

Tsunami Disaster Mitigation in Asia after the 2004

Indian Ocean and 2011 Tohoku Tsunamis

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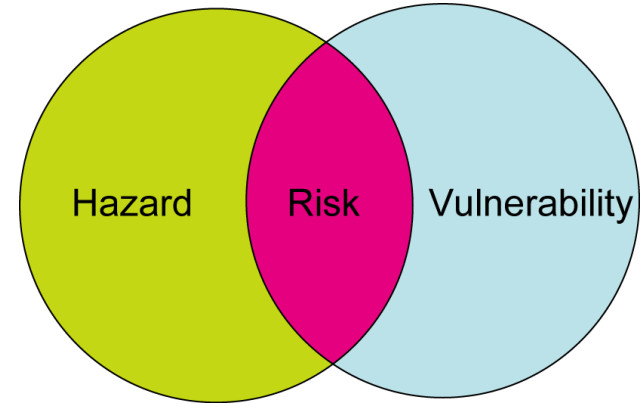
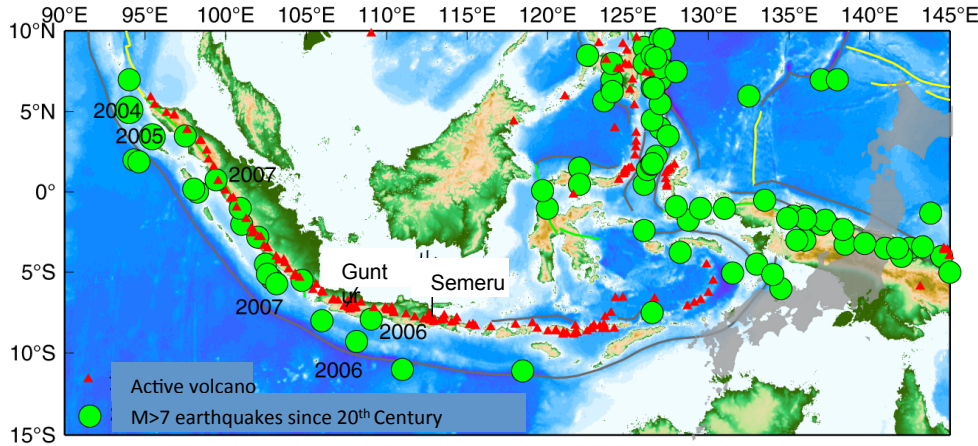
satake@eri.u-tokyo.ac.jp

Earthquakes with > 1,000 fatalities in last decade

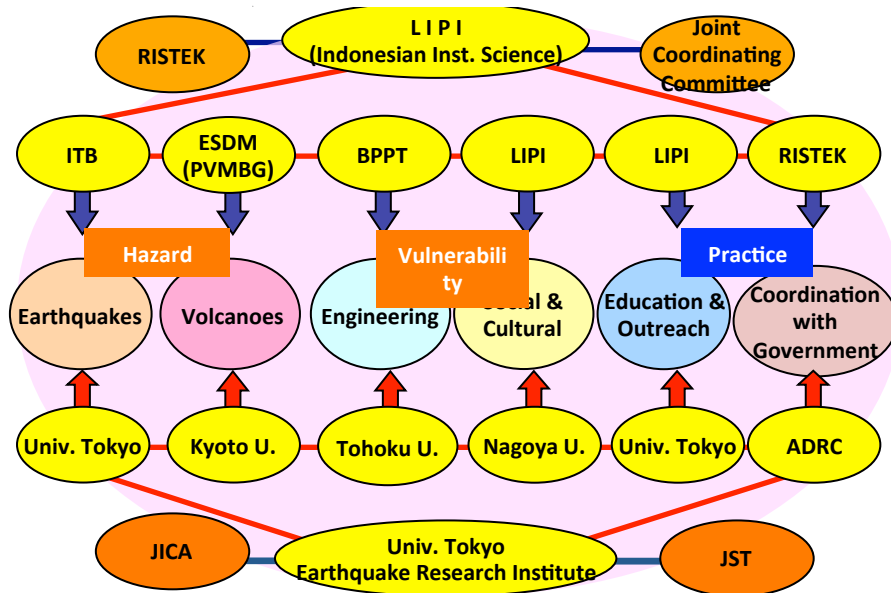
Date	Region	M	Fatalities
2011/3/11	Tohoku, Japan	9.0	20,896
2010/1/12	Haiti	7.0	222,570
2009/9/30	Padang, Indonesia	7.5	1,117
2008/5/12	Sichuan, China	7.9	87,587
2006/5/26	Java (Jogjakarta), Indonesia	6.3	5,749
2005/10/8	Kashmir, Pakistan	7.6	86,000
2005/3/28	Sumatra (Nias), Indonesia	8.6	1,313
2004/12/26	Sumatra (Aceh), Indonesia	9.1	227,898
2003/12/26	Bam, Iran	6.6	31,000
2003/5/21	Algeria	6.8	2,266
2002/3/25	Afghanistan	6.1	1,000
2001/1/26	Bhuj (Gujarat), India	7.6	20,023

Of these 12 events, 10 occurred in Asia and 4 in Indonesia

Multi-disciplinary Hazard Reduction Program from Earthquakes and Volcanoes in Indonesia



Disaster Risk =
Natural Hazard X Society's Vulnerability



- (1) Eq. Forecast
- (2) Volcanic eruption
- (3) Engineering
- (4) Social Sciences
- (5) Education and Awareness
- (6) Coordination with Governments

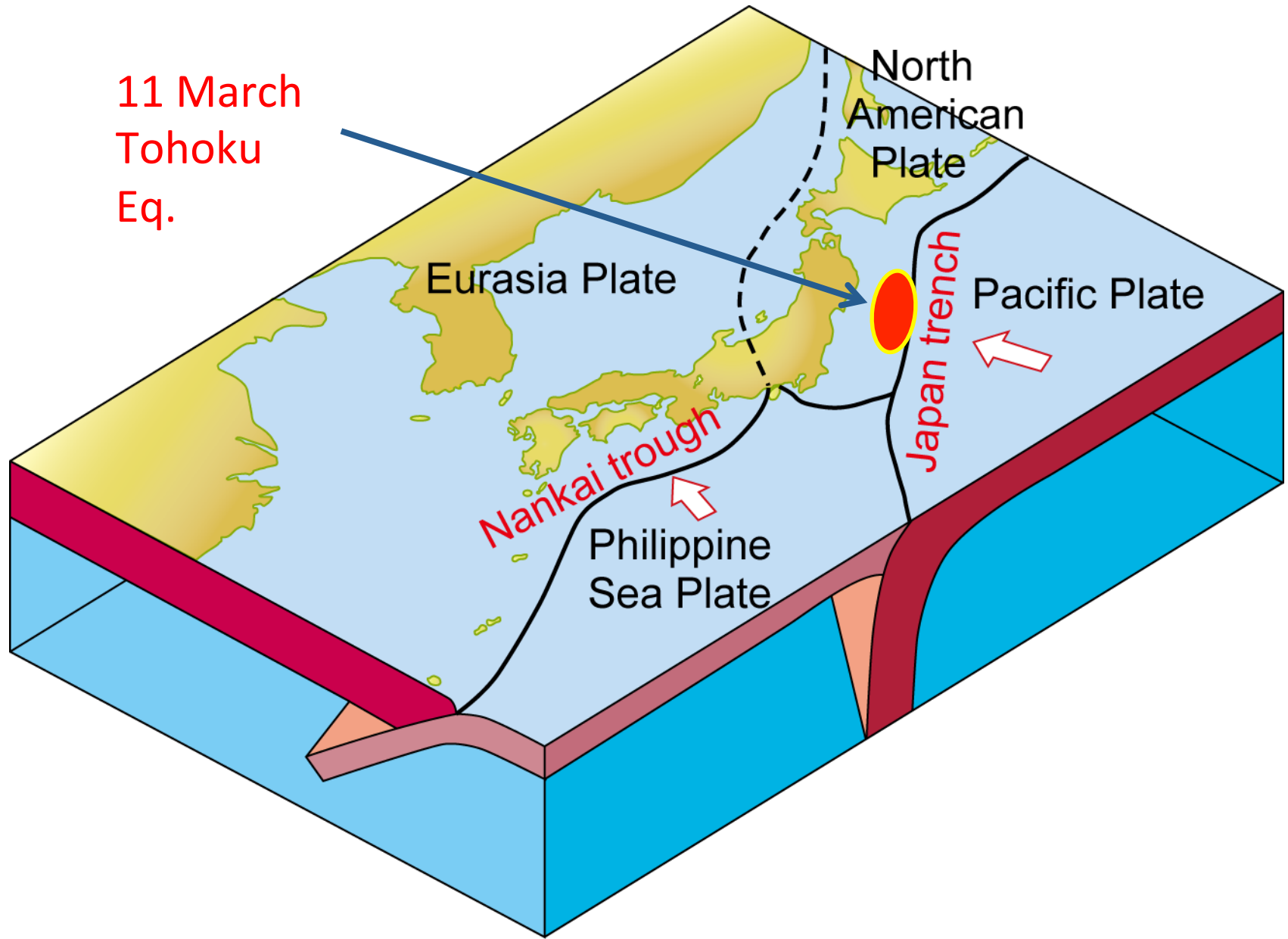
Outline

1. March 11 earthquake and tsunami
2. Long-term forecast of earthquake
3. Past tsunamis on Tohoku coasts
4. Observation and analysis of the 2011 tsunami
5. Giant earthquakes in the world

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1. **March 11 earthquake and tsunami**
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Plates around Japan



11 March
Tohoku
Eq.

North
American
Plate

Eurasia Plate

Pacific Plate

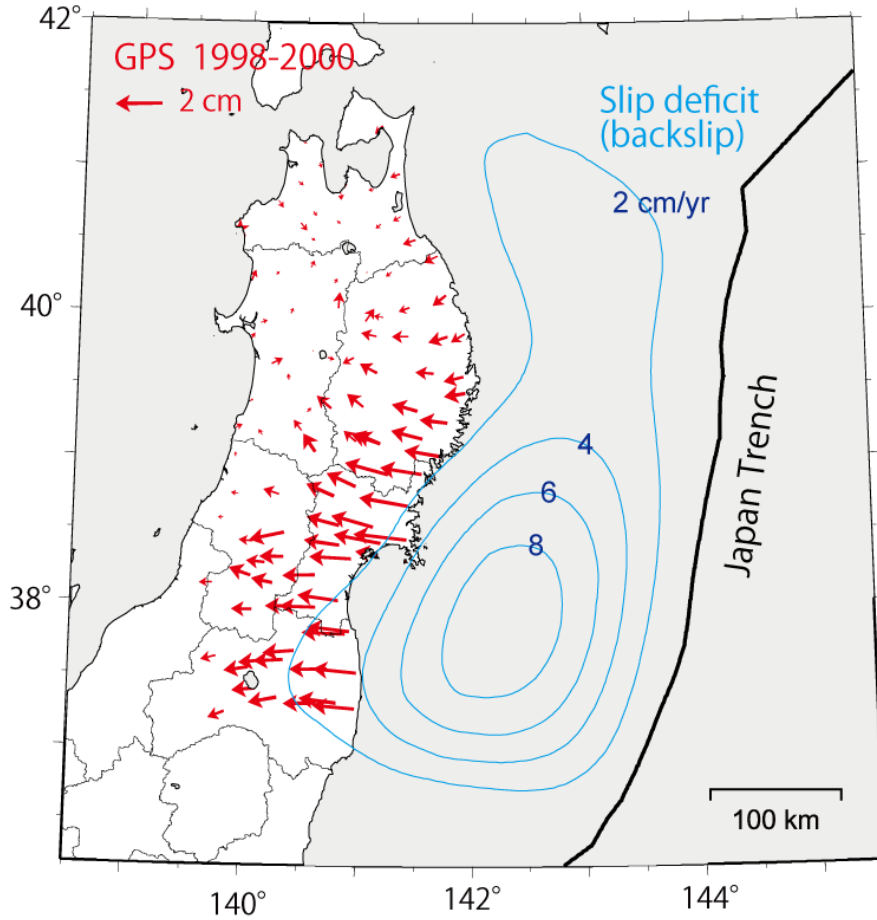
Japan trench

Nankai trough

Philippine
Sea Plate

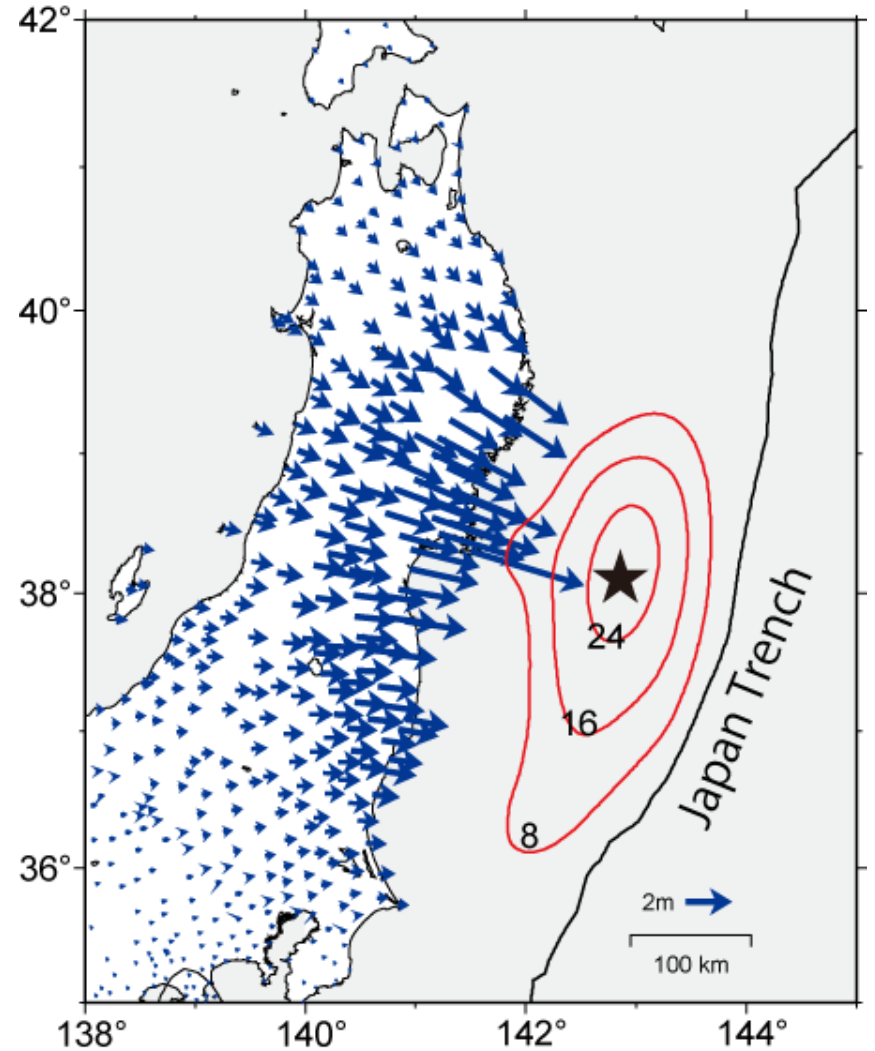
GPS data and Slip distribution

1998-2000



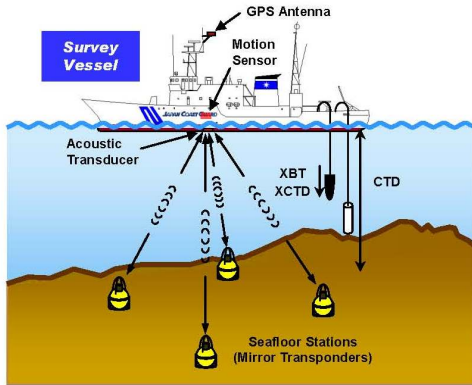
GSI (2010, 2011)

March 11, 2011

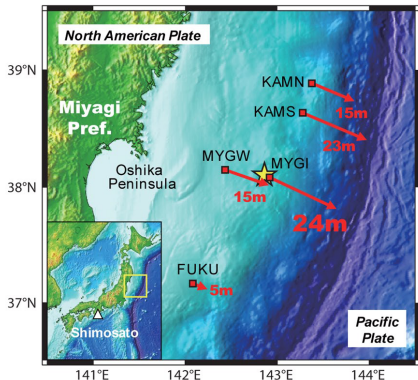


Seafloor displacement

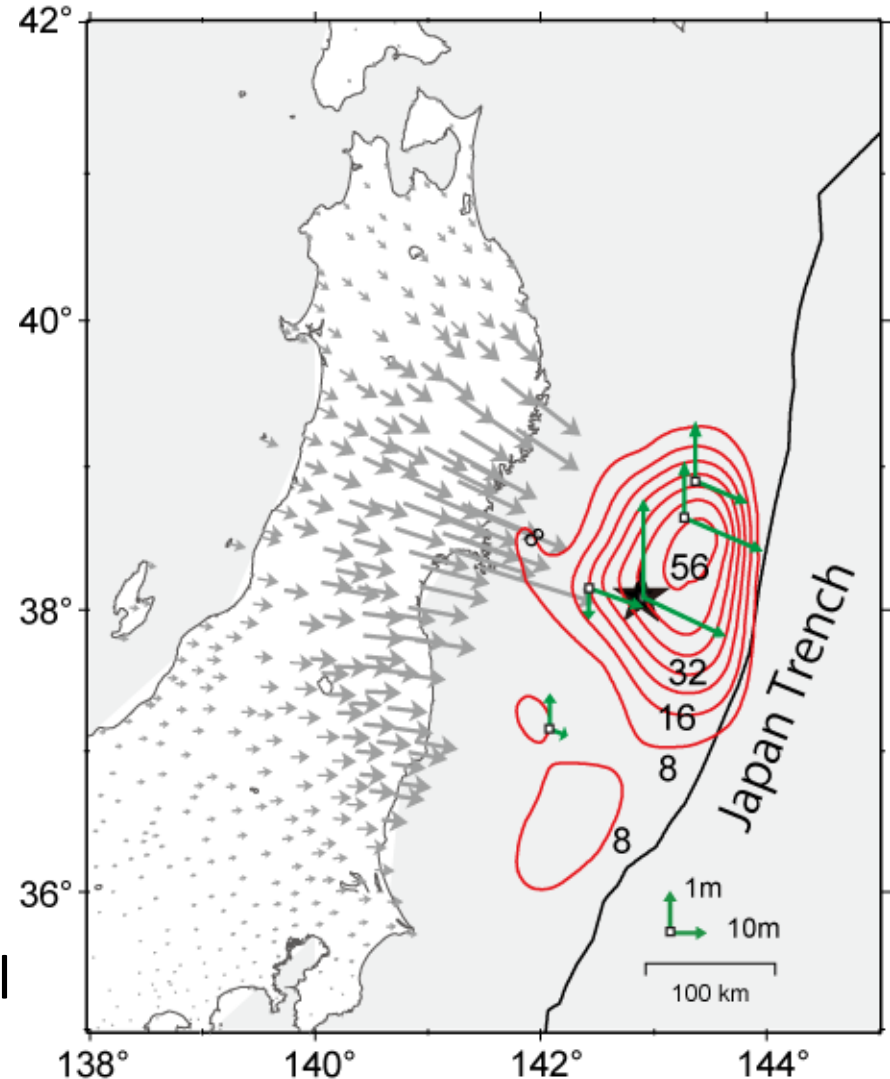
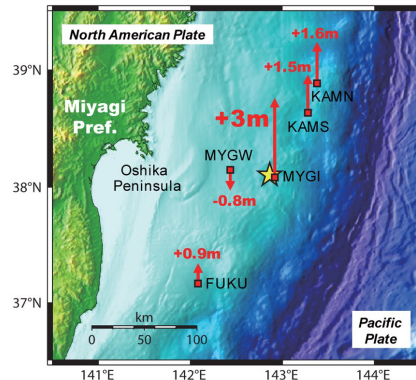
Max slip on fault (estimated): > 50 m



(A) Horizontal displacements



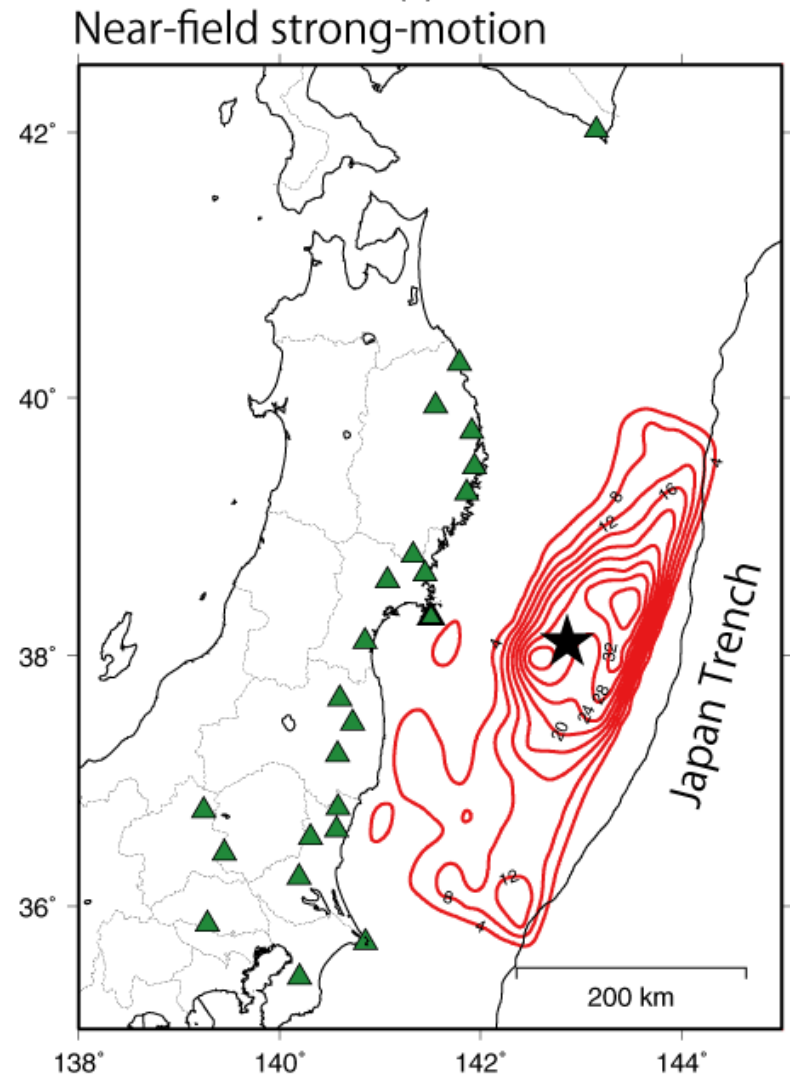
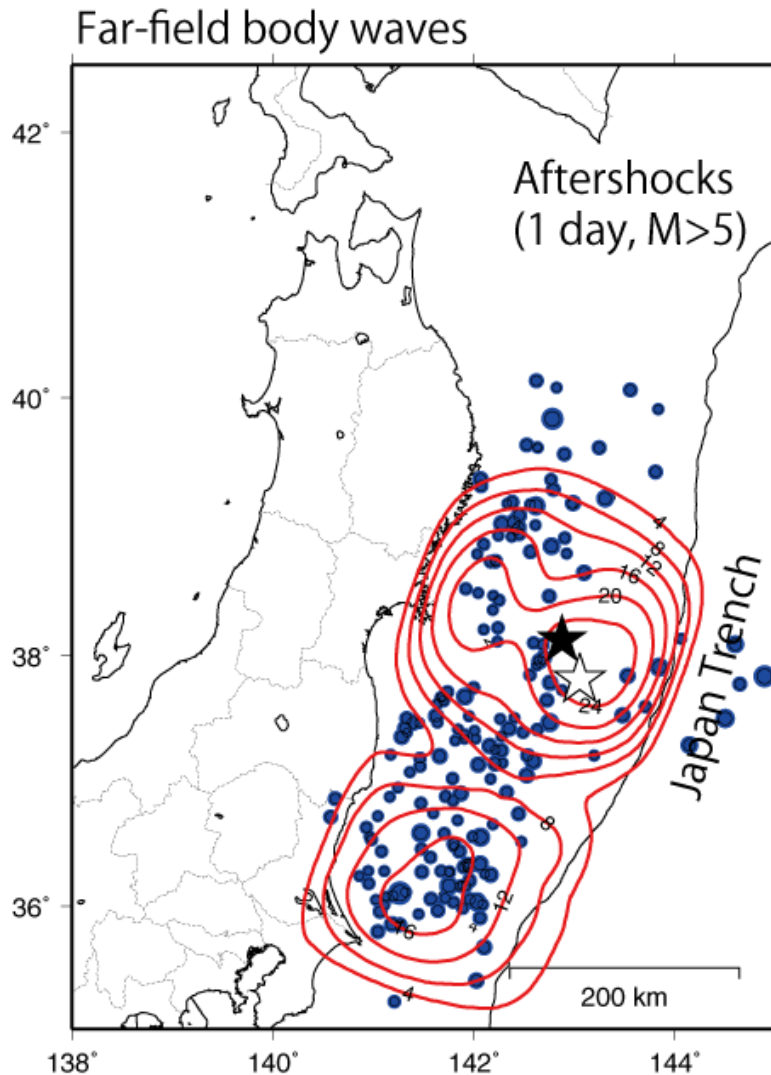
(B) Vertical displacements



Max observed slip: 24 m horizontal
3 m vertical

Sato et al. (Science 2011)

Slip Distribution from Seismic Waves



Seafloor displacement (cross-section)

Surface displacement

Subsidence

Uplift

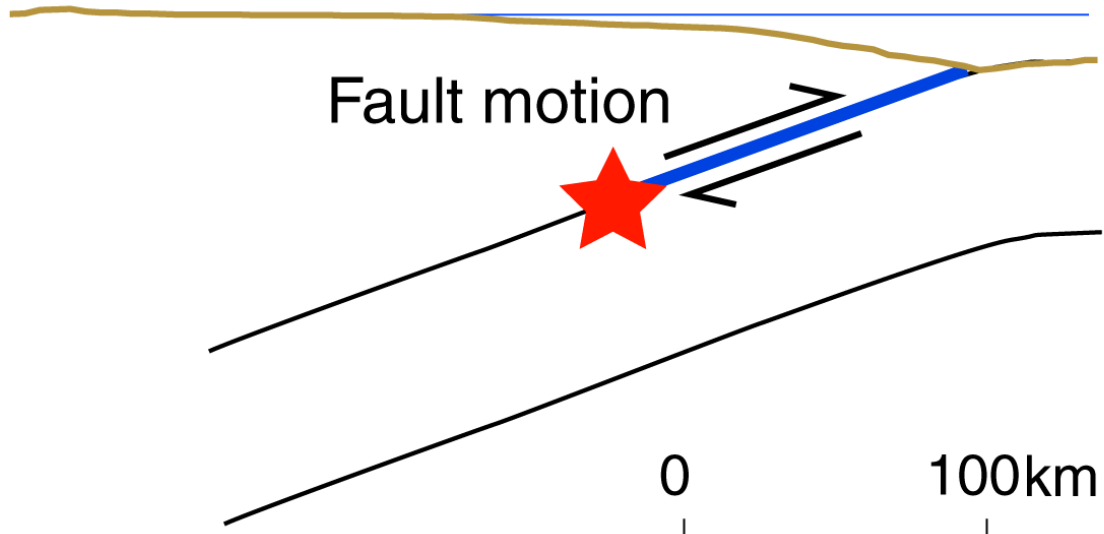
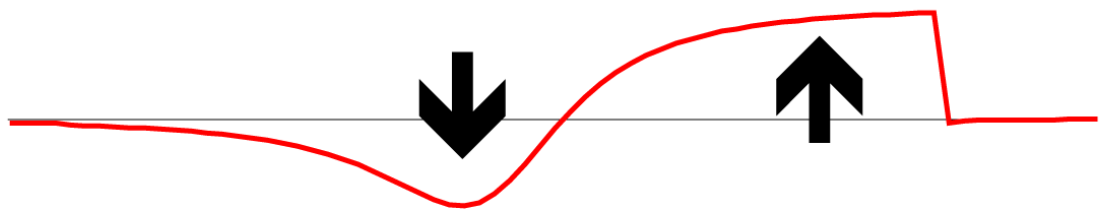
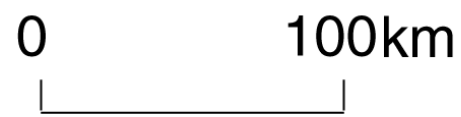
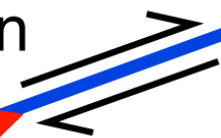
W

E

Tohoku coast

Japan trench

Fault motion



March 11, 2011 tsunami

Miyako, Iwate pref.

About 30 minutes
After the earthquake

Mainichi Newspaper



Natori, Miyagi pref.

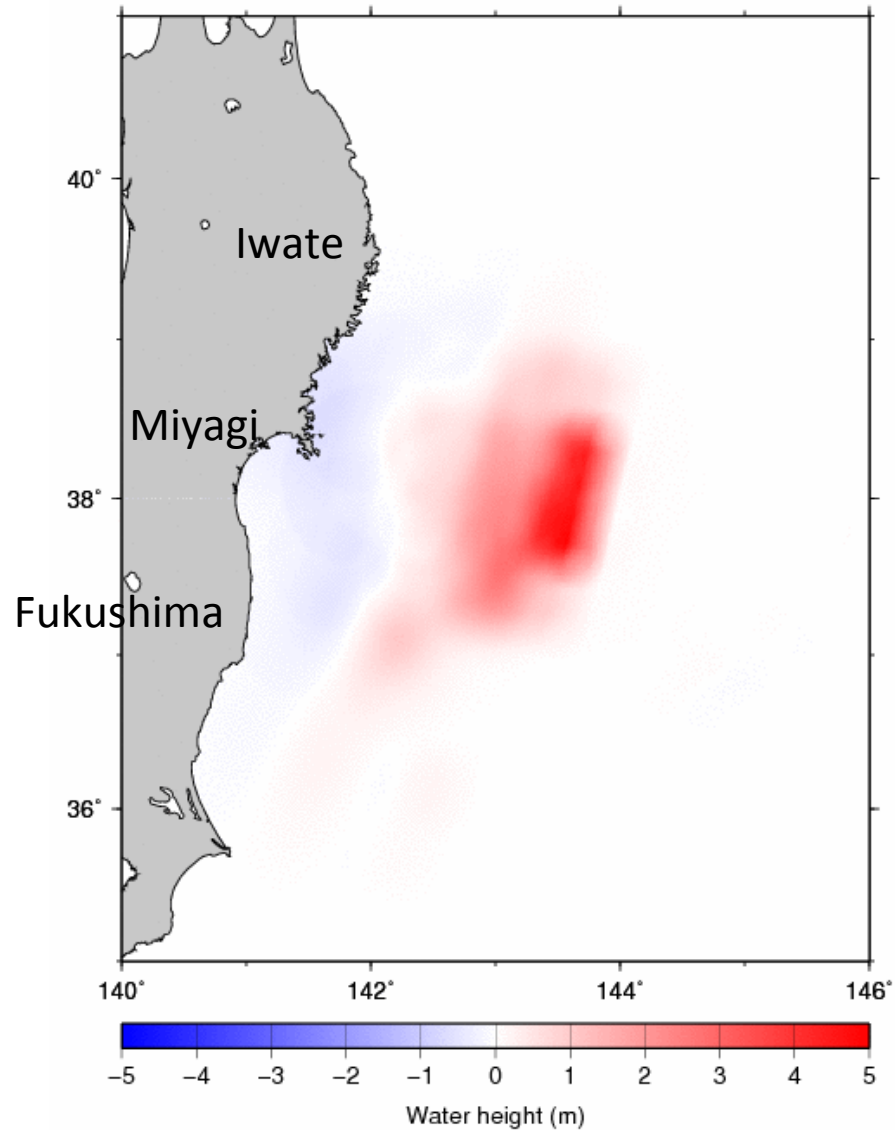
About 1 hour after eq.

AP



Tsunami generation and propagation

2011 off the Pacific coast of Tohoku earthquake 0001 min

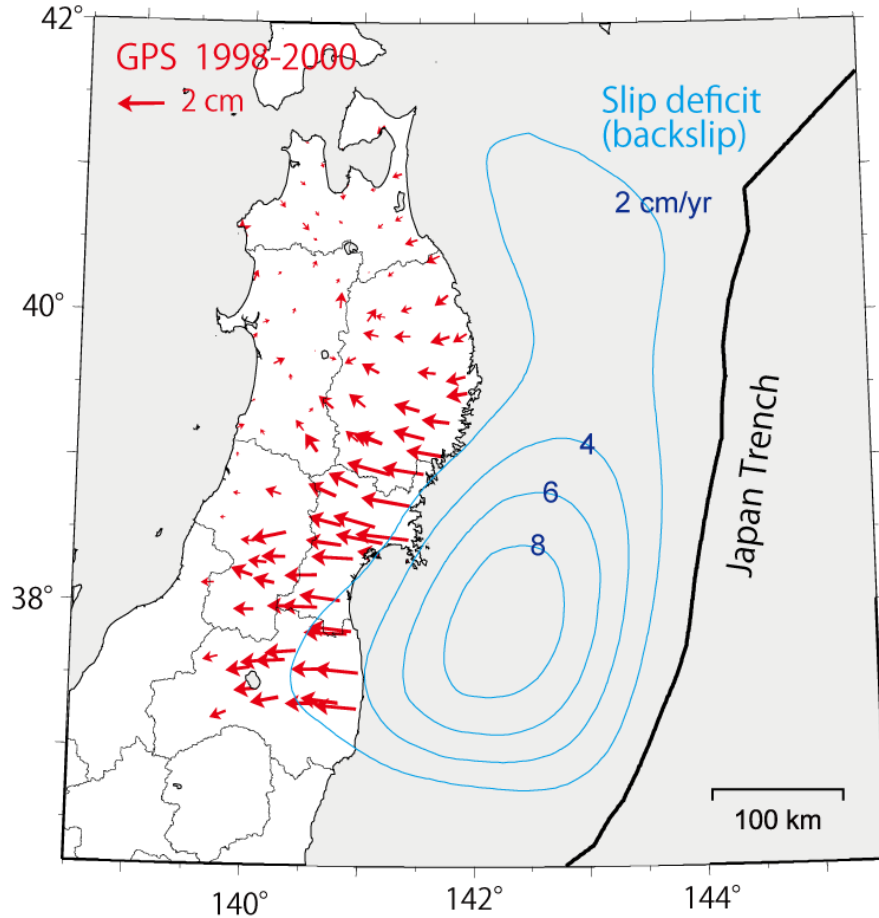


Outline

1. March 11 earthquake and tsunami
2. Long-term forecast of earthquake
3. Tsunami warning system
4. Past tsunamis on Tohoku coasts
5. Observation and analysis of the 2011 tsunami
6. Giant earthquakes in the world

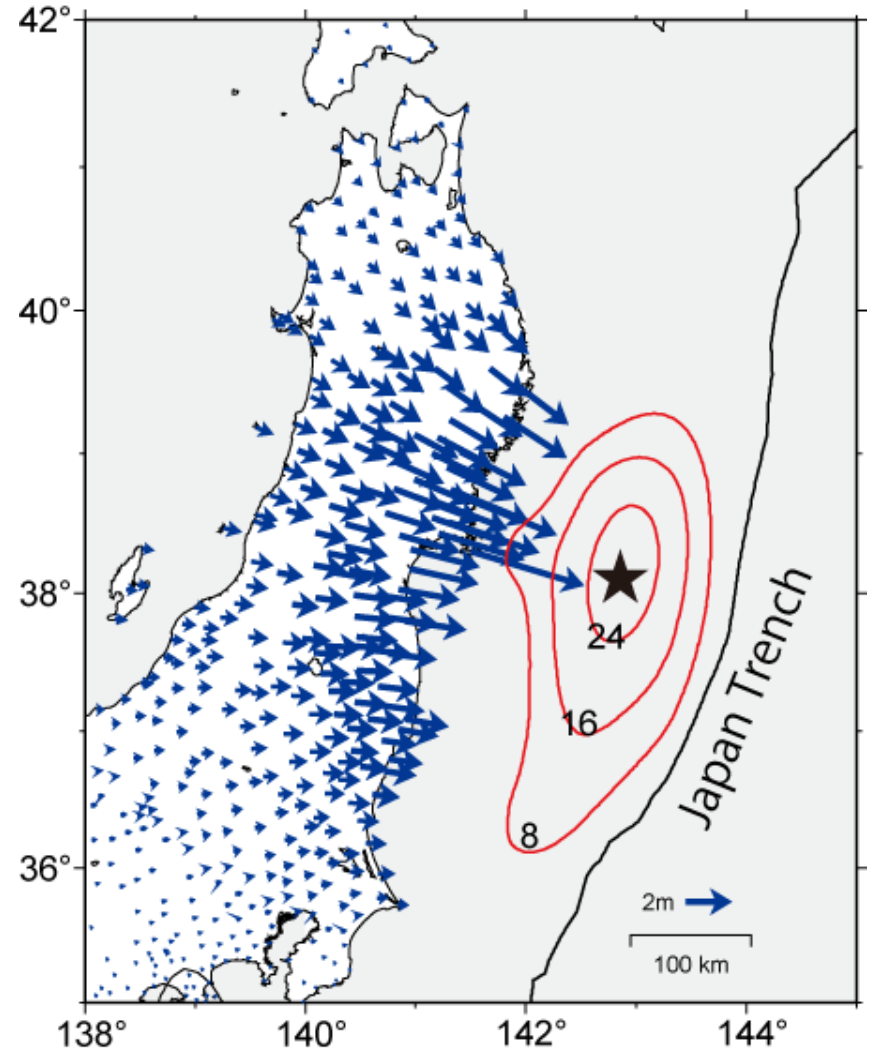
GPS data and slip distribution

1998-2000



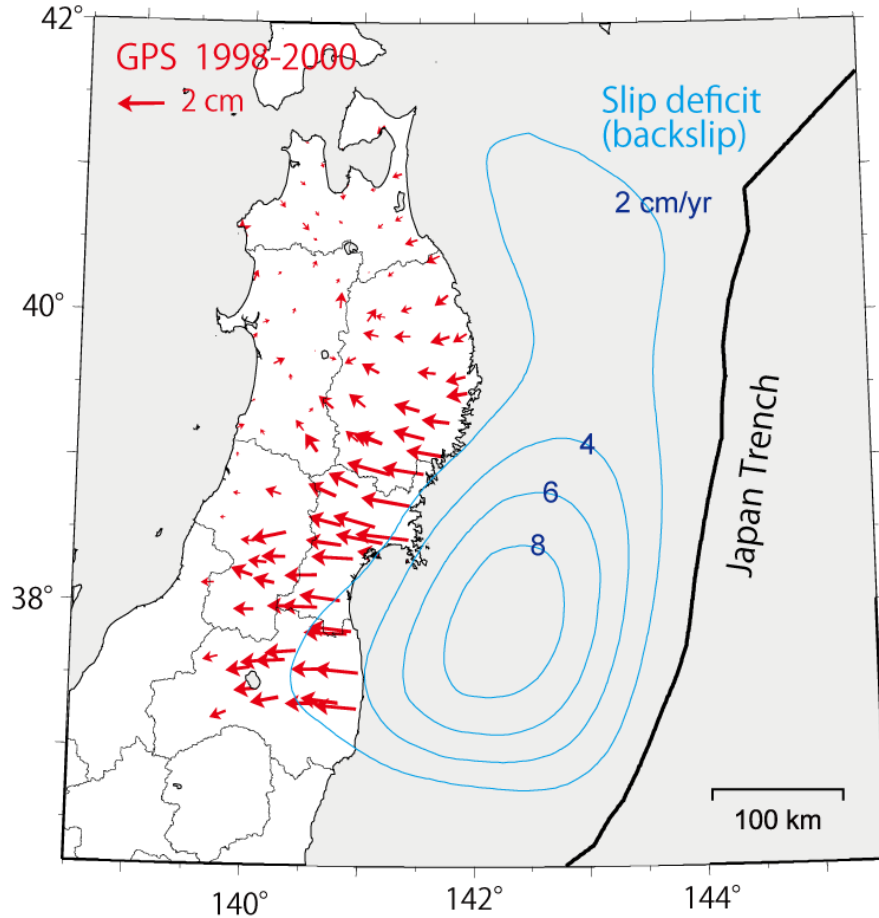
GSI (2010, 2011)

March 11, 2011



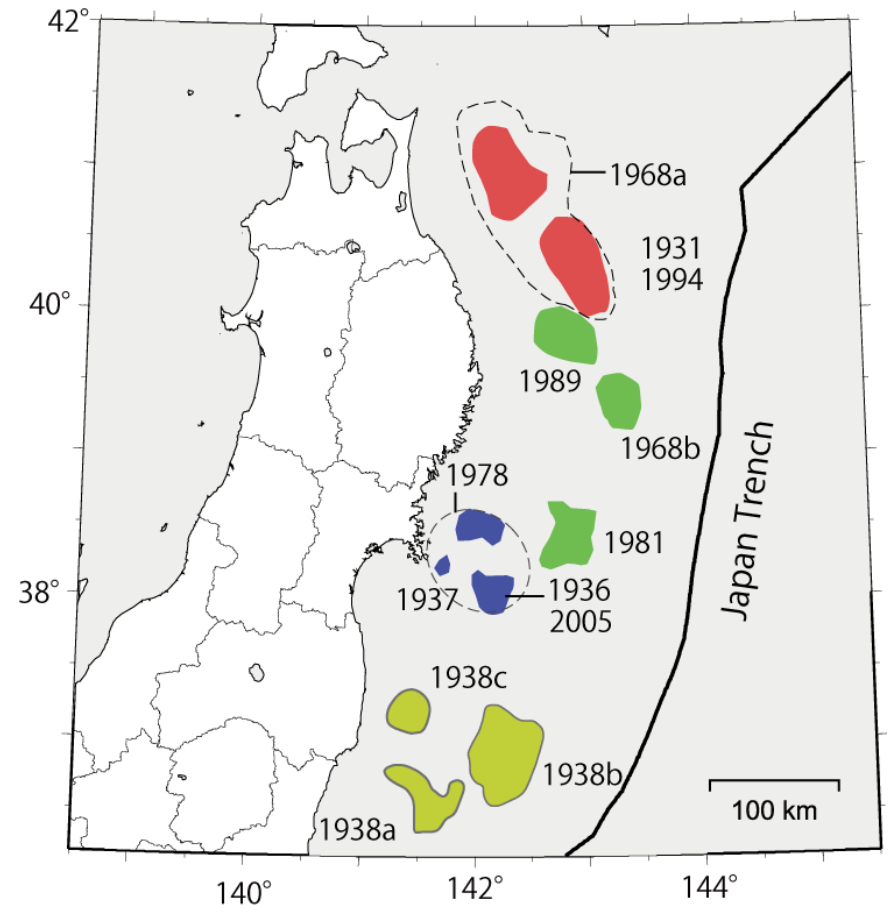
GPS data and past earthquakes

1998-2000



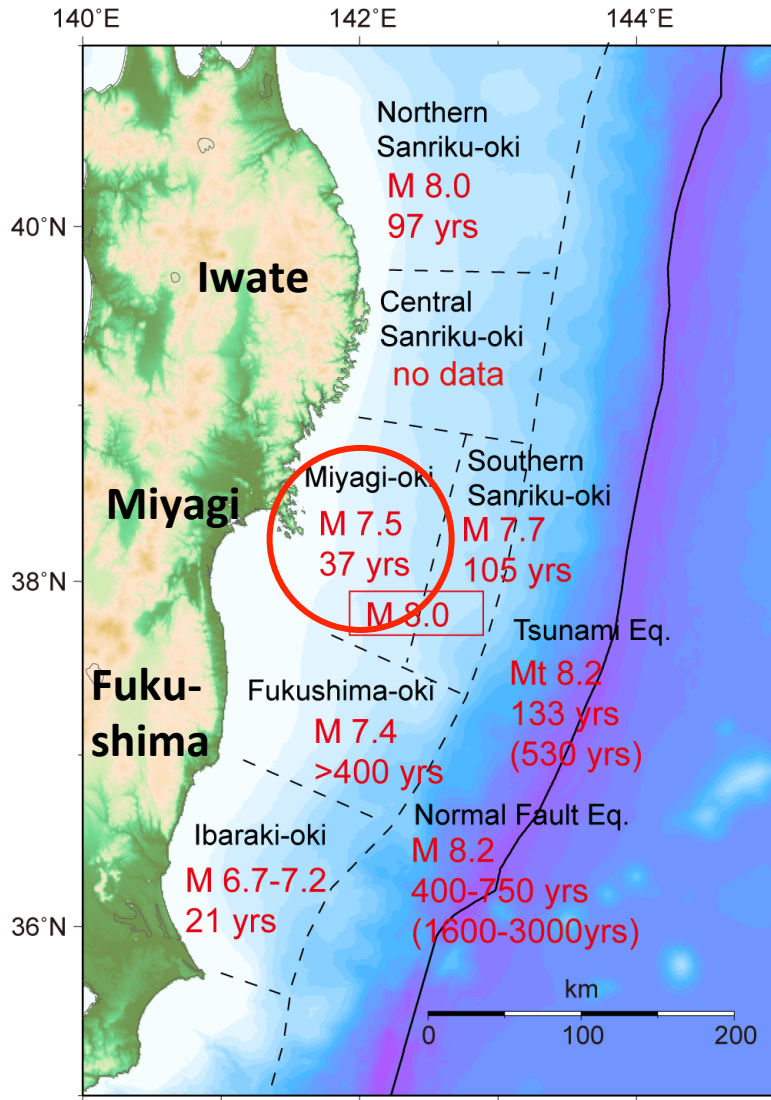
GSI (2010, 2011)

Large earthquakes since 1900



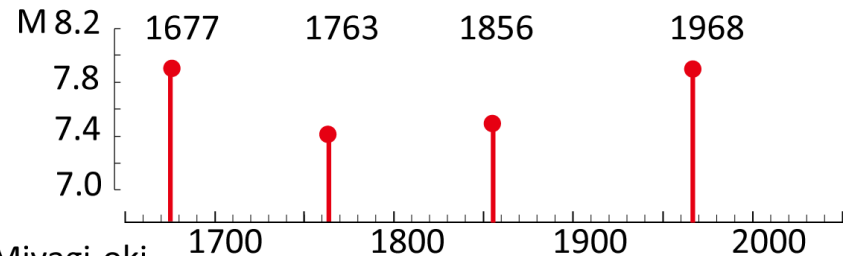
Yamanaka and Kikuchi (2004)

Long-term forecast of earthquakes

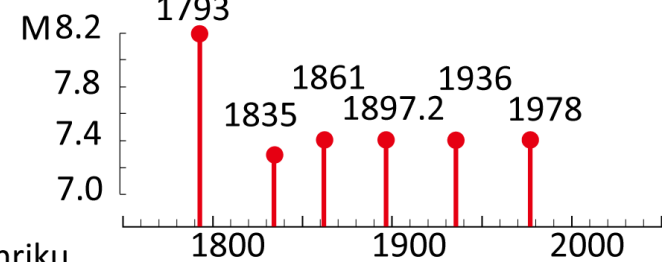


Long term forecast by ERC (2003)

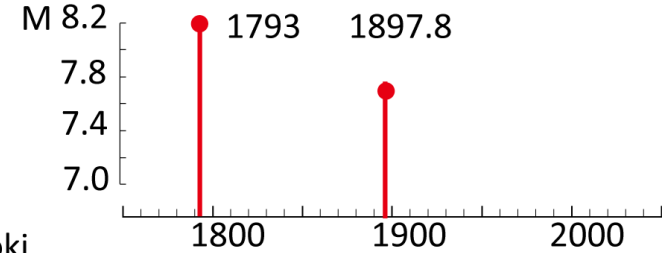
Northern Sanriku



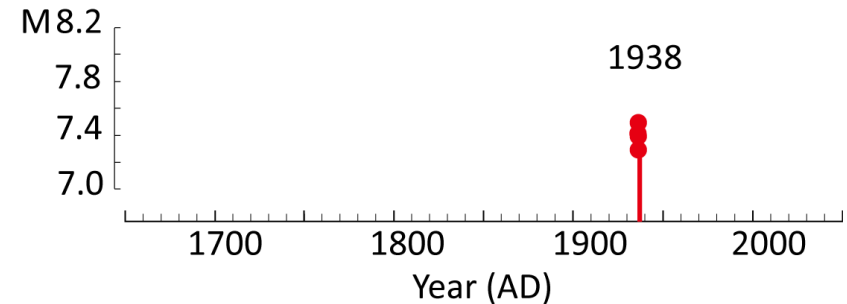
Miyagi-oki



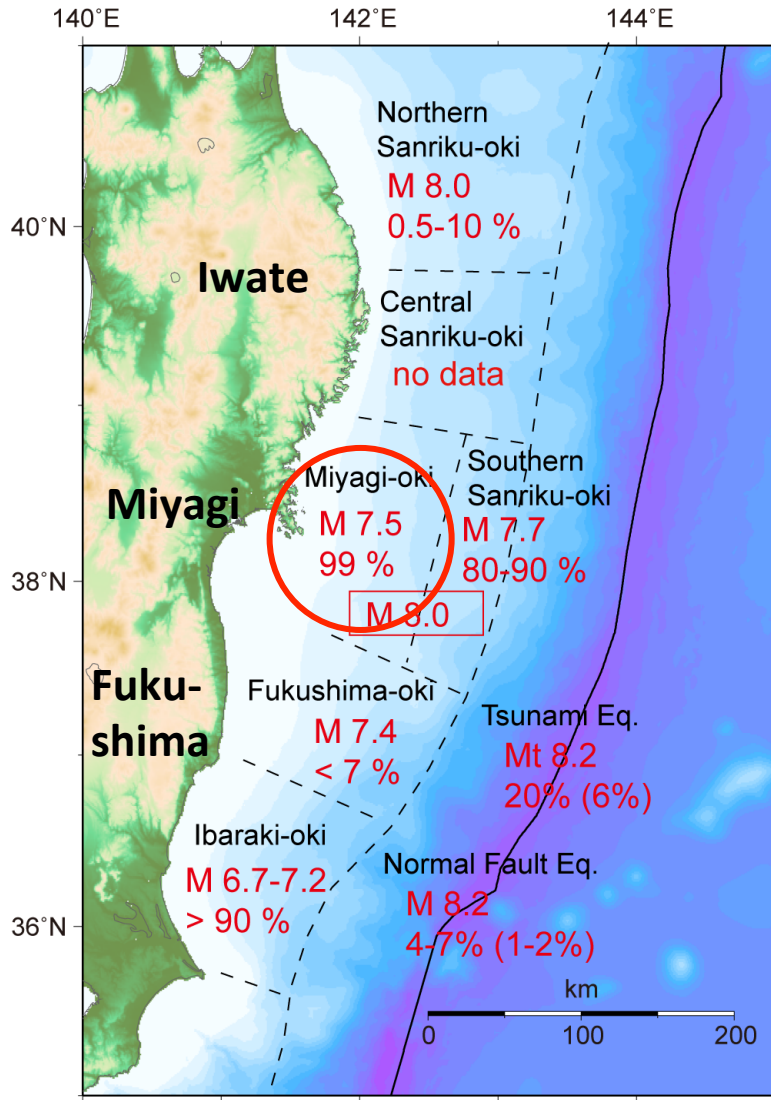
Southern Sanriku



Fukushima-oki

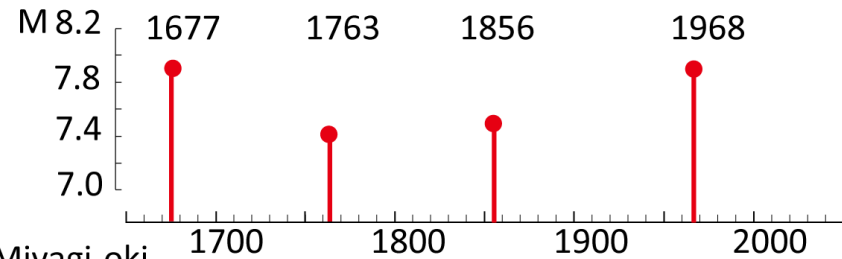


Long-term forecast of earthquakes

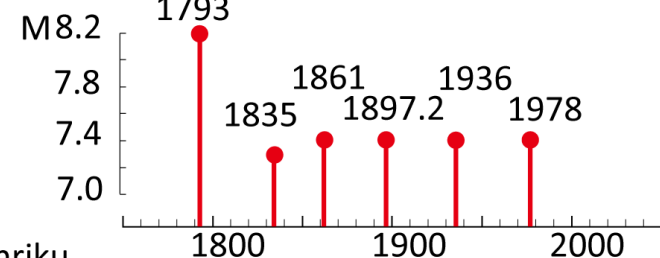


Long term forecast by ERC (2003)

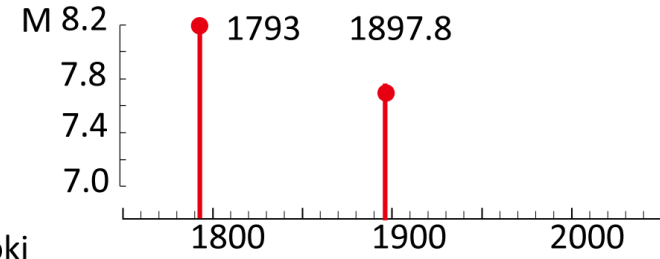
Northern Sanriku



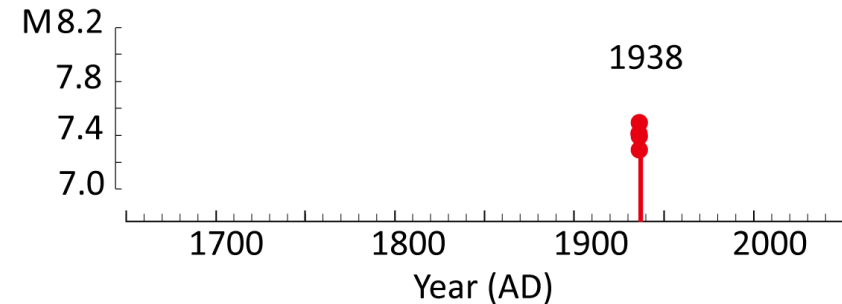
Miyagi-oki



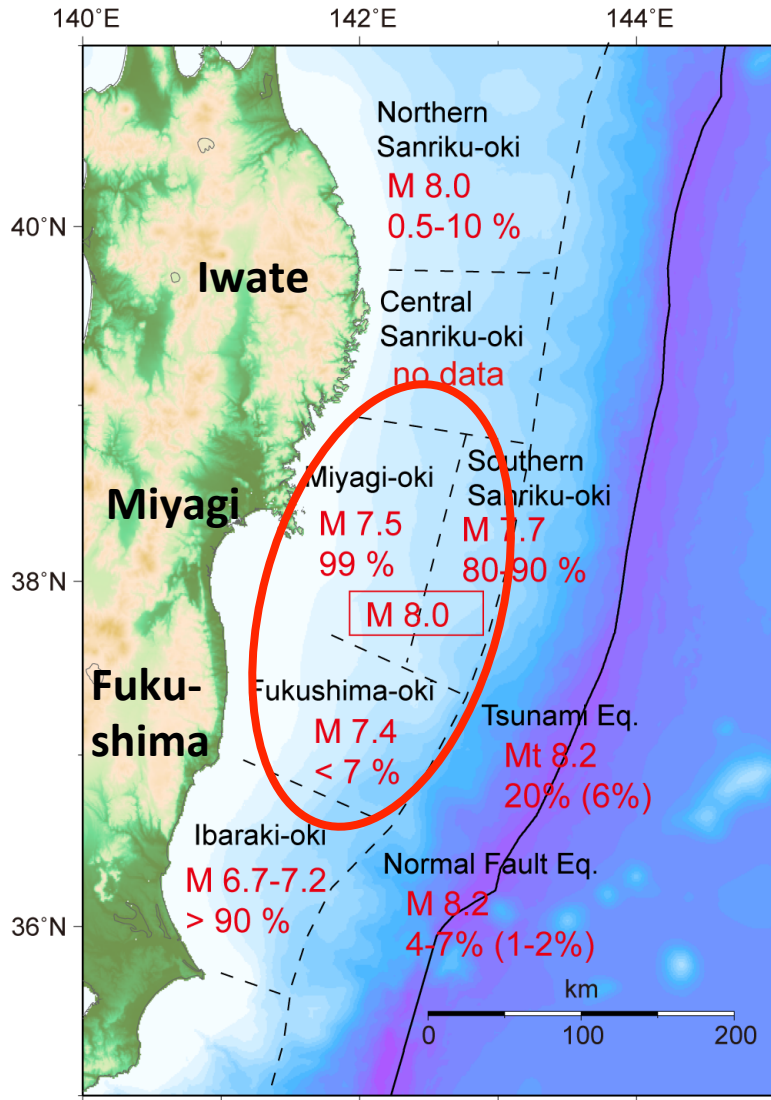
Southern Sanriku



Fukushima-oki

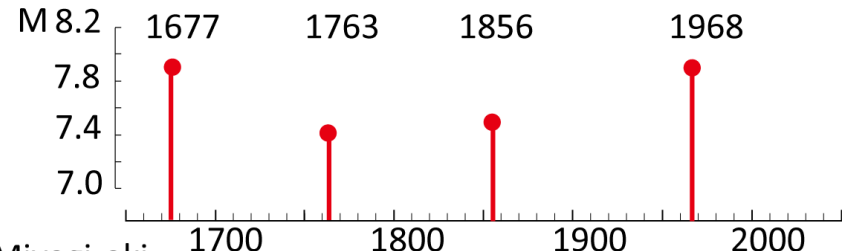


Long-term forecast of earthquakes

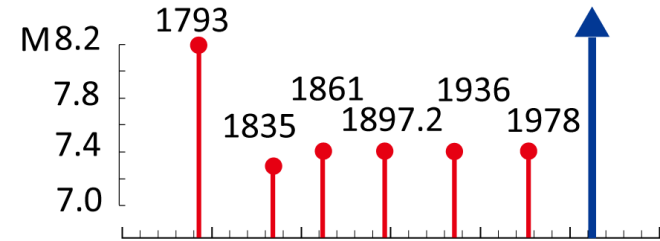


Long term forecast by ERC (2003)

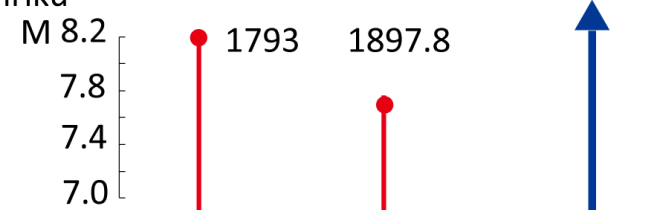
Northern Sanriku



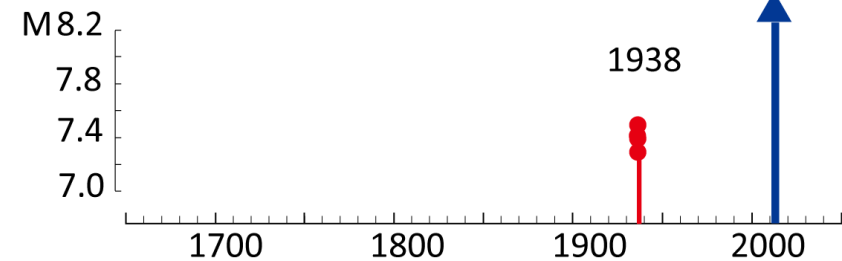
Miyagi-oki



Southern Sanriku

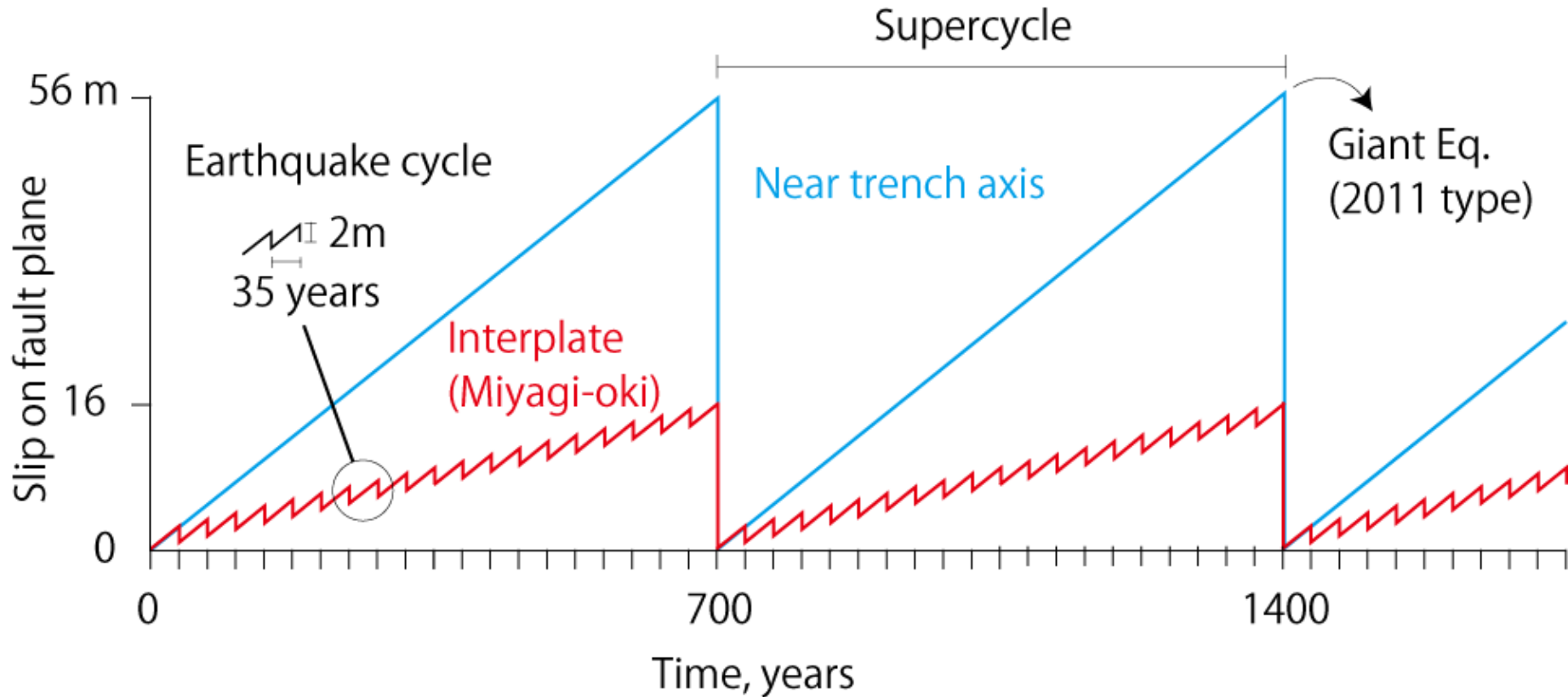


Fukushima-oki



Year (AD)

Supercycle of earthquakes



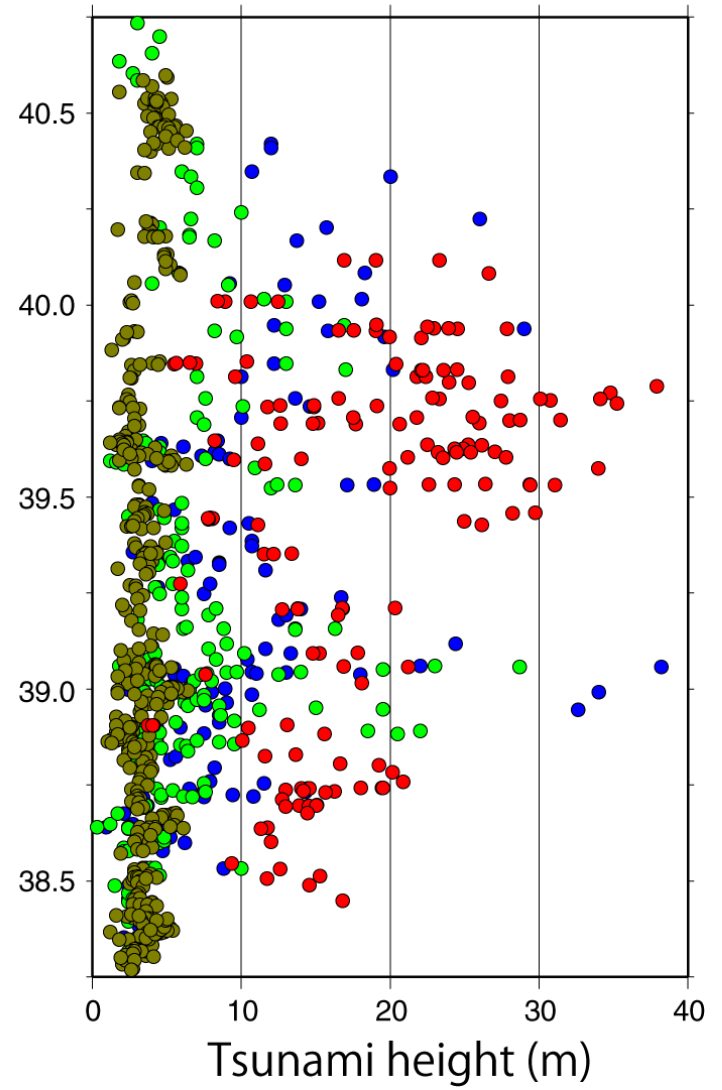
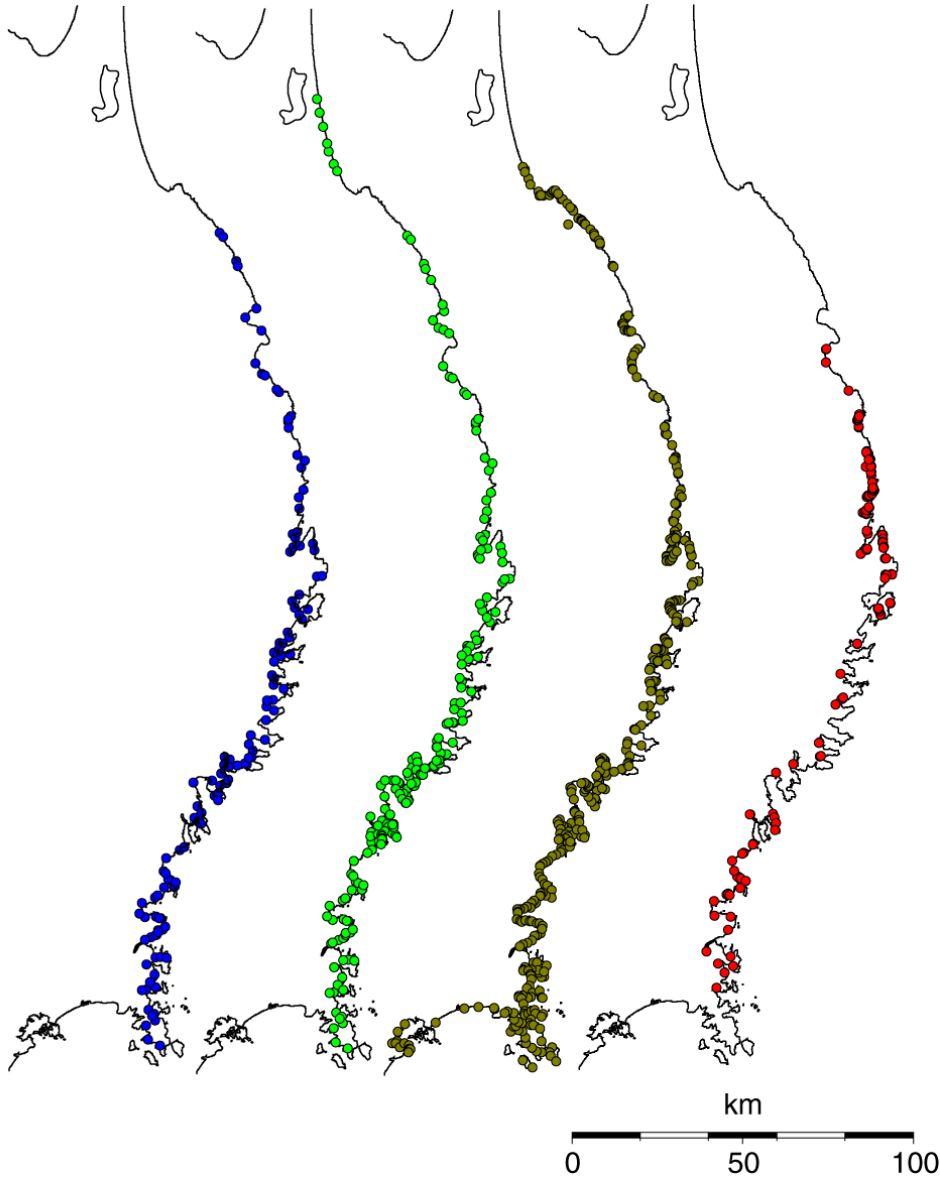
Seismologists assumed earthquake cycle (~35 years) from past records of two centuries and made forecast (99% in 30 years), but there seems to be a supercycle (~700 years) on top of it.

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Past tsunamis

1896 1933 1960 2011

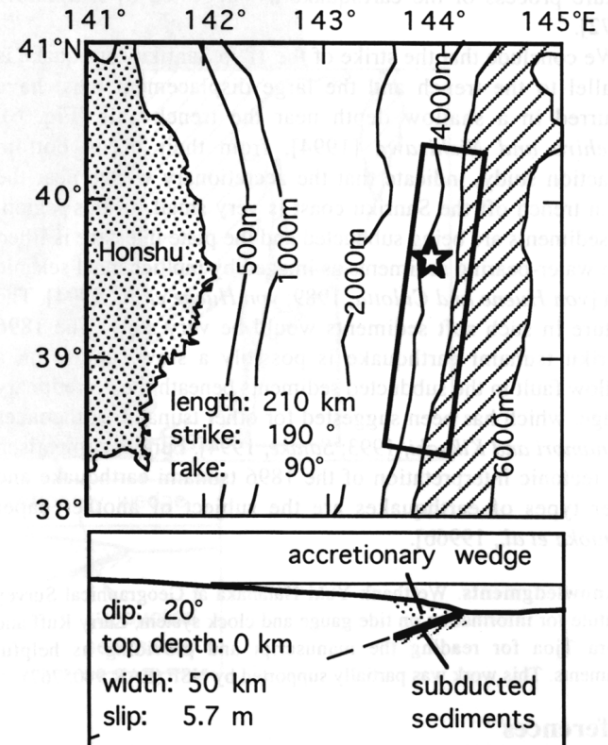


1896 Sanriku tsunami

1896 Meiji tsunami: 22,000 casualties (more than 2011 tsunami)



M 7.2, Max tsunami height 38 m
Weak shaking but large tsunami
“Tsunami earthquake”



Width: 50 km, slip: 6m
Near trench axis

The 869 Jogan earthquake

Nihon Sandai Jitsuroku (Chronicle of Japan)

A large earthquake in Mutsu

Panic stricken by violent tremblings

Fallen houses, wide-opened ground fissures

Roaring like thunder heard from the sea

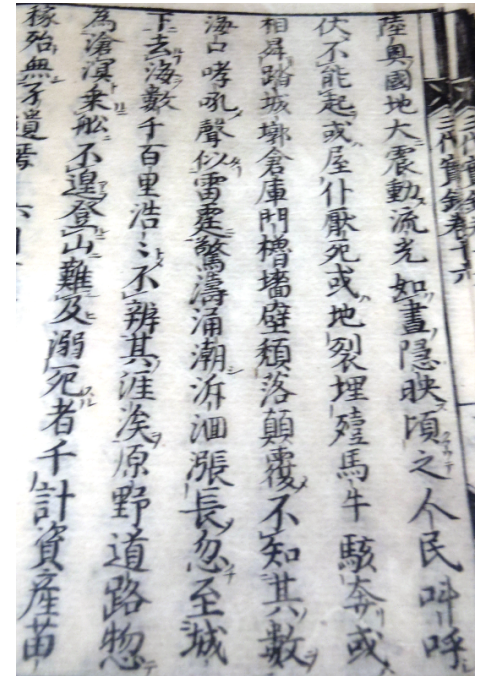
Sea rushed into castle, a few hundred miles

About 1,000 people were killed

Tsunami deposit studies

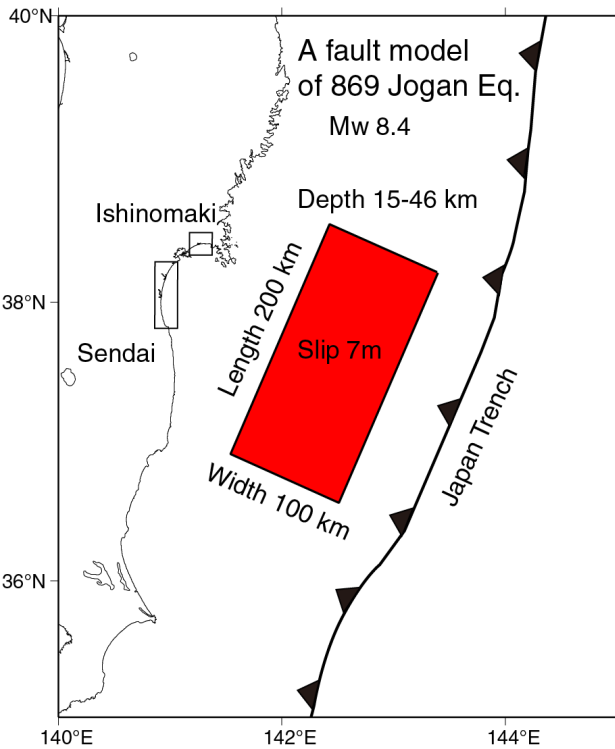
Sand layer brought by tsunami
below volcanic ash (AD915)

distributed ~ 5 km
from the coast



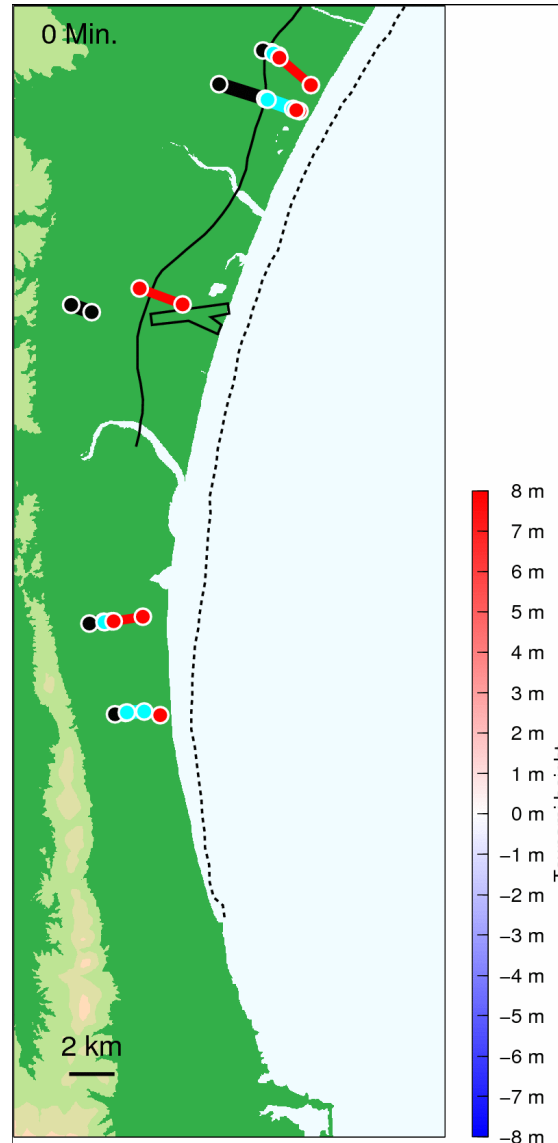
The 869 Jogan earthquake

A fault model proposed in 2008



- The 869 deposits
- Possible 869 deposits
- No deposits

869 Simulation



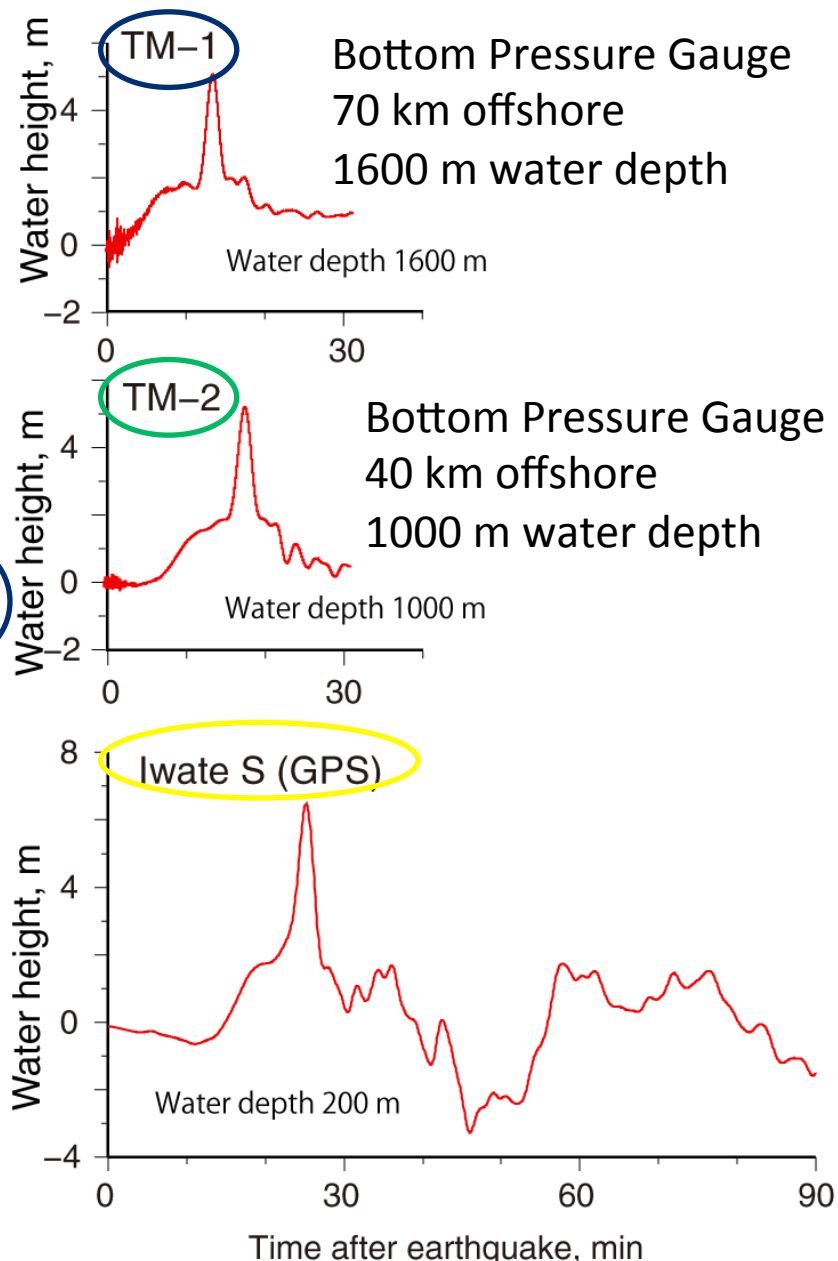
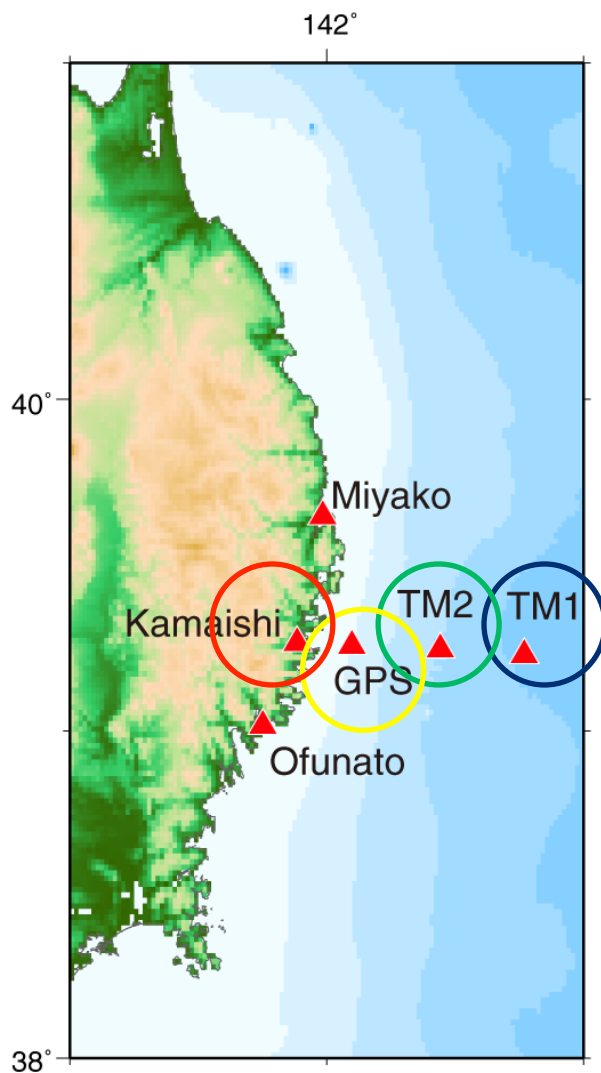
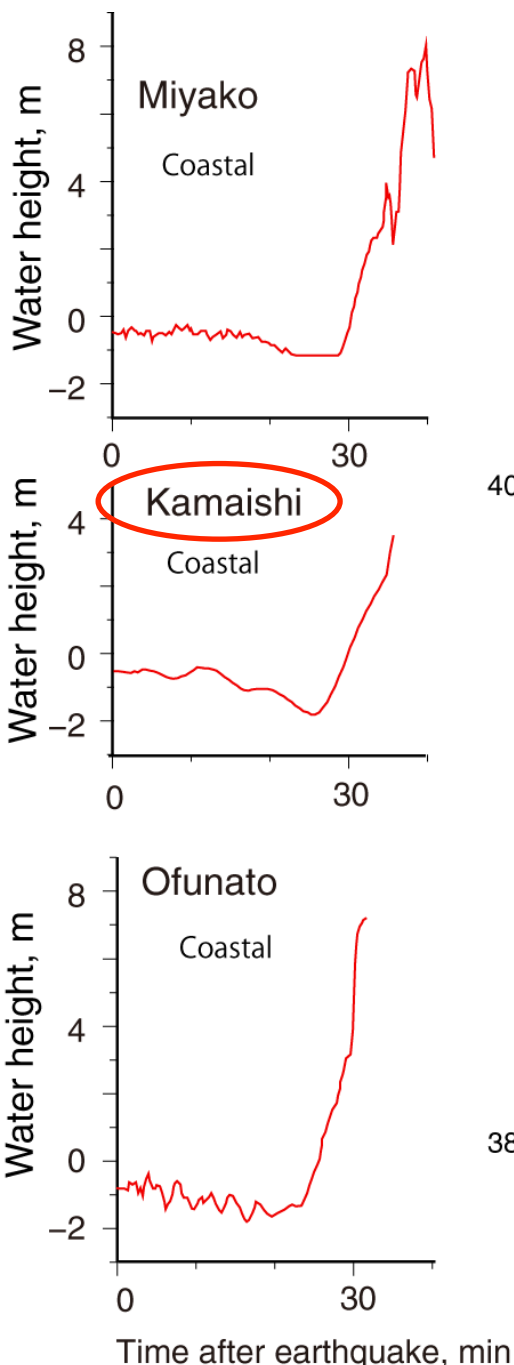
2011 inundation



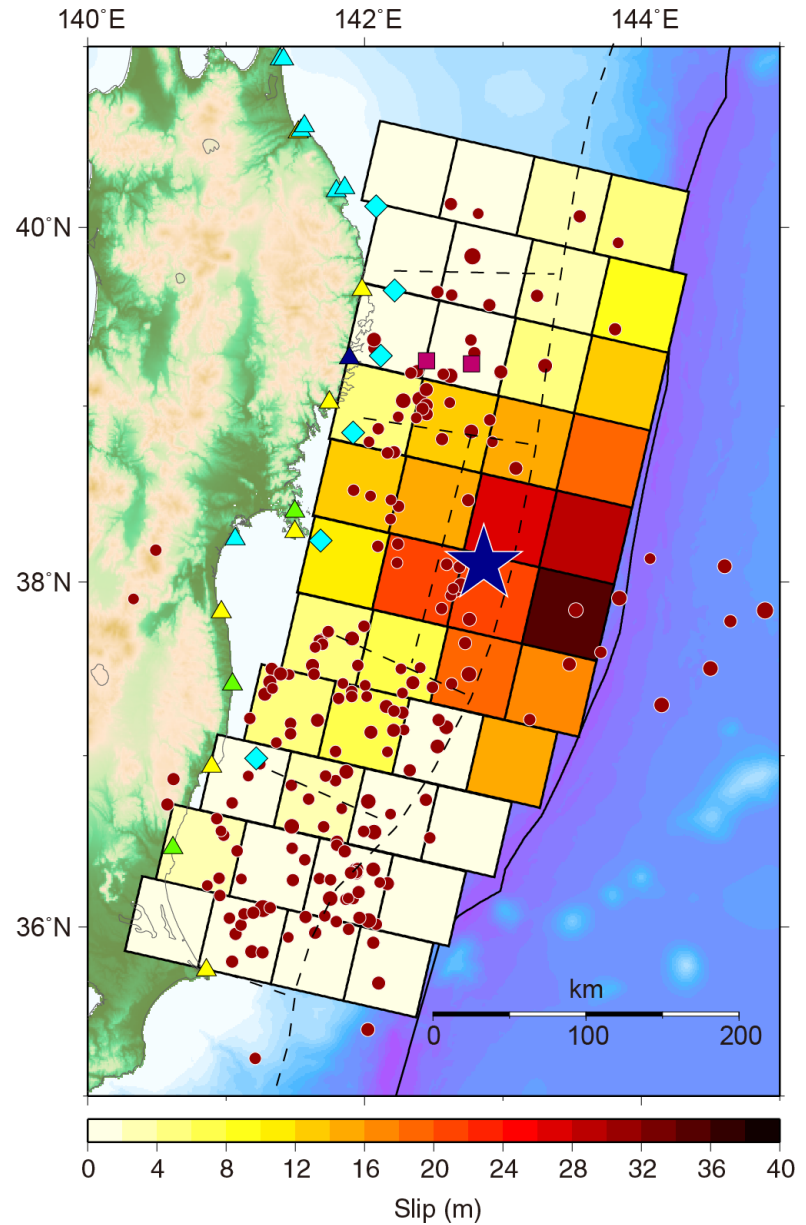
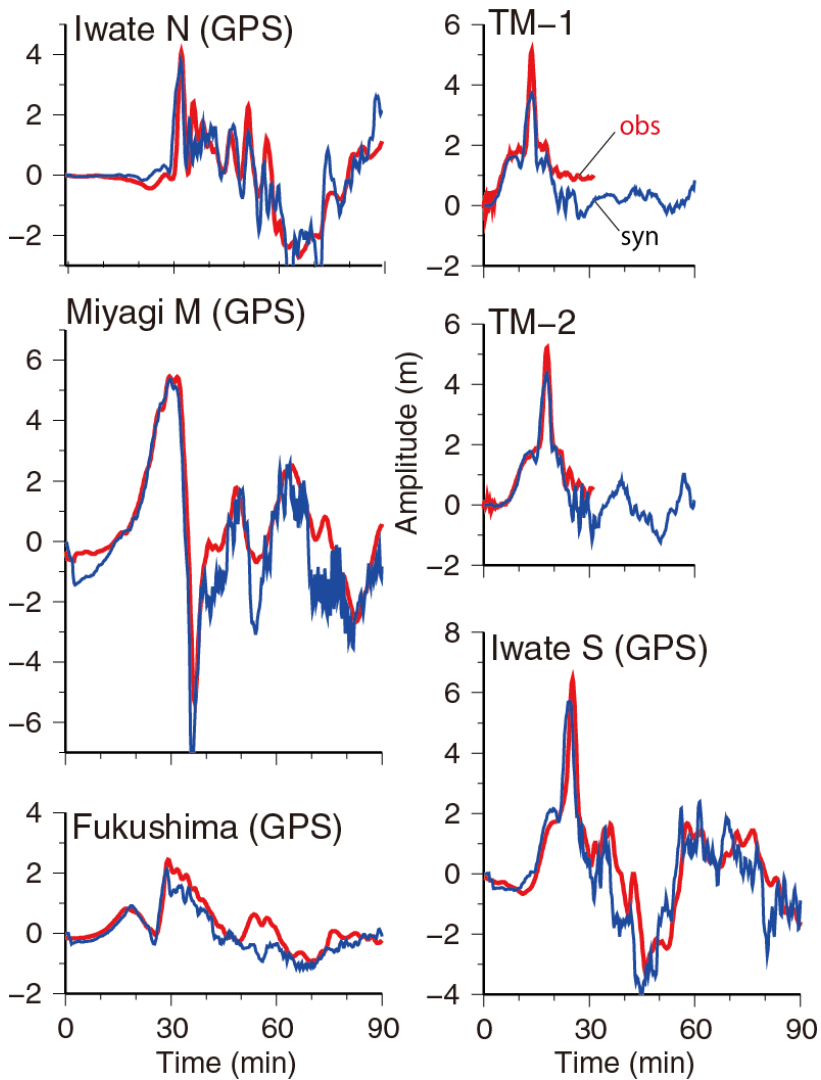
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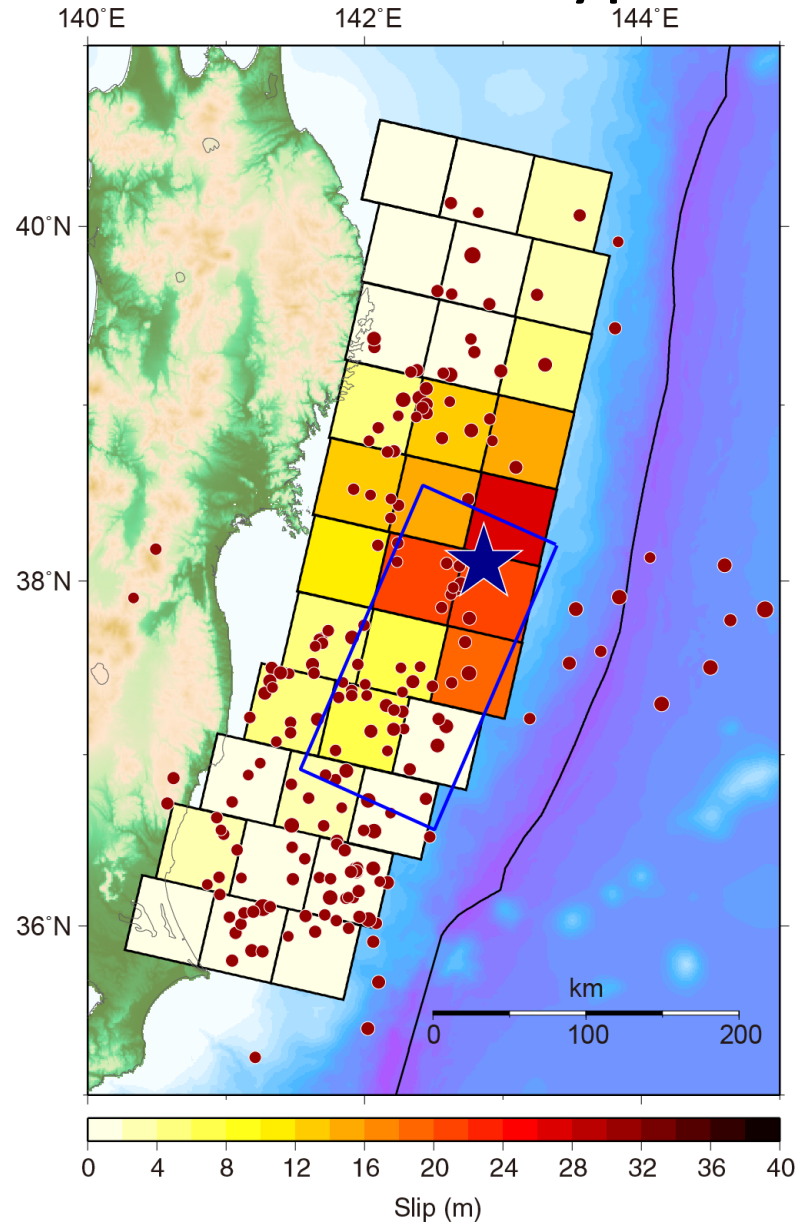
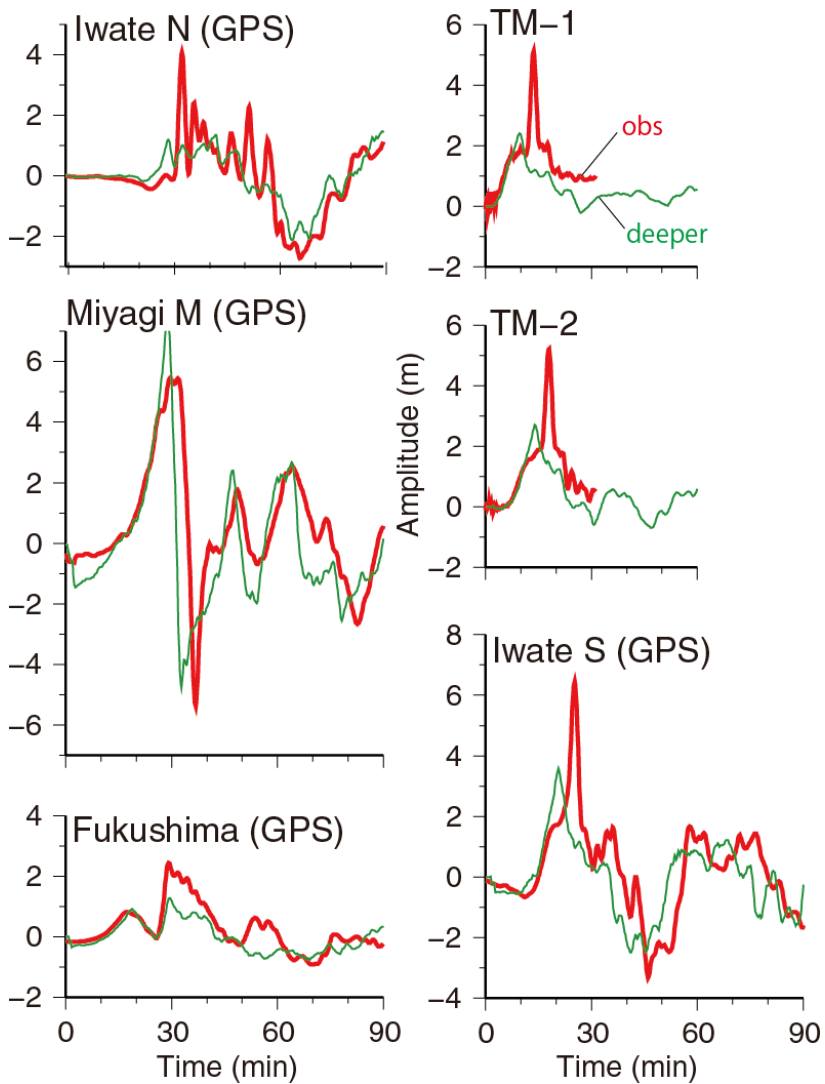
Tsunami observation



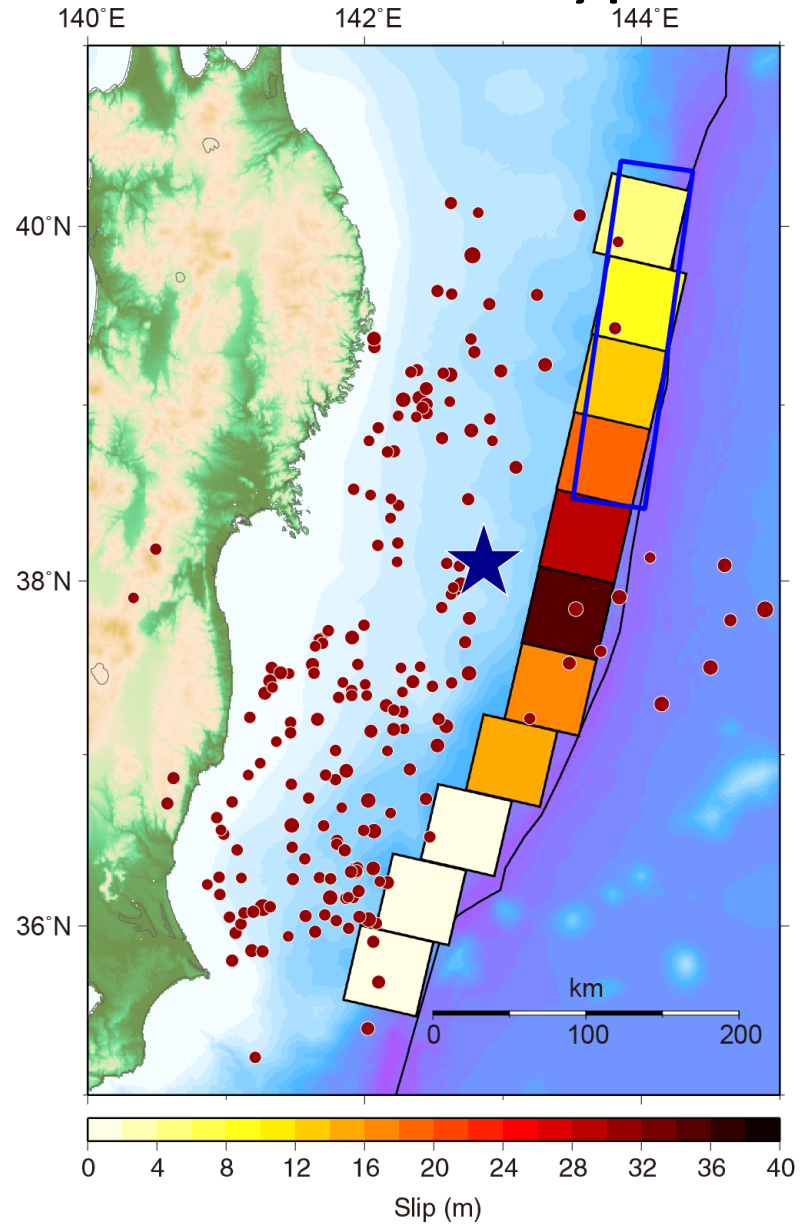
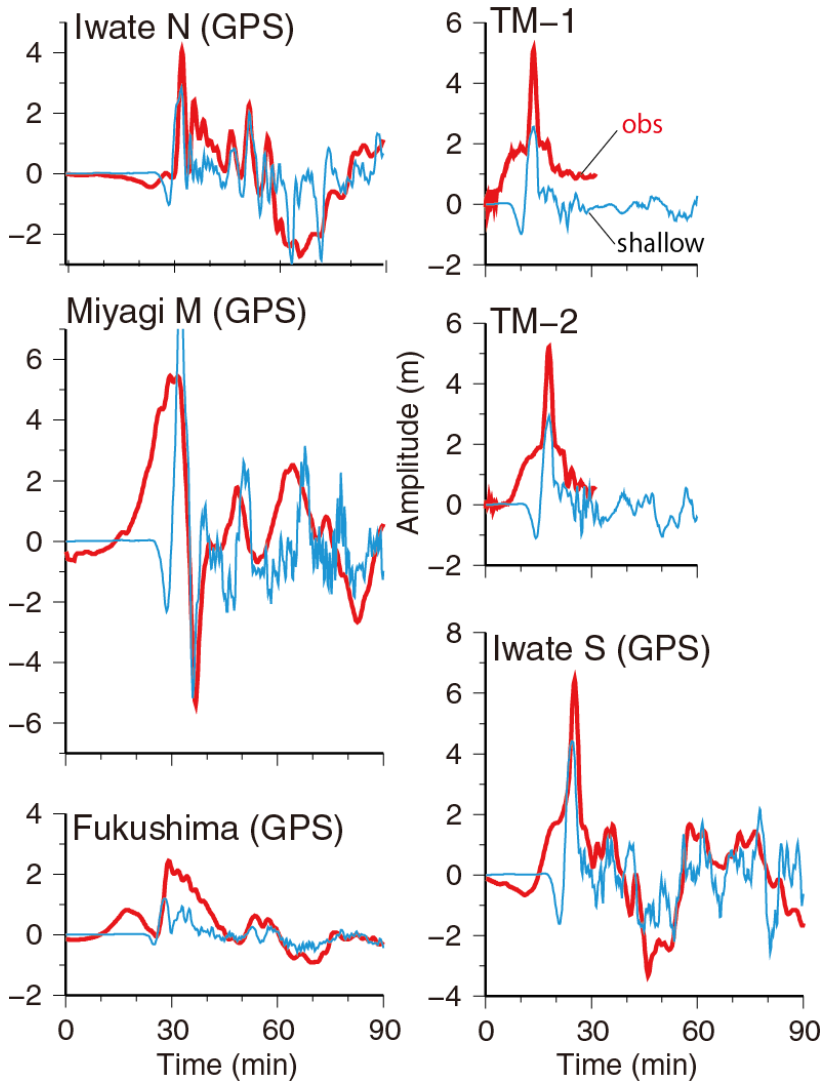
Slip distribution from tsunami waveforms



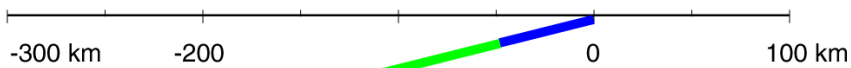
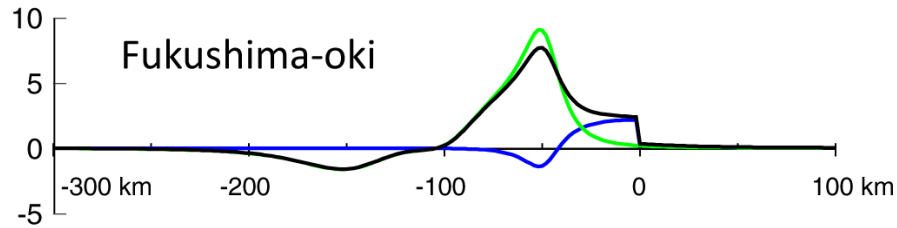
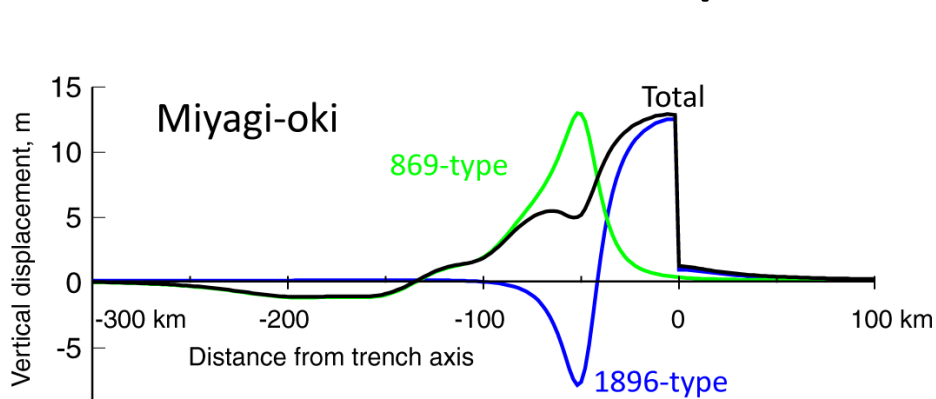
2011 earthquake: 1896 and 869 types



2011 earthquake: 1896 and 869 types

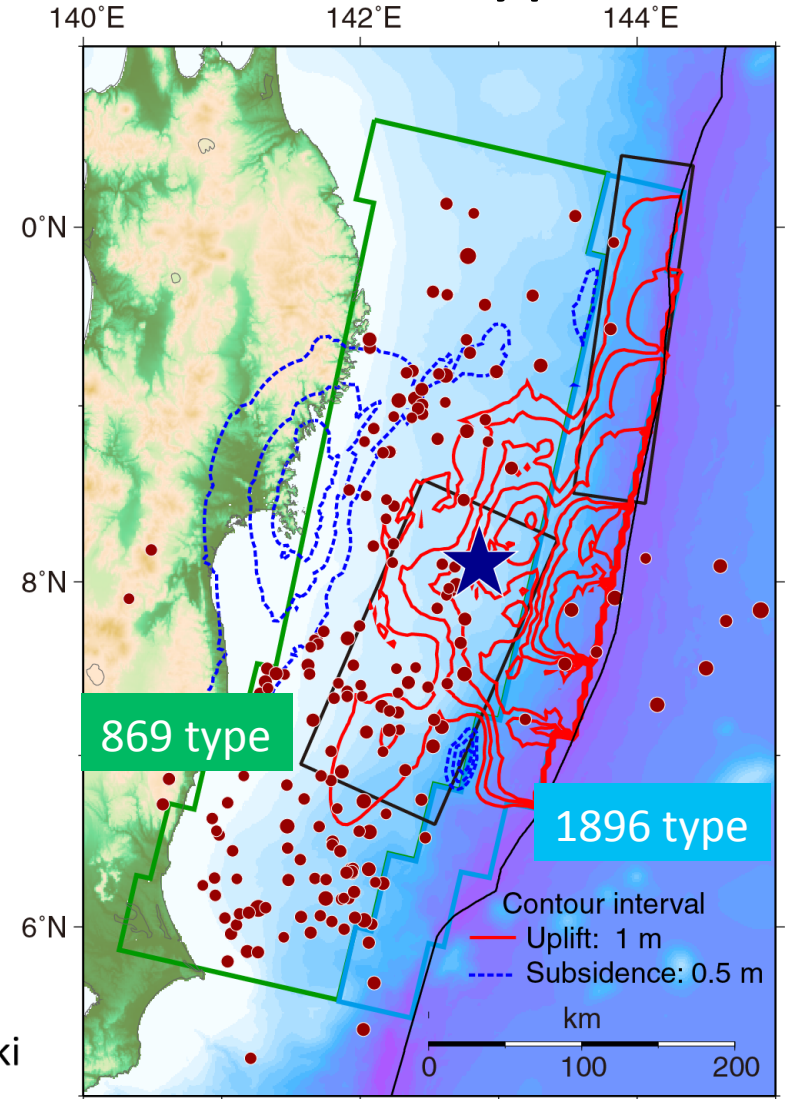


2011 earthquake: 1896 and 869 types



869 Jogan-type
15-20 m slip Miyagi-oki
<10 m slip Fukushima-oki

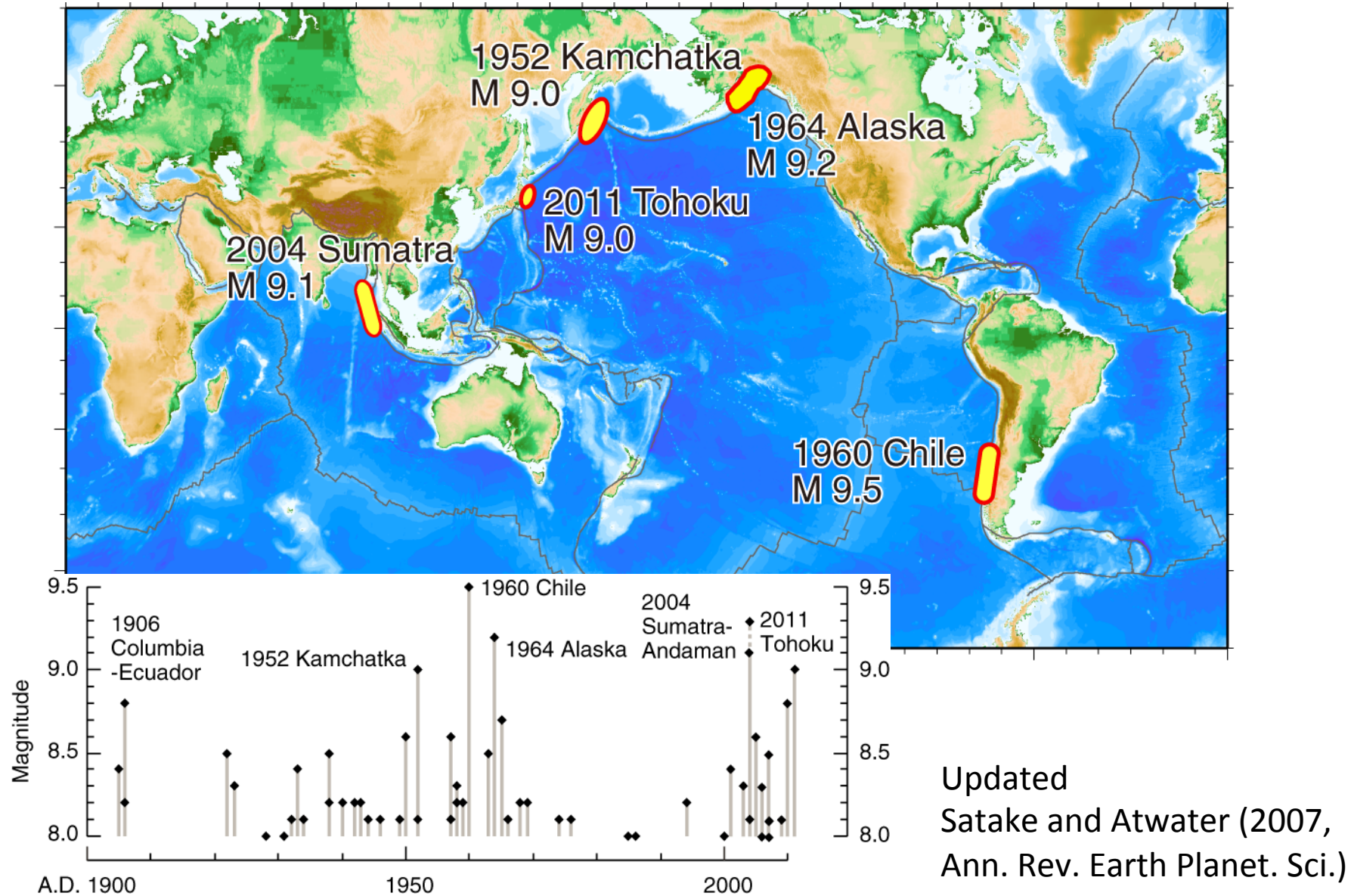
1896 Sanriku-type
>40m slip off Miyagi-oki



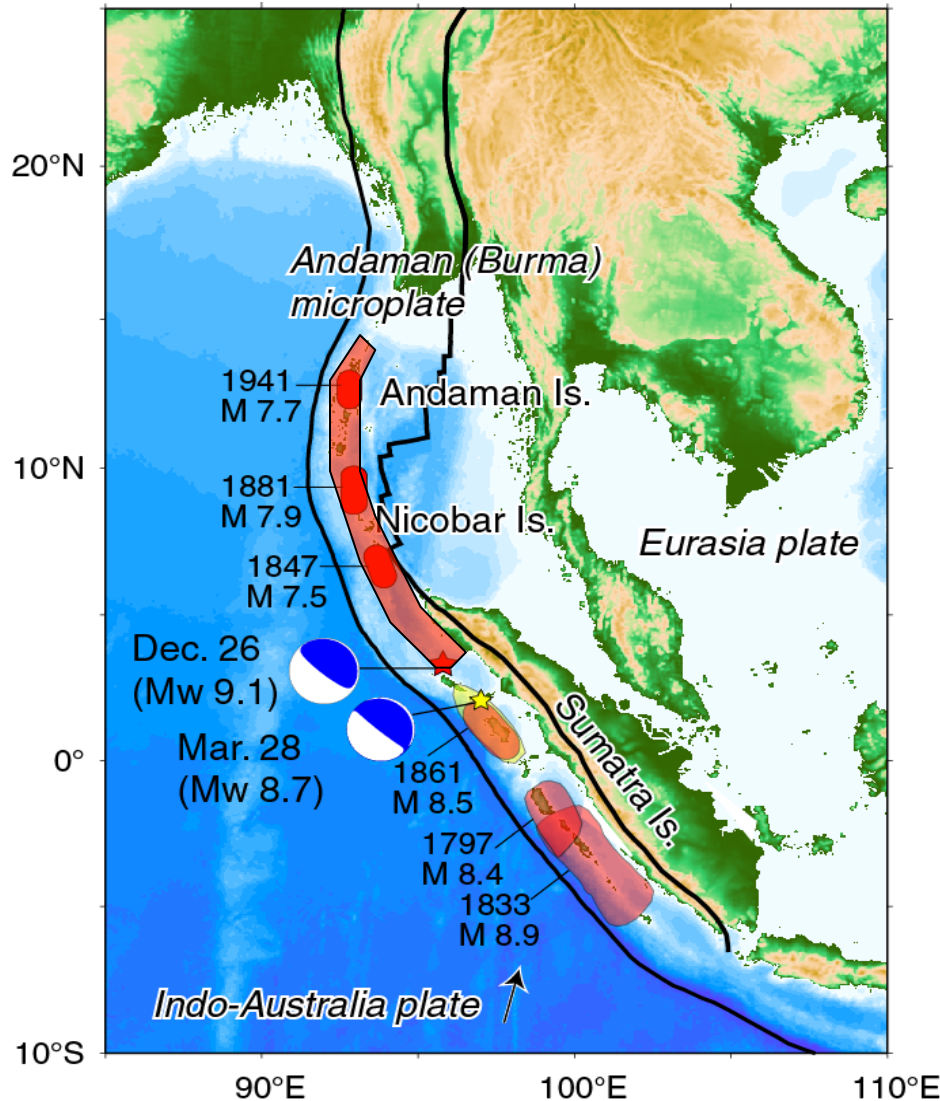
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Only five M9 earthquakes since 20th century



2004 Sumatra-Andaman earthquake



Andaman-Nicobar Is.

1941 M 7.7

1881 M 7.9

1847 M 7.5

(from historical records)

2004 M 9.1

2005 M 8.7

Sumatra

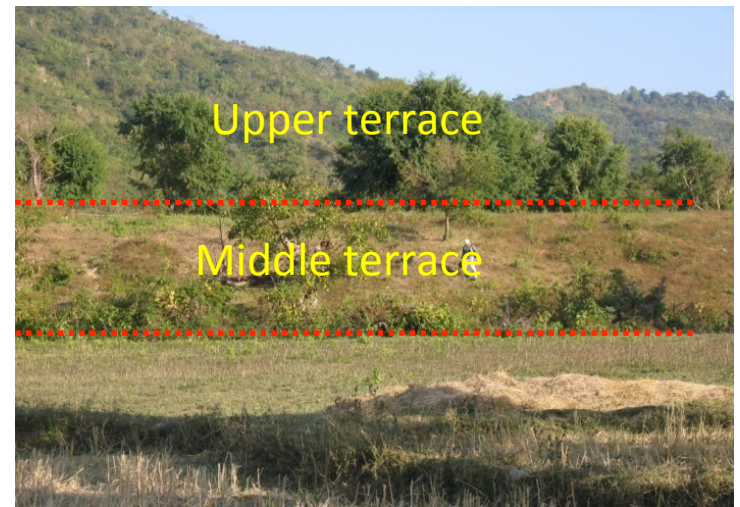
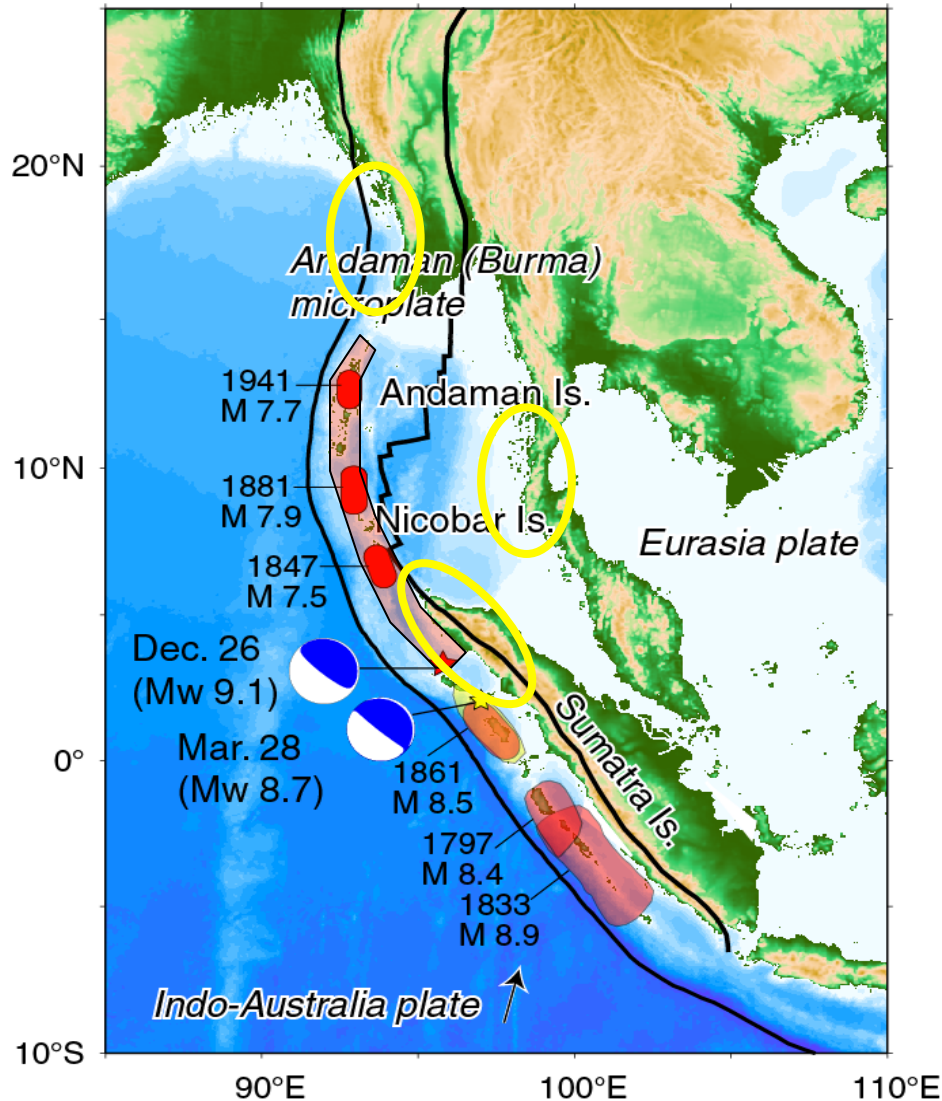
1861 M 8.5

1797 M 8.4

1833 M 8.9

(from coral studies)

Paleoseismological Studies since 2004

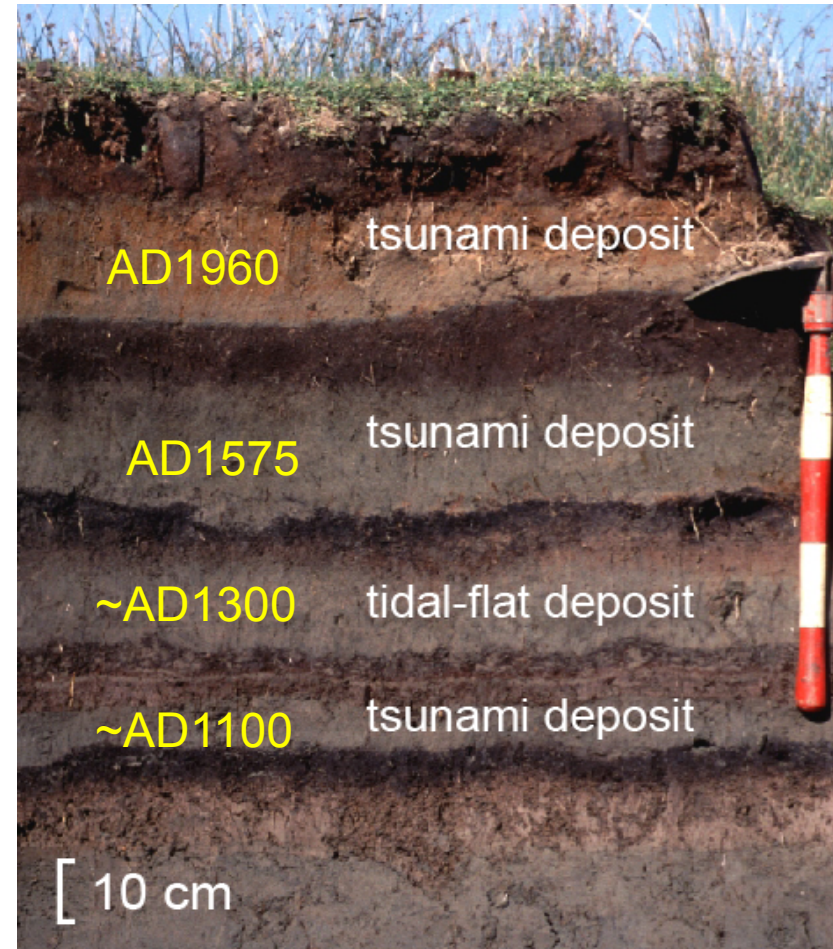
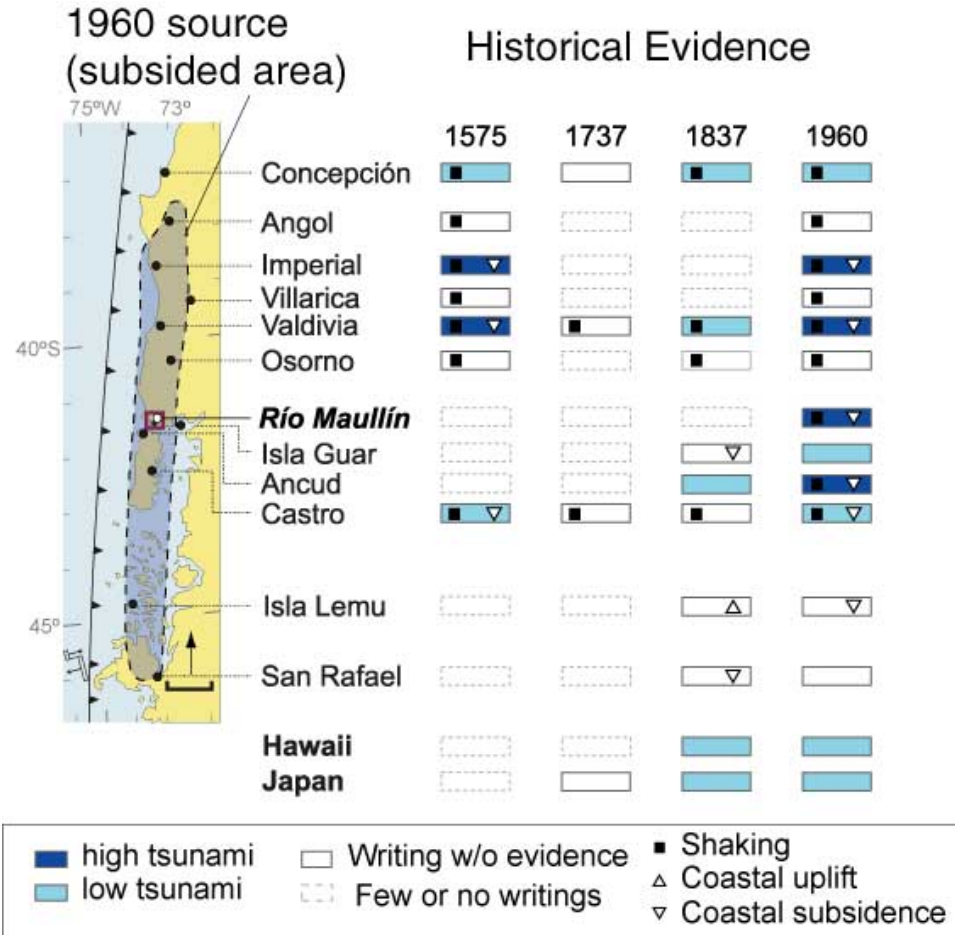


Aung *et al.* (2008 *J. Earthq. Tsunami*)



Jankaew *et al.* (2008 *Nature*)

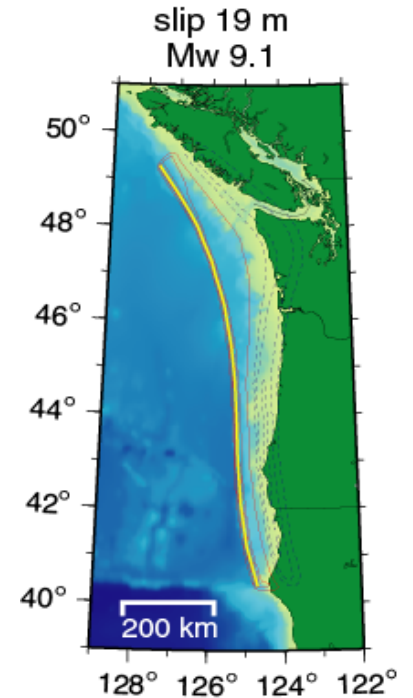
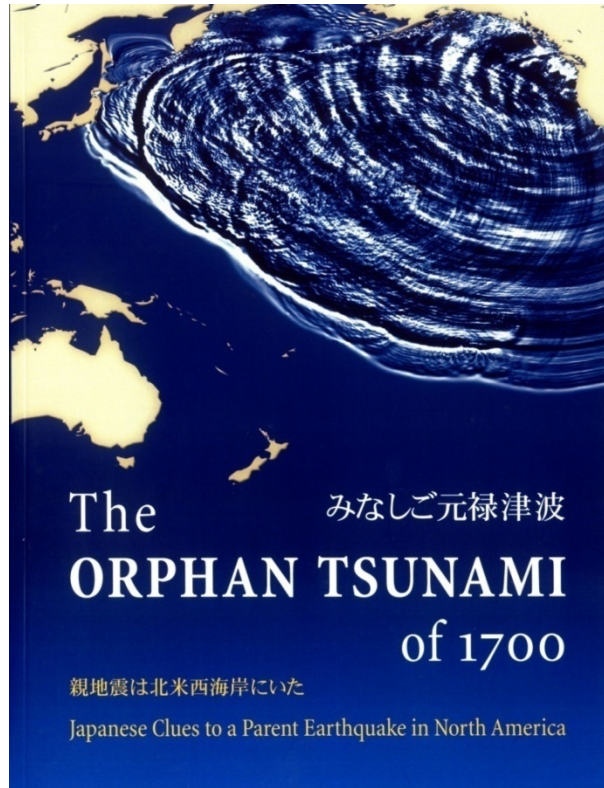
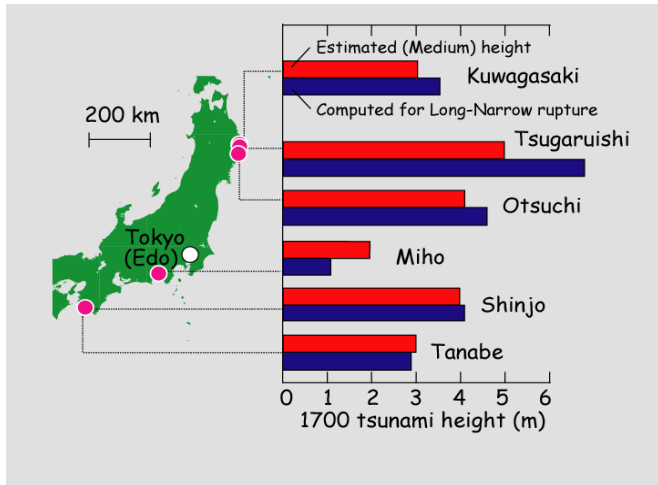
South-Central Chile



Giant ($M \sim 9.5$) earthquakes ~ 300 yr interval
 NOT ~ 130 yr as inferred from historic data

Cisternas et al. (2005 Nature)

Tsunami recorded in Japan in 1700

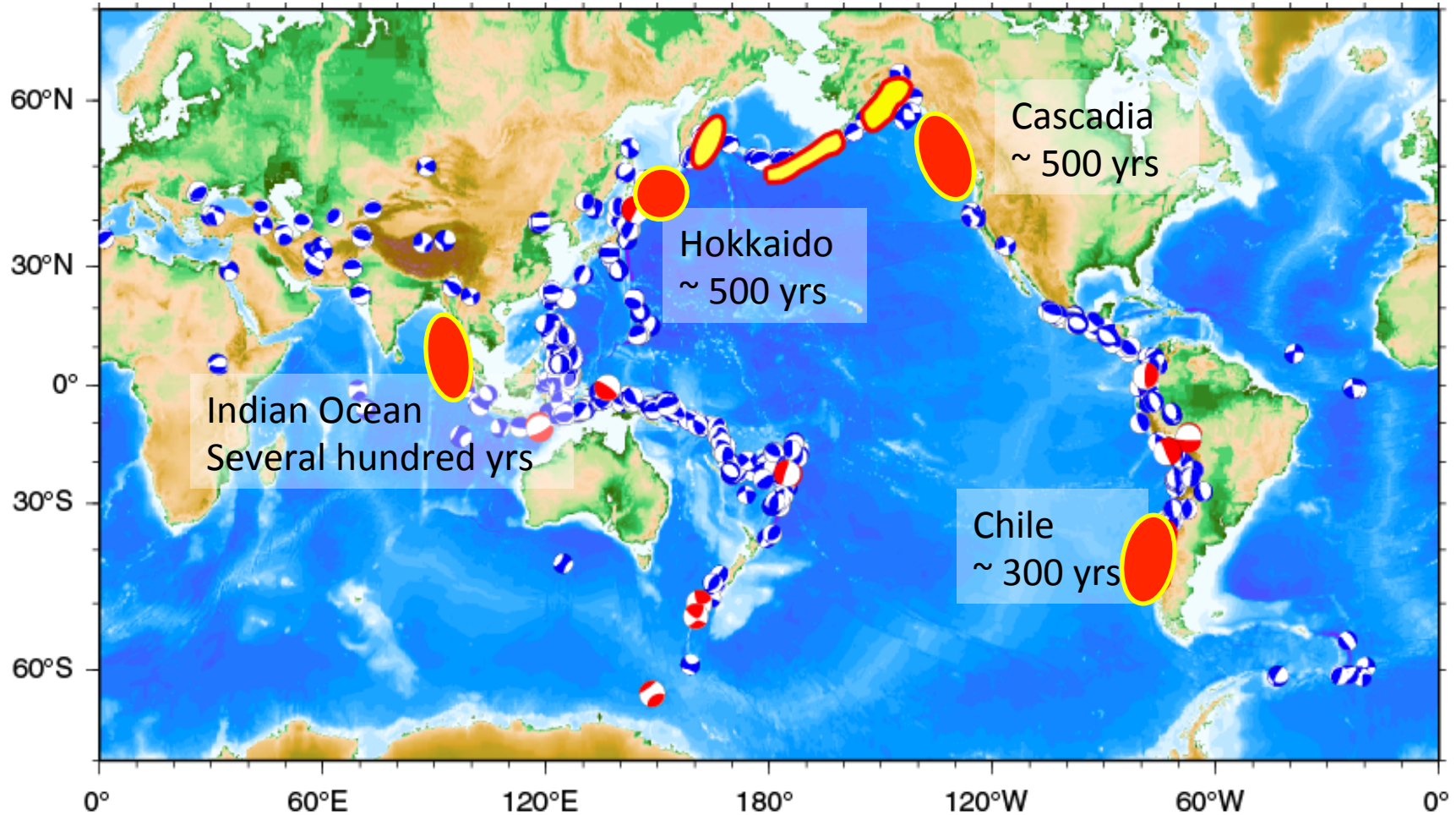


一回八百之秋時分満ちてあるも
強き新名所公儀御座りて
潮下全是れ新名所満ちて
地者化破亡とて此處之源を指
す

Fault length: 1,100 km, slip: 14 m,
 M_0 4.6×10^{22} Nm (Mw 9.0)
 similar to the 2004 Sumatra-Andaman earthquake
 Average recurrence interval: ~500 years

Satake, Wang, Atwater (2003, JGR)

Interval of Giant ($M \sim 9$) Earthquakes



Conclusions

1. 2011 Tohoku earthquake was the largest ($M \sim 9$) in Japan's history
2. Long-term forecast estimated 99 % probability but $M \sim 8$ in Miygai-oki
3. Tsunami warning was issued in 3 minutes but the heights were initially underestimated
4. The Tohoku coasts experienced similar tsunamis in the past
5. The 2011 tsunami was a combination of the 1896 and 869 type tsunamis
6. Giant earthquakes ($M \sim 9$) occur once in several centuries in the world's subduction zones