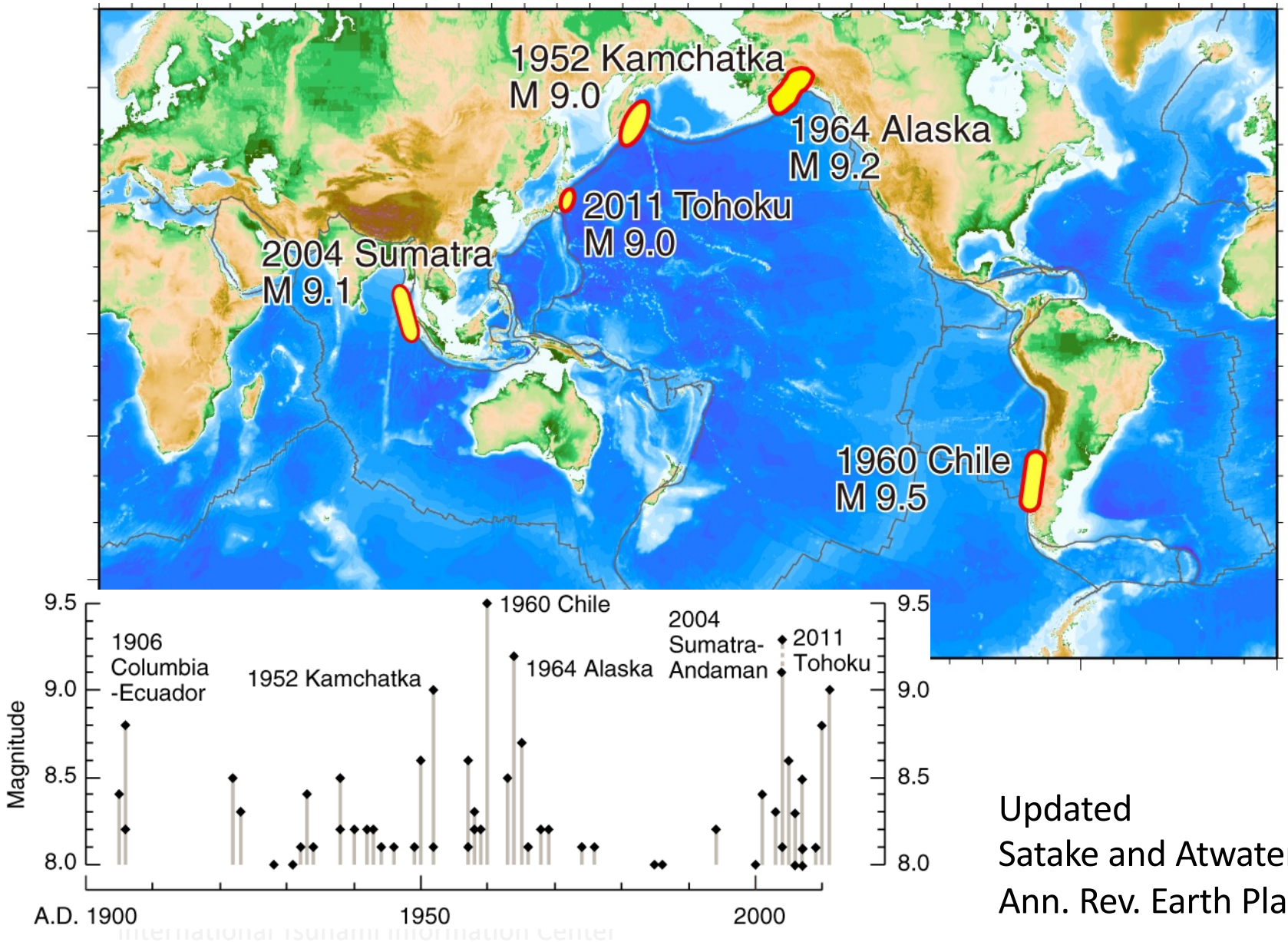
UNESCO/IOC – NOAA ITIC Training Program in Hawaii (ITP-TEWS Chile)
TSUNAMI EARLY WARNING SYSTEMS
AND THE PACIFIC TSUNAMI WARNING CENTER (PTWC) ENHANCED PRODUCTS
TSUNAMI EVACUATION PLANNING AND UNESCO IOC TSUNAMI READY PROGRAMME
19-30 August 2024, Valparaiso, Chile

Giant earthquakes and tsunamis

Kenji Satake
University of Tokyo

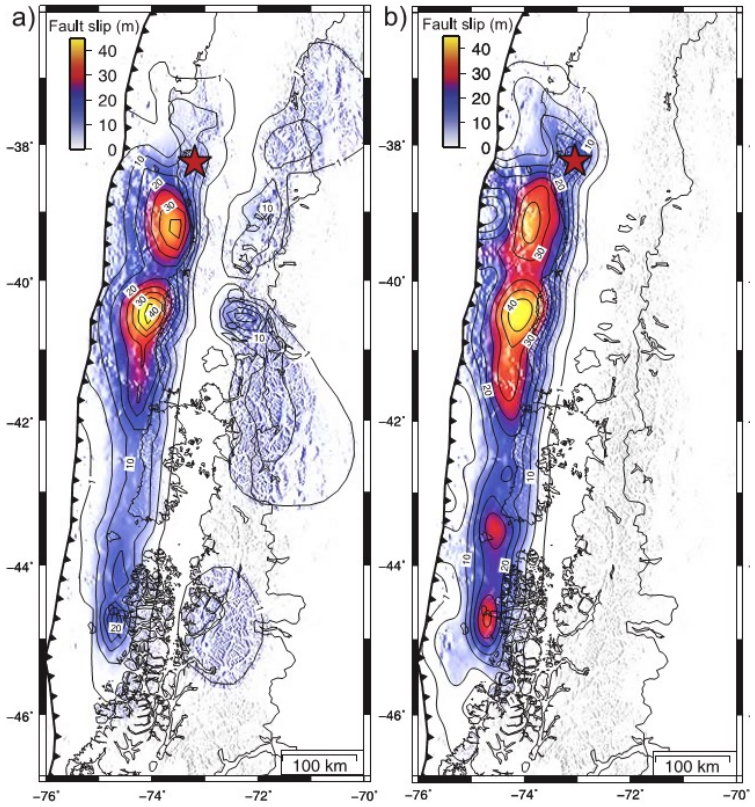
M9 earthquakes since 20th century



Updated
Satake and Atwater (2007, Ann. Rev. Earth Planet. Sci.)

1960 Chile earthquake

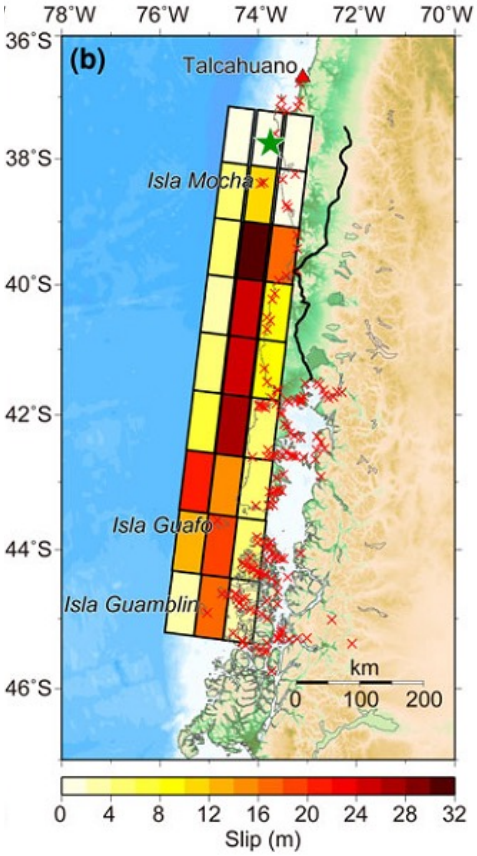
Barrientos and Ward (1990, GJI)
Moreno et al. (2009, GRL)



9.5×10^{22}Nm
$Mw \approx 9.3$

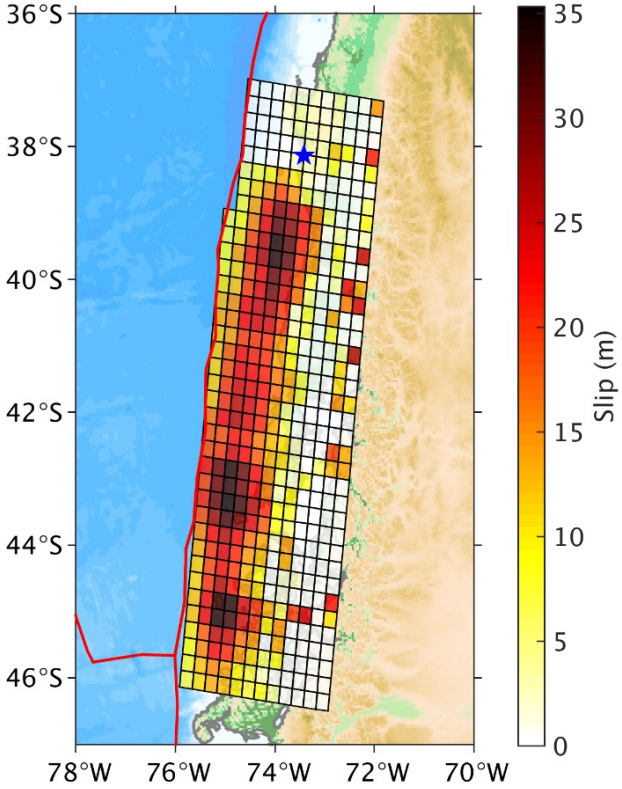
9.6×10^{22}Nm
$Mw \approx 9.3$

Fujii and Satake
(2013, Pageoph)



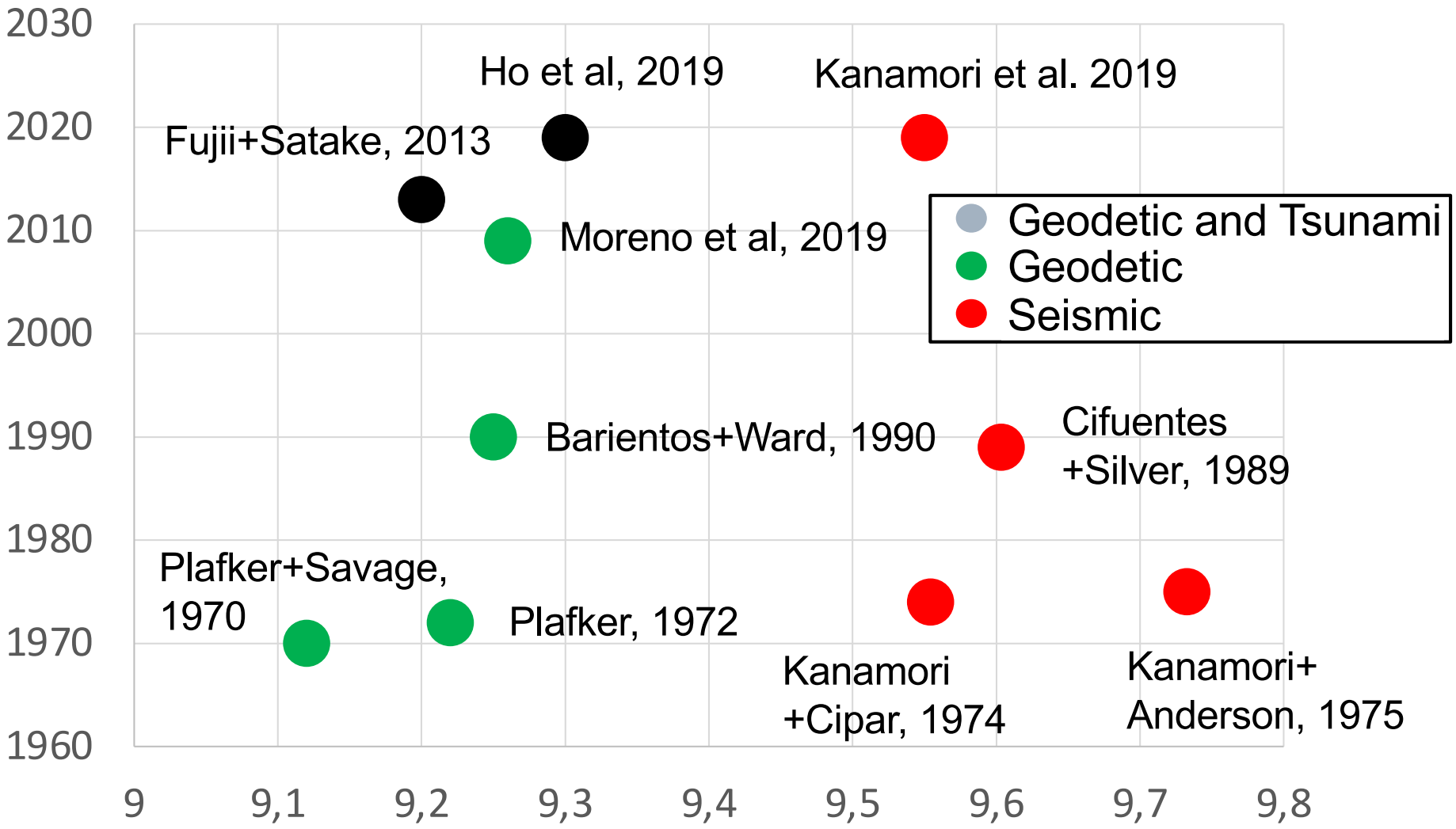
7.2×10^{22}Nm
$Mw \approx 9.2$

Ho et al.
(2019, JGR)



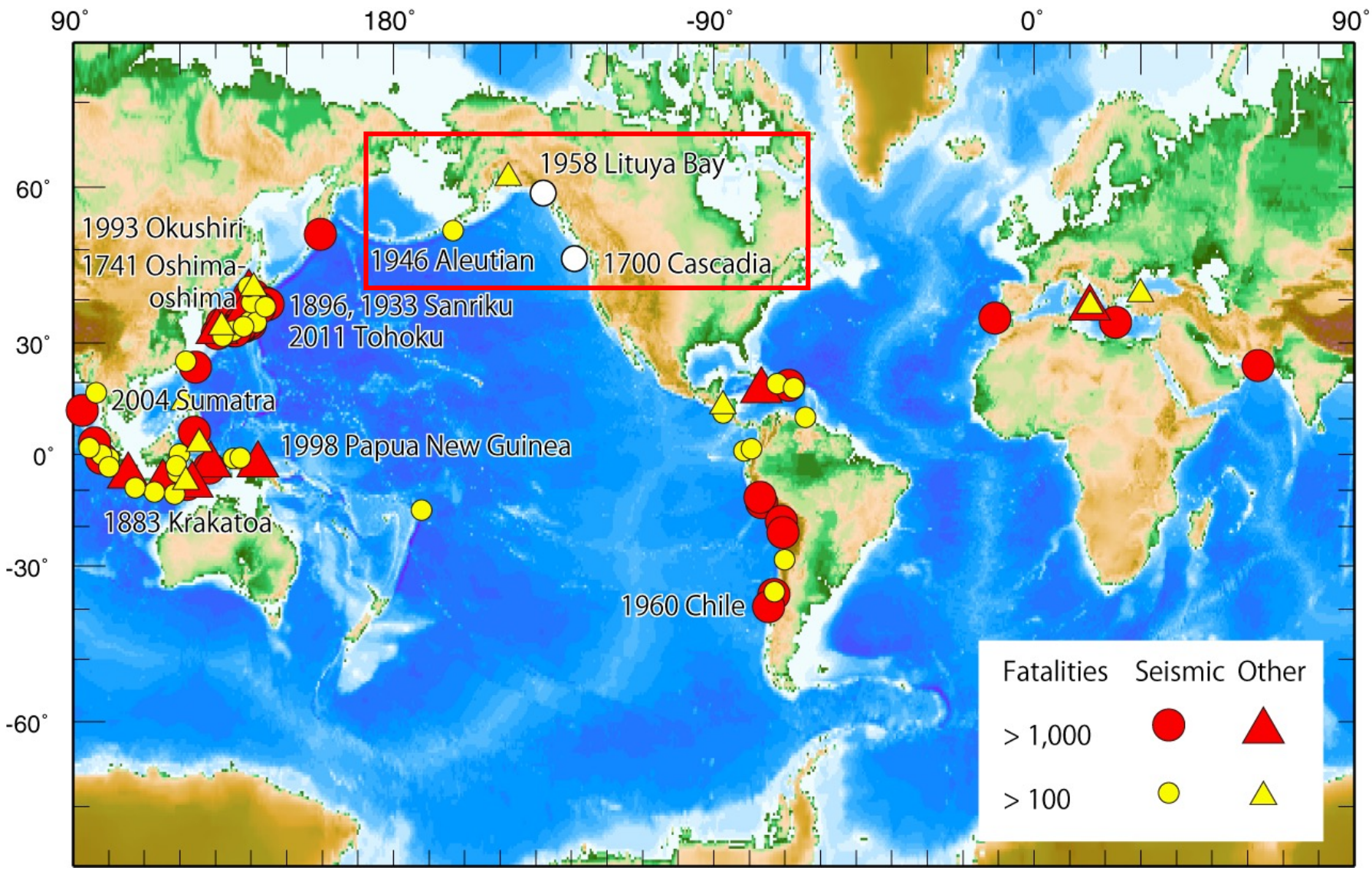
1.27×10^{23}Nm
$Mw \approx 9.3$

1960 Chile earthquake



Based on Kanamori et al. (2019, GJI)

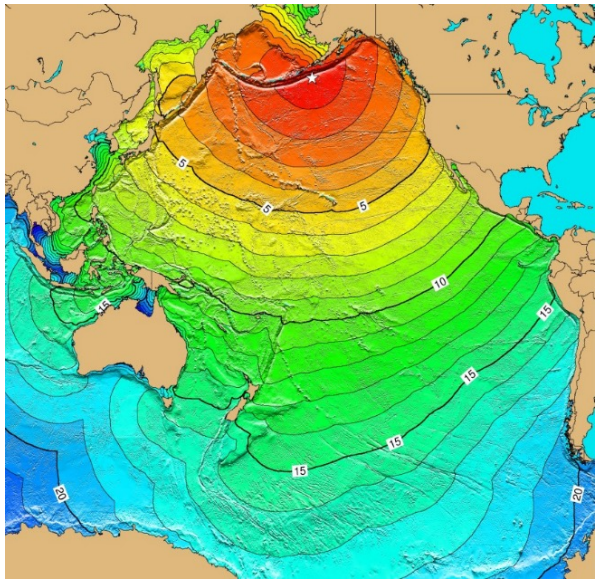
Tsunami Examples



NOAA/NGDC Tsunami Event Catalog

The 1946 Aleutian tsunami

Scotch Cap Lighthouse
Unimak Island



Pacific Tsunami Warning System

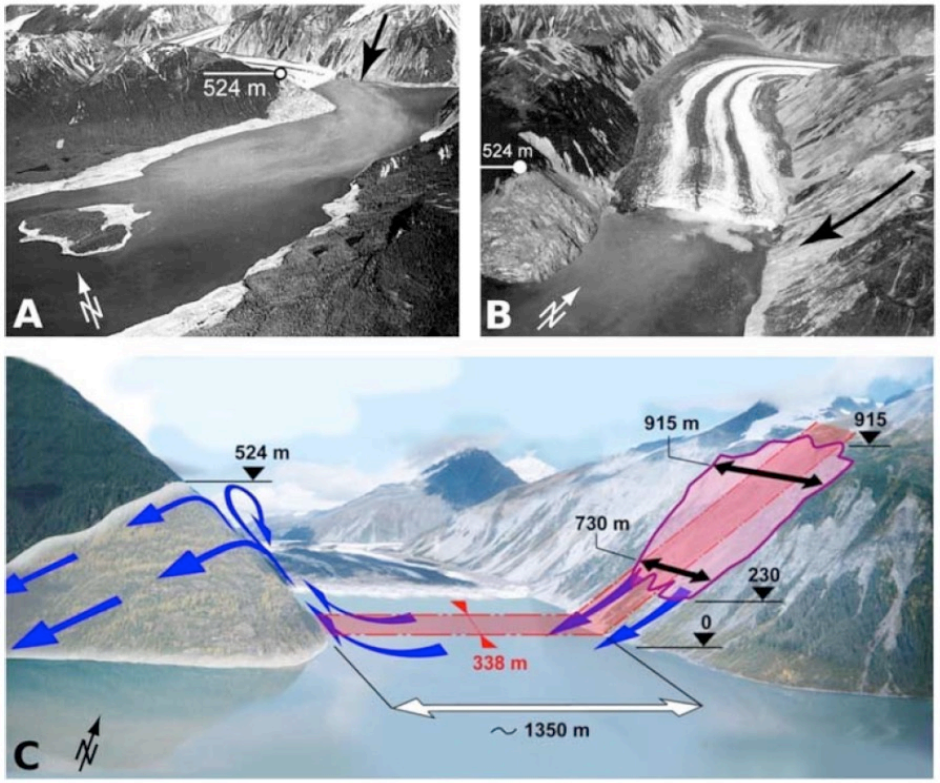
159 casualties in Hawaii, about 4,000 km from the source

Pier No.1 in Hilo, Hawaii

Lituya Bay, 1958

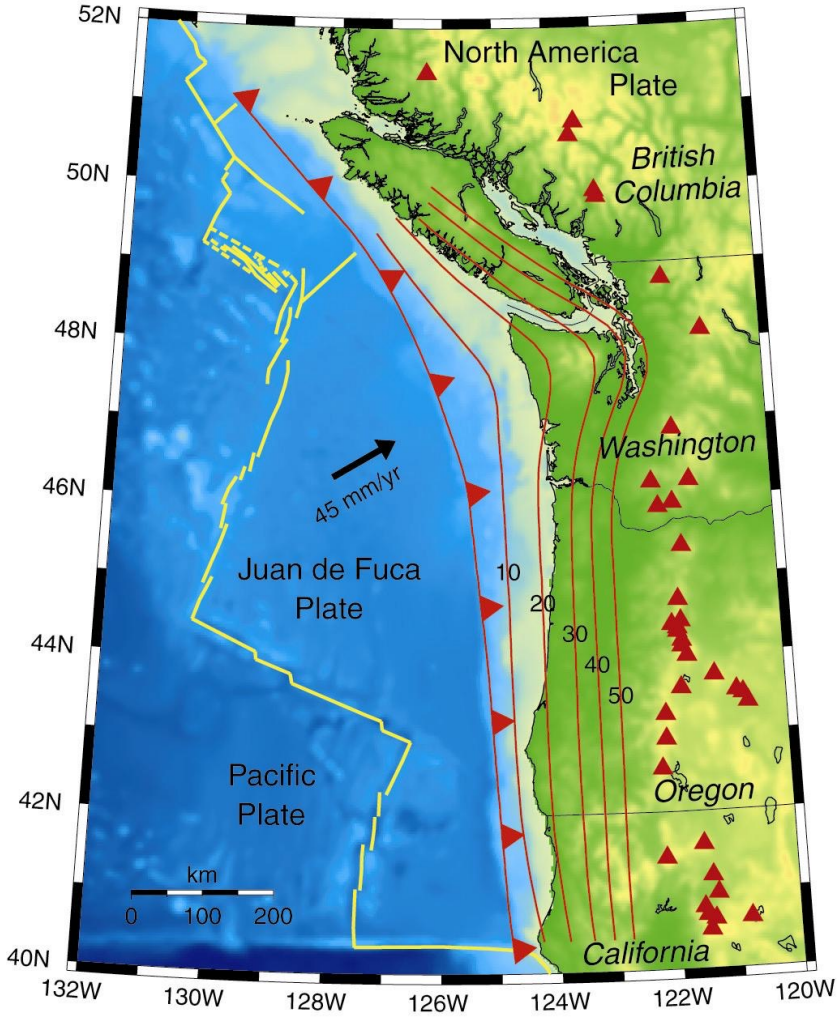
Water wave due to landslide
The largest water runup 524 m altitude

Waves limited in the bay



Weis et al. (2009, GRL)

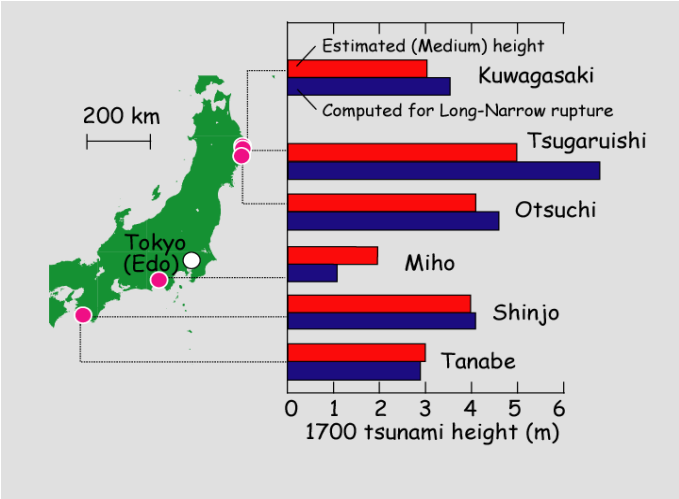
Cascadia Subduction Zone

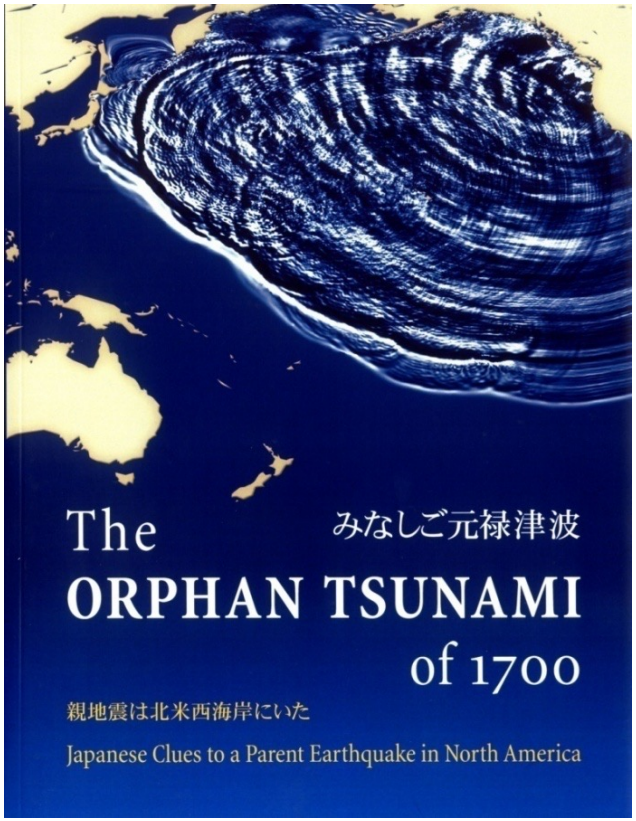


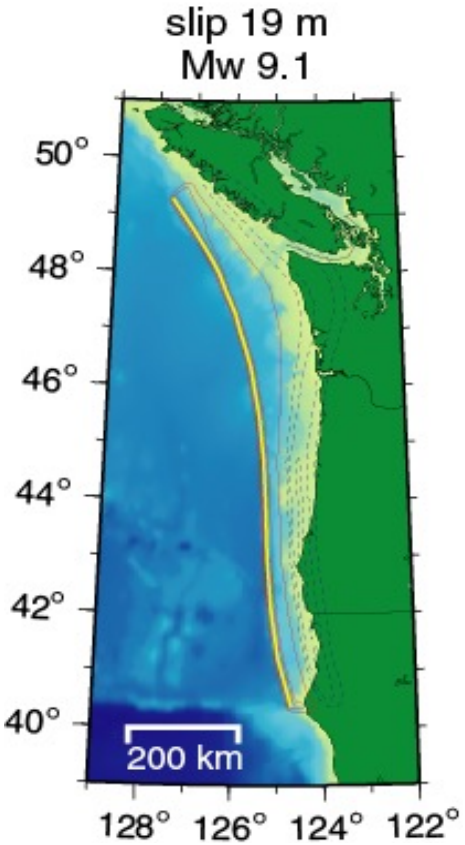
Coastal paleoseismology 1990's

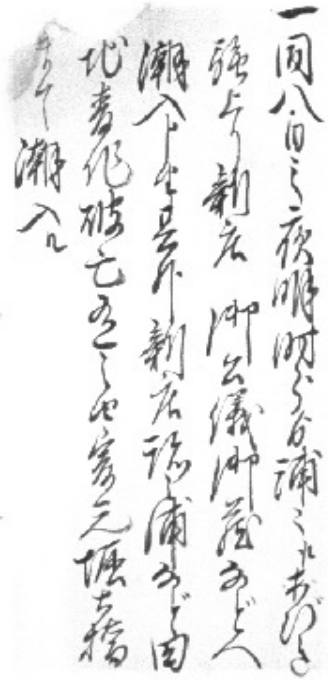
Photo by Brian Atwater

Tsunami recorded in Japan in 1700





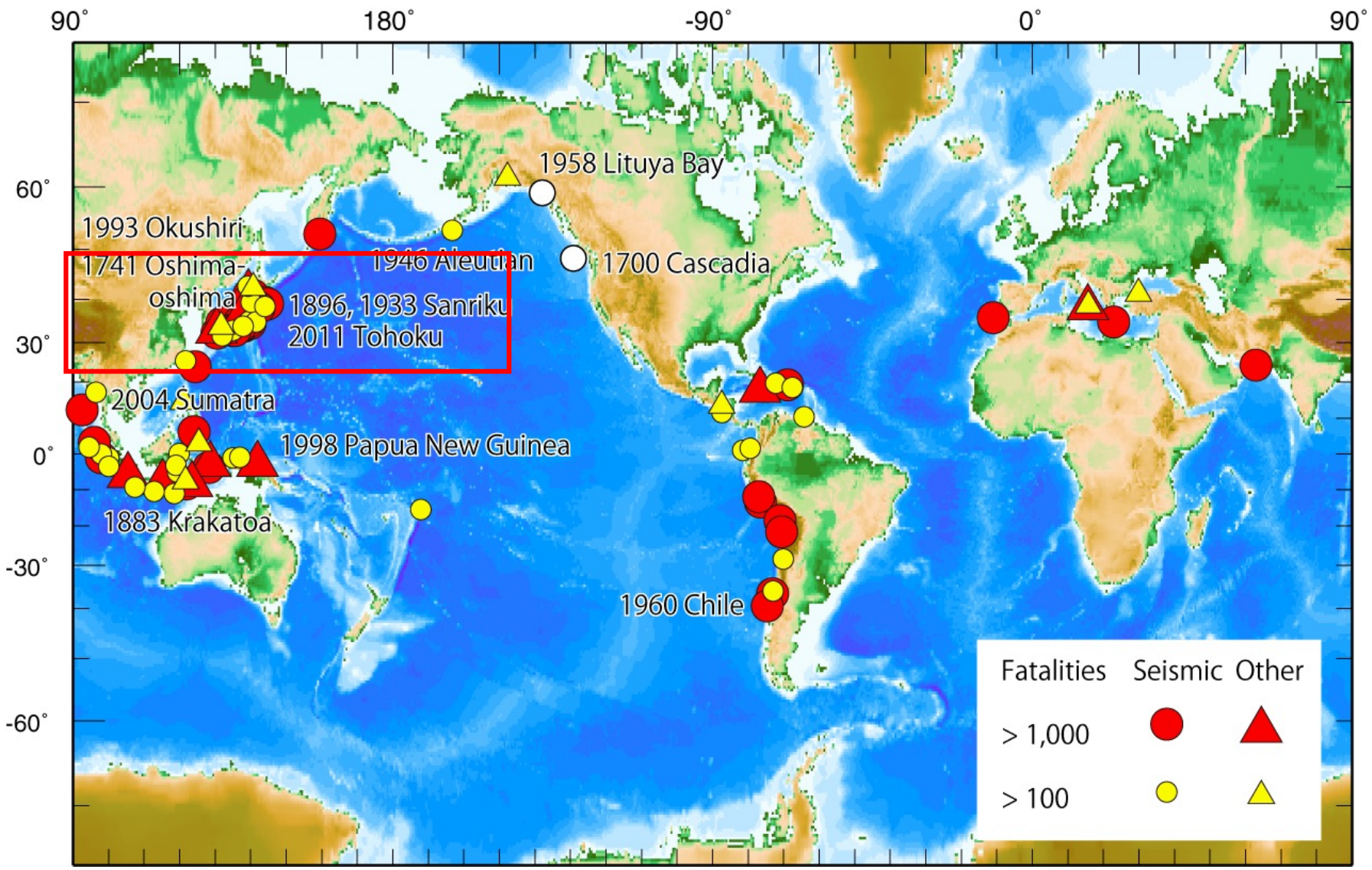




Fault length: 1,100 km, slip: 14 m,
Mo 4.6 x 10^{22} Nm (Mw 9.0)
similar to the 2004 Sumatra-Andaman earthquake
Average recurrence interval: ~500 years

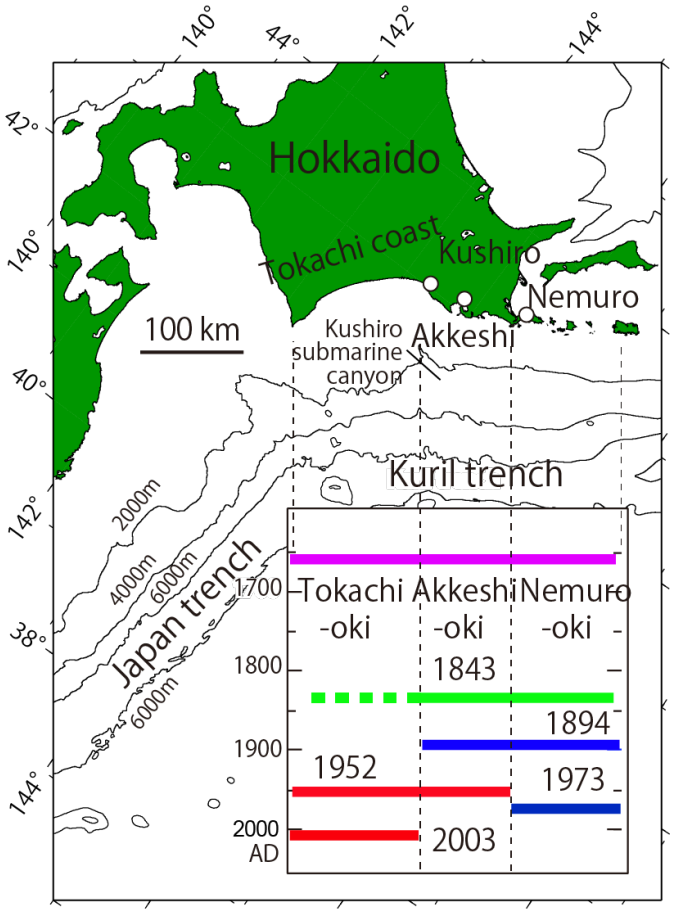
Satake, Wang, Atwater (2003, JGR)

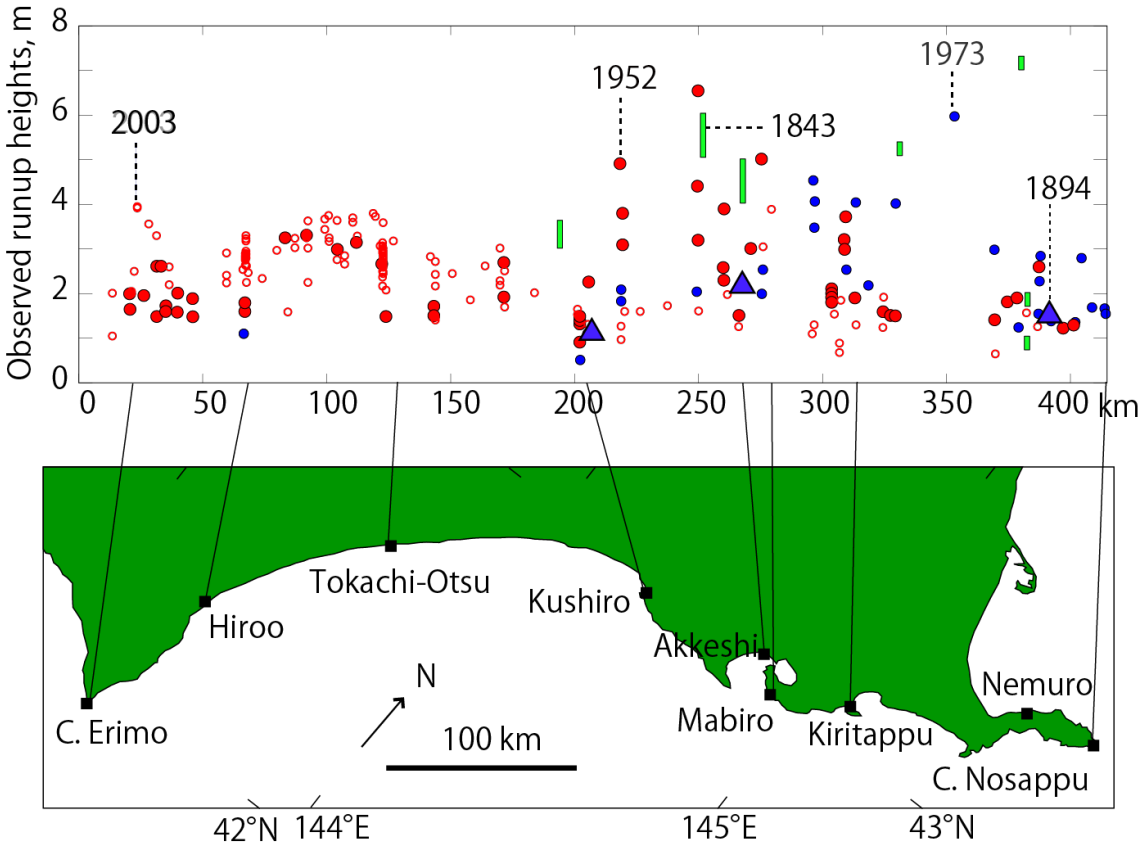
Tsunami Examples



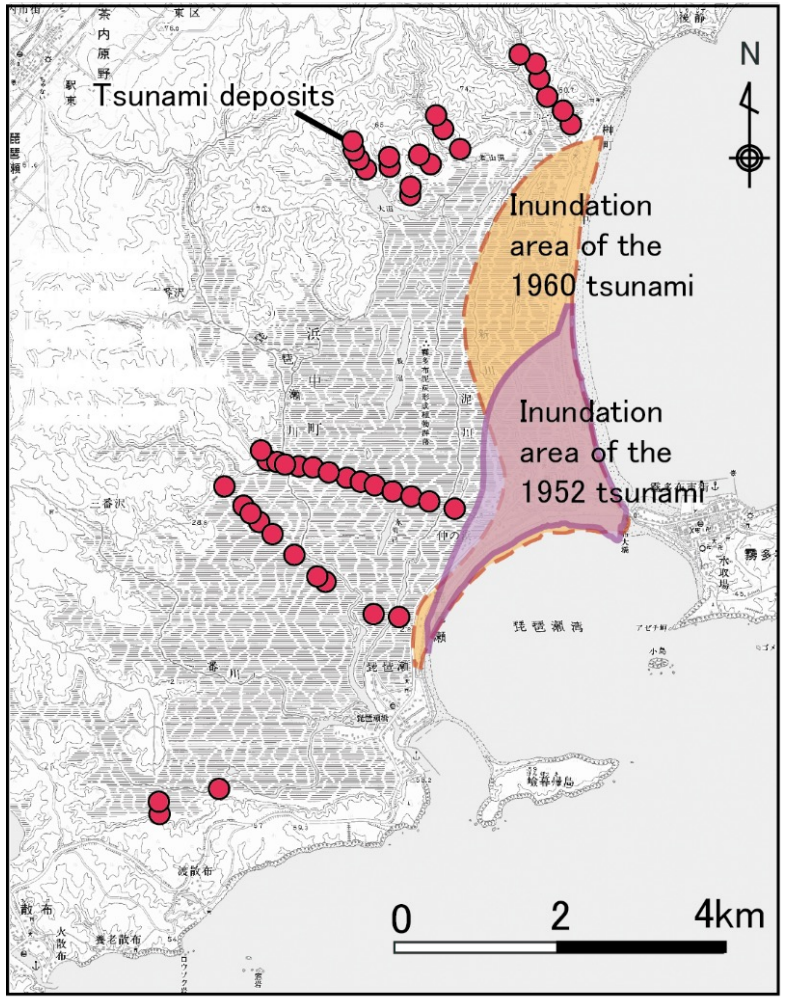
NOAA/NGDC Tsunami Event Catalog

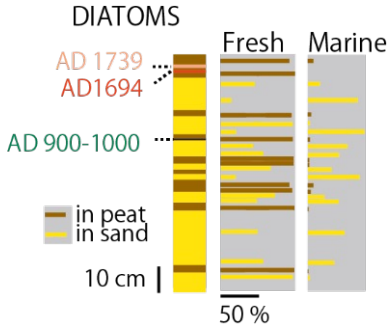
Historical earthquakes along Kuril trench

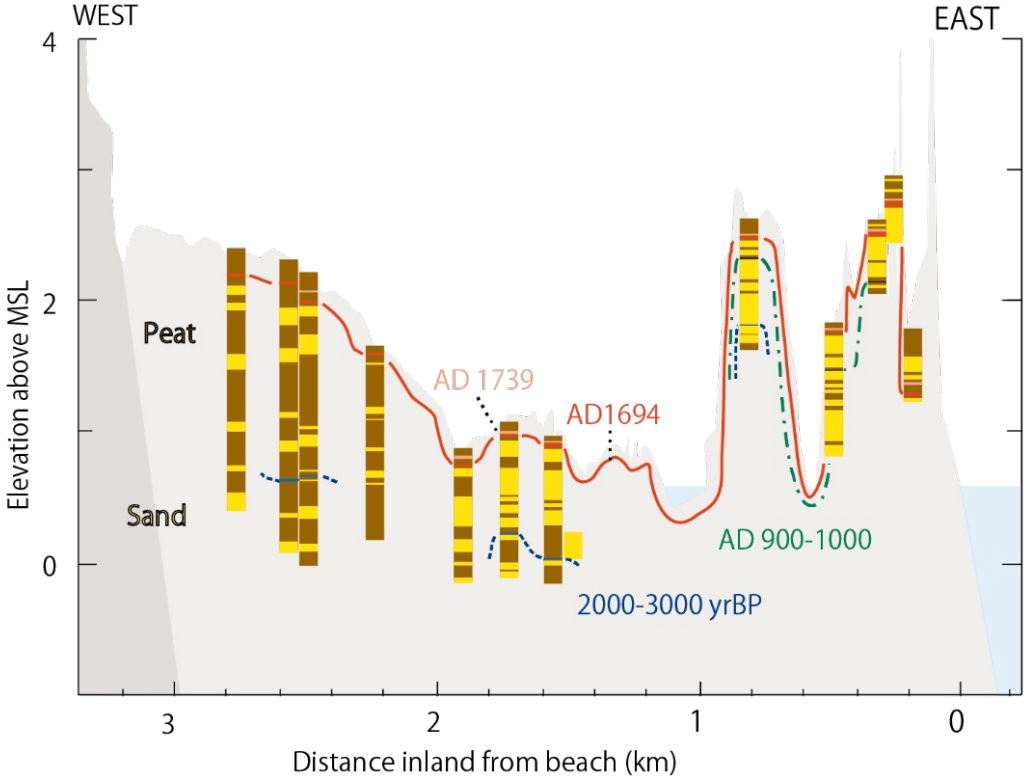




Tsunami deposits in Kiritappu marsh





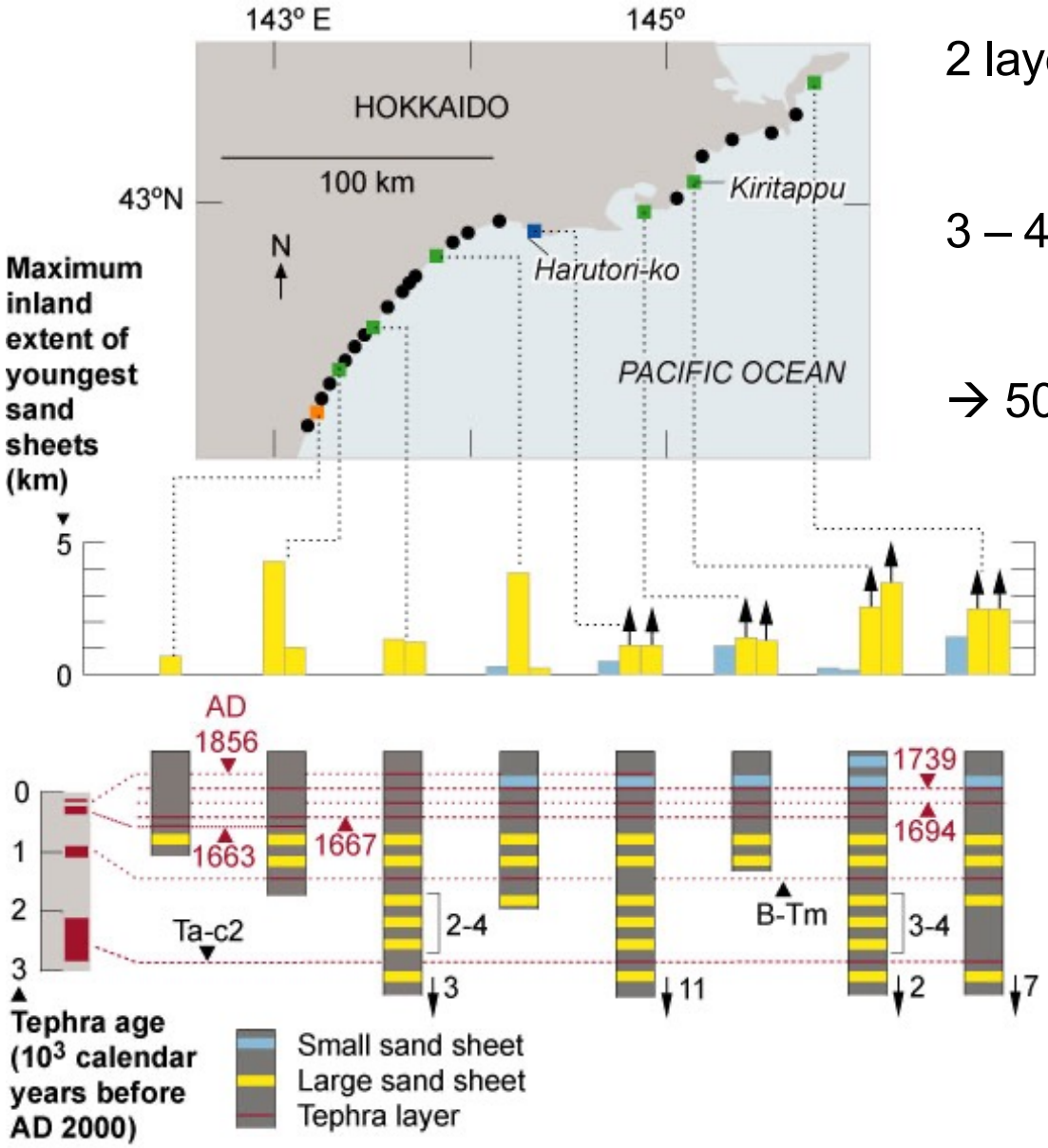


1739 Ta-a
1694 Ko-c2
1667 Ta-b

AD900-1000 B-Tm (946)
2000-3000 BP Ta-c2

Nanayama et al. (2003, Nature)

Tsunami deposits along Kuril Trench



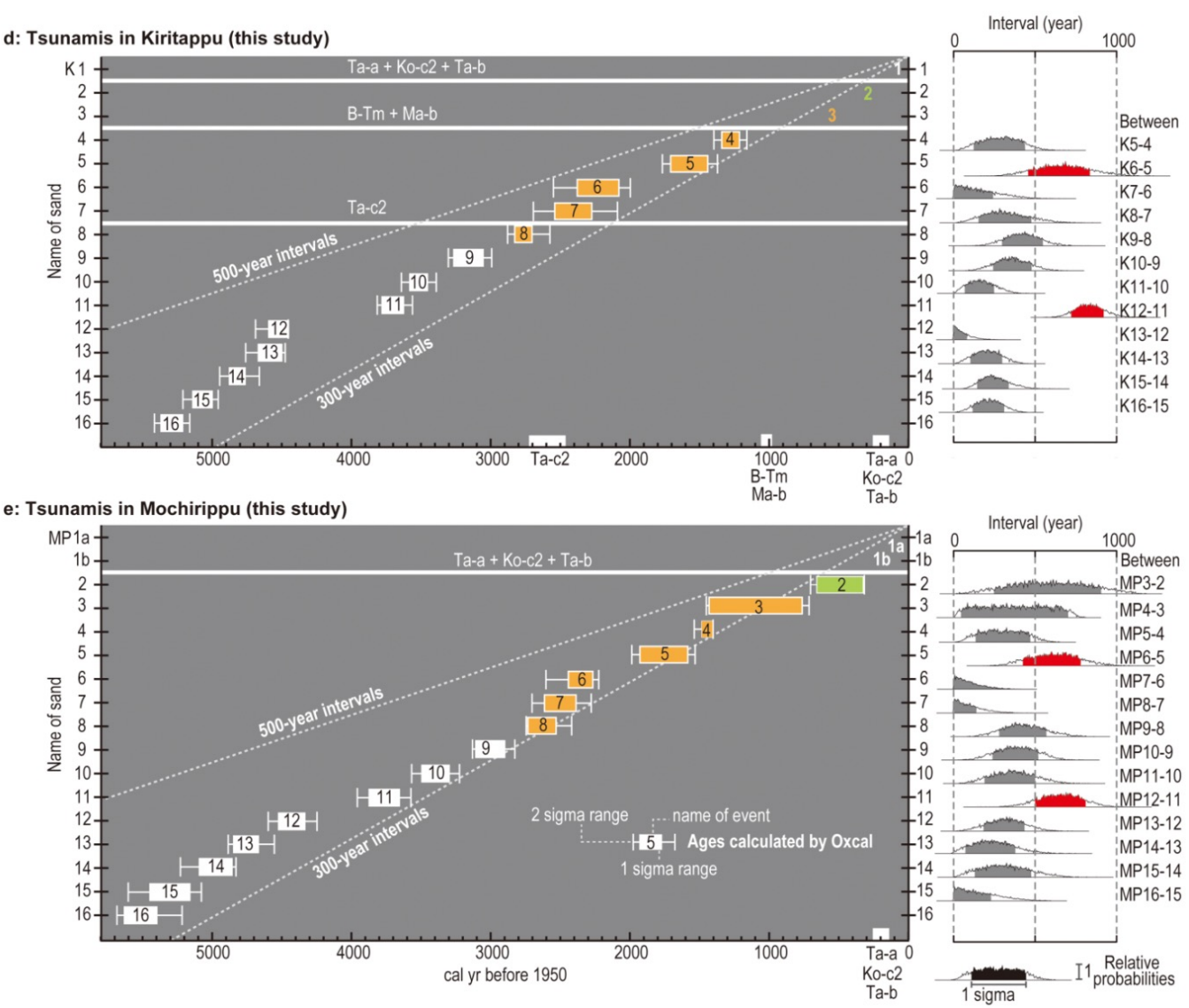
2 layers between Ko-c2/Ta-a and B-Tm
AD1694/1667 AD946

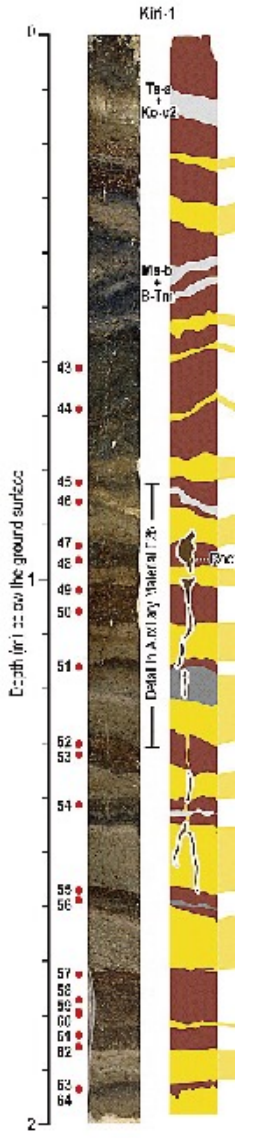
3 – 4 layers between B-Tm and Ta-c2
AD 946 2000 BP

→ 500-year events

Nanayama et al. (2003, Nature)

Tsunami deposits in Kuritappu marsh

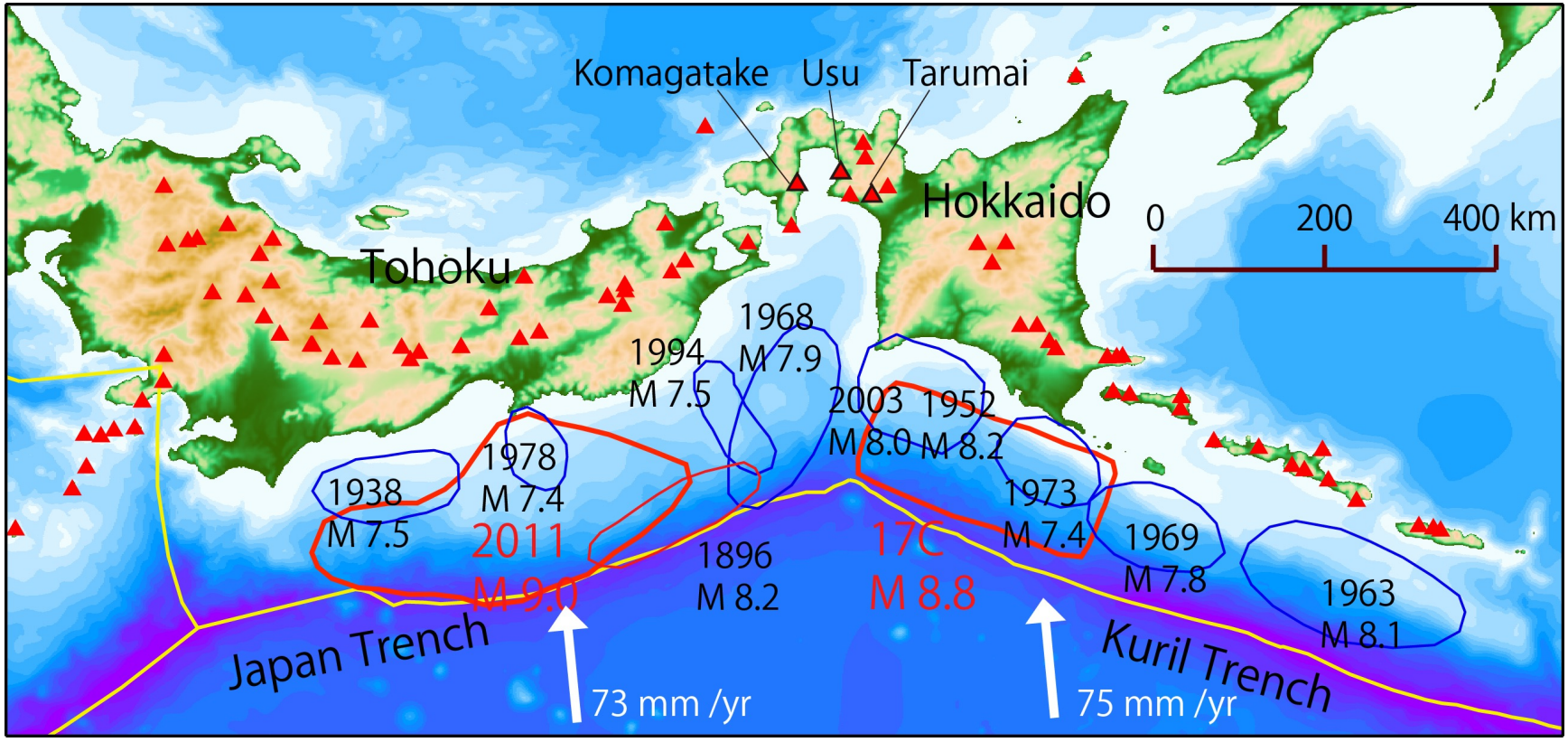




Recurrence interval: 100 – 800 (average 400 years)

Sawai et al. (2009)

Giant earthquakes along Japan/Kuril Trenches



Giant (M~9) earthquakes occurred ~ 500 year interval

The 2011 Tohoku Tsunami

Sanriku coast

- High (~ 40 m) tsunami
- ~ 30 min after the quake

©Miyako City

- Sendai plain
- Large (~ 5 km) inundation
- ~ 1 hour after eq.

©Sendai City

Fukushima Dai-ichi NPP accident

Earthquake ground motion

- Reactors automatically shutdown
- Electricity lines disconnected
- Cooling using Diesel Generators

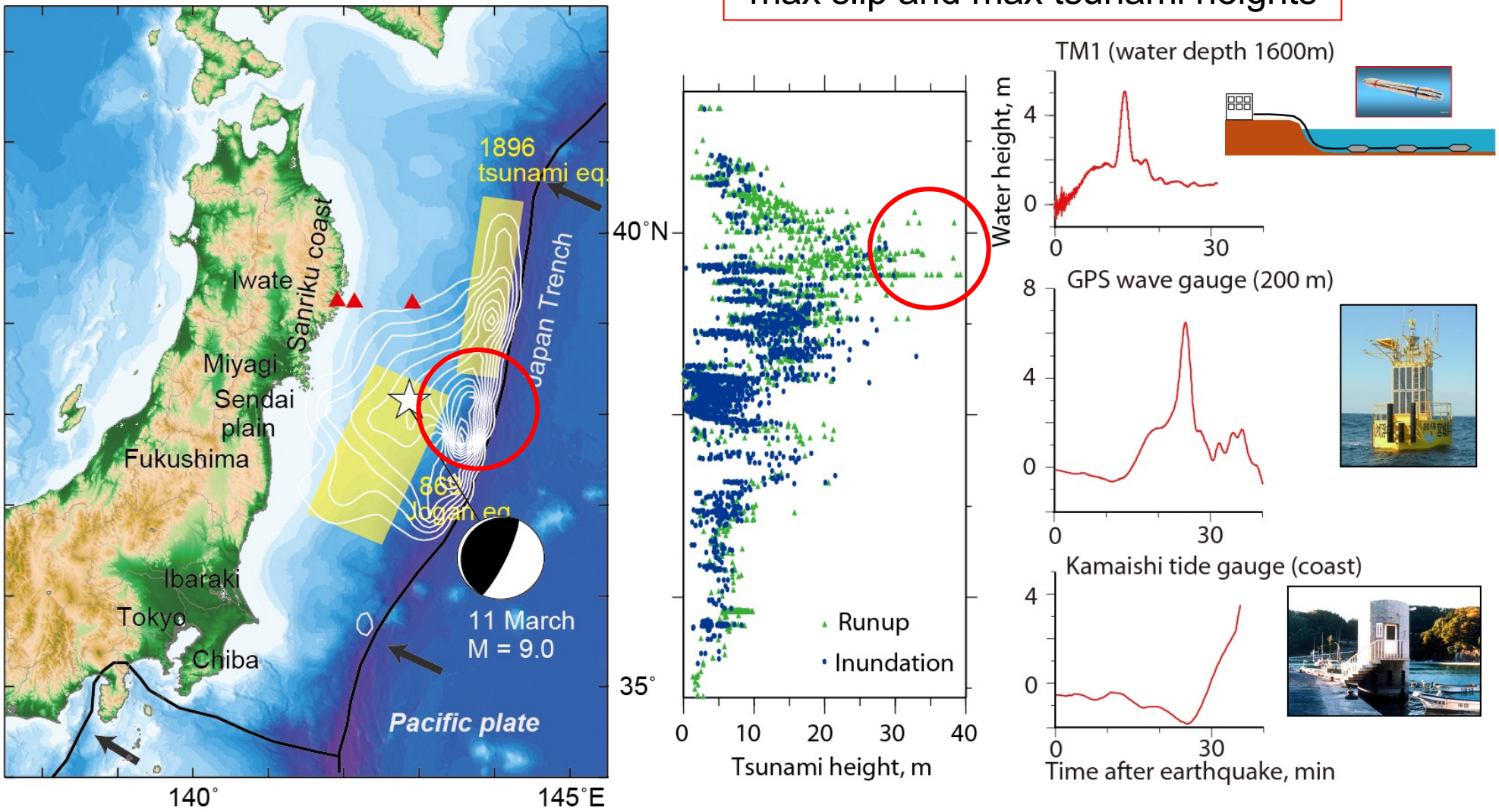
Tsunami arrived

- DG was flooded, failed to cooldown
- Core Damage
- Hydrogen Explosion
- Release of radioactive materials

TEPCO

The 2011 Tohoku Tsunami

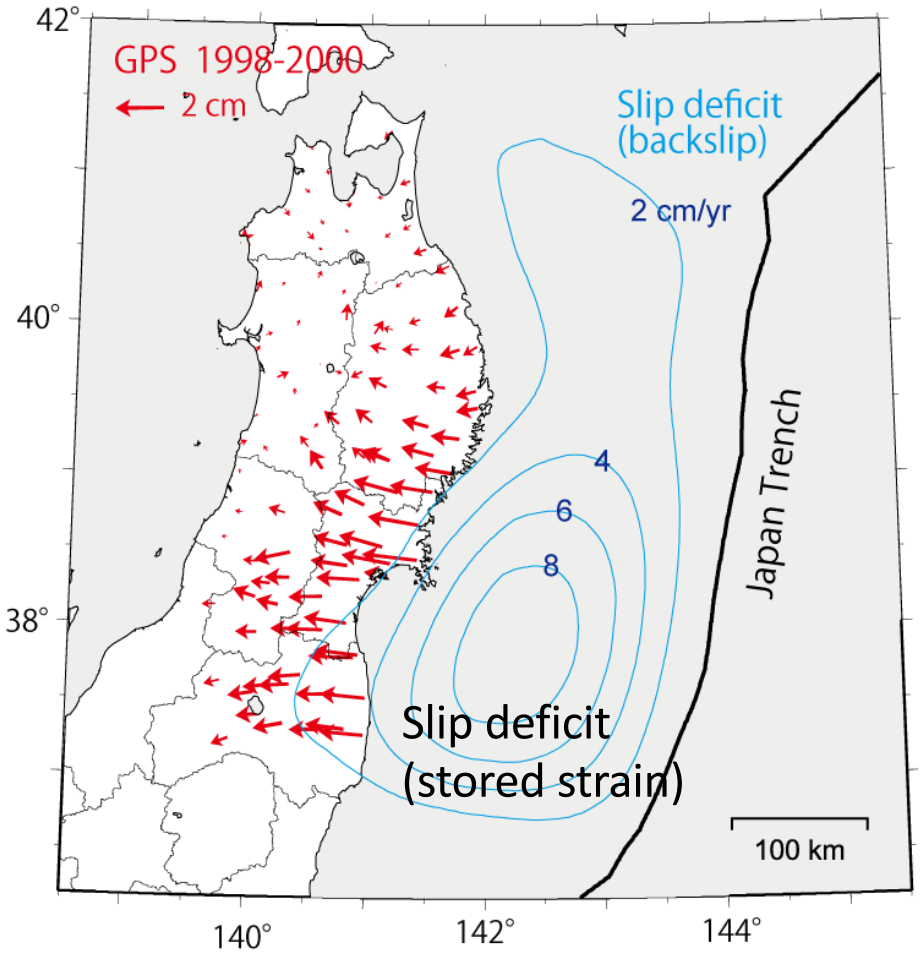
~ 100 km difference between
max slip and max tsunami heights



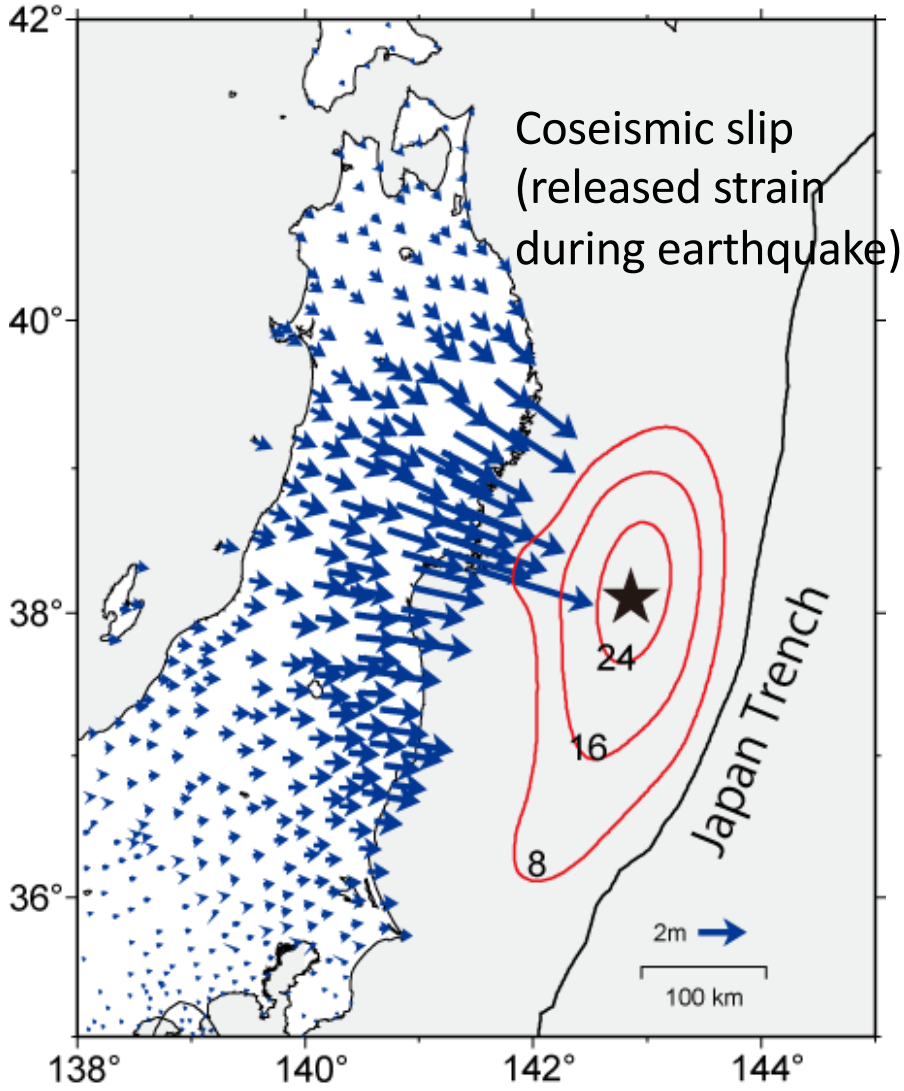
GPS data and slip distribution

About 1,300 GPS stations monitor the movement of Japan

Westward motion in 1998-2000

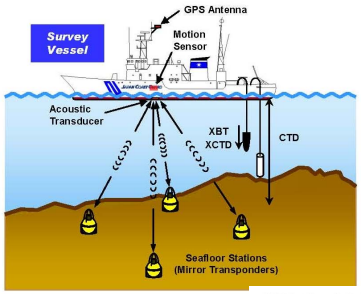


Eastward rebound on March 11



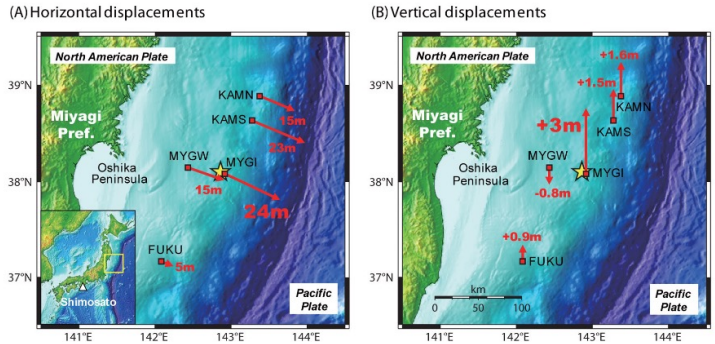
GSI (2010, 2011)

Seafloor displacement

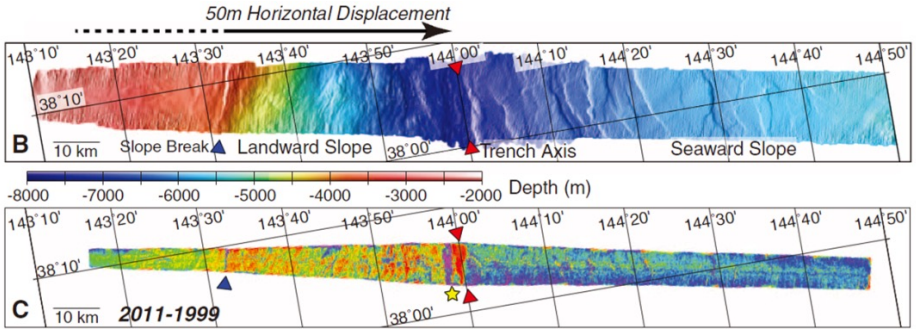


Sato et al.
(Science 2011)

Max slip on fault (estimated): > 50 m

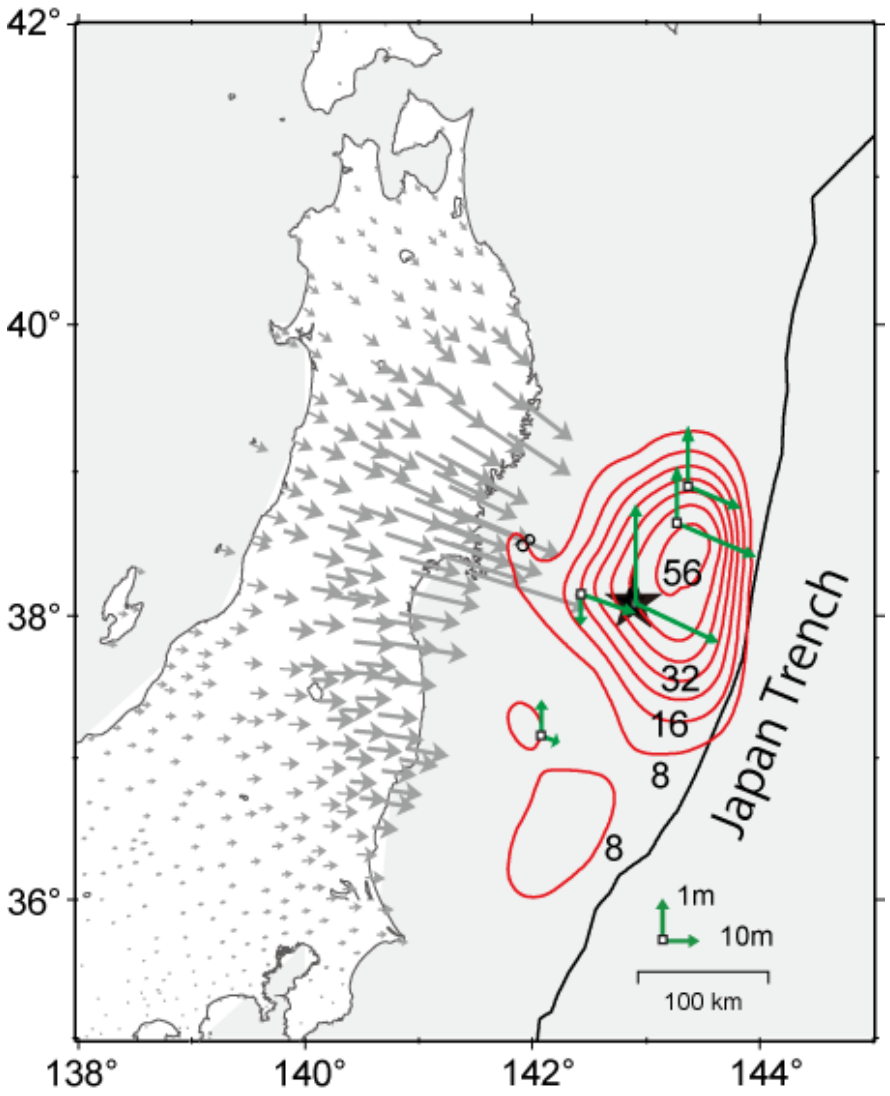


Max observed slip: 24 m horizontal
3 m vertical

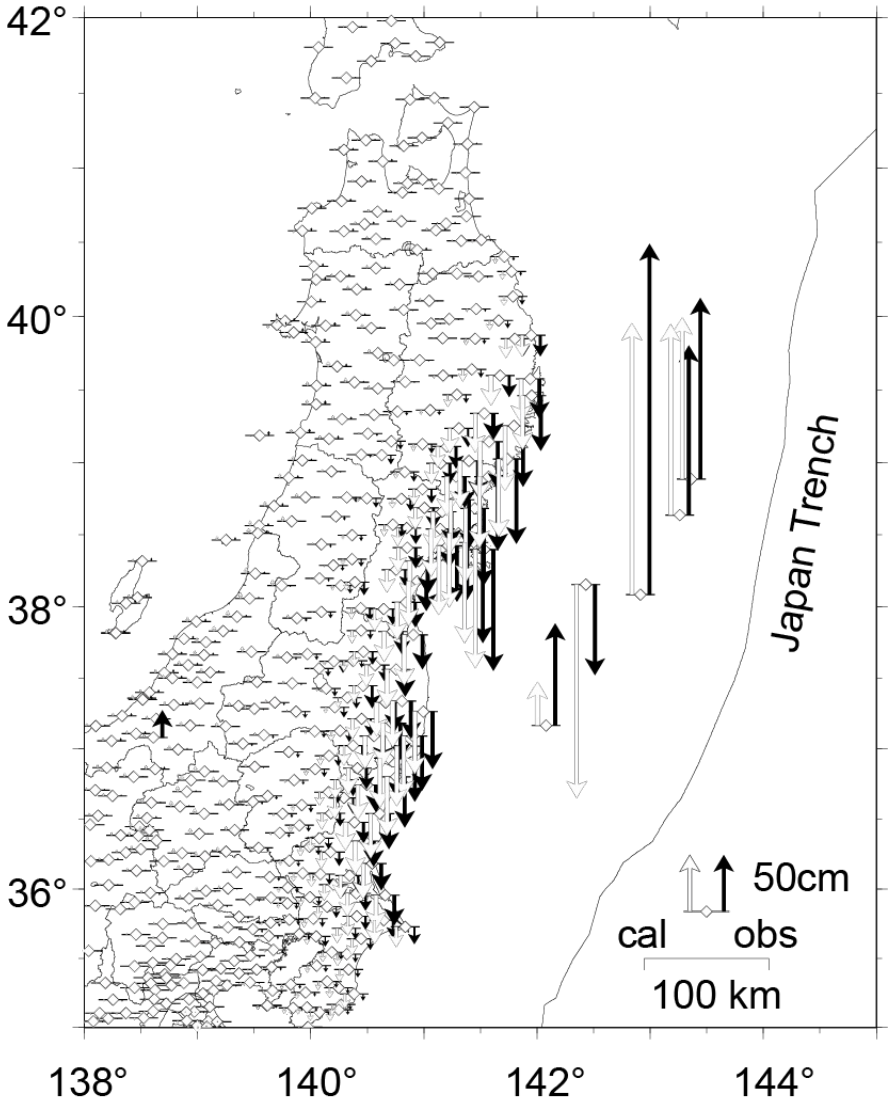


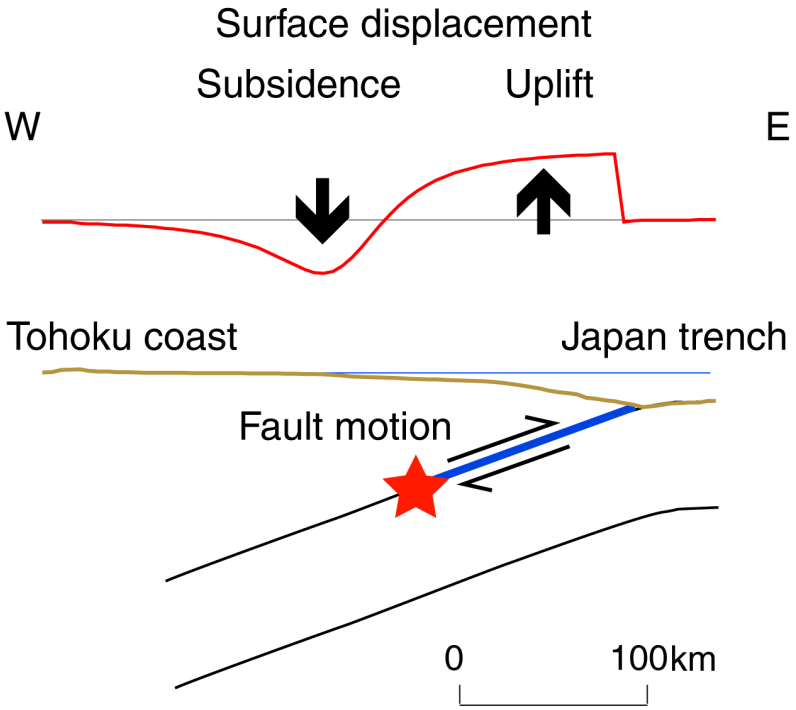
Repeated bathymetry sounding: ~ 50 m offset

Fujiwara et al. (Science 2011)



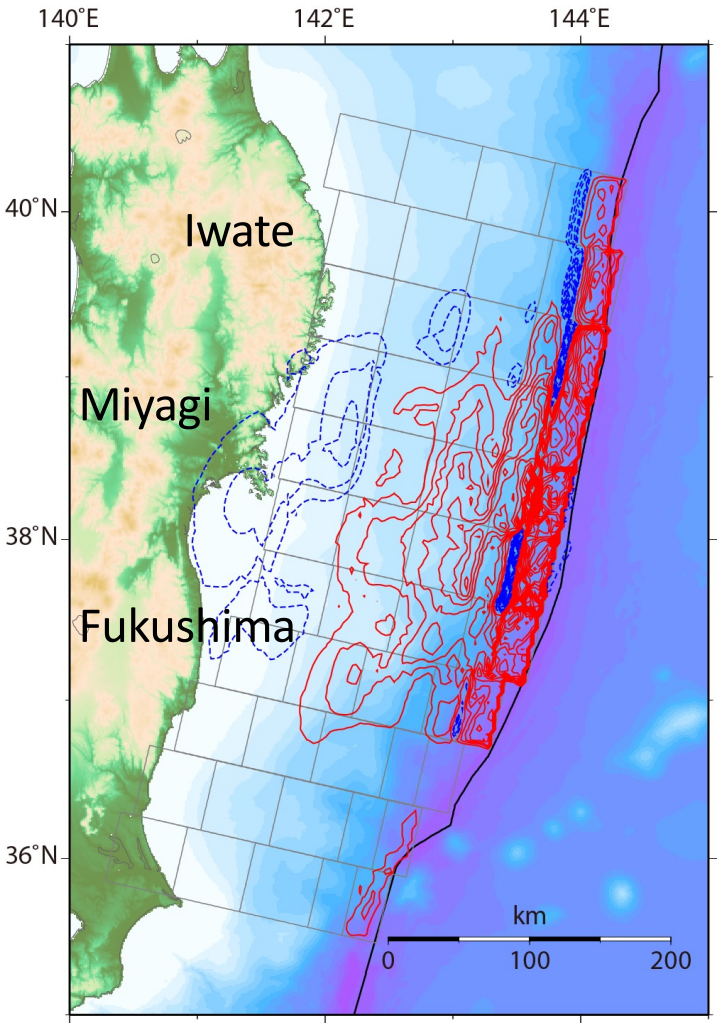
Vertical displacements

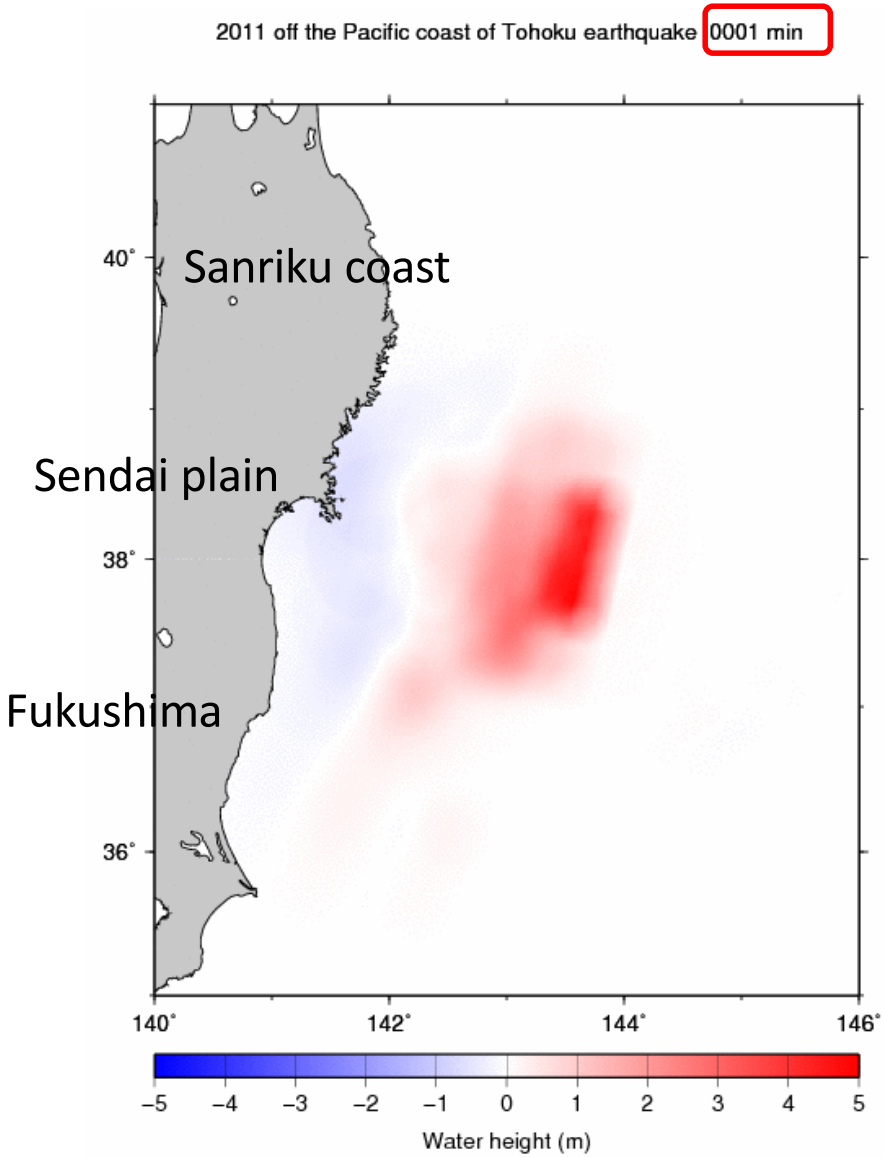




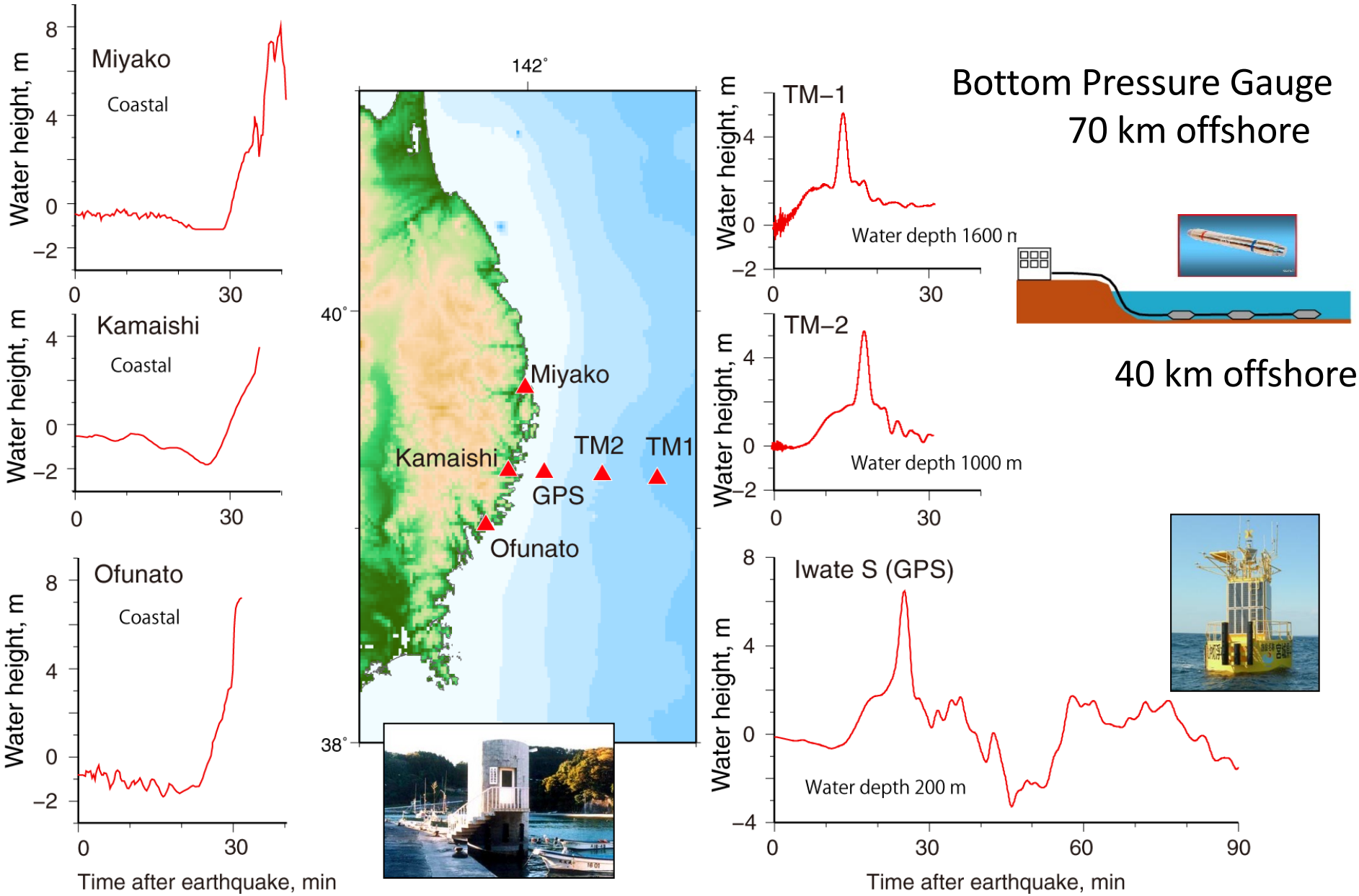
GSI (2011)

The tsunami source and propagation

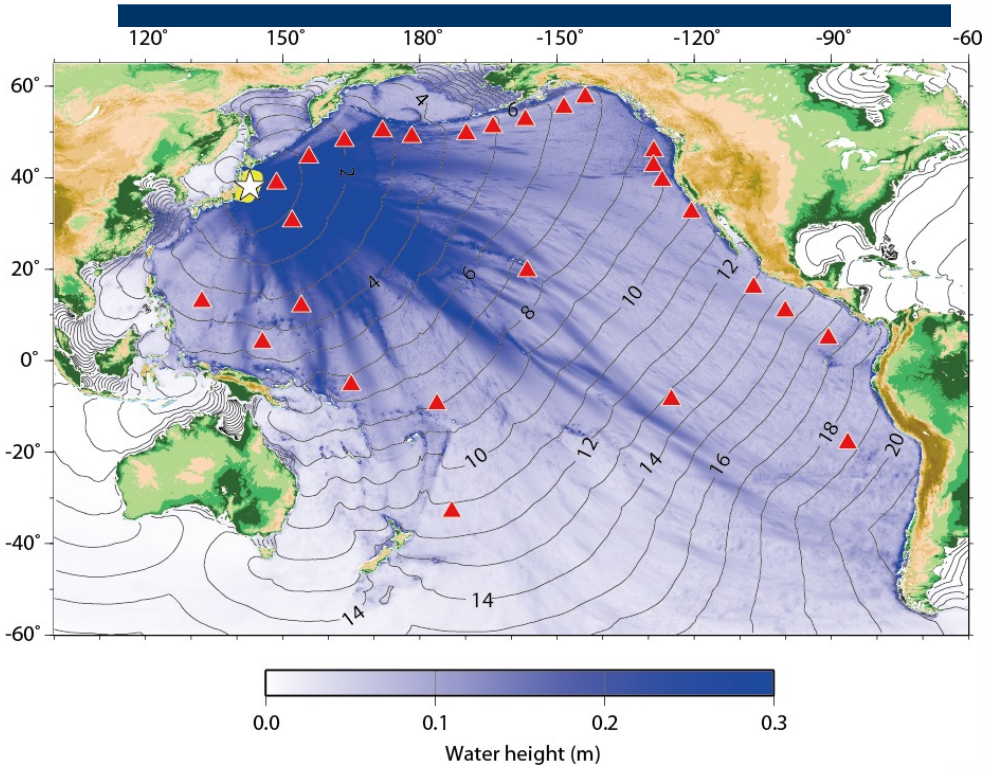


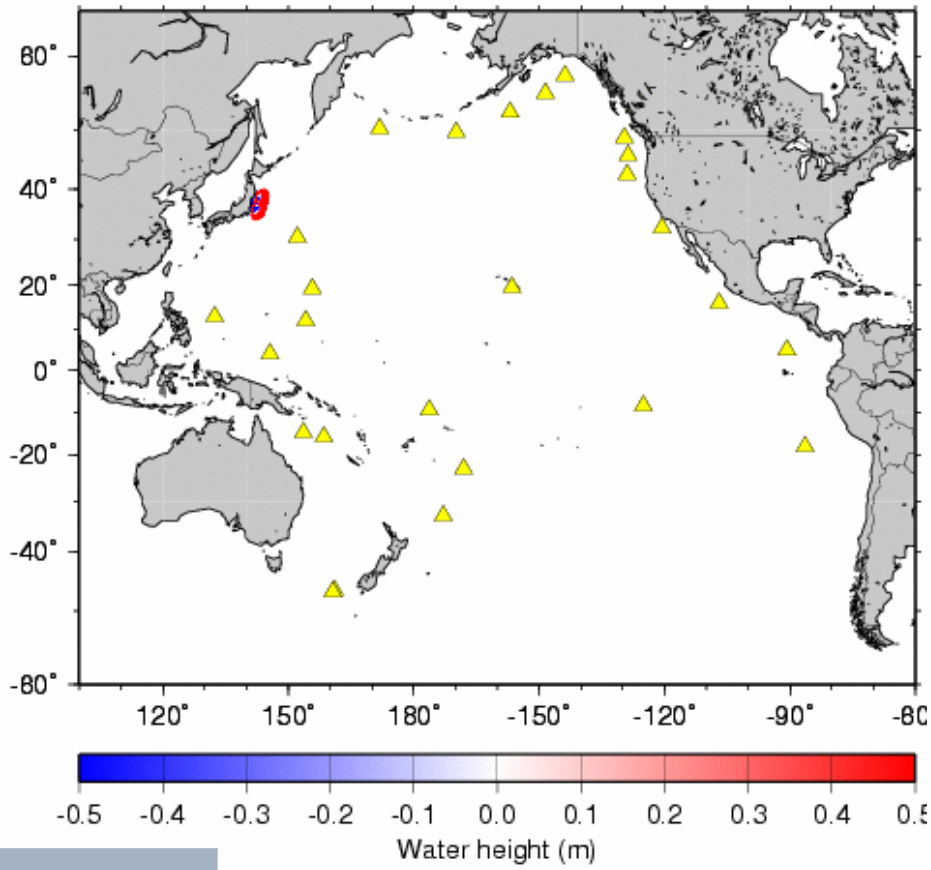


Recorded tsunami



Effects to other countries

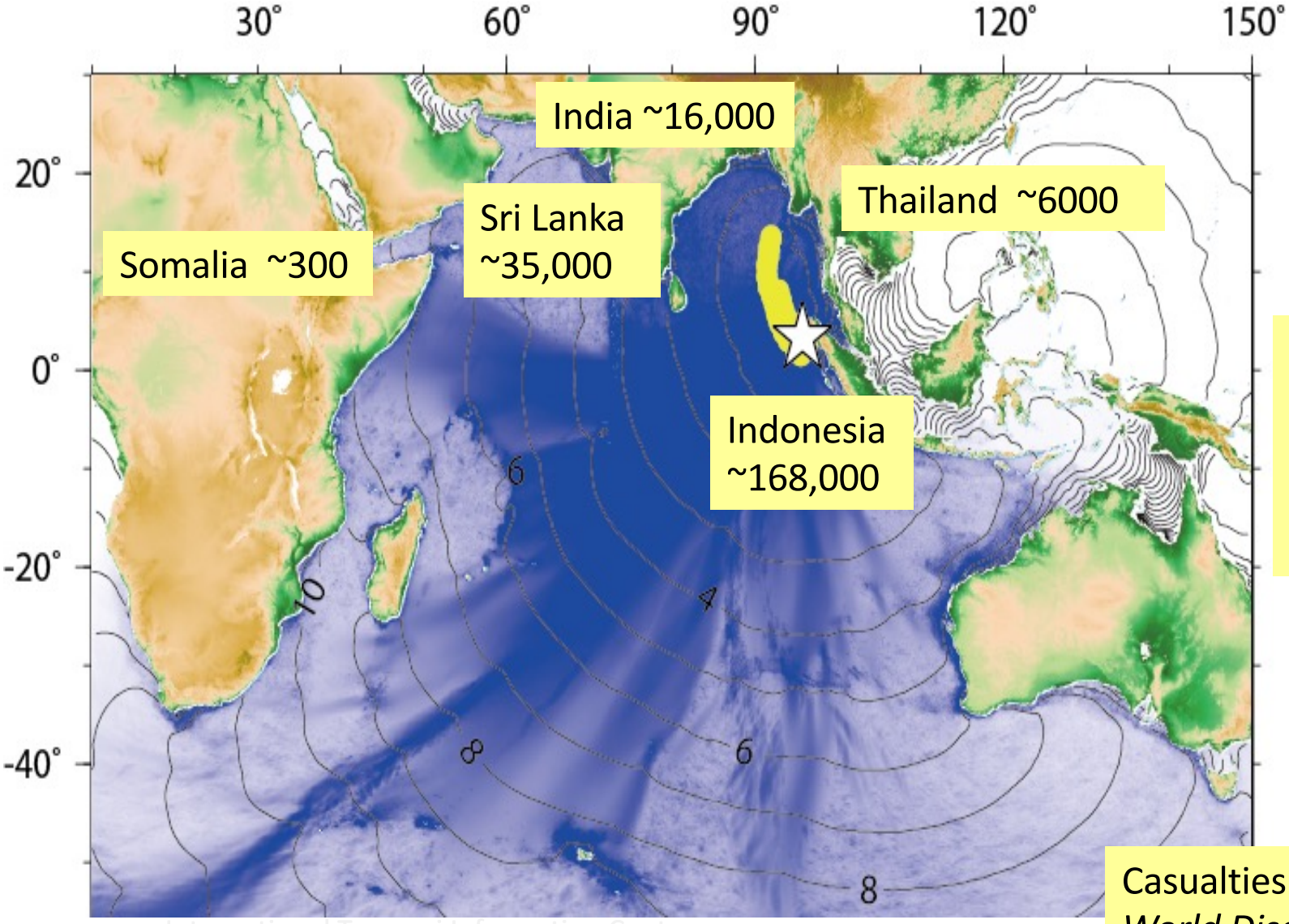




Area	time	heights	damage
Hawaii	7 hrs	5 m	$ 8 million
California	12 hrs	3 m	1 death, $20 million
Chile	22 hrs	3 m	$ 4 million
Indonesia	6 hrs		1 death

The 2004 Indian Ocean tsunami

Total casualties: 228,000 from 14 countries

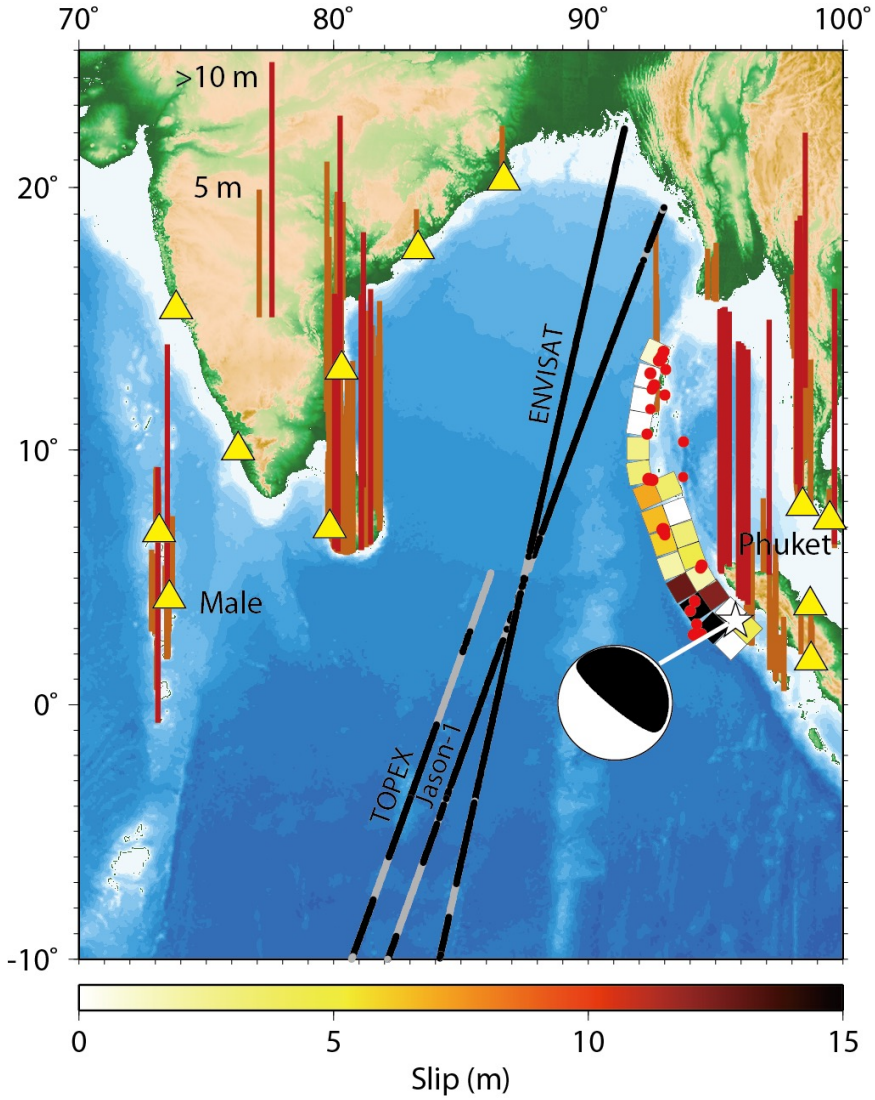


Germany	~500
Sweden	~500
Finland	~180
UK	~160
Switzerland	~110

Casualties from tsunami
World Disaster Report

The 2004 Sumatra Earthquake and Tsunami

Thailand



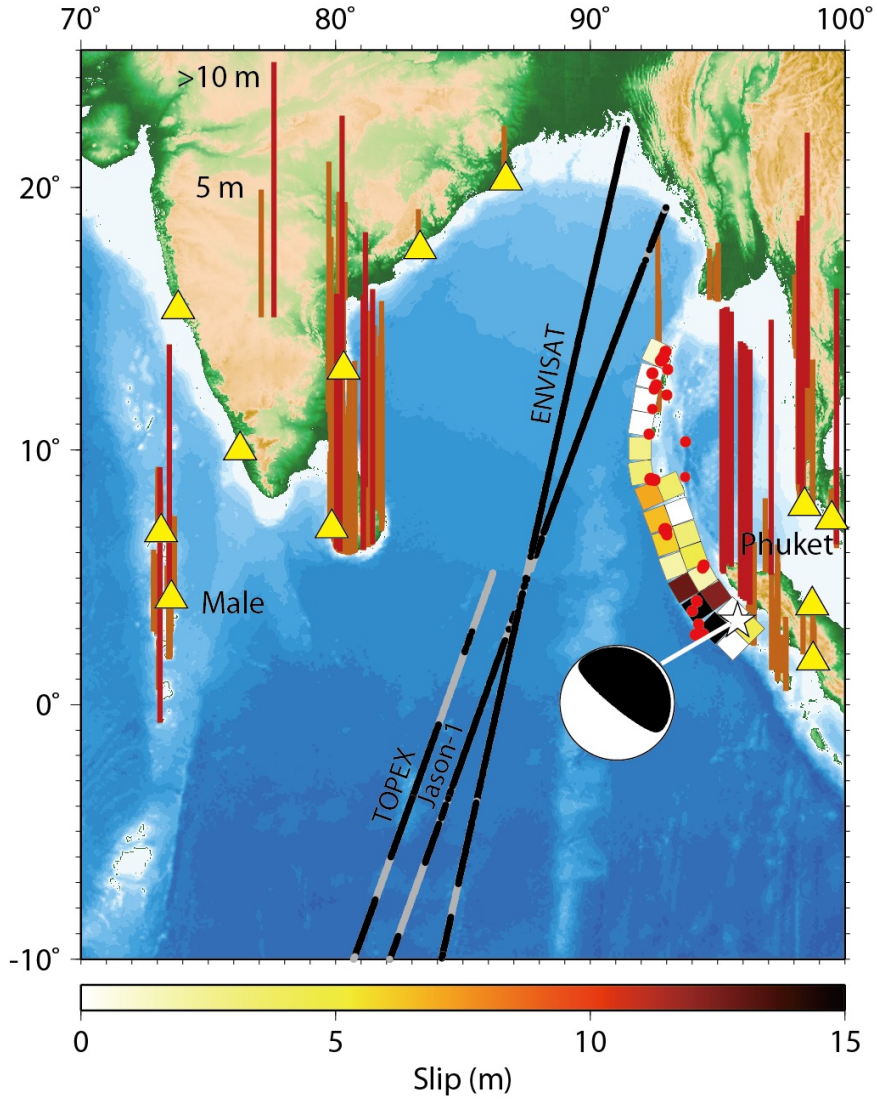
About 8,000 casualties

Including Royal family member

Nearly a half were foreign tourists

The 2004 Sumatra Earthquake and Tsunami

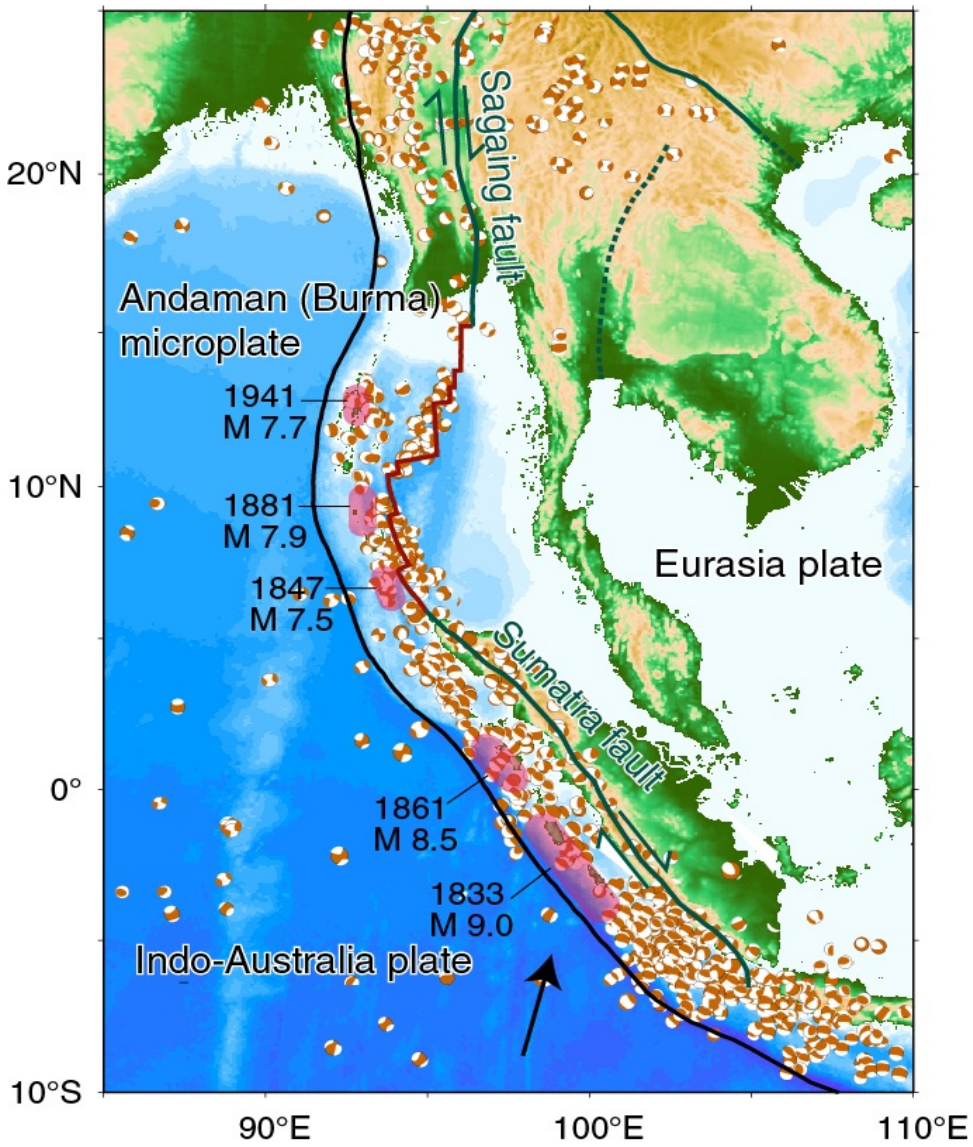
Banda Aceh, Indonesia



About 60,000 casualties
(original population 260,000)

Prof. Iemura, Kyoto Univ.

The 2004 Sumatra-Andaman Earthquake



Andaman-Nicobar Is.

1941 M 7.7

1881 M 7.9

1847 M 7.5

(from historical records)

Sumatra

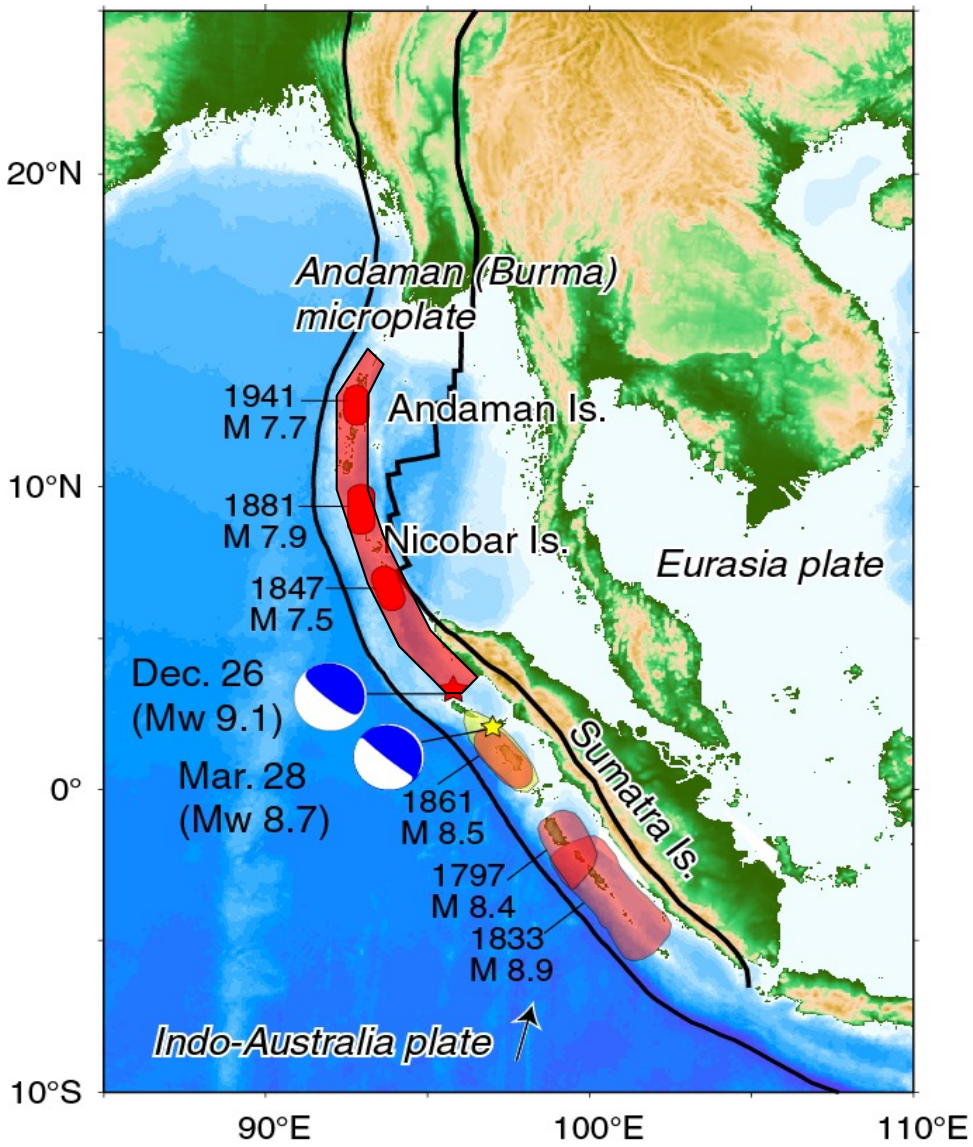
1861 M 8.5

1797 M 8.4

1833 M 8.9

(from coral studies)

The 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

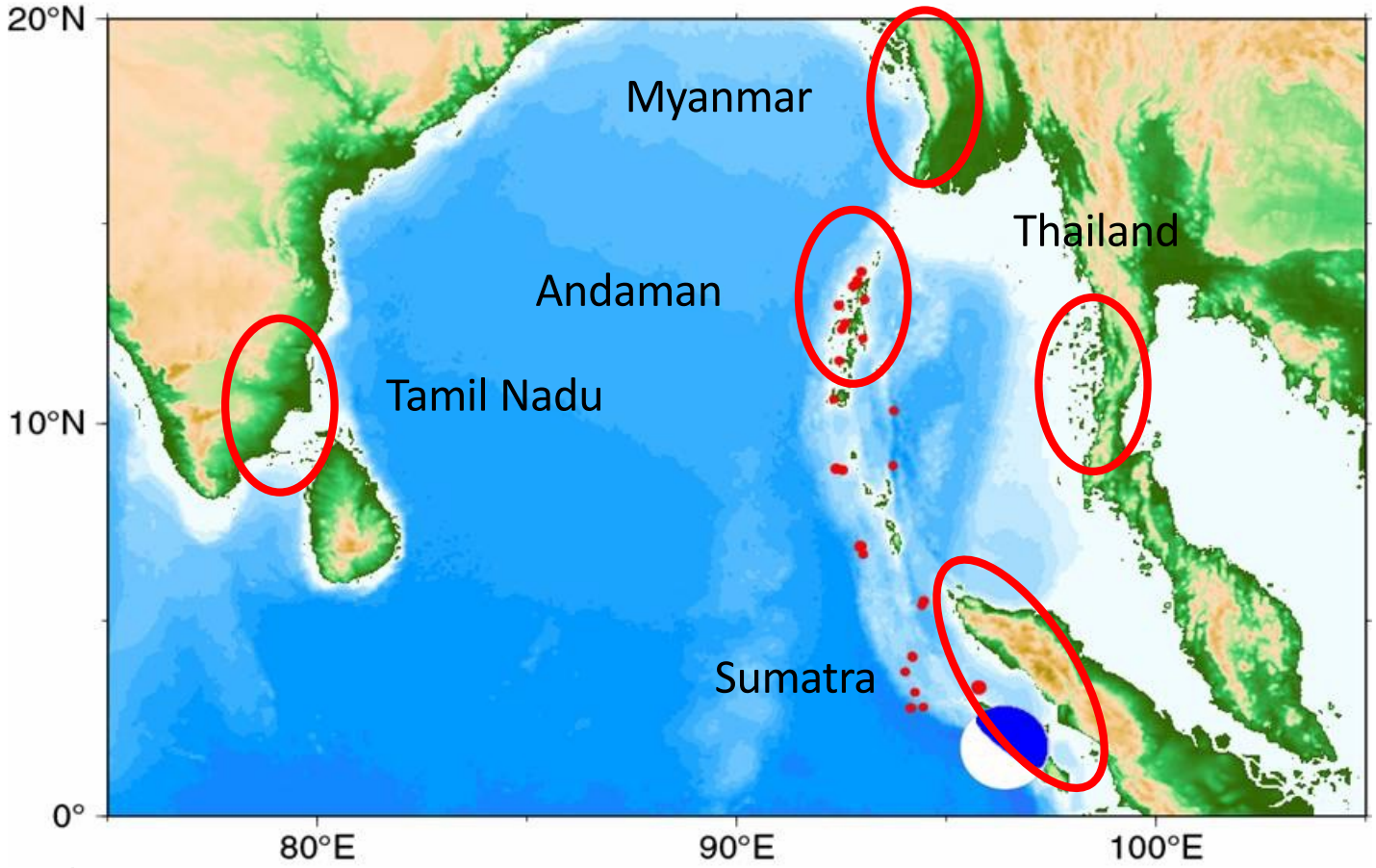
1797 M 8.4

1833 M 8.9

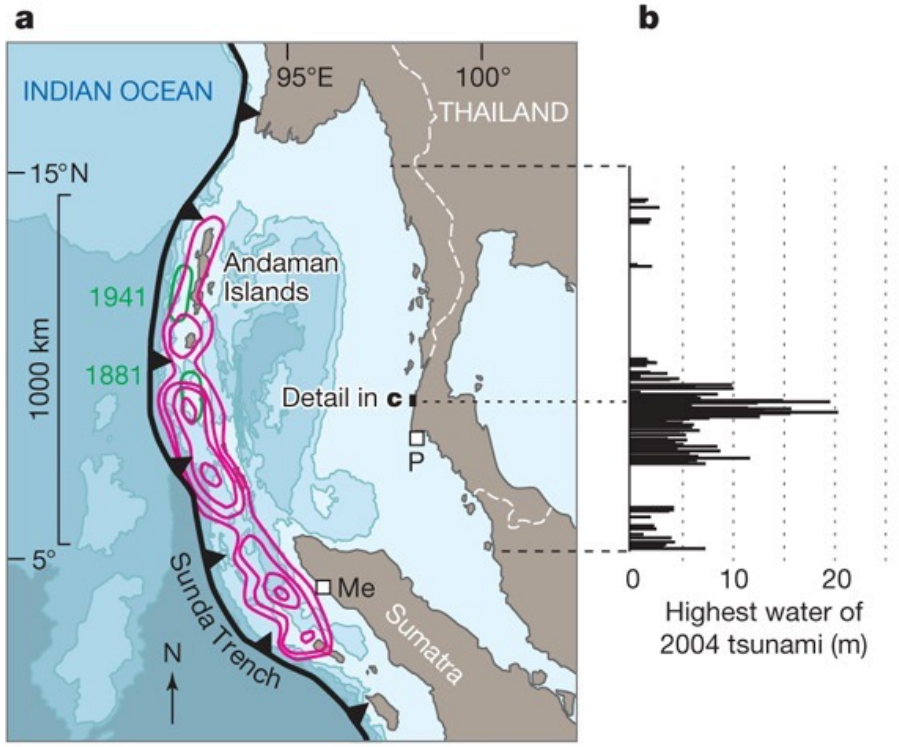
(from coral studies)

Paleoseismology around Indian Ocean

Paleoseismological studies (corals, tsunami deposits, marine terrace, buried peat) indicate that earthquakes similar to the 2004 earthquake occurred a few hundred yrs ago.



Tsunami deposits in Thailand

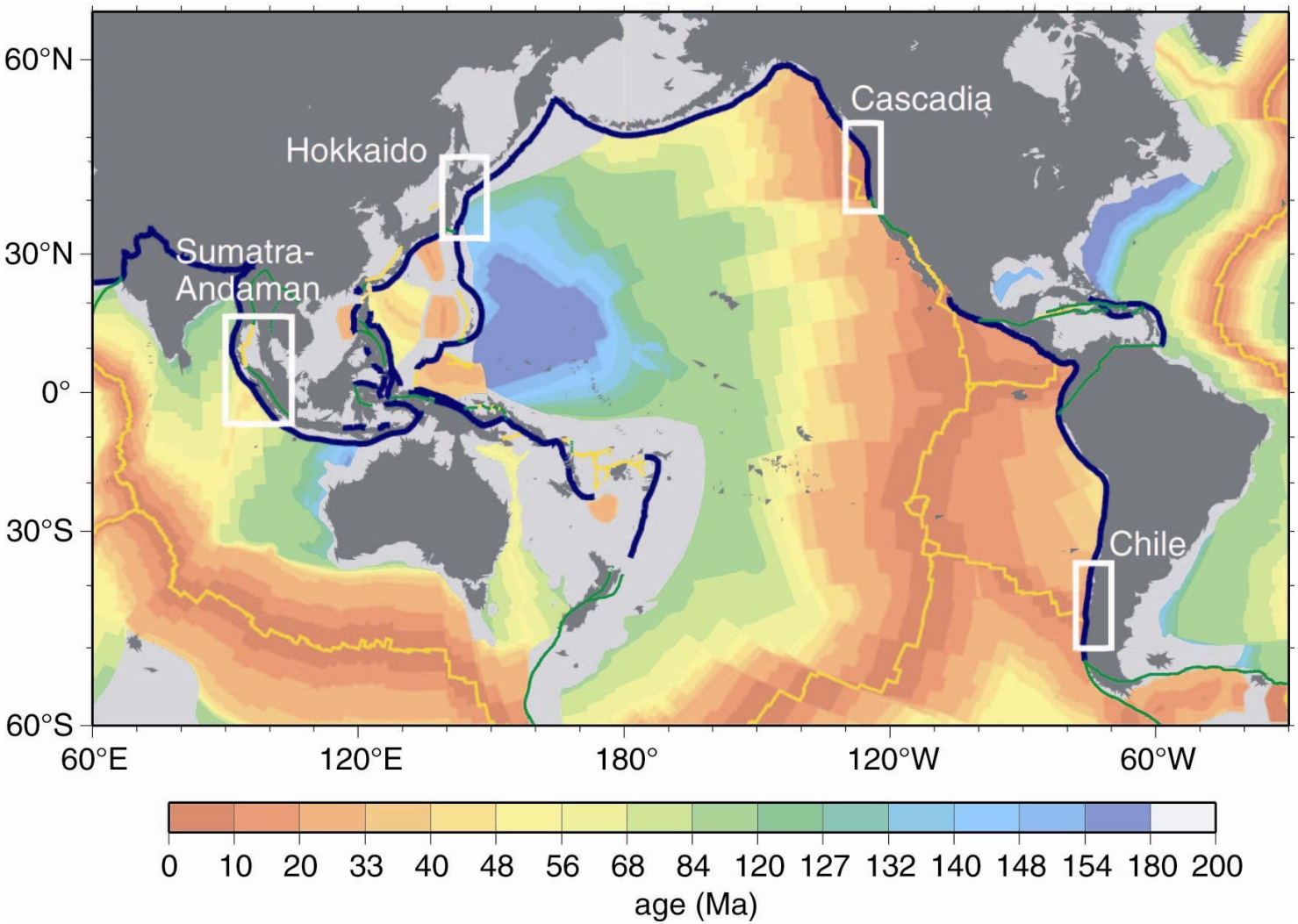


Sheet A: 2004 tsunami deposit

Sheet B: 550- 700 years BP

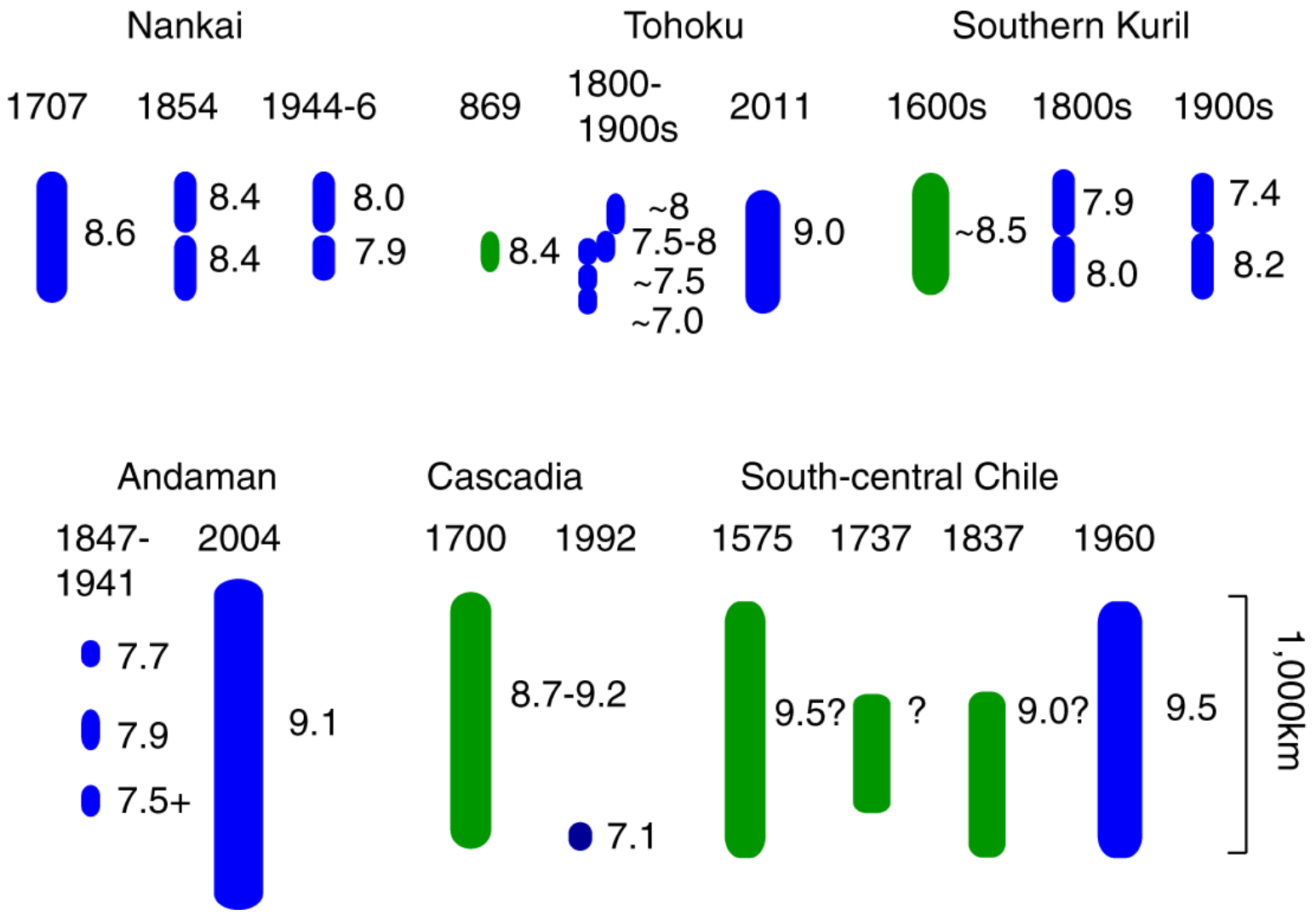
Jankaew *et al.* (2008 Nature)

World's Subduction Zones



Muller et al 1997

Variability in subduction-zone earthquakes



Updated
Satake and Atwater (2007, Ann. Rev. Earth Planet. Sci.)

Giant earthquakes in the world

South America (Chile)

1960: M 9.2-9.5

average interval (from paleoseismology) ~ 300 yrs

North America (Cascadia)

1700: M ~9.2

average interval (from paleoseismology) ~ 500 yrs

Southern Kuril Trench

17th century: Mw ~ 8.8

average interval (from paleoseismology) ~ 400 yrs

Japan Trench

2011: Mw 9.0

average interval (from historical seismology) ~ 500 yrs

Southeast Asia (Sumatra-Andaman)

2004: M 9.1-3

recurrence interval ~ a few hundred to thousand year

Thank You

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