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Special Session:
Great East Japan (Tohoku) Earthquake

Earthquake Source

Kazuki Koketsu

Earthquake Research Institute, University of Tokyo

Names and features of the earthquake and disaster

- The earthquake was officially named “2011 off the Pacific coast of Tohoku Earthquake” by the Japan Meteorological Agency, but we abbreviate it as “2011 Tohoku earthquake” because of its awkward length.

- The disaster was officially named “Great East Japan Earthquake Disaster” by the Cabinet of Japan.

<General Feature>
Their hugeness

<Specific Features>

1. Observed by dense networks of geophysical instruments

2. Severe tsunami damage but moderate ground motion damage

3. They had not been foreseen at all

<General Feature> Their Hugeness

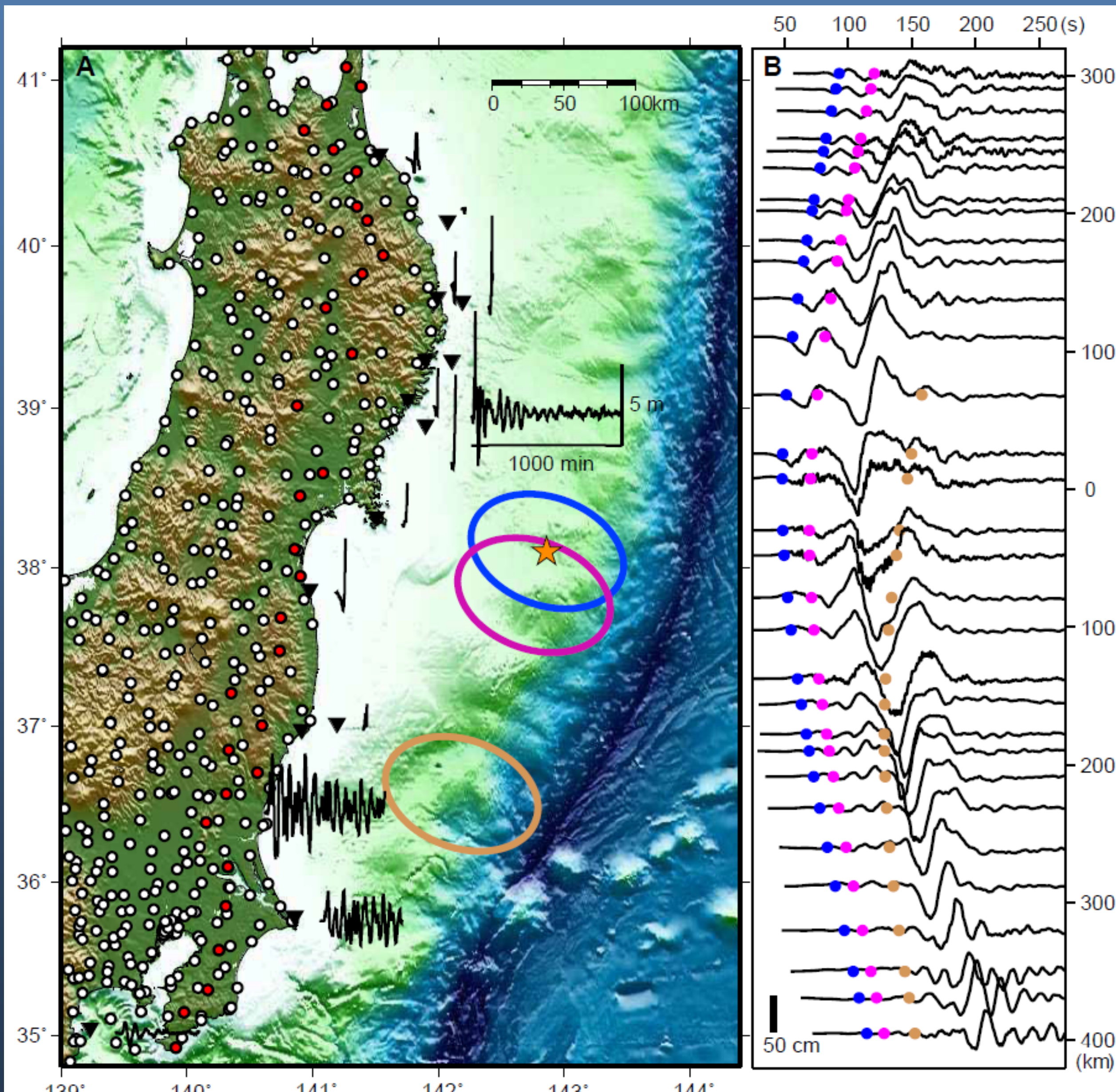
- The earthquake's moment magnitude (M_w) of 9.0 (JMA) to 9.1 (Global CMT Project) is the largest ever recorded in Japan and the fourth in "Largest Earthquakes in the World Since 1900" compiled by the United States Geological Survey (USGS).
- The disaster resulted in 16,131 fatalities, 3,240 missing, 5,994 injured, and 128,497 house collapses as of 13 January 2012 including the toll from the aftershocks and triggered events (Fire and Disaster Management Agency of Japan).
- The number of fatalities is the second for Japanese earthquakes in "Earthquakes with 1,000 or More Deaths since 1900" (USGS), preceded by only the 1923 Kanto earthquake.

<First Specific Feature>

1. Observed by dense networks of geophysical instruments

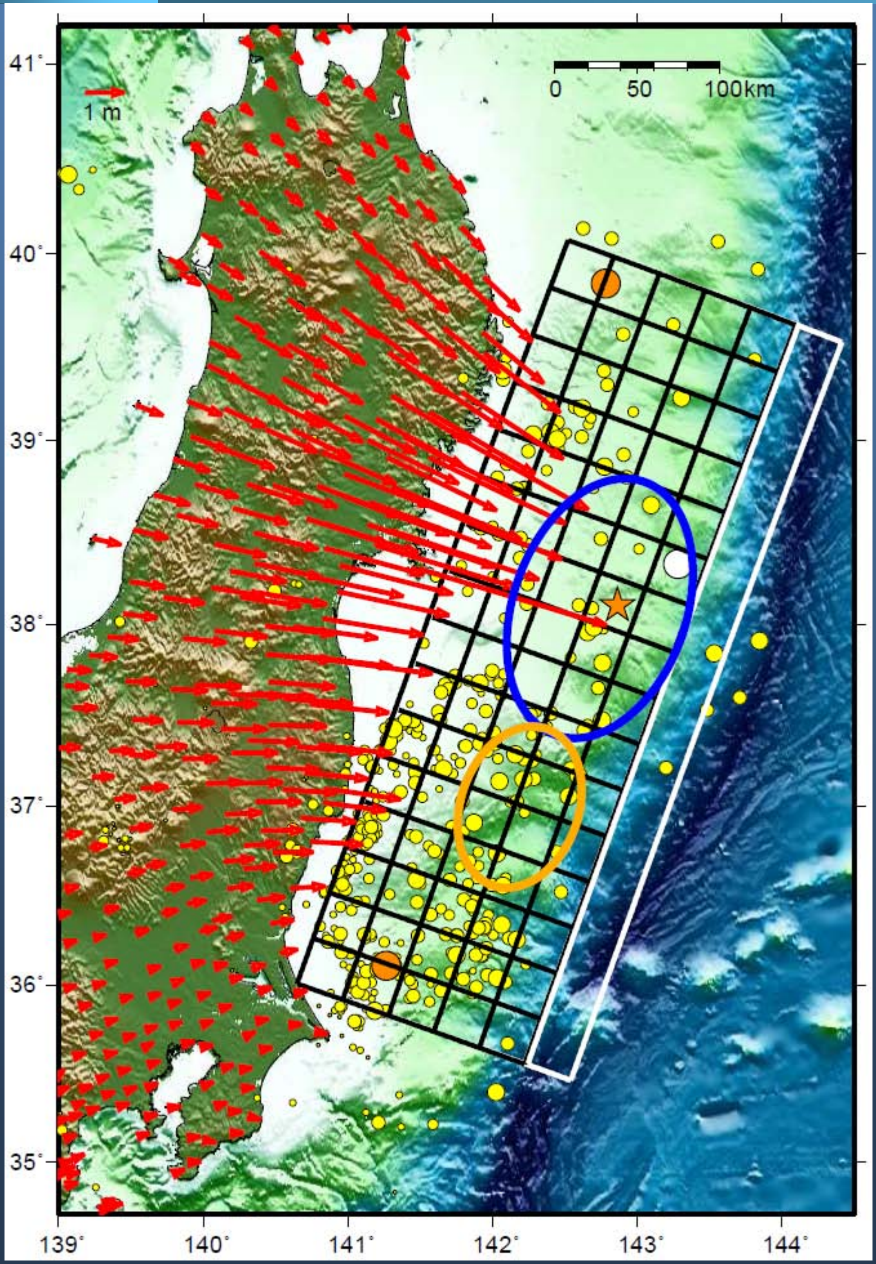
The 2011 Tohoku earthquake is a megathrust event in a subduction zone like most others in the list of “Large Earthquakes in the World Since 1900” but the first that was observed by dense networks of geophysical instruments. Abundant data obtained from the dense networks include teleseismic, strong motion, geodetic, and tsunami datasets.

Strong motion dataset

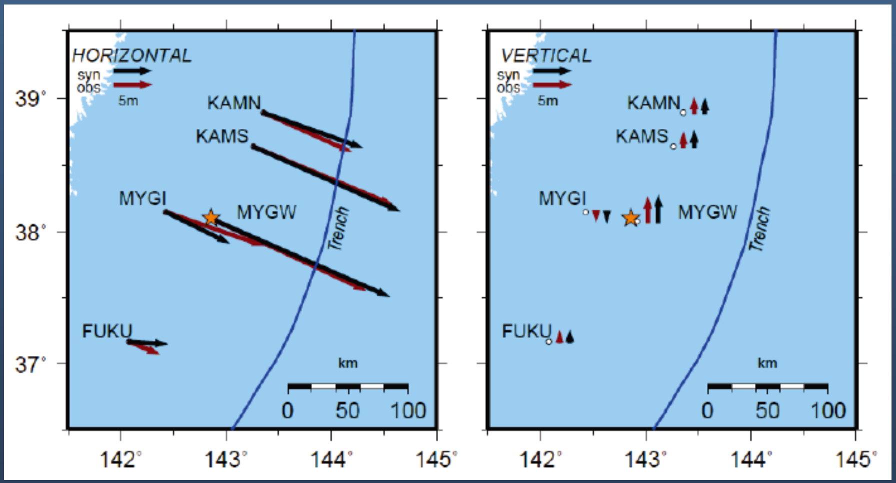


The strong motion records at 31 stations selected along the Pacific coast were doubly integrated into ground displacements using highpass filter with a corner period of 100 s. They were aligned along the coast to form the record section. Three pulses can be seen in this record section, and their arrival times indicated by blue, red, and brown dots suggest that they were generated in the zones drawn with the same colors. The first two zones are located around the epicenter of the mainshock determined by JMA, while the third zone is 150 to 180 km south of the epicenter.

Geodetic dataset

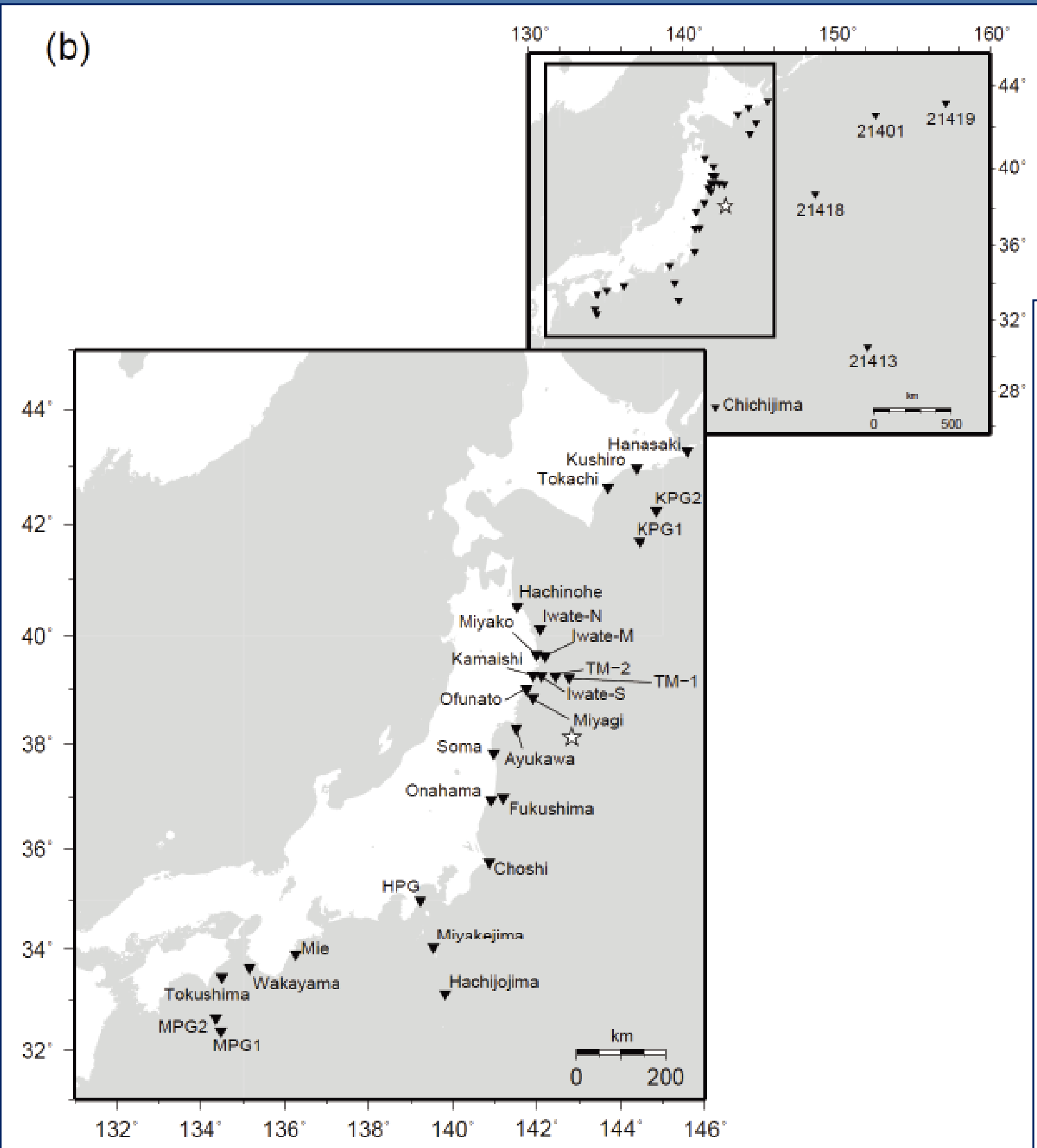


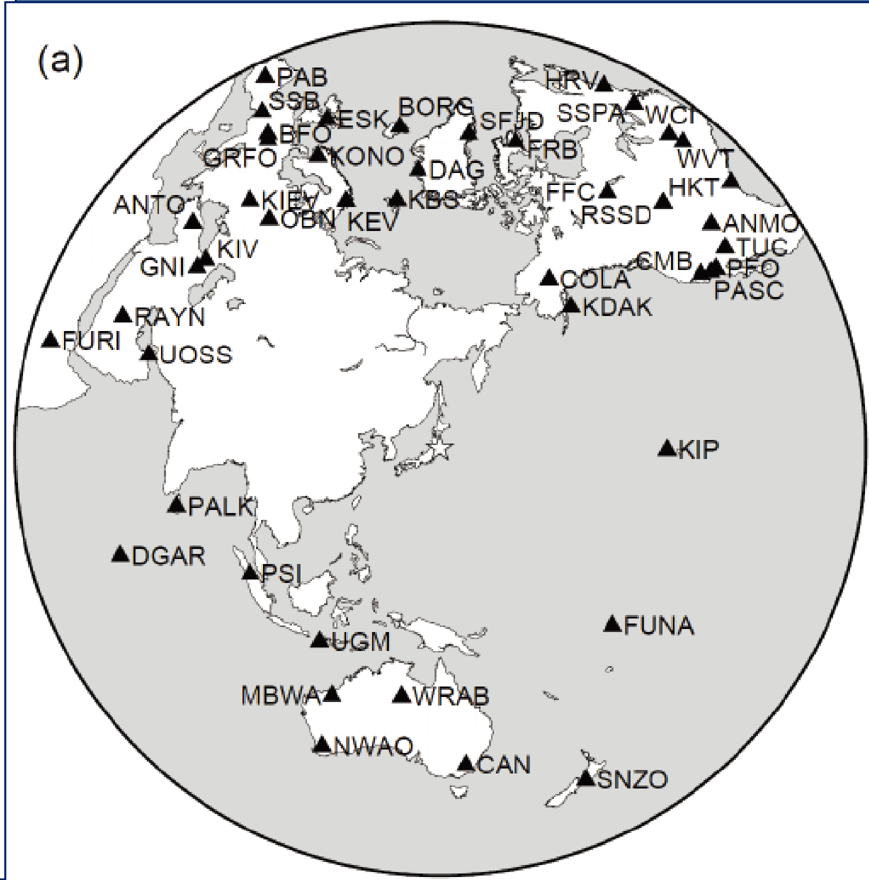
The GEONET of Geospatial Information Authority of Japan, which is a nation-wide network of 1,200 GPS-based control stations, observed crustal deformations due to the earthquake as shown by static displacements. These static displacements point toward these zones, though they cannot distinguish the first two zones because of their limited resolving power.



The Japan Coast Guard observed seafloor displacements due to the earthquake.

Tsunami and teleseismic datasets





<Second Specific Feature>

2. Severe tsunami damage but moderate ground motion damage

This disaster resulted in 16,131 fatalities, 3,240 missing, 5,994 injured, and 128,497 house collapses as of 13 January 2012 including the toll from the aftershocks and triggered events (Fire and Disaster Management Agency of Japan).

Since more than 90% of the fatalities were from drowning (Kyodo News, 2011), and the number of injured people is relatively small, the tsunami damage was very severe.

Back slip, earthquake, and tsunami

(1) back slip

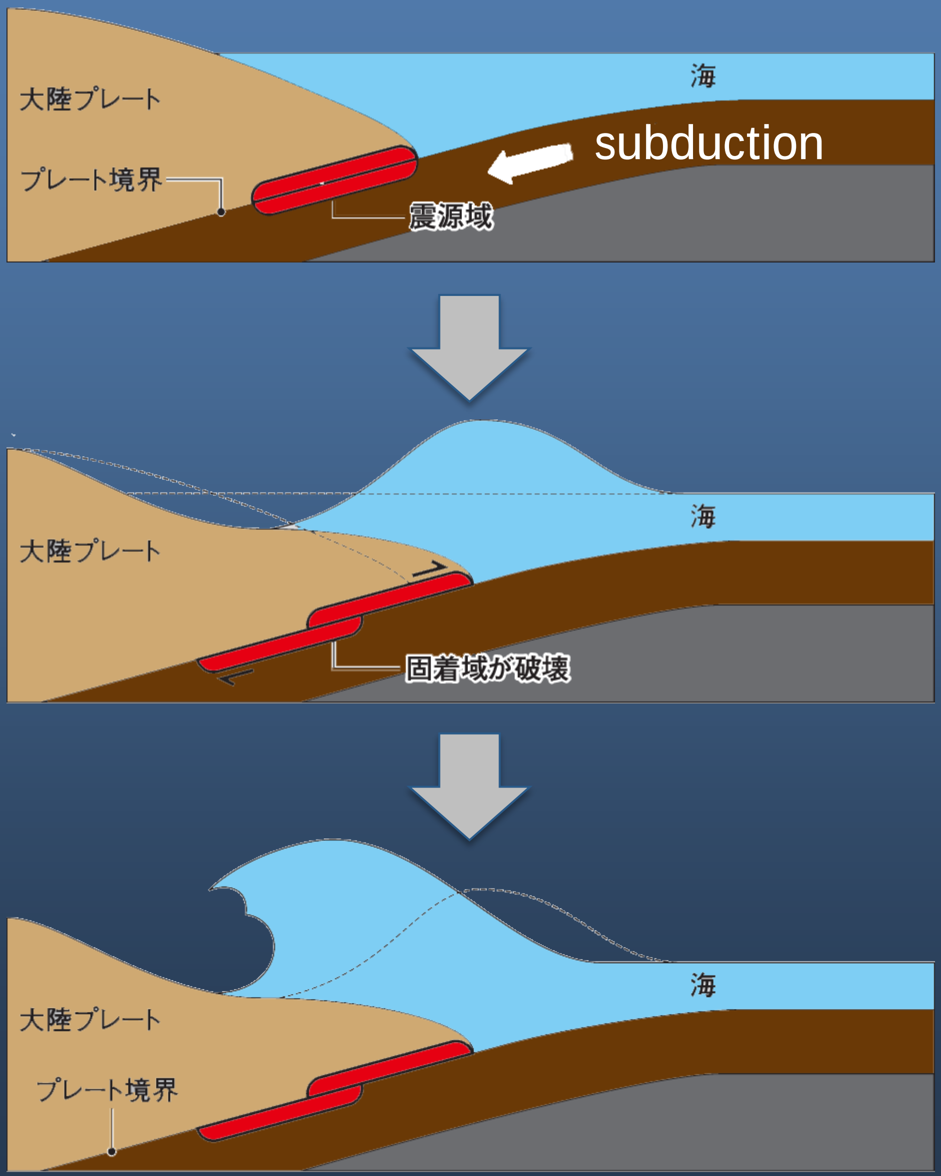
The both sides of source region (震源i域) are strongly coupled. The Japan side is continuously dragged in the direction of subduction.

(2) earthquake

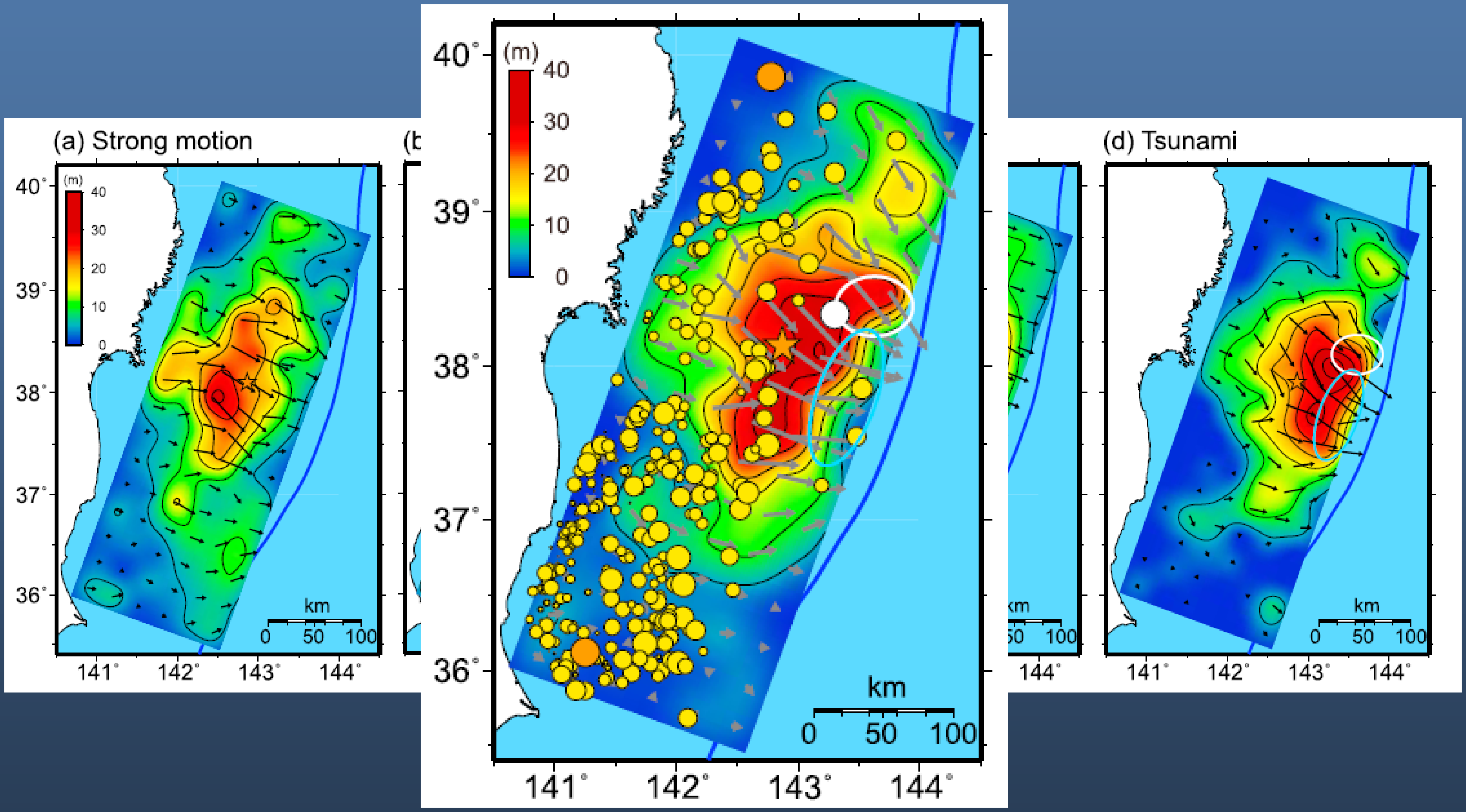
When the accumulated strain reaches the strength of the coupling, the coupled area (固着域) is ruptured and an earthquake occurs.

(3) tsunami

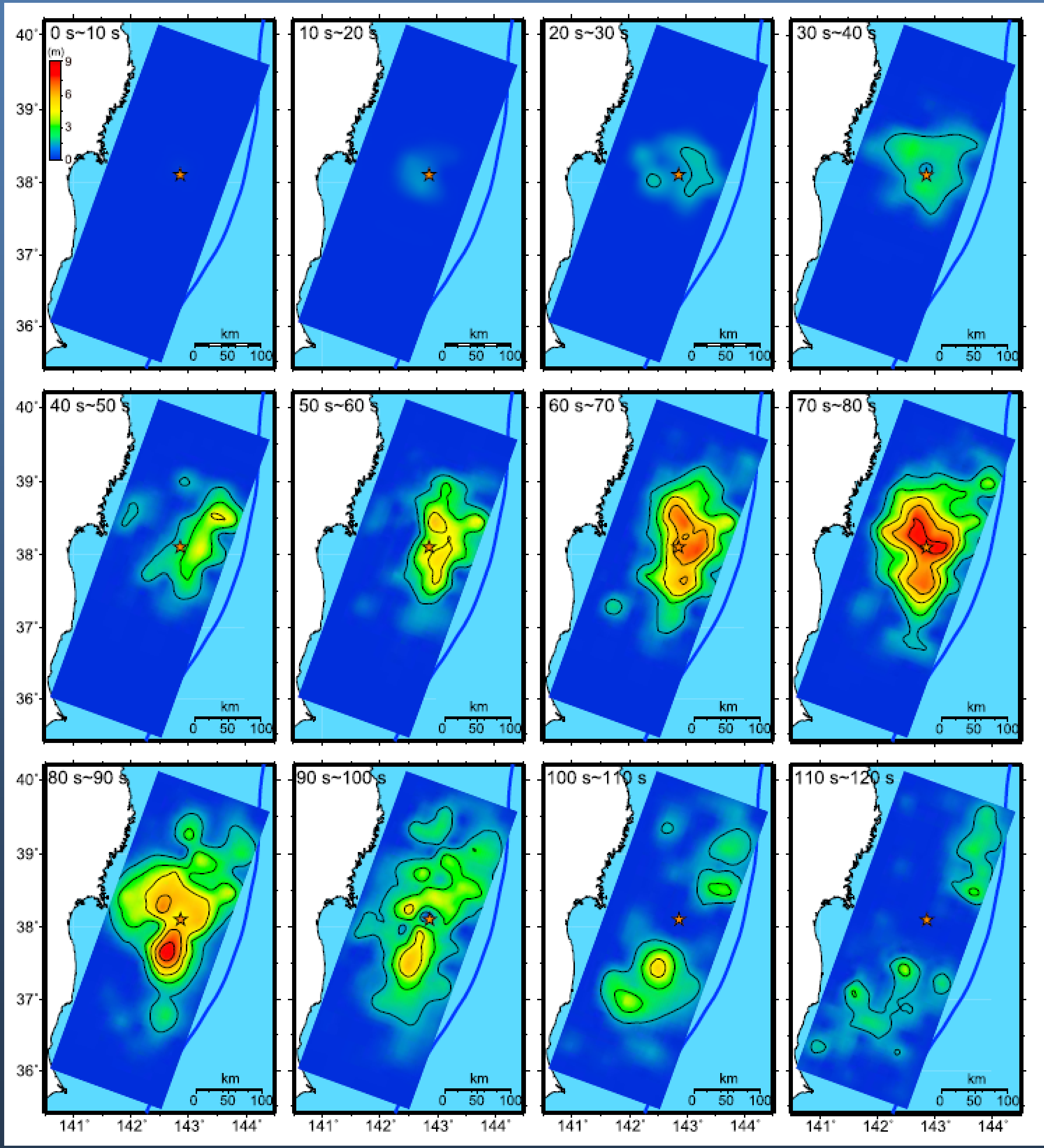
The upheaval happens due to the movement of the hanging wall, and this upheaval generates tsunamis in the sea (海).



Slip distributions recovered by the source inversions of Yokota et al. (2011)



Rupture progress in the earthquake



Slow rupture propagation in the main zone (Vr = 1.5 ~ 1.8 km/s)

→ Released energy was largely consumed by fault rupture and the radiated energy was reduced.

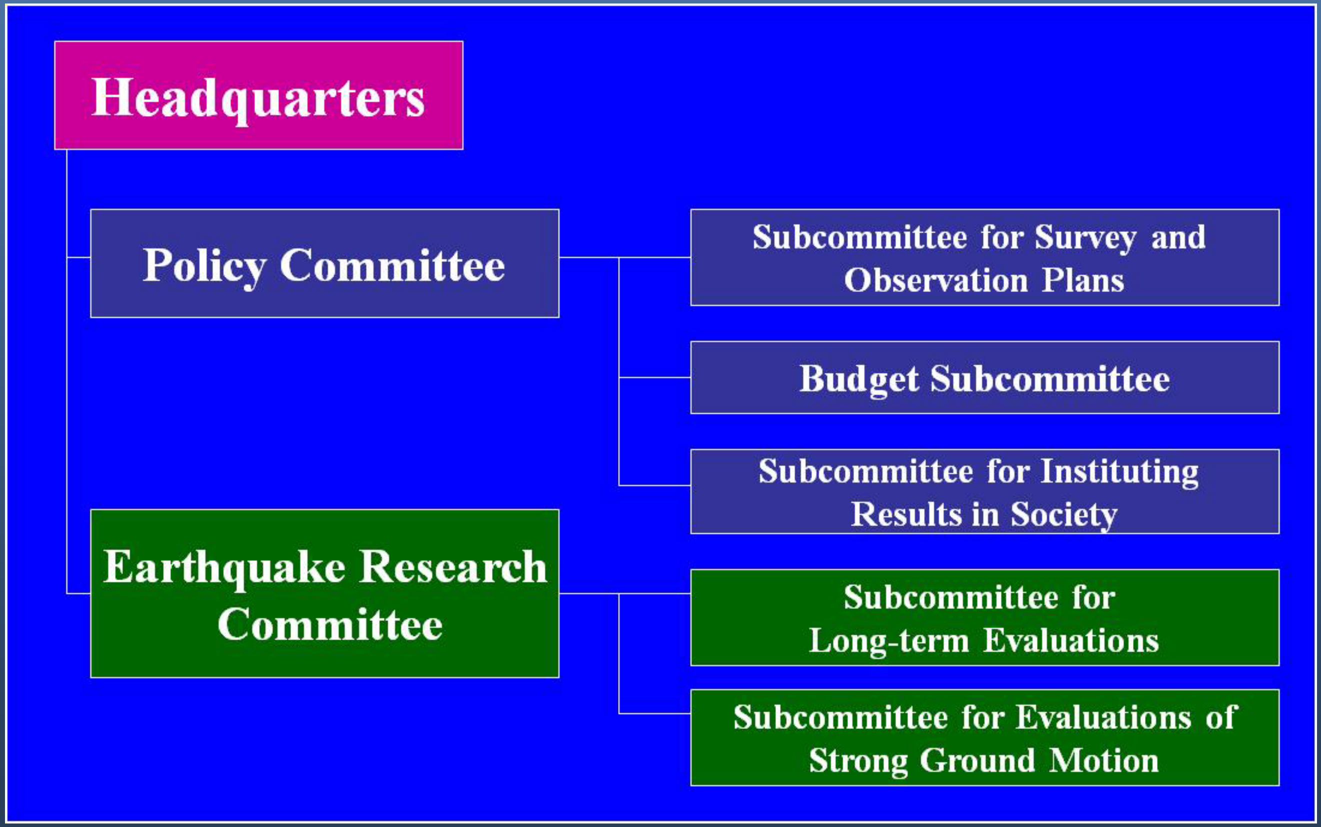
→ This caused moderate ground motion damage.

<Third Specific Feature>

3. They had not been foreseen at all

After the 1995 Kobe earthquake

The Japanese government built (1) a national program of seismic hazard assessment and (2) nation-wide dense arrays of seismometers and GPS receivers by establishing the Headquarters for Earthquake Research Promotion (HERP).



Structure of the Headquarters for Earthquake Research Promotion
(from Fujiwara *et al.*, 2004)

National program of seismic hazard assessment

"National Seismic Hazard Maps for Japan" are being made by the Earthquake Research Committee (ERC) of HERP. They consist of "Probabilistic Seismic Hazard Maps" and "Scenario Earthquake Maps."

Flowchart for Probabilistic Seismic Hazard Maps

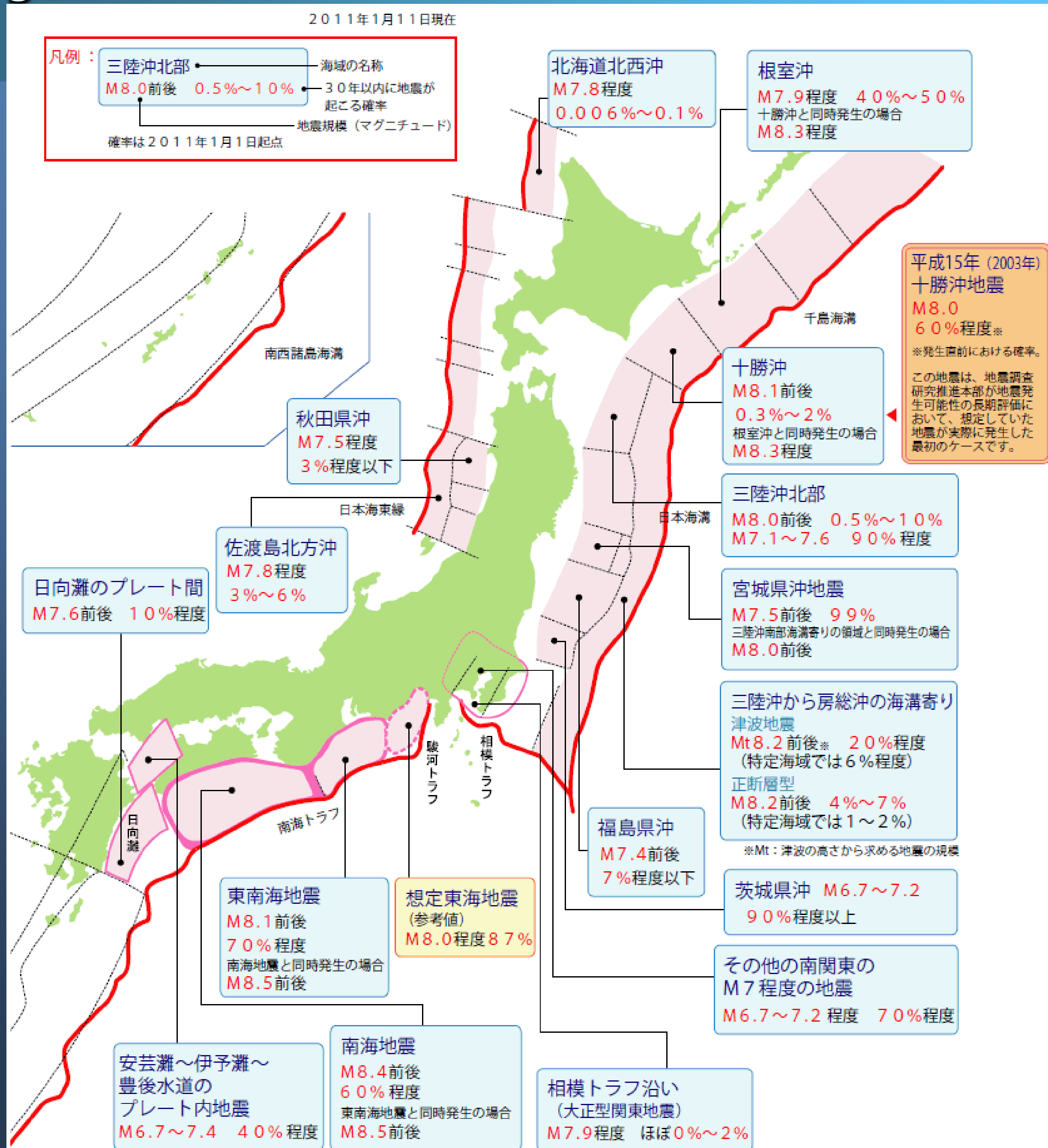
Long-term Evaluations

- Modeling of seismic activity
- ↓
- Evaluation of occurrence probability of earthquakes
- ↓

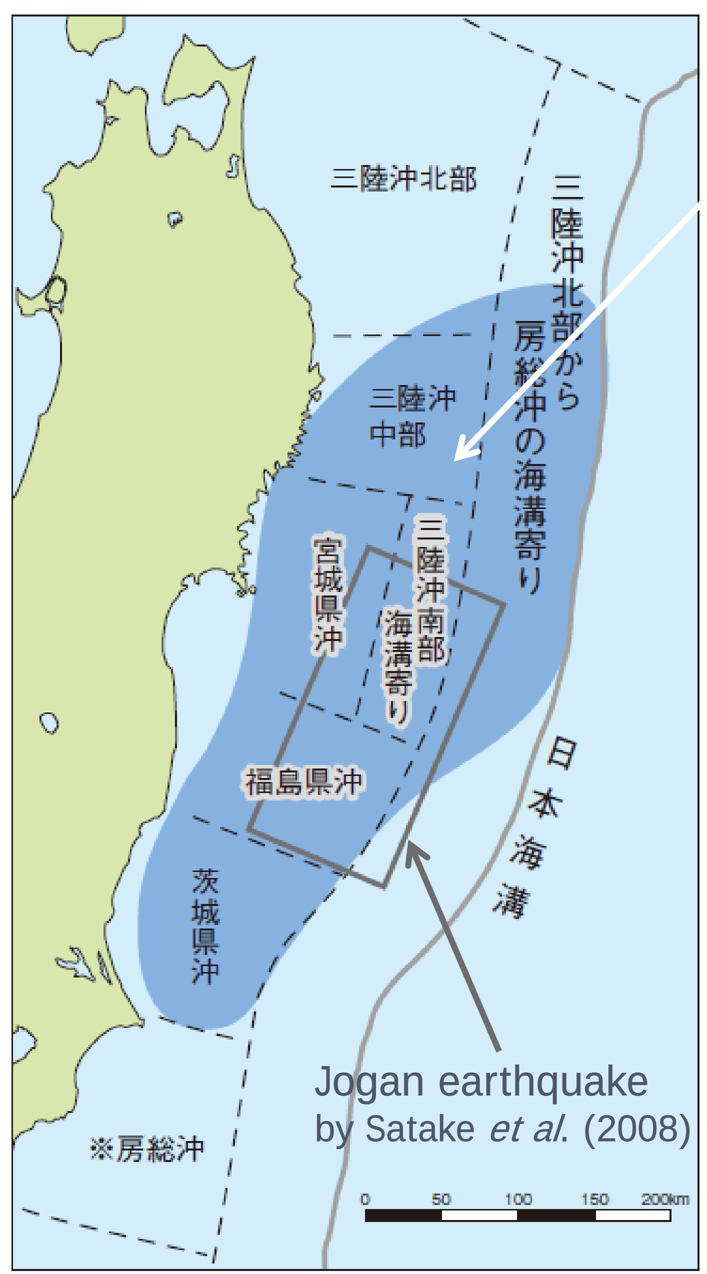
Evaluations of Strong Ground Motion

- Probabilistic evaluation of strong-motion level
- ↓
- Evaluation of probabilistic seismic hazard for each earthquake
- ↓
- Evaluation of probabilistic seismic hazard for all earthquakes

Long-term evaluations of subduction zone earthquakes



Long-term evaluations in Tohoku District

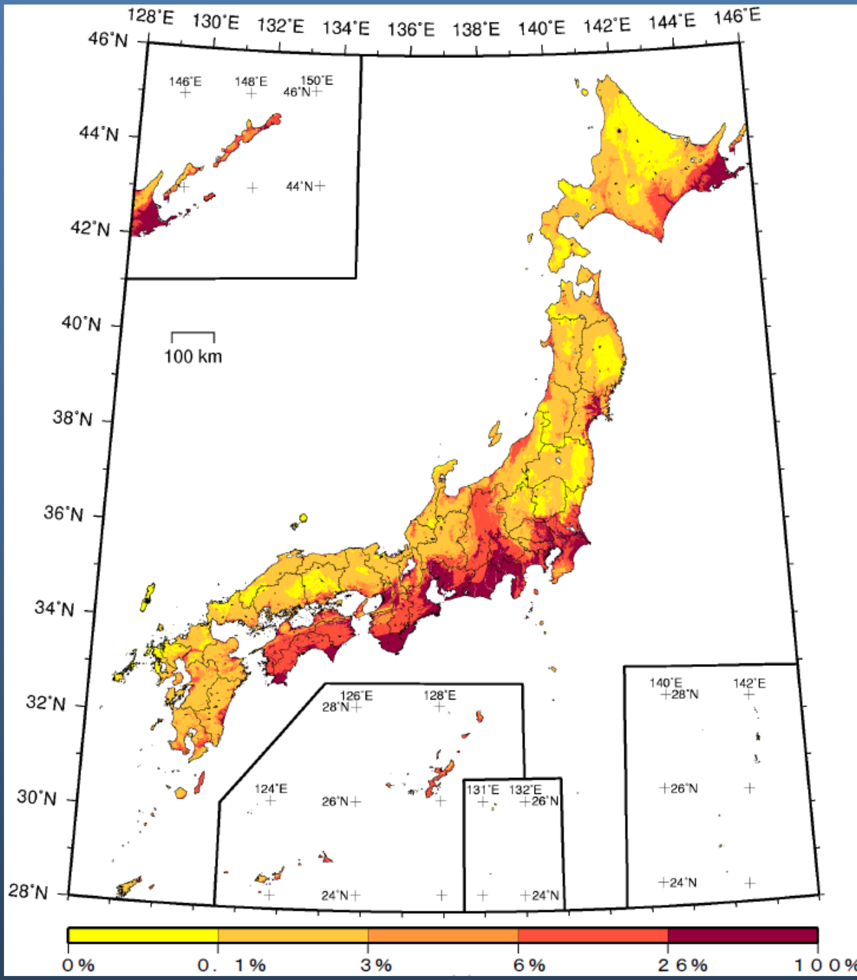


Tohoku earthquake

			Expected Magnitude	Probability within 30 years
三陸沖から房総沖にかけての地震	三陸沖から房総沖の海溝寄り	津波地震	Mt8.2前後（Mtは津波の高さから求める地震の規模）	20%程度（6%程度）*
	三陸沖から房総沖の海溝寄り	正断層型	8.2前後	4%～7%（1%～2%）*
	三陸沖北部		8.0前後	0.5%～10%
		固有地震以外のプレート間地震	7.1～7.6	90%程度
	宮城県沖		7.5前後（連動 8.0前後）	99%
	三陸沖南部海溝寄り		7.7前後（連動 8.0前後）	80%～90%
	福島県沖		7.4前後（複数の地震が続発する）	7%程度以下
	茨城県沖		6.7～7.2	90%程度以上

It had not been foreseen at all.

- Since the Tohoku earthquake was not foreseen and so its occurrence probability was not evaluated, the national seismic hazard maps did not include its effects; as a result, they were not useful at all for the public preparedness.
- Even if that the 869 Jogan earthquake was taken into consideration, it could not useful for the public preparedness and the safety of the nuclear power plant. Its magnitude was estimated to be only 8.4 and the tsunami height close to the plant was observed from tsunami deposits to be only 4.6 m (Satake et al., 2008; Namegaya et al., 2010).



Seismic hazard map of probabilities of ground motions equal to or larger than seismic intensity 6 Lower, occurring within 30 years from January 1, 2010.

Geller (2011)

Actually, two in green circles could be foreseeable, but the others occurred at unknown active faults or plate boundary segments. So, they are located at places assigned a relatively low probability.

However, since 1979, earthquakes that caused 10 or more fatalities in Japan actually occurred in places assigned a relatively low probability. This discrepancy — the latest in a string of negative results for the characteristic earthquake model and its cousin, the seismic-gap model[2–4] — strongly suggests that the hazard map and the methods used to produce it are flawed and should be discarded.

Implications of the previous

- We think that the methods are not flawed and the probabilistic approach is not necessarily inappropriate.
- The reason why the probability maps were not useful was that our knowledge on past earthquakes is very limited.
- For example, there remain many unknown active faults and plate boundary segments. This limitation leads to the large uncertainties in scientific forecast.
- A real problem is that the Japanese government has not clearly stated these limitations to the public.
- Good communication of risk is indispensable in sciences related to natural disasters.