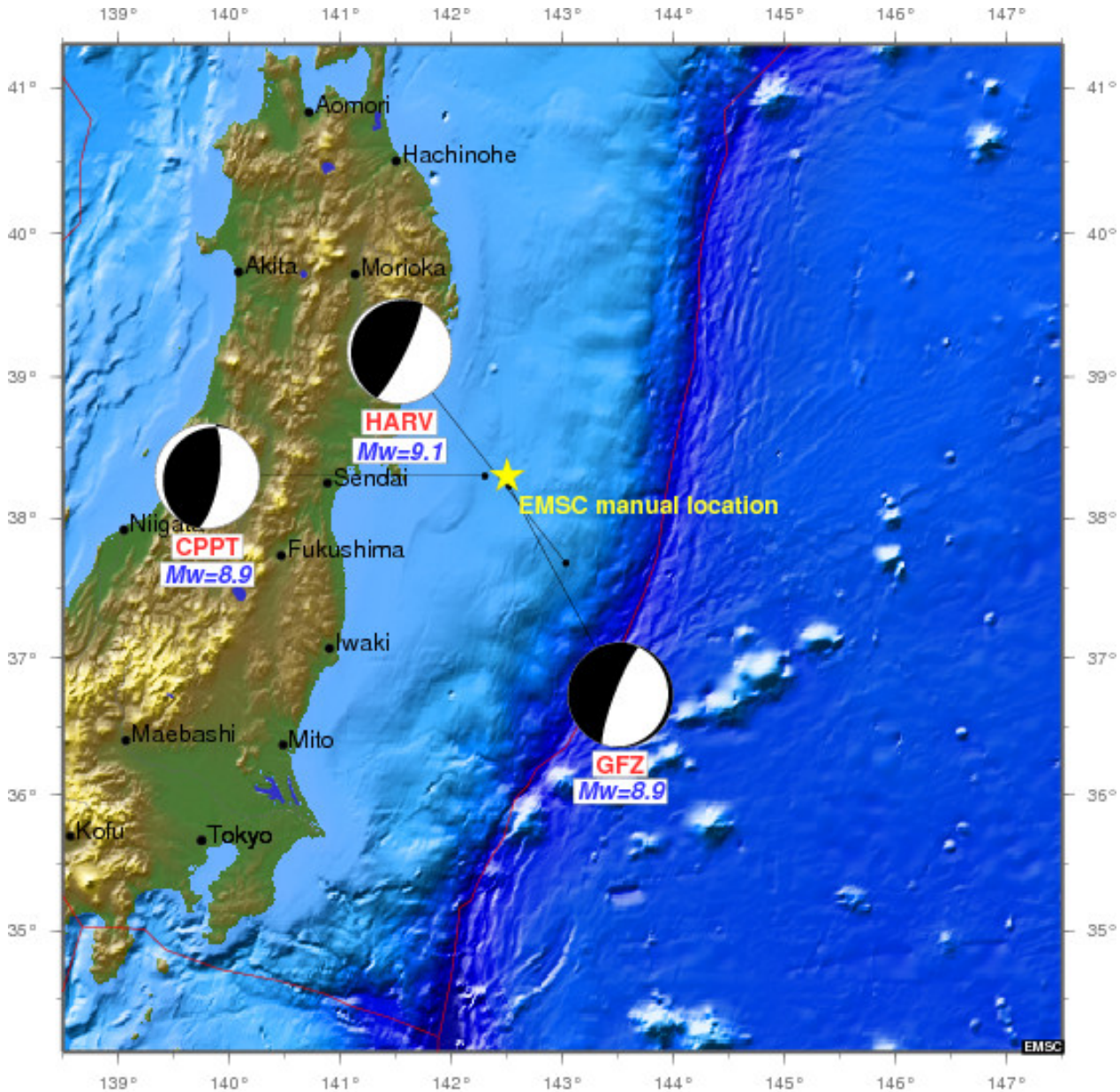

SECTION ALONG A-A'
DEPTH (km)
0
100
200
300
400
0
300
600
900
Data from USGS

Focal Mechanisms of Past Events



From EMSC

Focal Plane Solutions of Main Shock

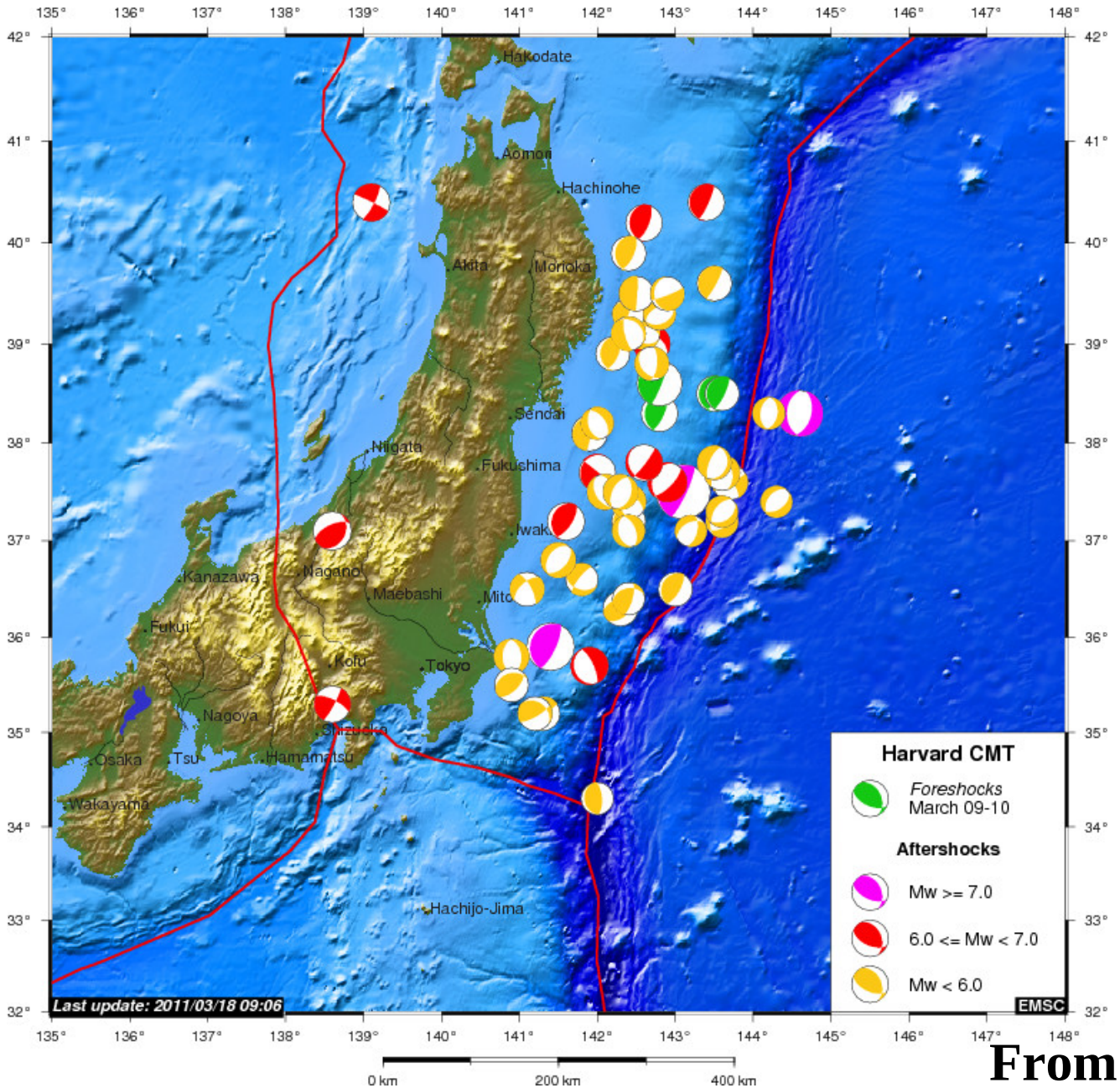


West dipping thrust faulting

0 km 100 km 200 km

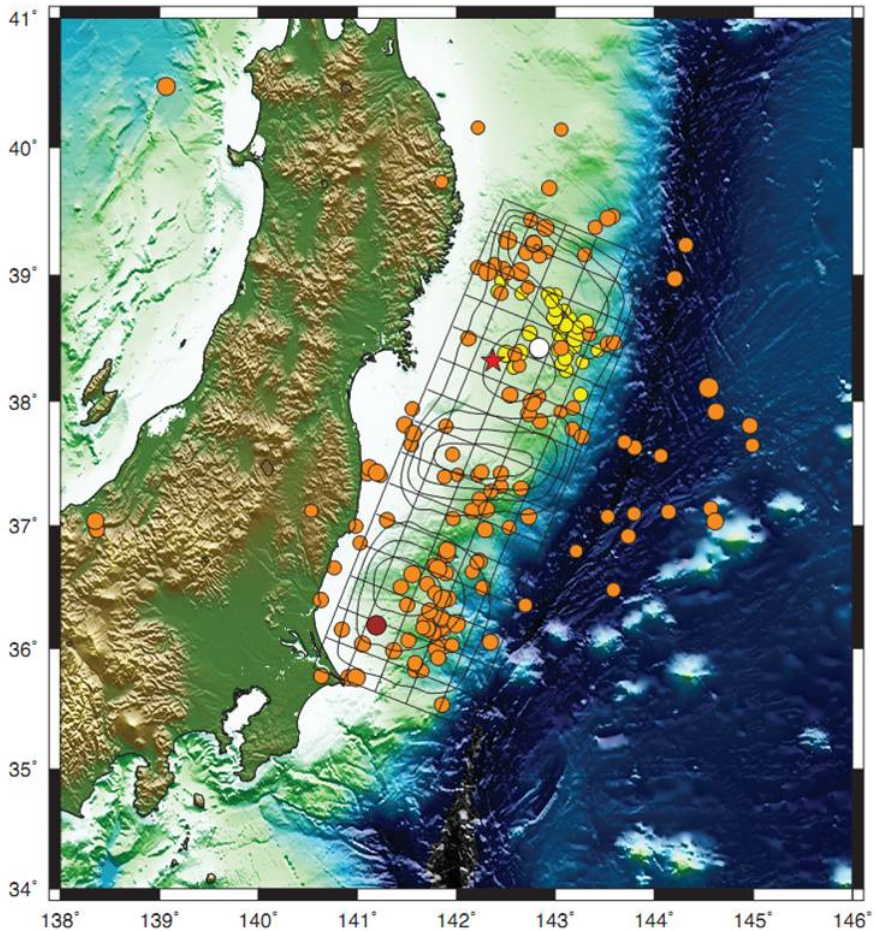
From EMSC

Focal Mechanisms of Earthquakes after 2011 March 11 Event

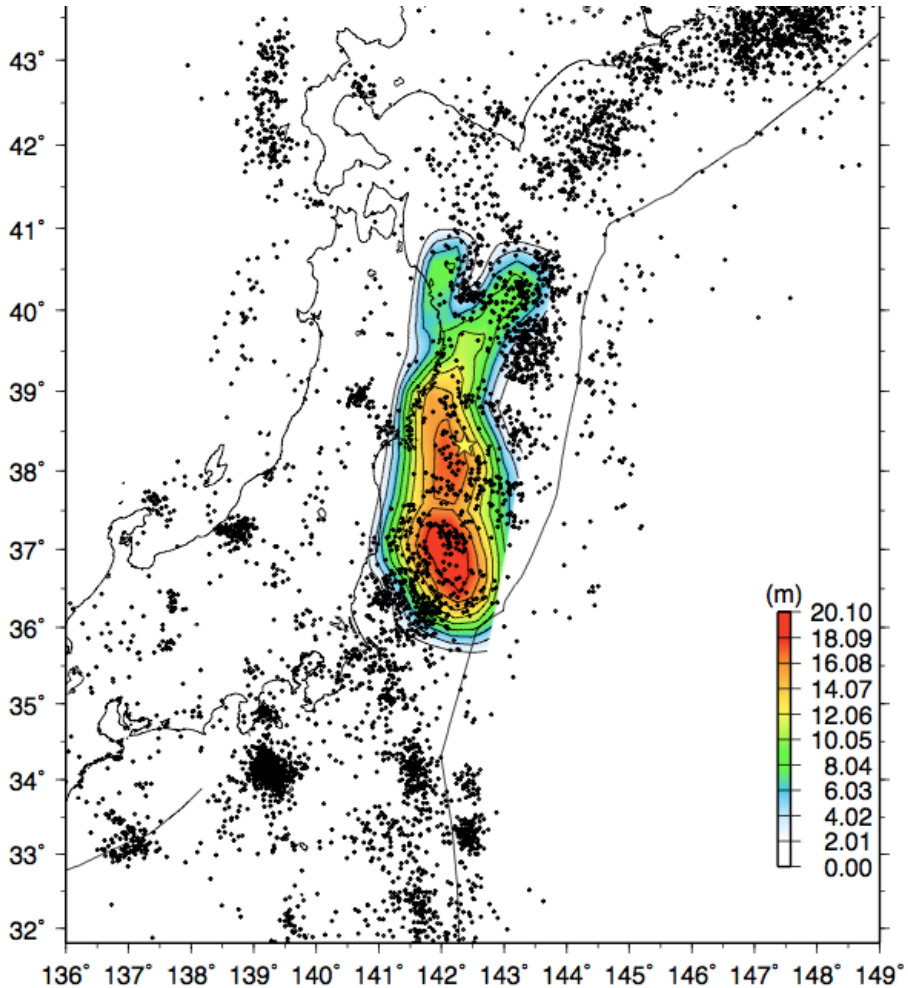


From EMSC

Rupture Process-1



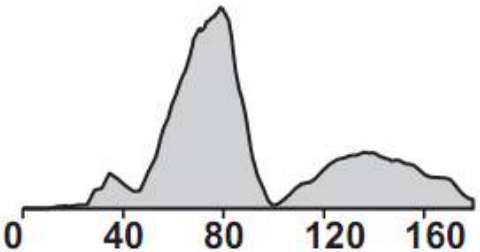
From ERI

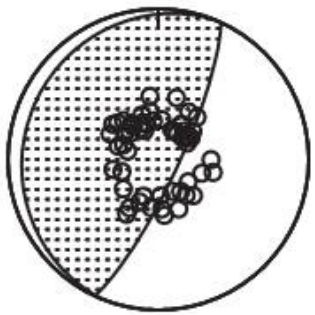


From Yagi

Rupture Process-2

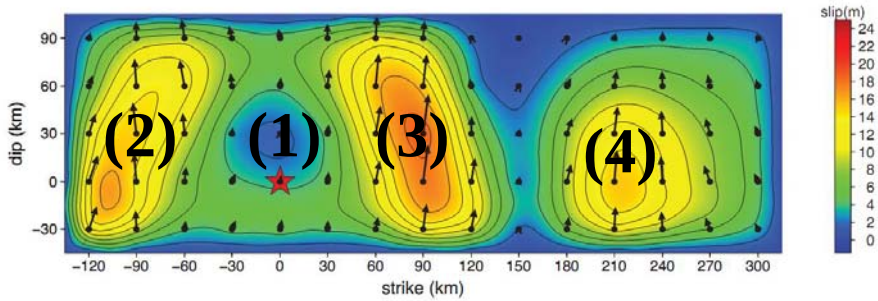
H = 24.4km T = 30. s Dmax = 18 m





(202.,11., 87.)

N S

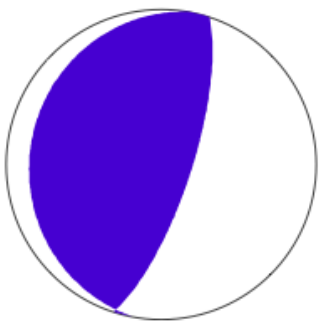


Successively 4 segments were ruptured (1,2,3,4)

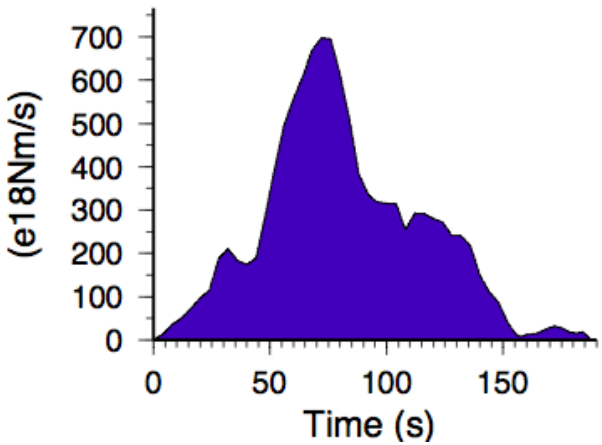
ERI-TU

Moment = 0.4365E+23(Nm); Mw = 9.0

Depth = 25.00(km) ; Vrmax = 2.50(km/sec)



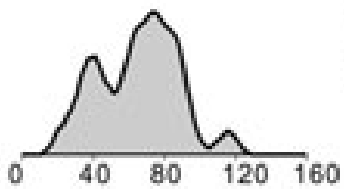
190.0, 16.0, 82.3

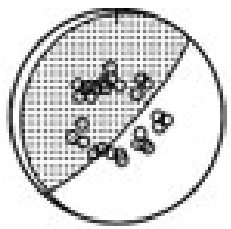


Yagi (Tsukuba University)

Mo = 0.230E+23 Nm Mw = 8.84

H = 24.0km T = s var. = 0.5912

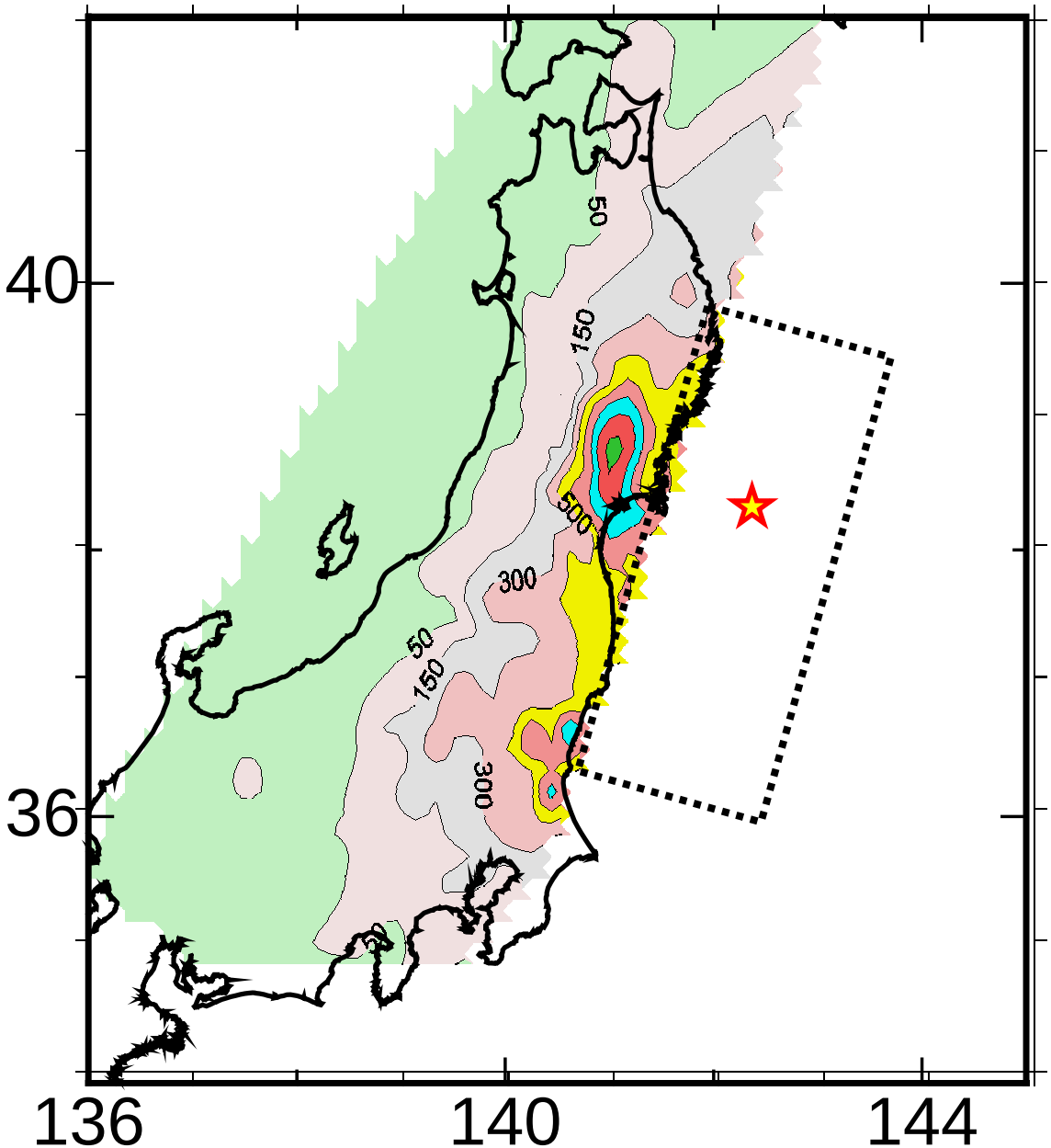




(200.,12., 67.)

Yamanaka (Nagoya University)

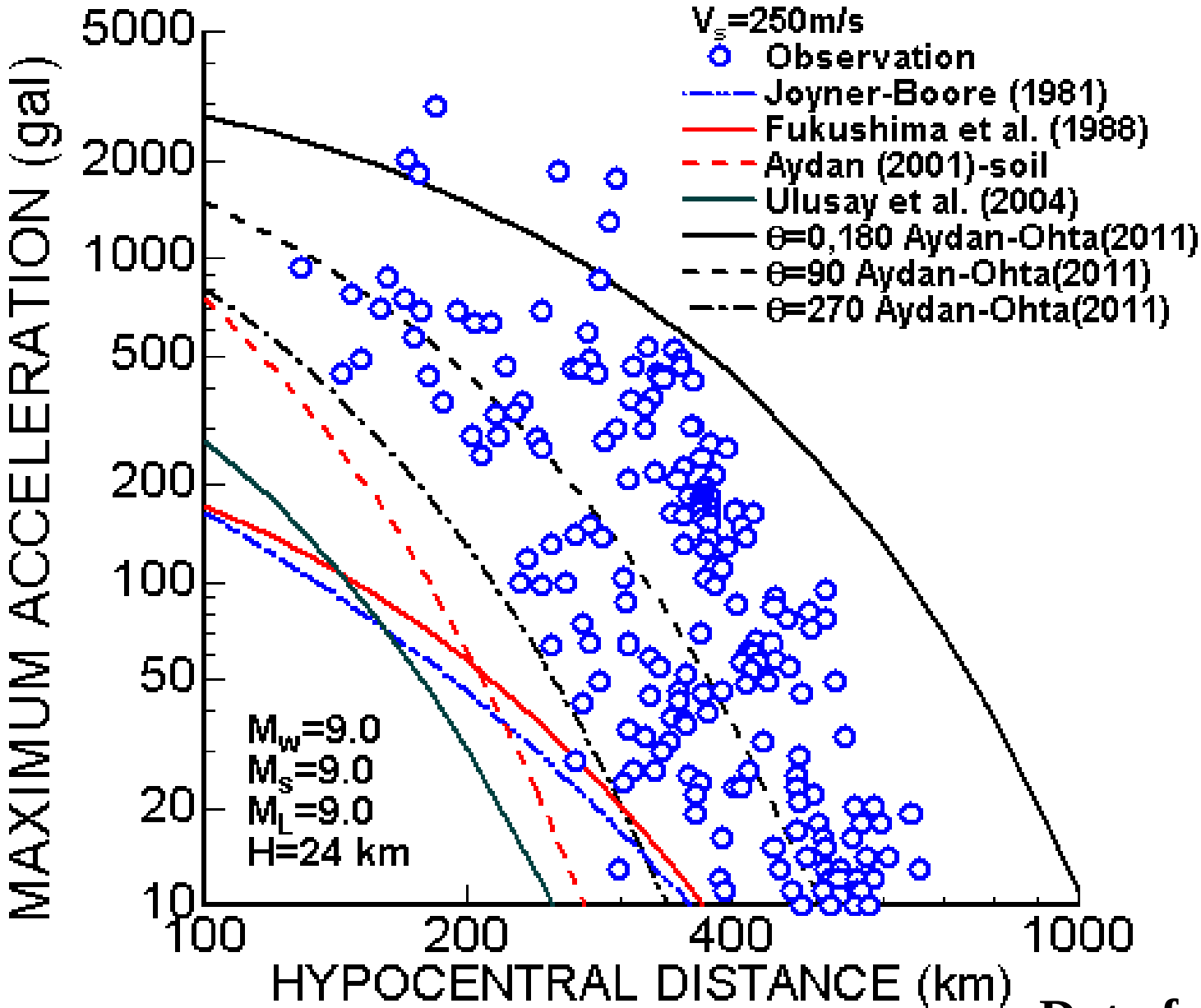
Maximum Ground Acceleration



Unit: gals

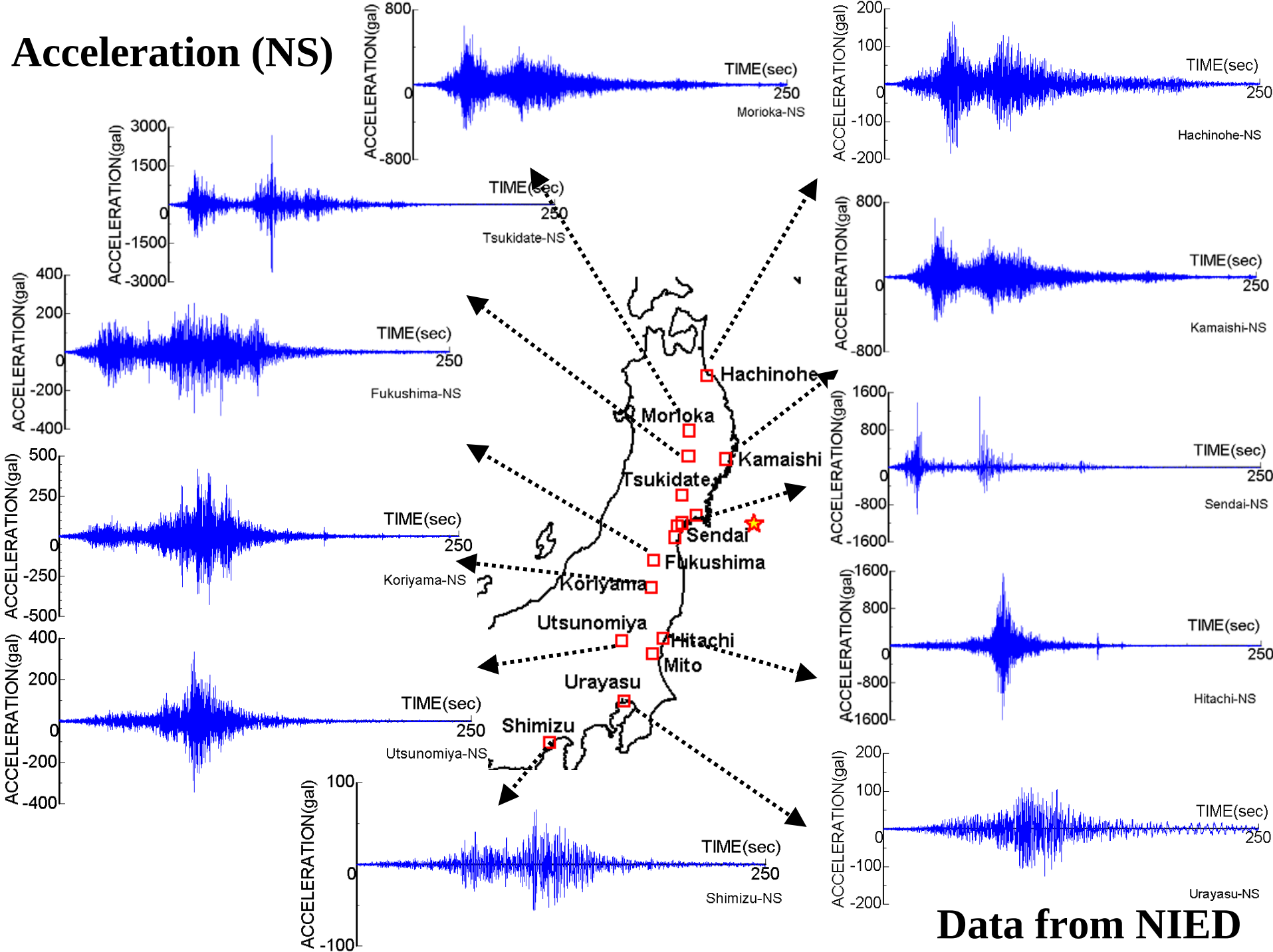
Data from NIED

Attenuation of Maximum Ground Acceleration



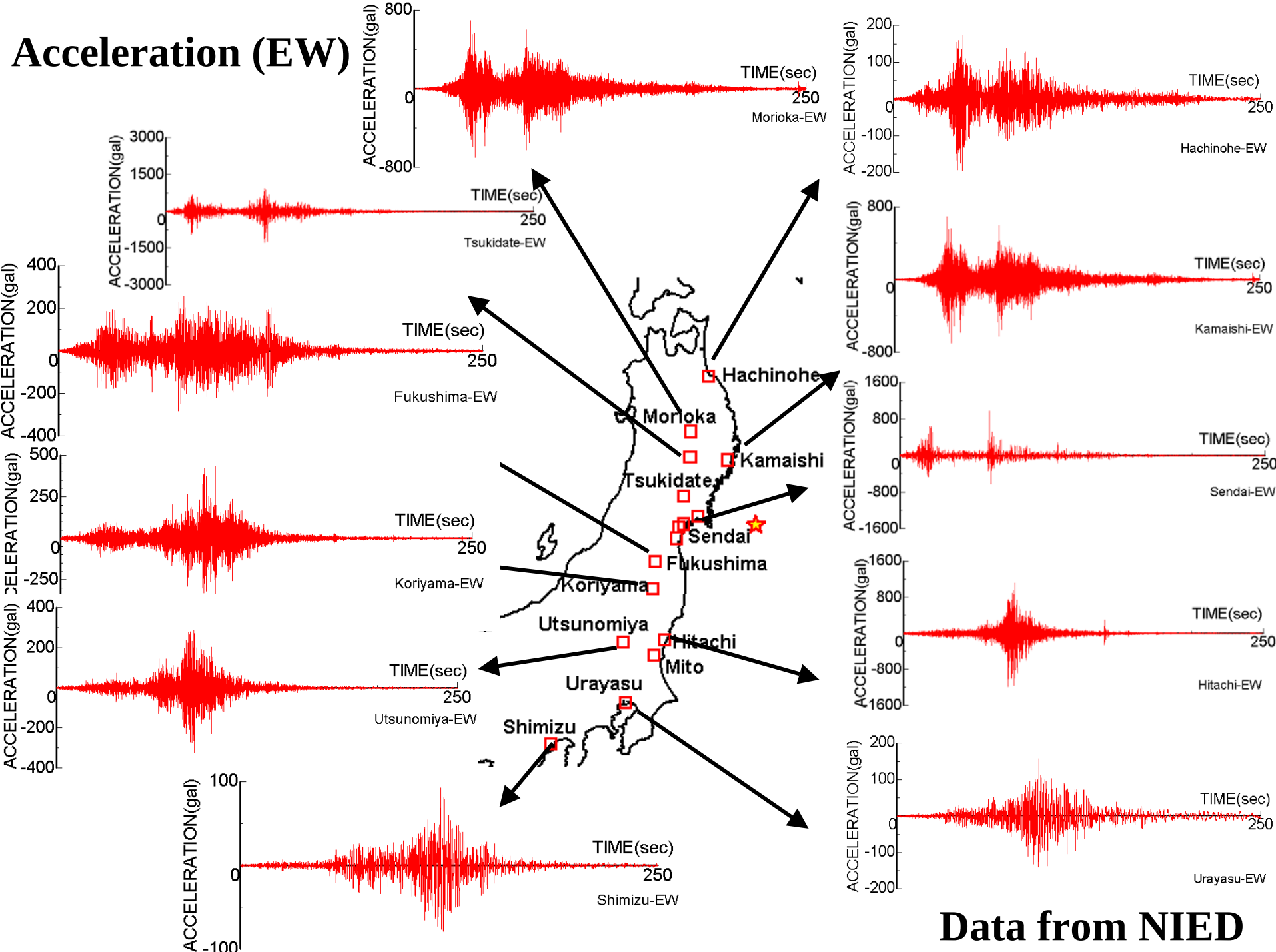
Data from NIED

Acceleration (NS)



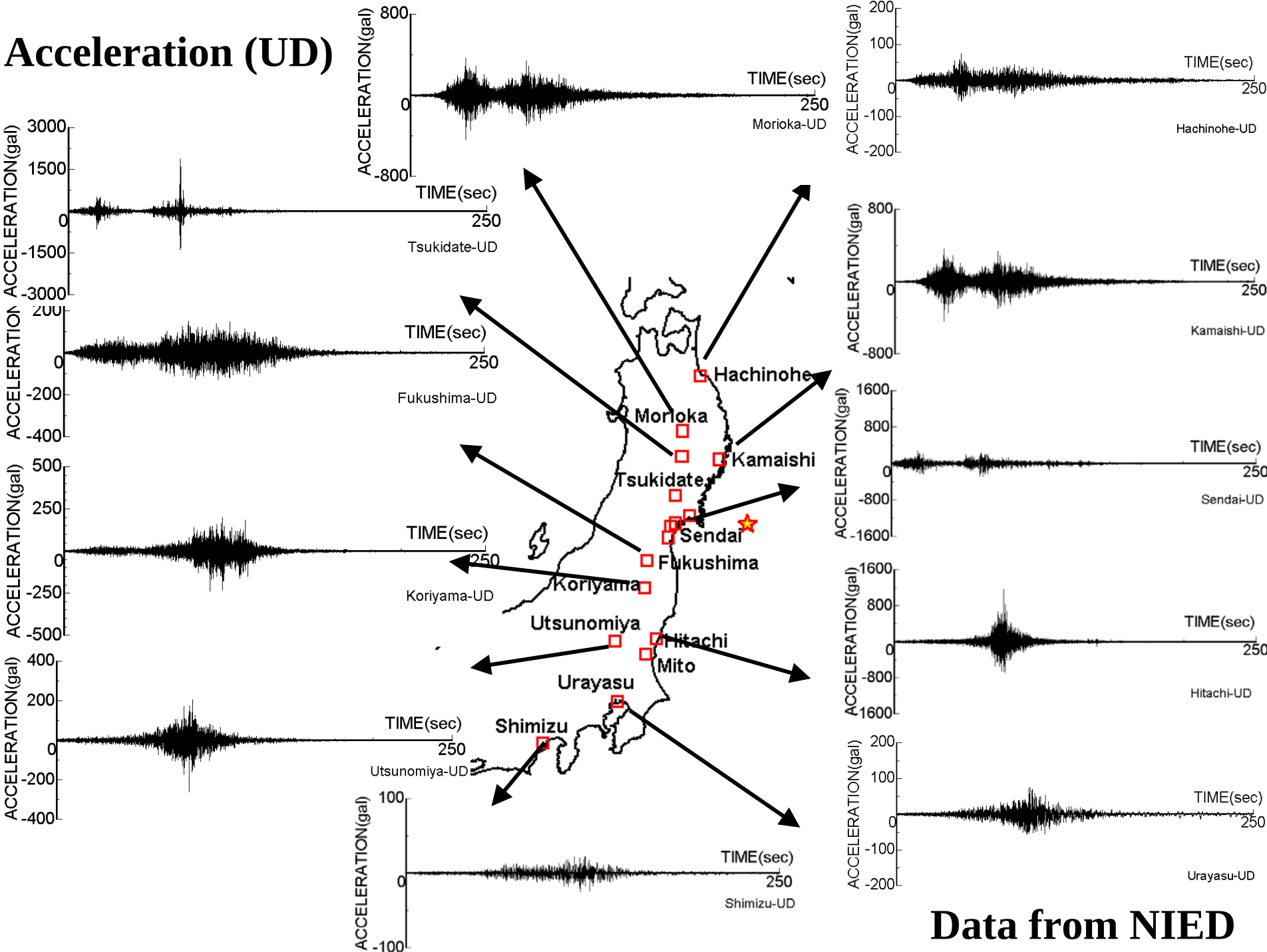
Data from NIED

Acceleration (EW)



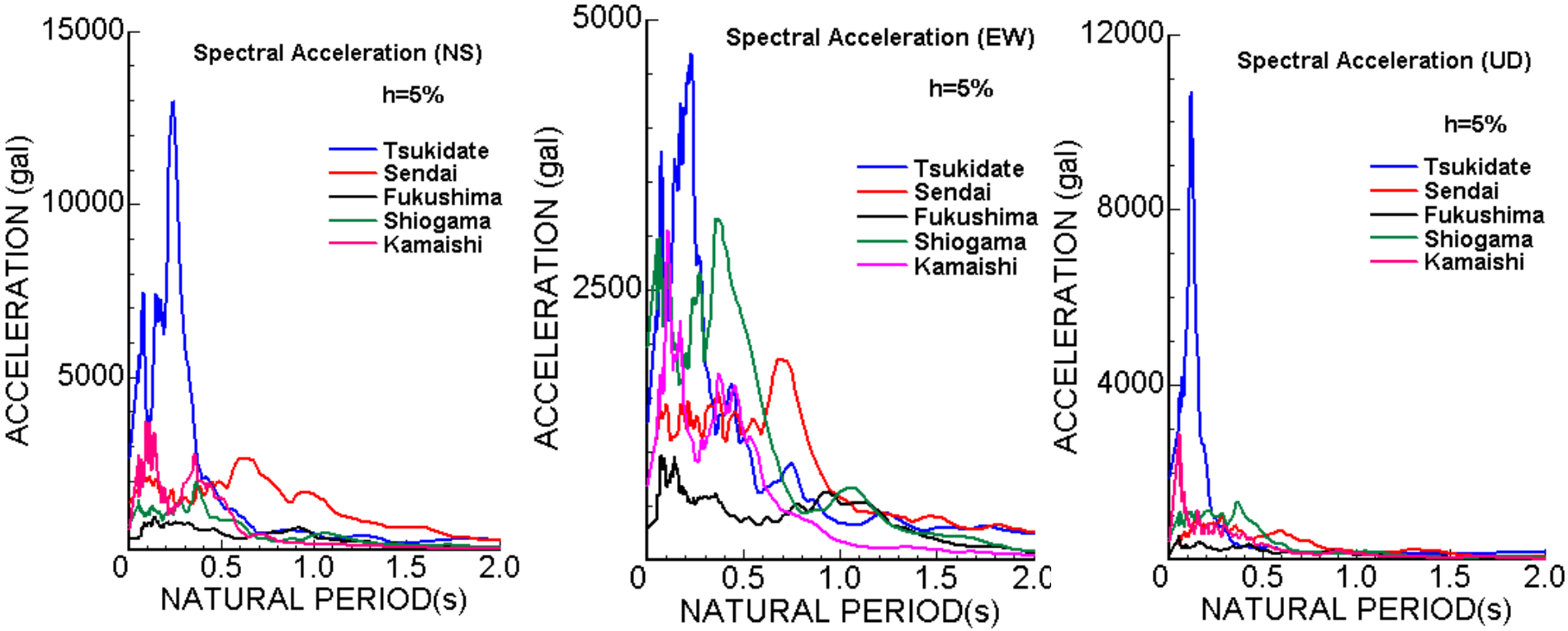
Data from NIED

Acceleration (UD)



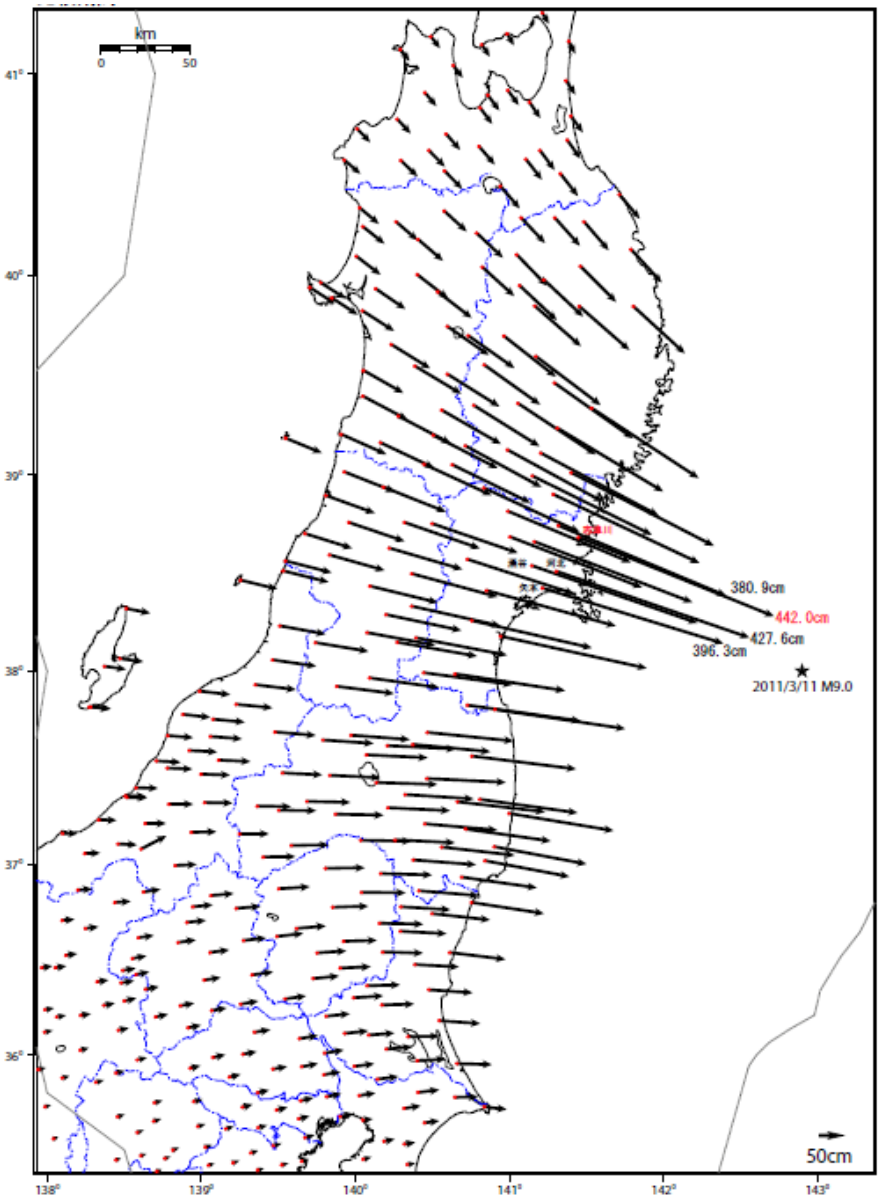
Data from NIED

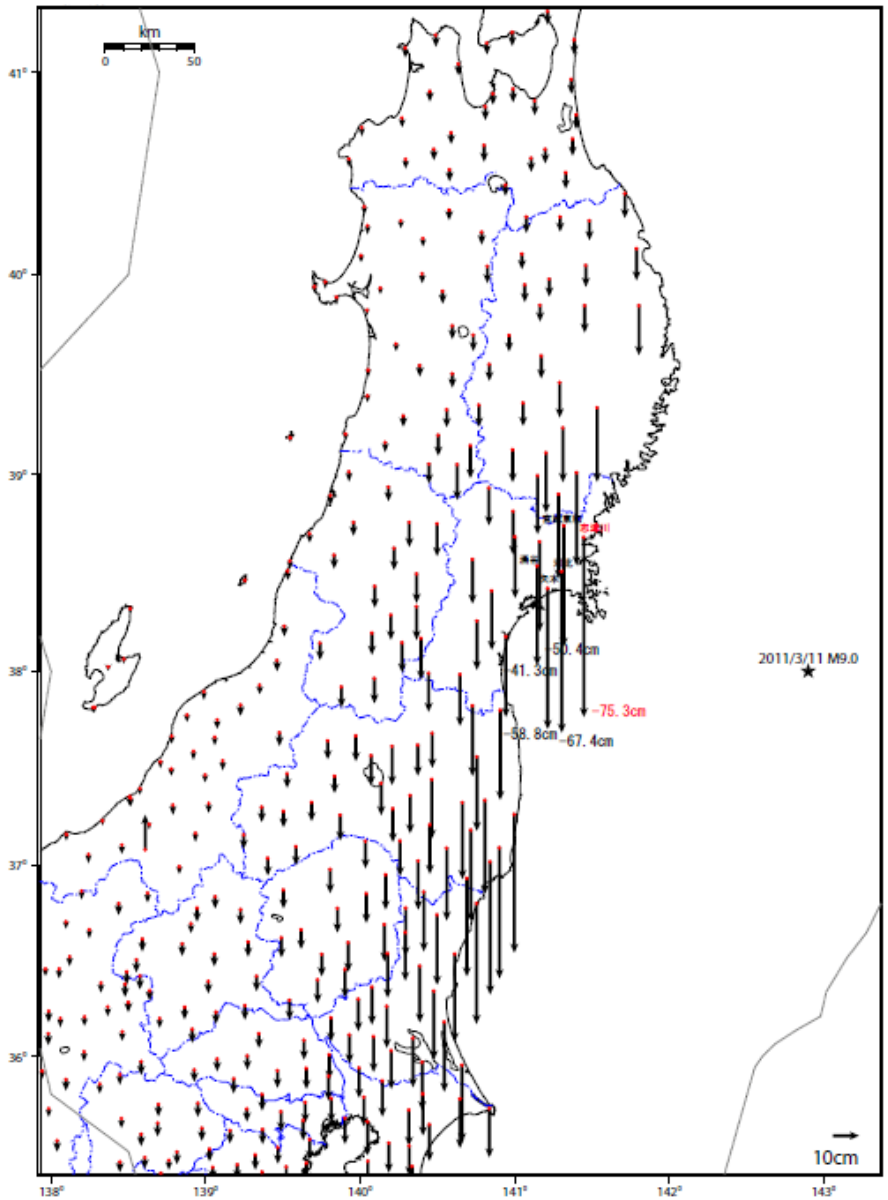
Spectral Acceleration of Selected Stations



The spectral accelerations of Tsukidate station are unusually high and it is limited to short period structures.

Co-seismic Ground Deformations from GPS





From GSI

Geotechnical Damage

Liquefaction and Lateral Spreading

Slope failure

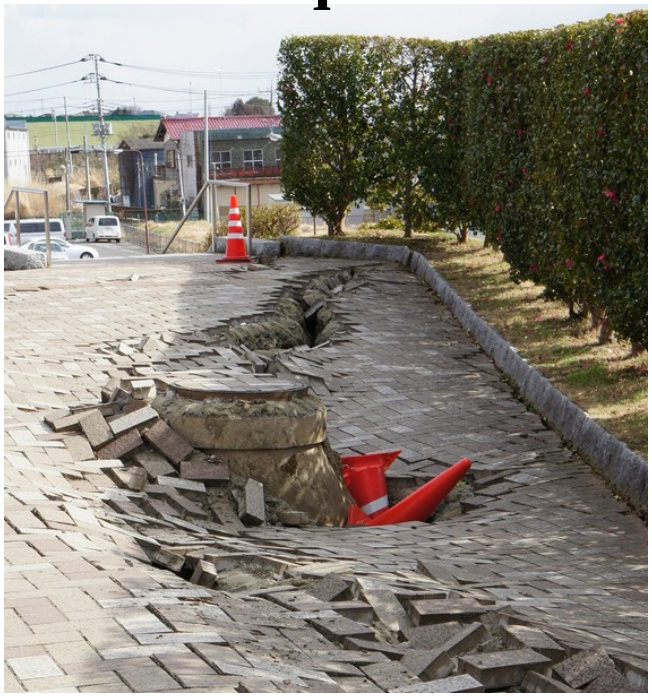
Embankment Failure

Retaining Wall failure

Liquefaction and Lateral Spreading-1

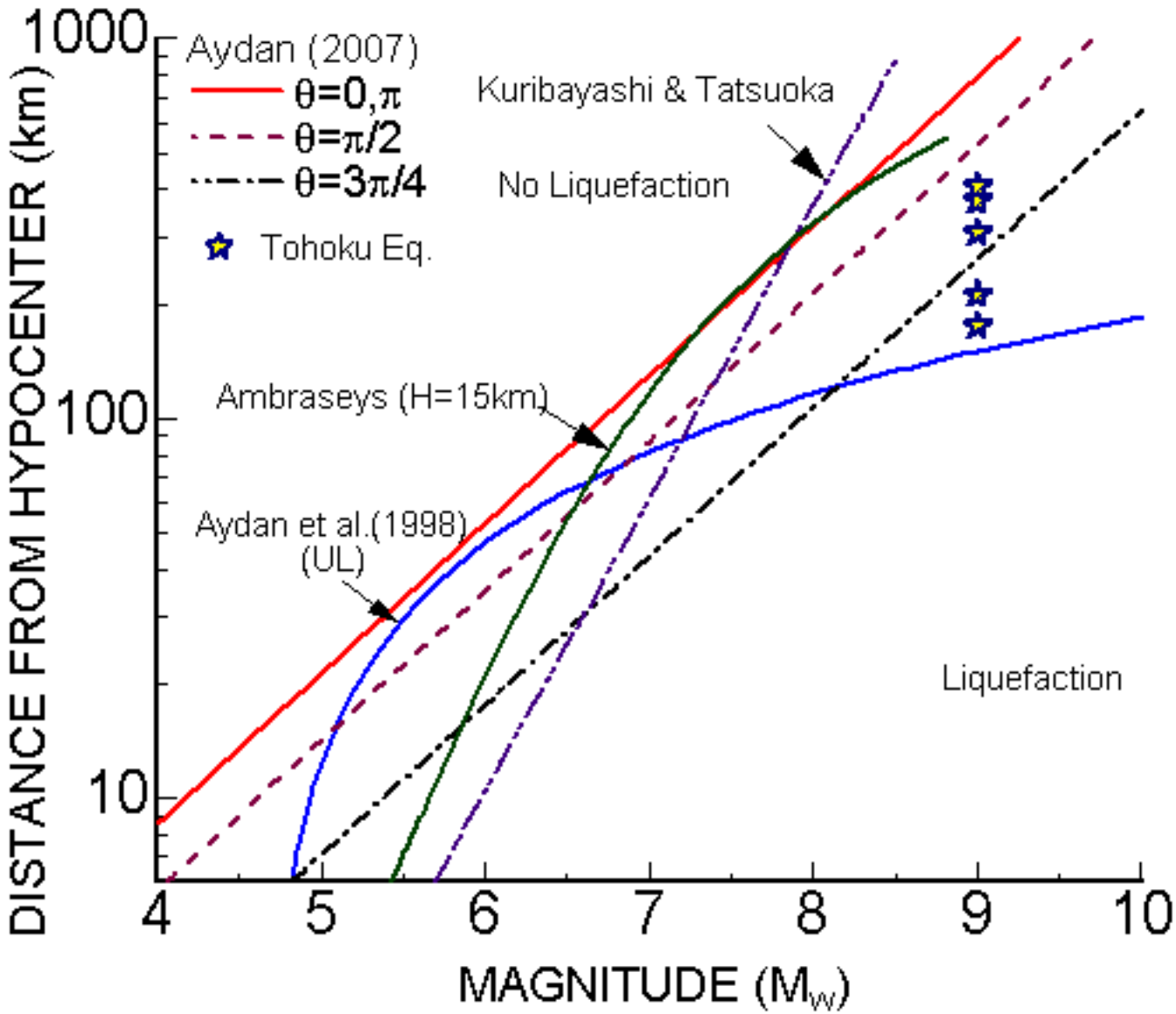
Compiled from Flickr

Liquefaction and Lateral Spreading-2



Compiled from Flickr

Relation between Earthquake Magnitude and Liquefaction Distance



Slope Failure and Rockfall-1

Compiled from Newspapers

Slope Failure & Rockfall-2

Compiled from Newspapers

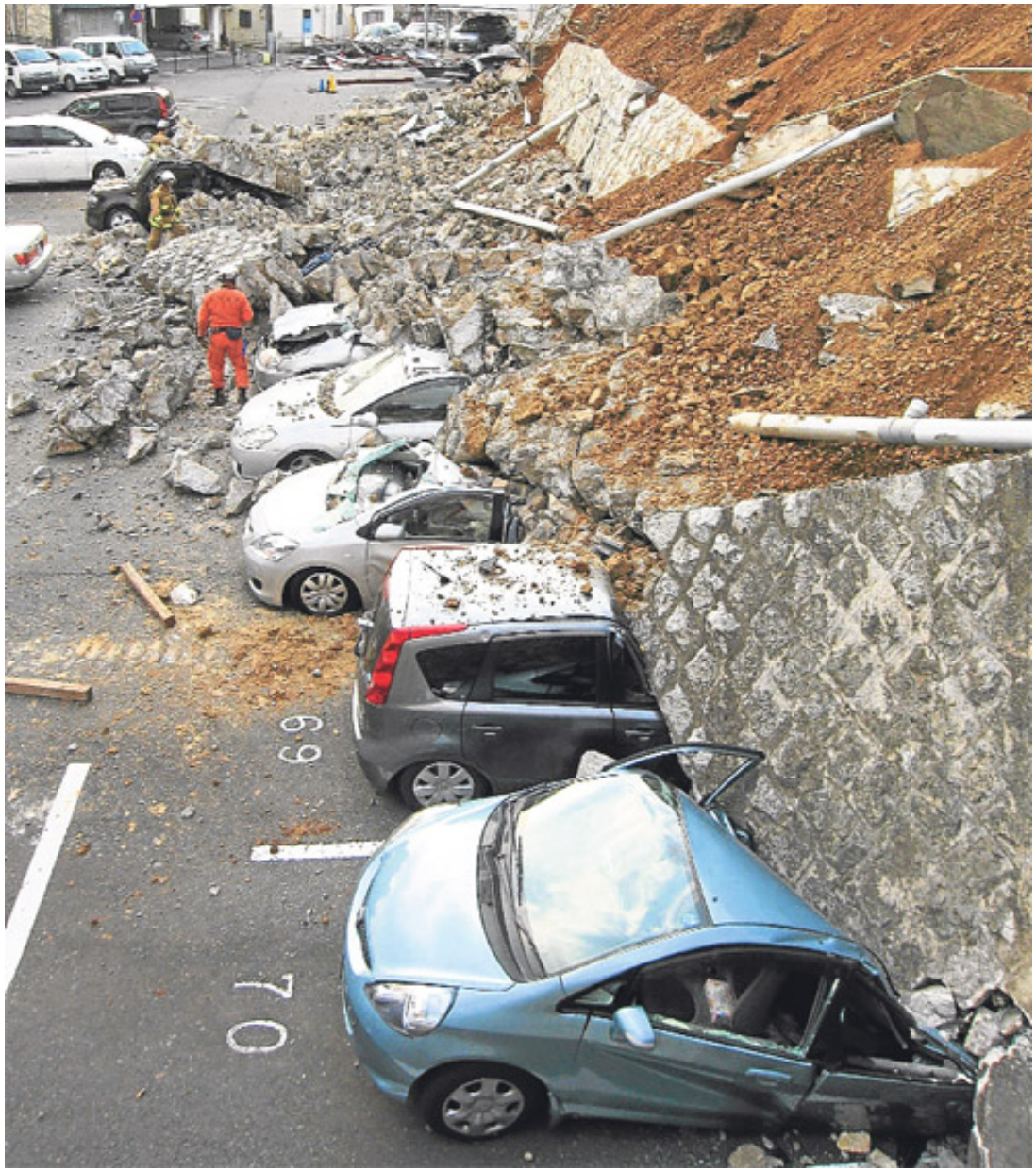
Embankment Failure-1

Compiled from Newspapers

Embankment Failure-2

From NEXCO

Retaining Wall Failure



Compiled from Newspapers & Flickr

An Aerial Photo of Sendai after the earthquake

(Amax: 2g)

Damage to Buildings-1

Compiled from Newspapers

Damage to Buildings-2

Newspapers & Flickr

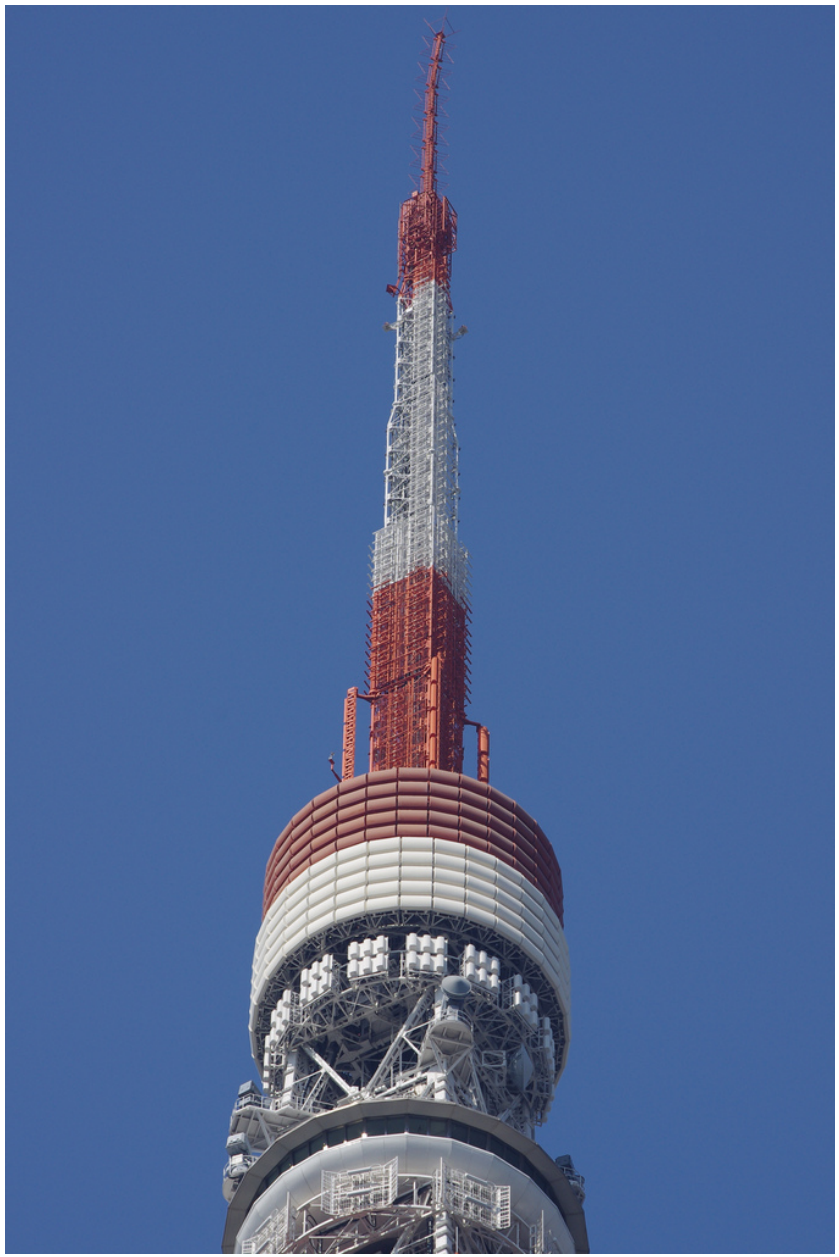
Damage to Buildings-3

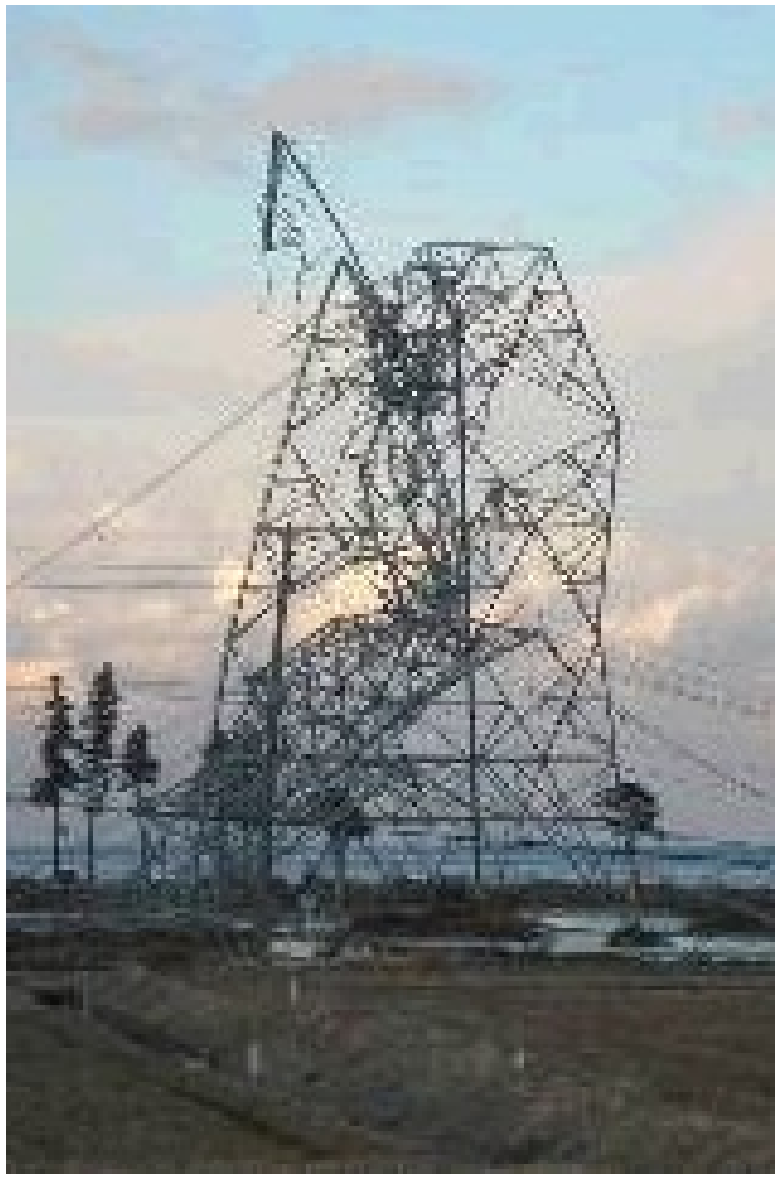
Newspapers & Flickr

Collapse of Roof Panels

Compiled from Newspapers

Damage to Towers and Pylons





Compiled from Newspapers

Damage to Masonary Structures

Compiled from Flickr

Damage to Transportation Facilities

Damage to Tohoku Shinkansen Viaducts (Kitakami)

Damage to Railways

Toppled Freighter Cars

Damage to Expressways

Damage to Sendai Airport

Damage to Port Facilities

Damage to Tohoku Shinkansen Viaducts (Kitakami)

Note no damage to retrofitted viaducts

(Pictures by Assoc. Prof. Dr. Takahashi, Kyoto University)

Damage to Railways

Compiled from Newspapers

Toppled Freight Cars

Compiled from Newspapers

Damage to Expressways

(Shaking induced damage is light)

Pictures by NEXCO

Damage to Sendai Airport

Damage due to tsunami

Compiled from Newspapers

Damage to Ports

Damage is due to tsunami

Compiled from Newspapers

Damage to Industrial Facilities

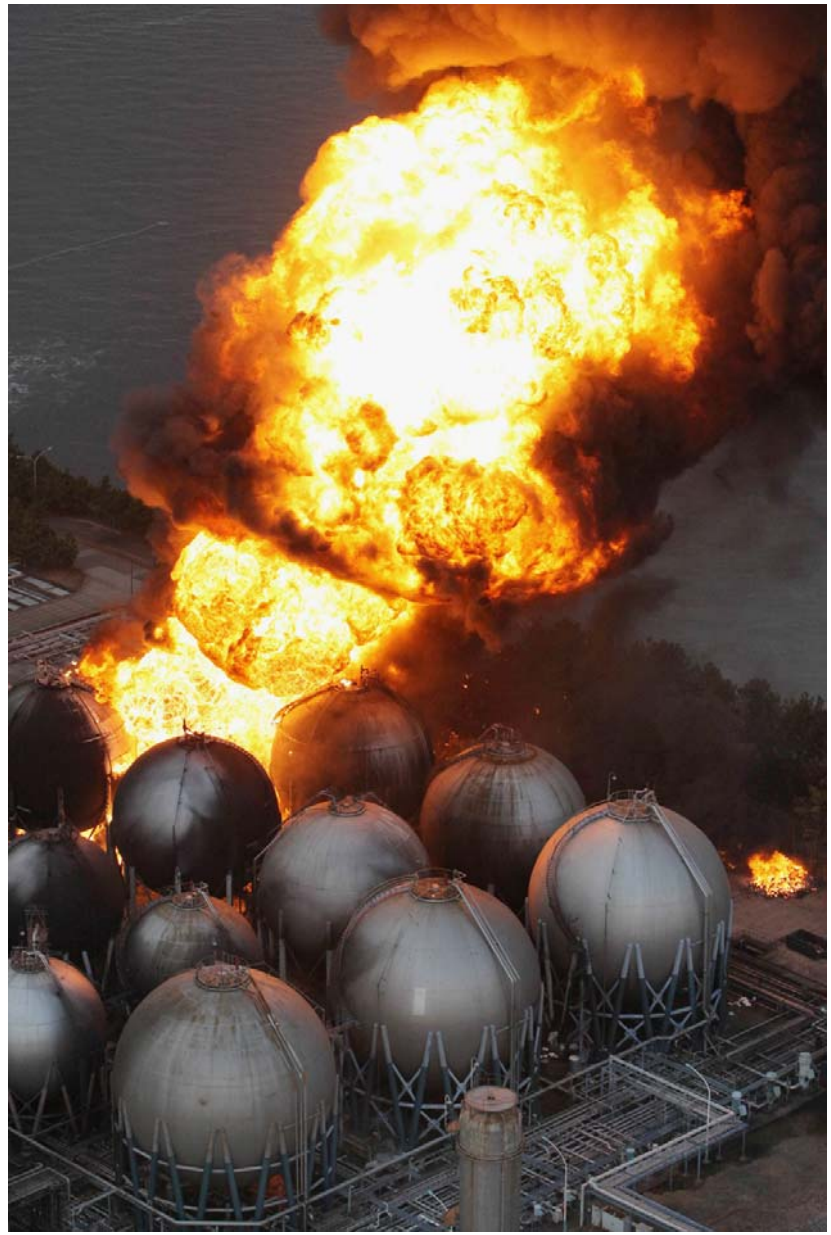
Toppling of Storage Tanks of Kirin Beer Factory

Compiled from Newspapers

Fire at Tank Yard in Sendai Port

Compiled from Newspapers

Fire at Cosmos refinery and Tank Yard (Ichihara)

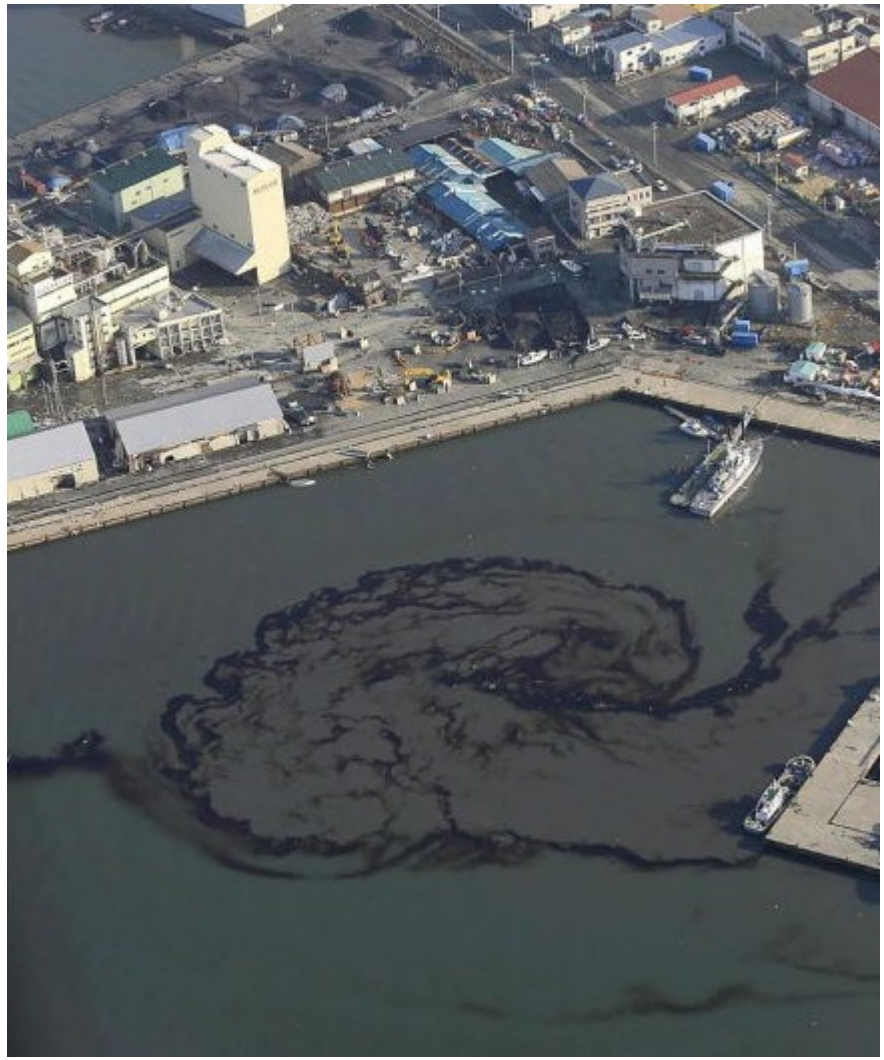


Compiled from Newspapers

Oil Slick due to Tank Damage

Minami Soma

Shiogama



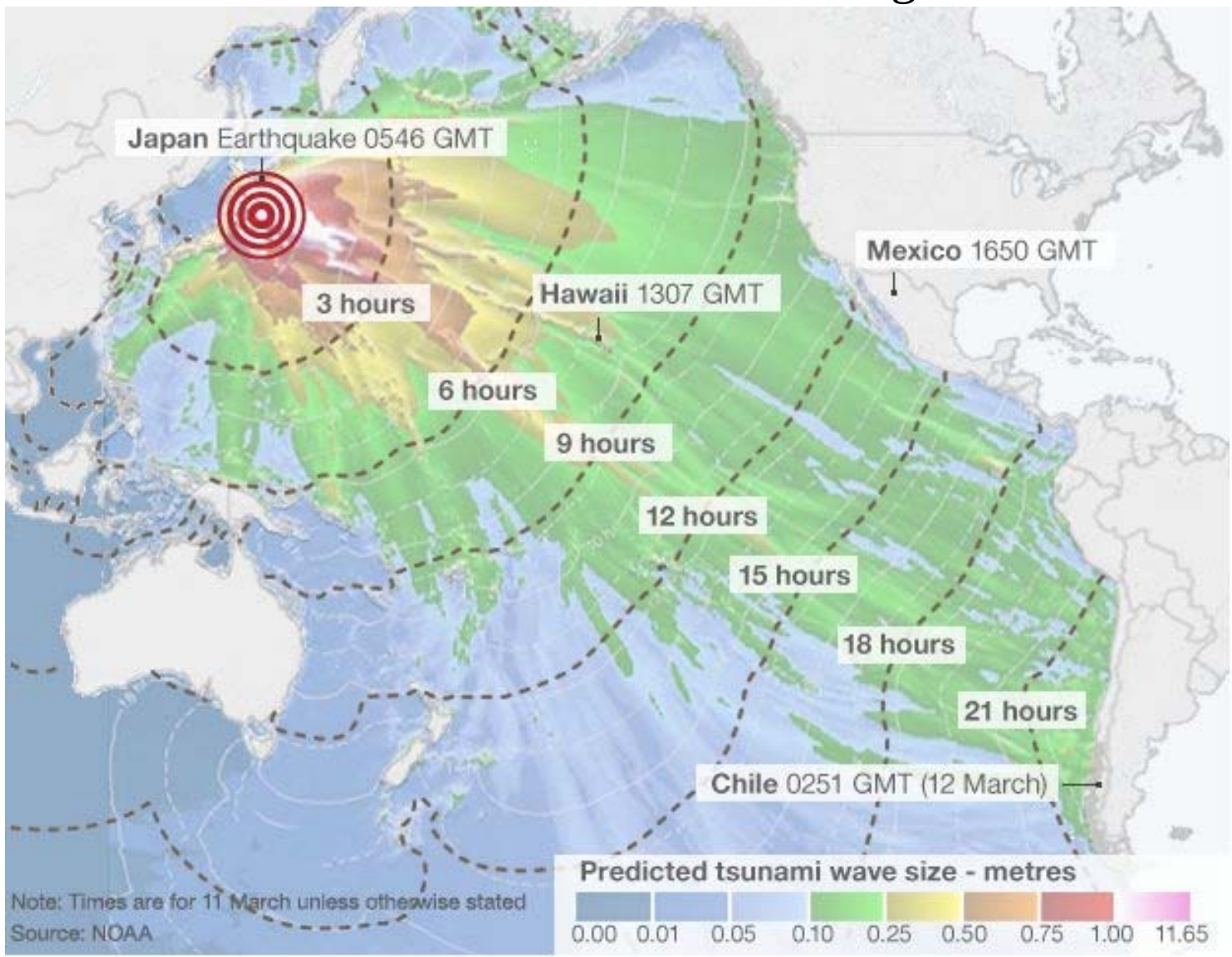
Compiled from Newspapers

Tsunami and Its effects on Built Environment

1) **Characteristics of Induced Tsunami**
2) **Warning of Public Against Tsunami for Evacuation**
3) **Effects of Counter Measures Against Tsunami**
4) **Response of Structures to Tsunami**

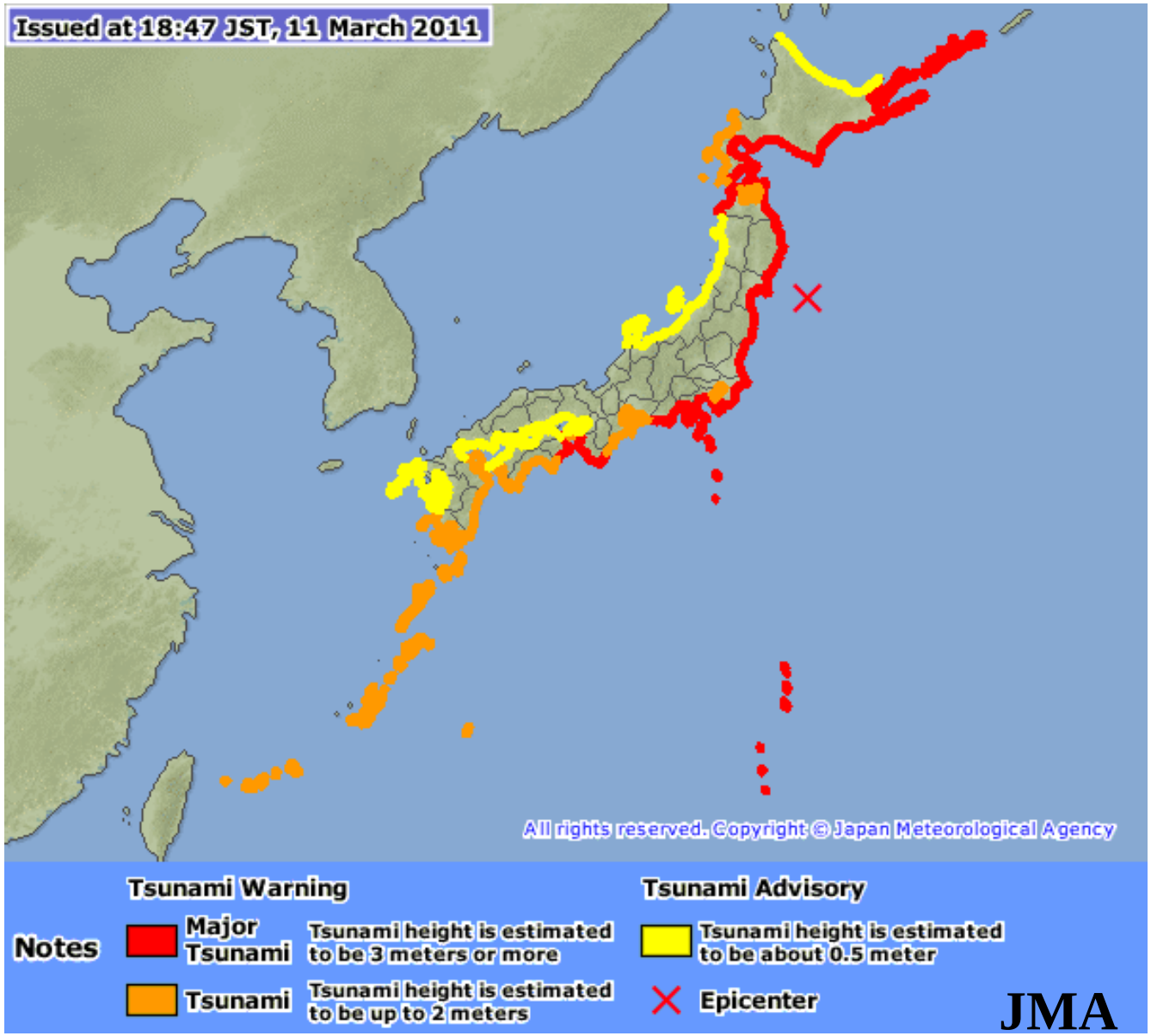
Characteristics of Induced Tsunami

Estimated Tsunami Arrival Time and Wave Height for Pacific Region



From NOAA

Warning of Public Against Tsunami for Evacuation



JMA issued a major tsunami warning for the region

Effects of Counter Measures Against Tsunami

Software Countermeasures:

Warning people to move higher ground or upper floors of high buildings

Horizontal evacuation is hard for elderly or sick people, pregnant women and small kids. If higher ground is far away, it is also difficult for ordinary people

Hardware Measures

1) Constructing High Break-waters

2) Constructing evacuation terraces

3) Tsunami gates at the estuary of rivers

4) Planting trees

Tsunami wave height is assumed to be up to 5m in hardware countermeasures

Performance of High Break-waters-1

Tsunami wave height was higher than that of break-waters

Compiled from Newspapers

Performance of High Break-waters-2

Breakwater height was insufficient

Compiled from Newspapers

Performance of tsunami gates at the estuary of rivers

Compiled from Newspapers

Response of Structures to Tsunami

1) Timber and RC or Steel Frame Buildings
2) Railways
3) Roadways
4) Bridges
5) Airports

Timber and RC or Steel Frame Buildings

Timber buildings can not stand against high tsunami waves. RC buildings performance was best to resist tsunami waves. Therefore, timber buildings must not allowed in tsunami-vulnerable areas.

Railways

Compiled from Newspapers

Roadways

Compiled from Newspapers & Miyagi Prefectural Government

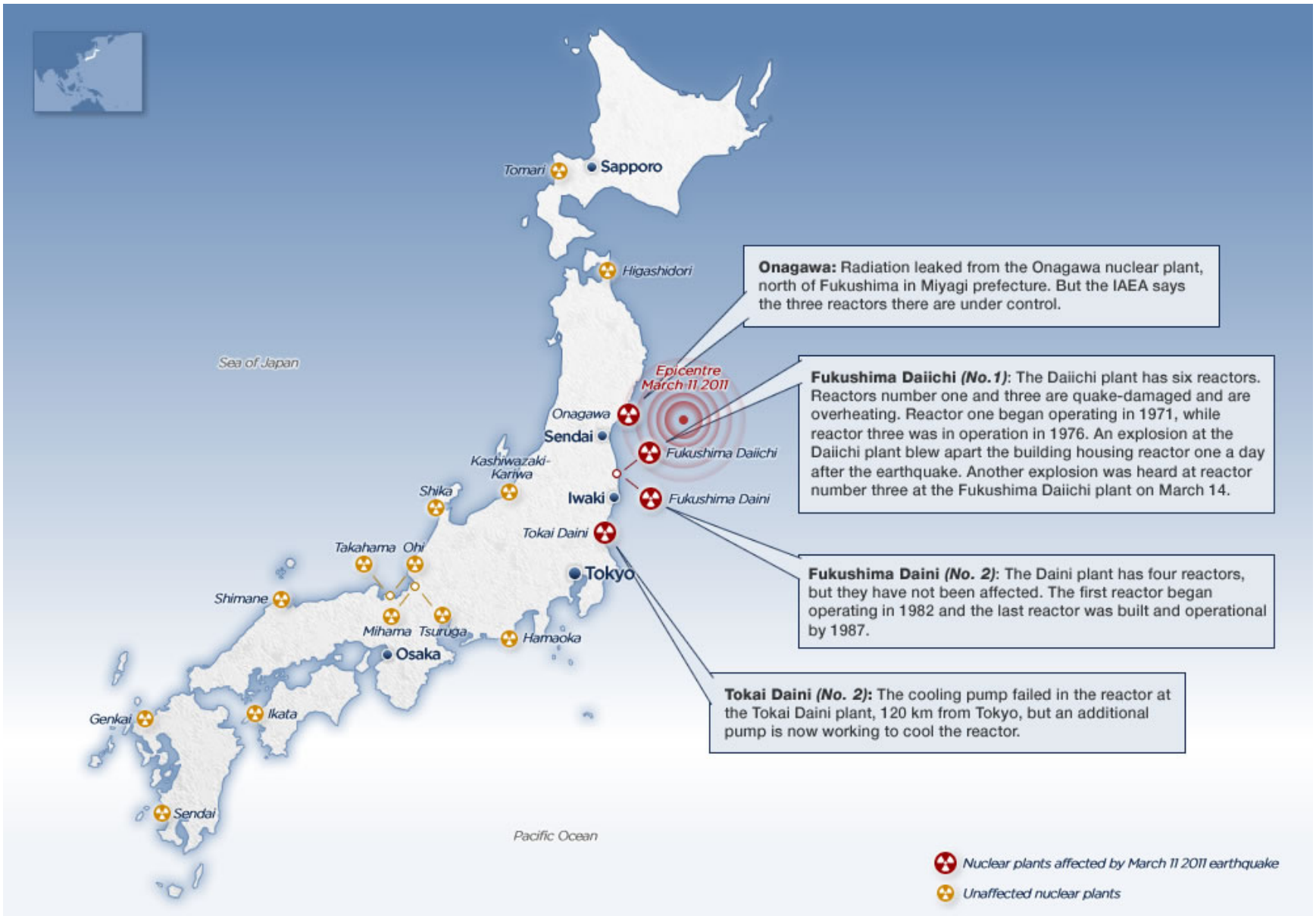
Bridges

Compiled from Newspapers

Airport

Compiled from Newspapers

Damage to Nuclear Power Plants and Lifelines



Source: IAEA

Onagawa NPP was the most heavily shaked NPP. However, it performed as expected during and after the earthquake.

Fukushima No.1 NPP has 6 units: The states of units are:

Units 1,2 and 3 were shutdown automatically during the earthquake.

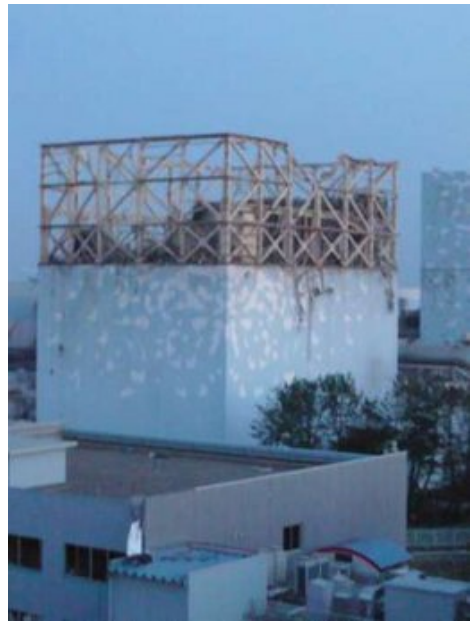
However, pumps were cooling the fuel and spent fuel were damaged by induced tsunami. Despite some problems to Units 1 and 2 are stabilized while efforts are continuing to stabilize Unit 3 and provide electricity for cooling system of the units.

Unit 4:All fuel had been removed from the reactor core for routine maintenance before the earthquake and placed into the spent fuel pool.

Units 5 & 6: Shut down for outage before the earthquake. No major problem except cooling pumps for spent fuel are damaged

Fukushima No.2 NPP performed as expected during and after the earthquake and no damage or leakage of radiation was reported.

Damage to Fukushima No.1 NPP



Compiled from Newspapers

Damage to Sewage Plant at Sendai

From Sendai Prefectural Government Civil. Eng. Dept.

Damage to Lifelines Facilities

Compiled from Newspapers & Flickr

LESSONS

The seismologists of Japan failed to anticipate this earthquake, although they anticipated an earthquake with a magnitude of 7.5 off Miyagi prefecture.

The seismologists of Japan pointed out that there was no earthquake of this scale in Japan in the past in some mass media. However, this plate boundary caused great earthquakes of similar magnitudes in the 20th century, which are 1952 Kamchatka, 1958 Aleutian and 1964 Alaska earthquakes. This fact challenges their scientific reasoning from the past seismicity of Japan.

The underestimation of the magnitude of potential interplate earthquakes such as the 2011 March 11 event was probably the main reason that the tsunami waves overflowed or destroyed hardware countermeasures causing tremendous number of casualties.

This earthquake also showed that the vertical evacuation in relatively flat areas was important to save lives.

Timber buildings can not stand against high tsunami waves. RC buildings performance was best to resist gigantic tsunami waves. Therefore, timber buildings must not allowed in tsunami-vulnerable areas.

The nuclear power pants performed well during the earthquake. However, the underestimation of the potential tsunami and the vulnerability of pumps of their cooling systems caused severe problems and concerns to people and environment.

Ground motions were extremely high particularly in the initial rupture area. The current attenuation relations are mostly incapable of estimating the attenuation of maximum ground motions.

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