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Title:	Millenium Earthquake: Understanding Rare Events Like the Great Tohoku Earthquake
Author(s):	Terry C. Wallace and Janet A. Mercer-Smith
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Millenium Earthquake: Understanding Rare Events Like the Great Tohoku Earthquake

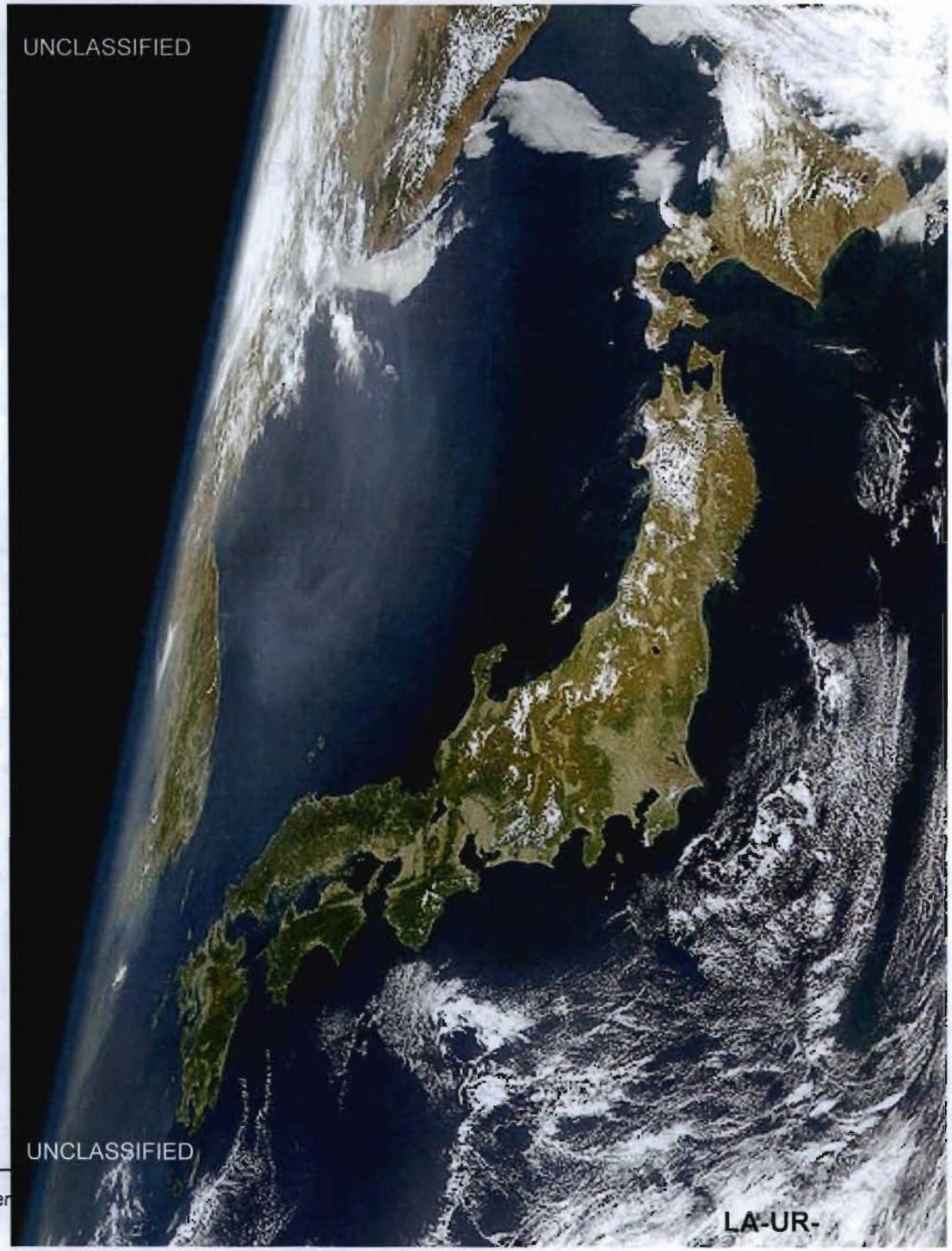
Terry C. Wallace, Jr. and Janet A. Mercer-Smith

On March 11, a major earthquake occurred around 3 P.M. local time, east of the island of Honshu, Japan. The earthquake is a subduction thrusting event in the Japan Trench which is the convergent plate boundary between the Pacific and North American plates. The earthquake had a moment magnitude of slightly larger than 9.0, making it the fourth or fifth largest earthquake in recorded history. The earthquake epicenter was approximately 120 km east of the Japanese city Sendai. Although shaking was experienced widely across Honshu, the damage associated with the shaking was modest considering the size of the event; however, the earthquake triggered a major tsunami. The tsunami caused extensive damage along 350 km of the eastern coast of Honshu.

Millenium Earthquake:

Understanding Rare Events Like the Great Tohoku Earthquake

Terry C. Wallace
Principal Associate Director
Science, Technology and Engineering



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Earthquake March 11, 2011 Mw = 9.1

Destruction in Sendai

Fukushima 1 Plant

Recent Major Earthquakes

• May 22, 1960	Chile	Mw ~ 9.6
• March 27, 1964	Alaska	Mw ~ 9.4
• December 26, 2004	Indonesia	Mw ~ 9.3
• March 11, 2011	Japan	Mw ~9.1
• November 4, 1952	Kamchatka	Mw ~9.0

Plate Tectonics and the Earthquake

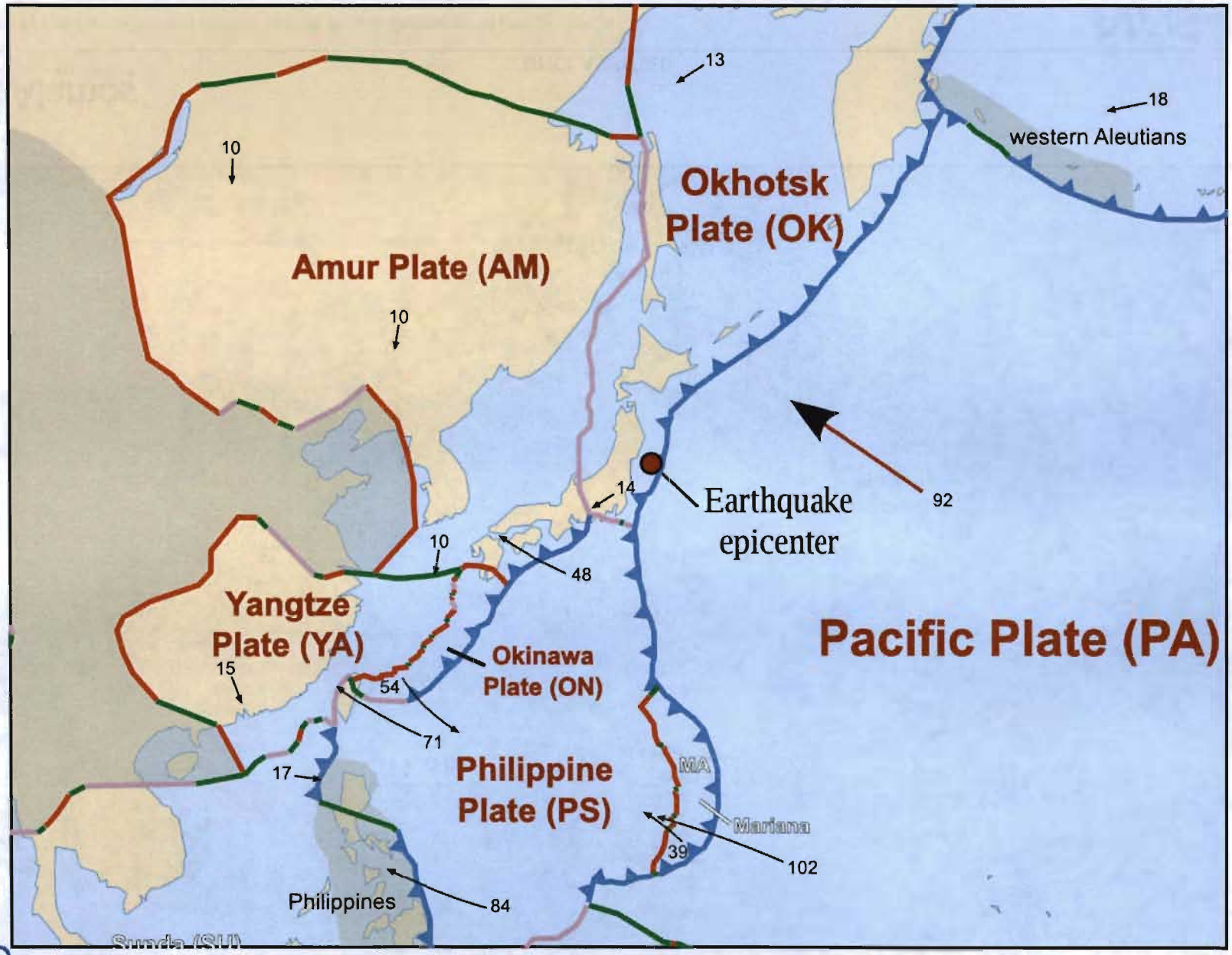

Plate Tectonics and the Earthquake

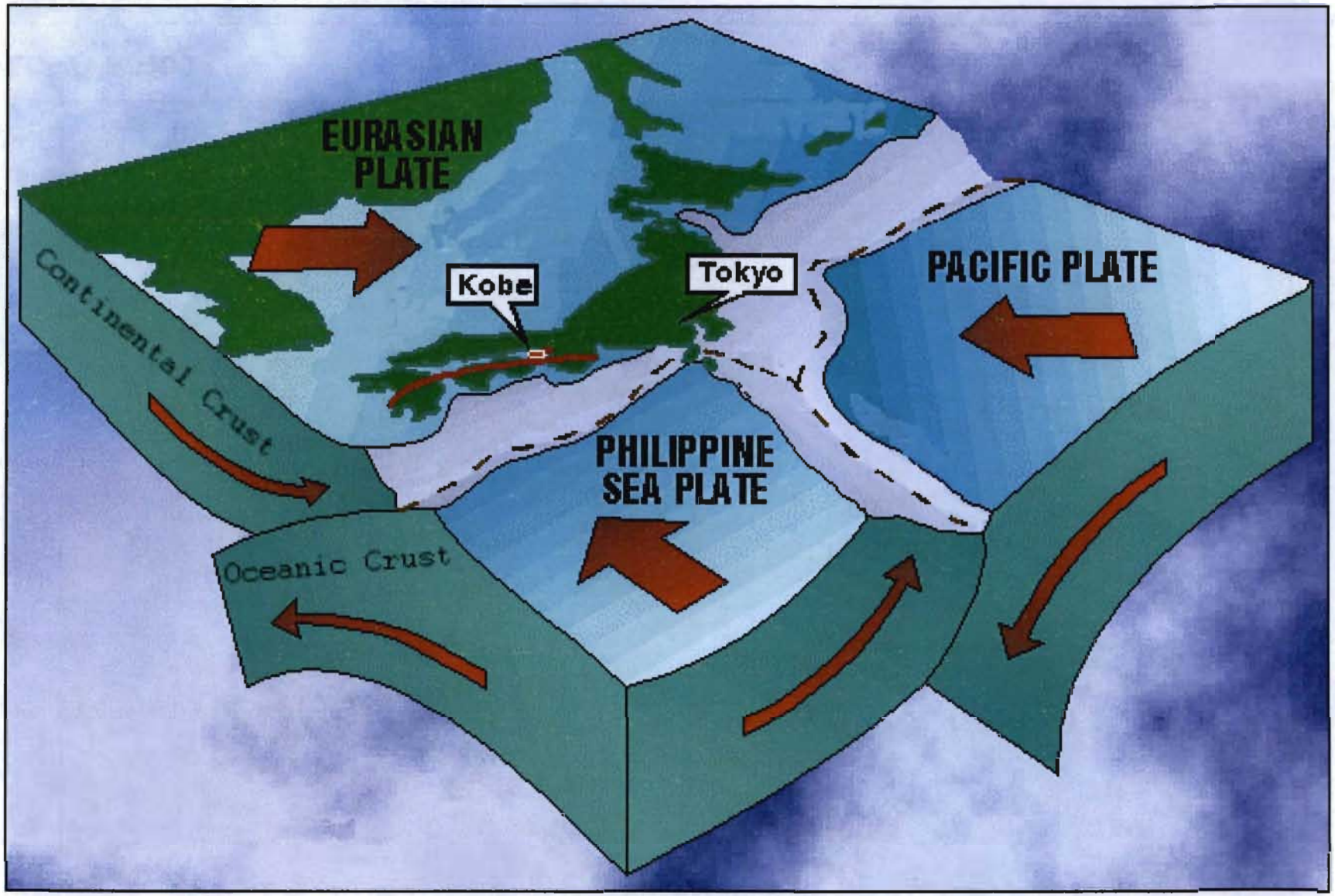

Plate Tectonics and the Earthquake

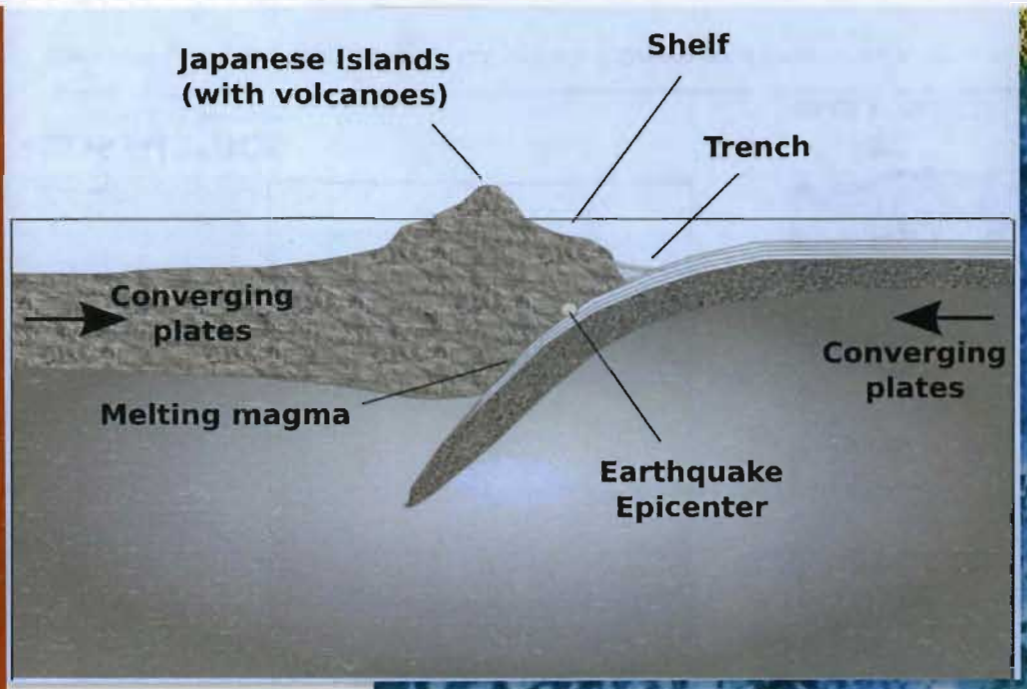

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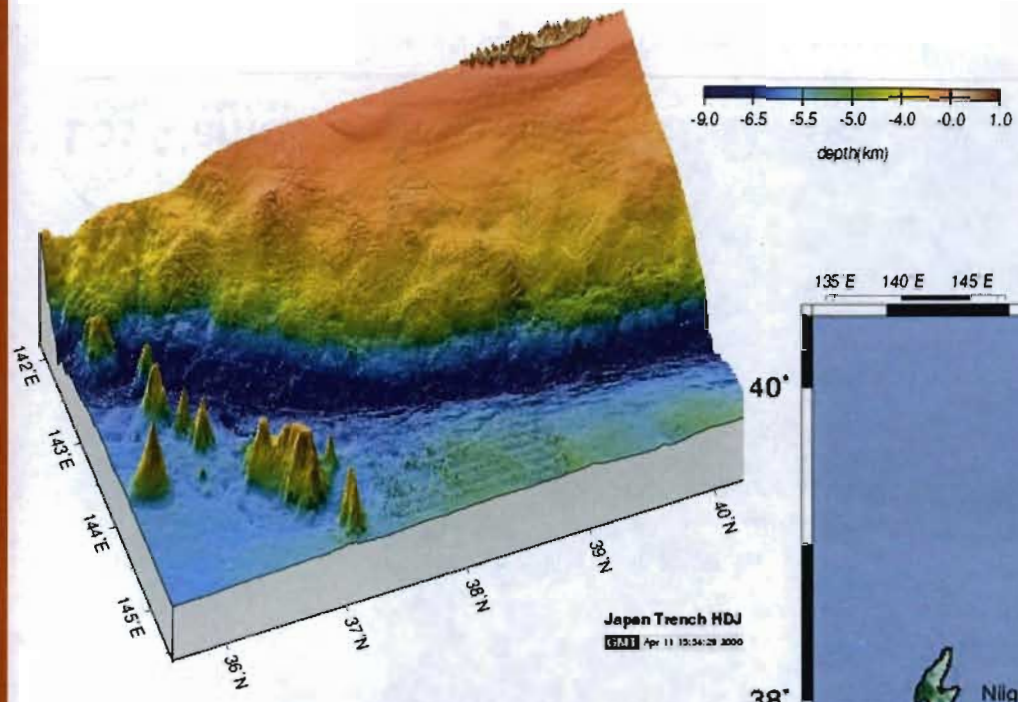
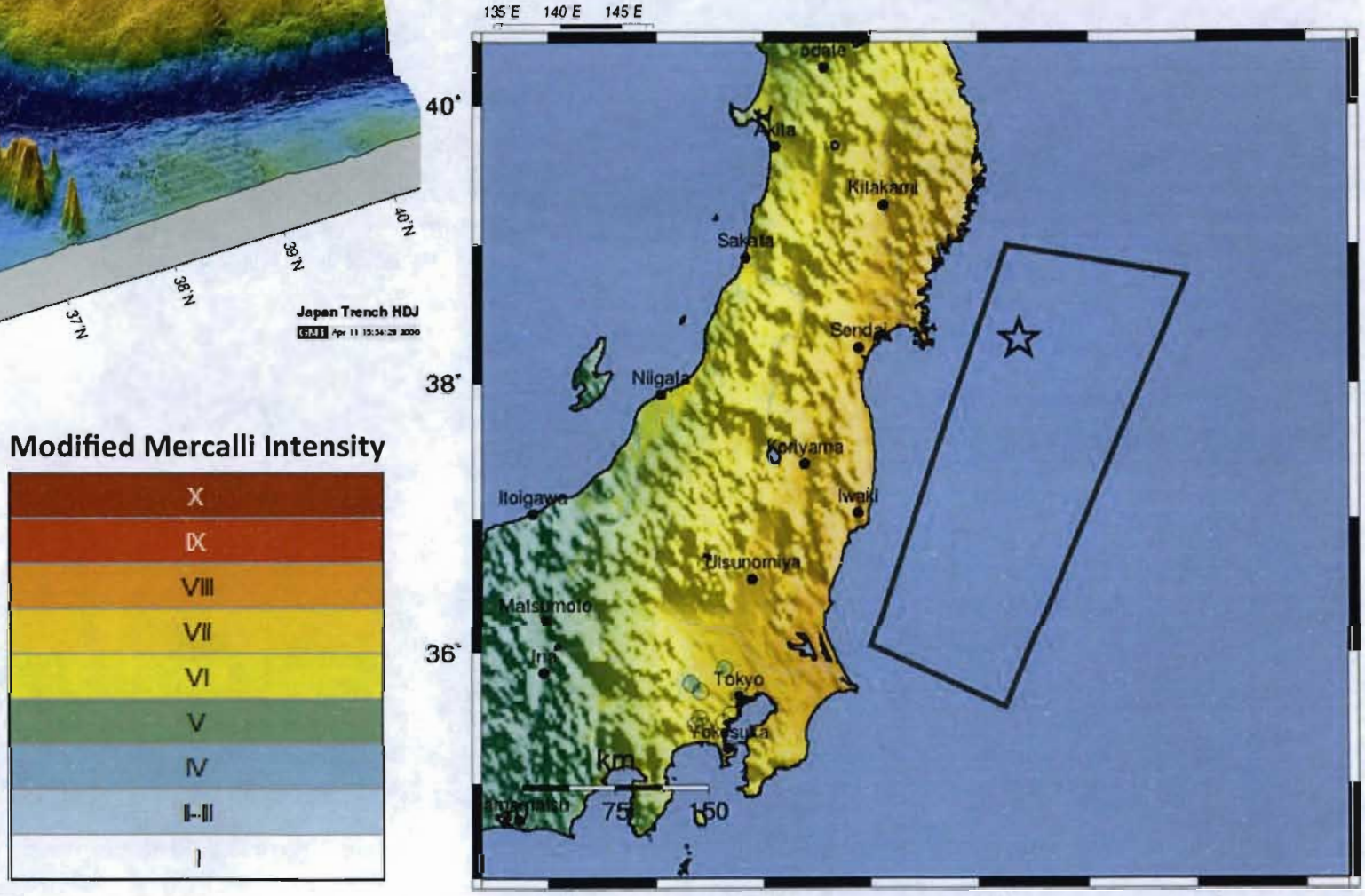
Plate Tectonics and the Earthquake



The earthquake occurred at a depth of 25 km.



Modified Mercalli Intensity

X
IX
VIII
VII
VI
V
IV
II-III
I

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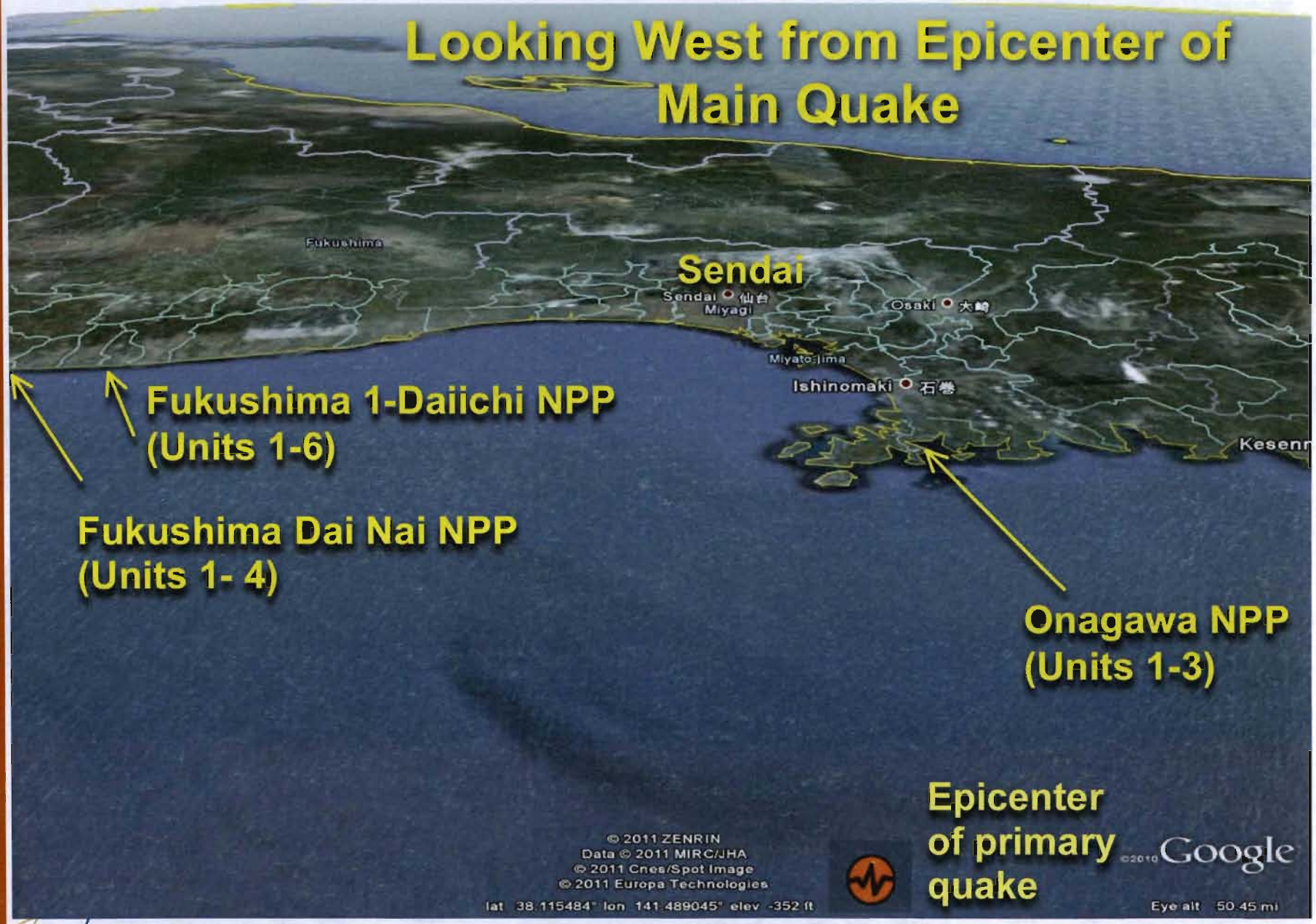
Looking West from Epicenter of Main Quake
Fukushima
Sendai
Sendai 仙台
Miyagi
Osaki 大崎
Miyato-jima
Ishinomaki 石巻
Kesenn
Fukushima 1-Daiichi NPP (Units 1-6)
Fukushima Dai Nai NPP (Units 1- 4)
Onagawa NPP (Units 1-3)
Epicenter of primary quake
© 2011 ZENRIN
Data © 2011 MIRC/JHA
© 2011 Cnes/Spot Image
© 2011 Europa Technologies
lat 38.115484° lon 141.489045° elev -352 ft
©2010 Google
Eye alt 50.45 mi

Plate Tectonics and the Earthquake

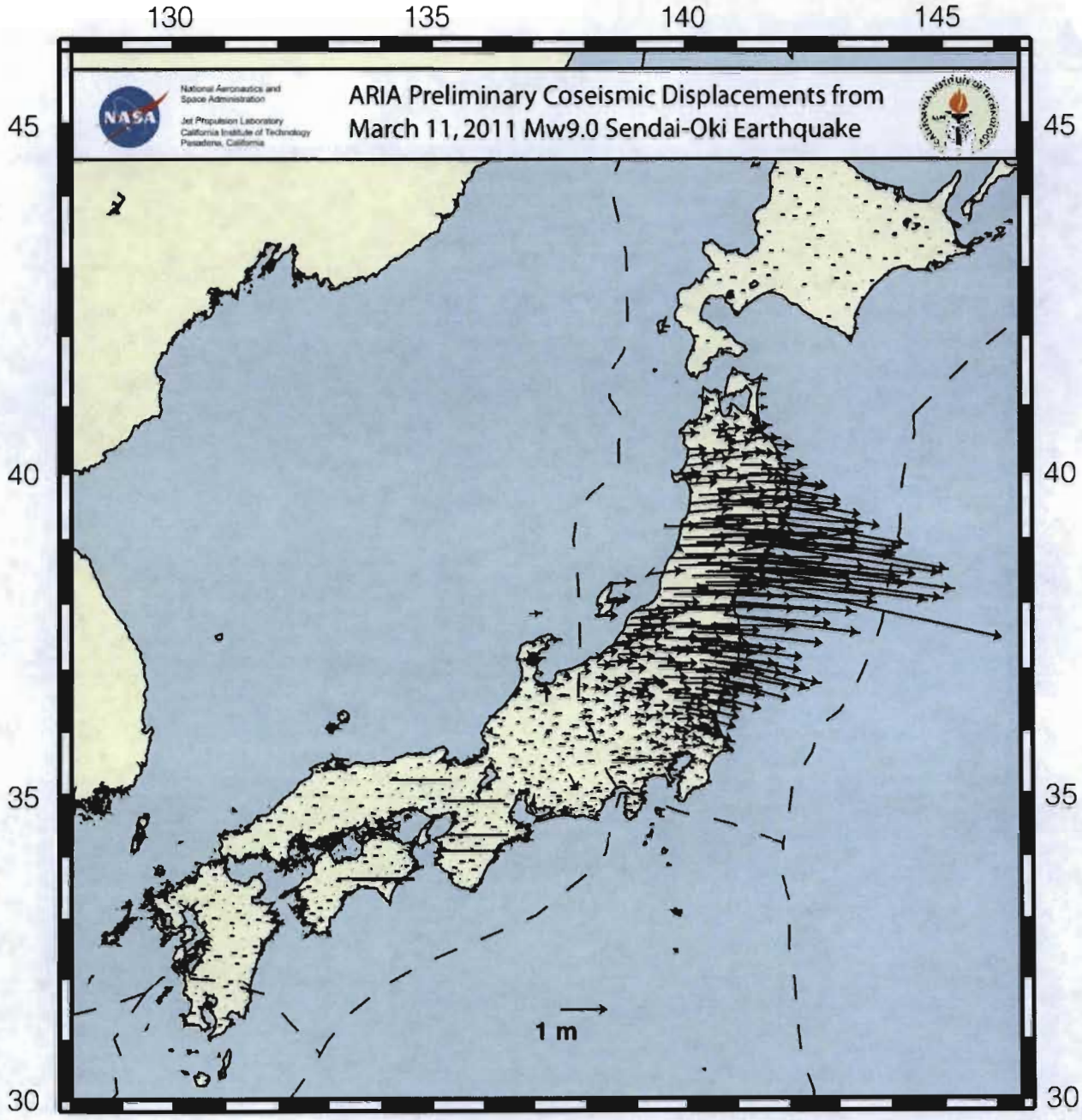

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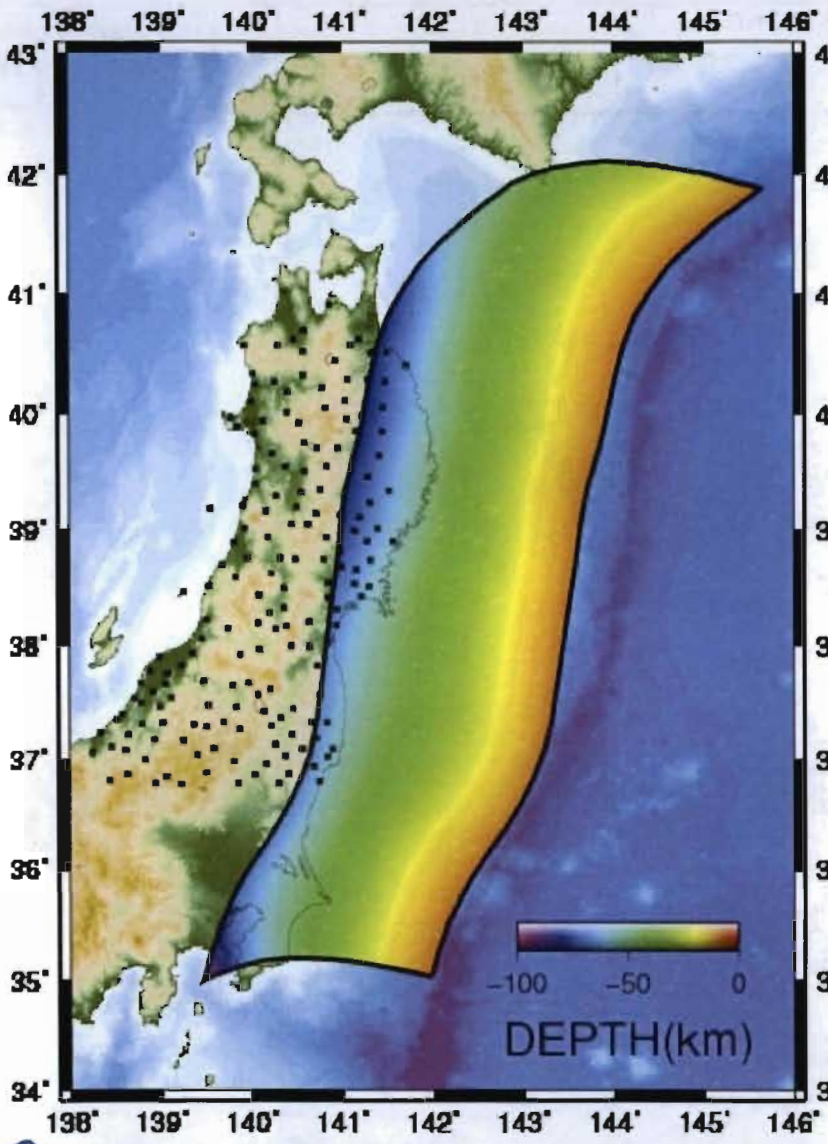
Plate Configuration



Slip Distribution

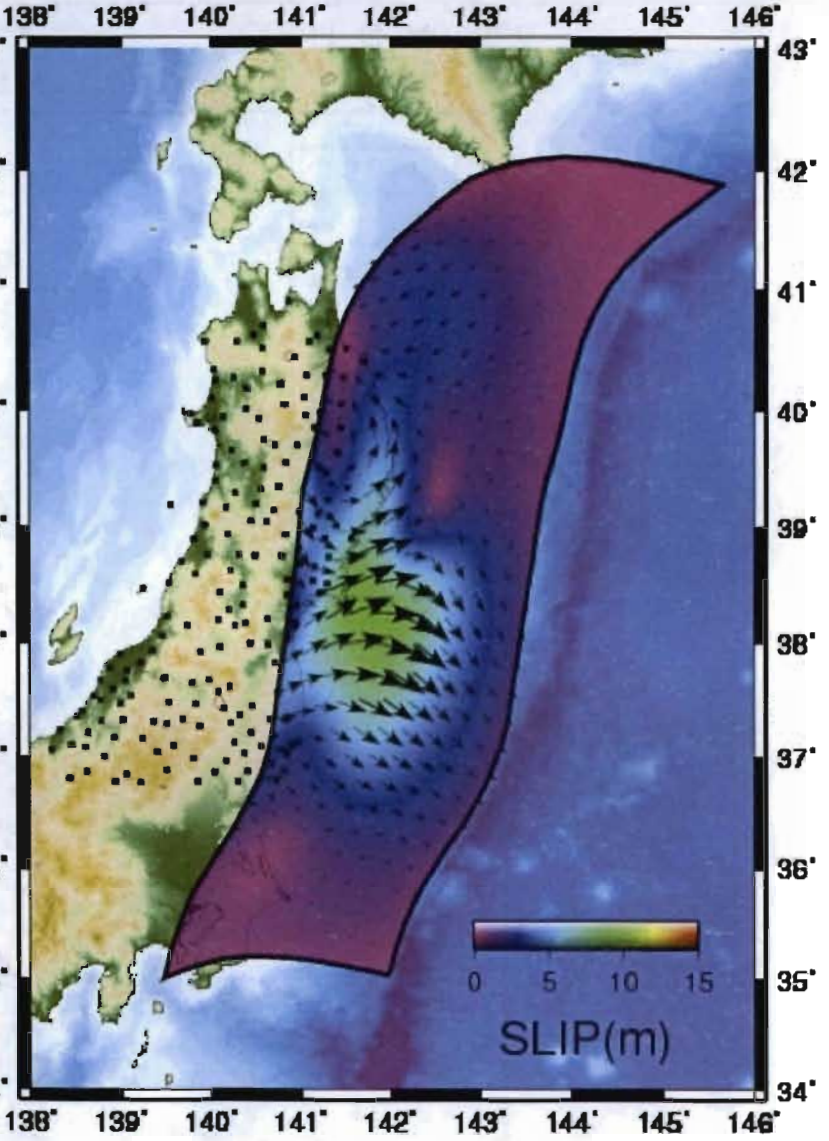


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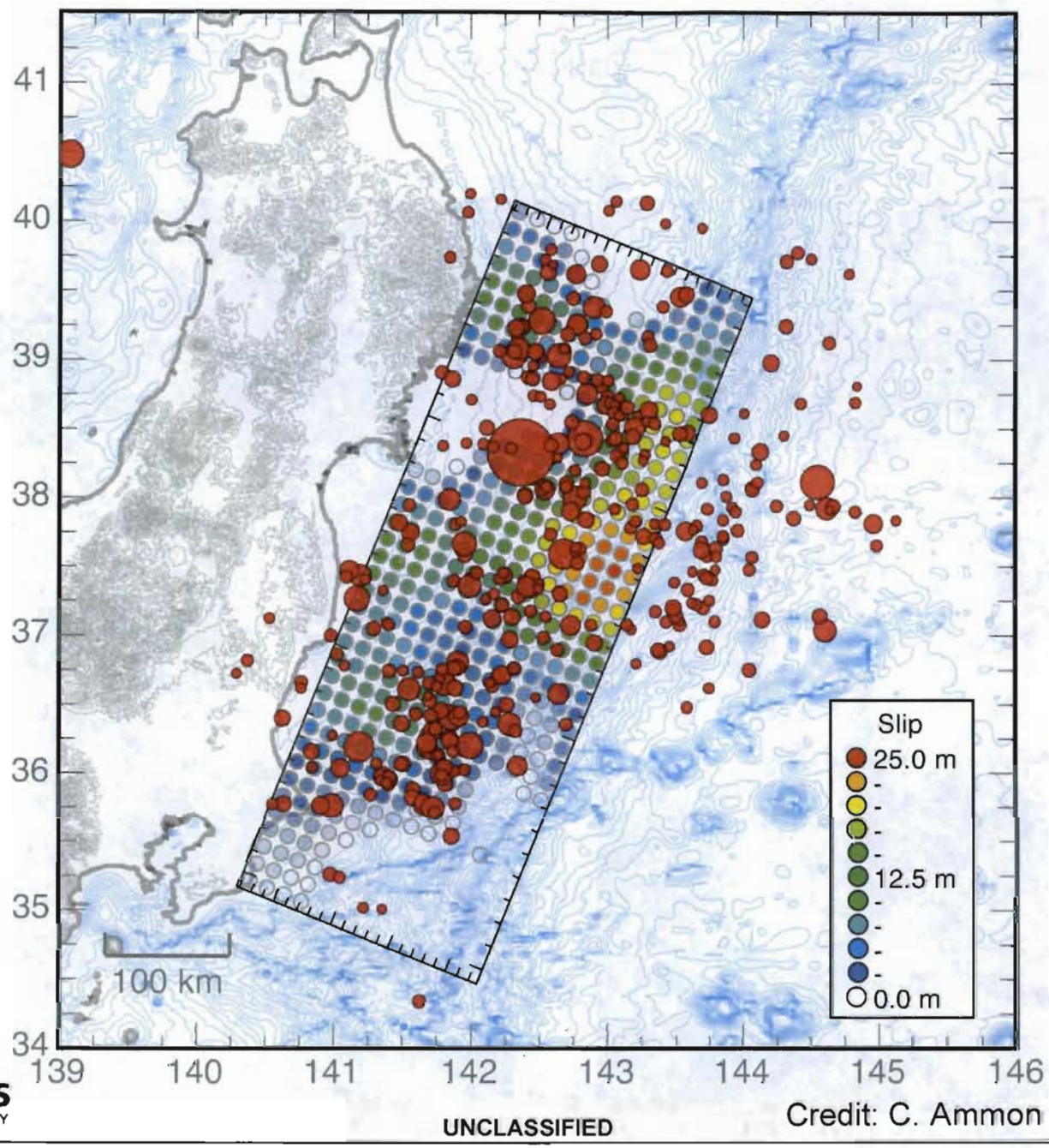
Plate Tectonics and the Earthquake



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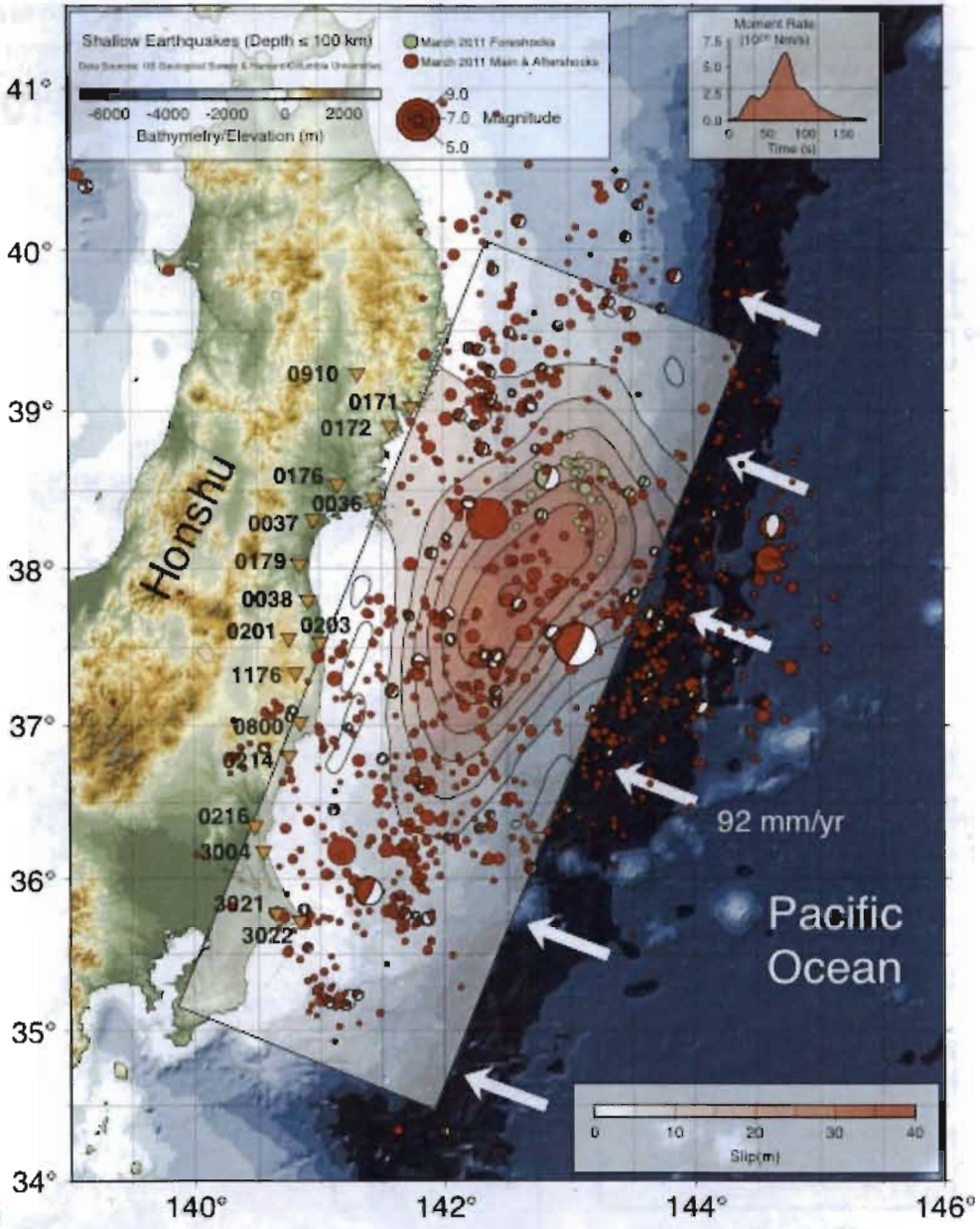
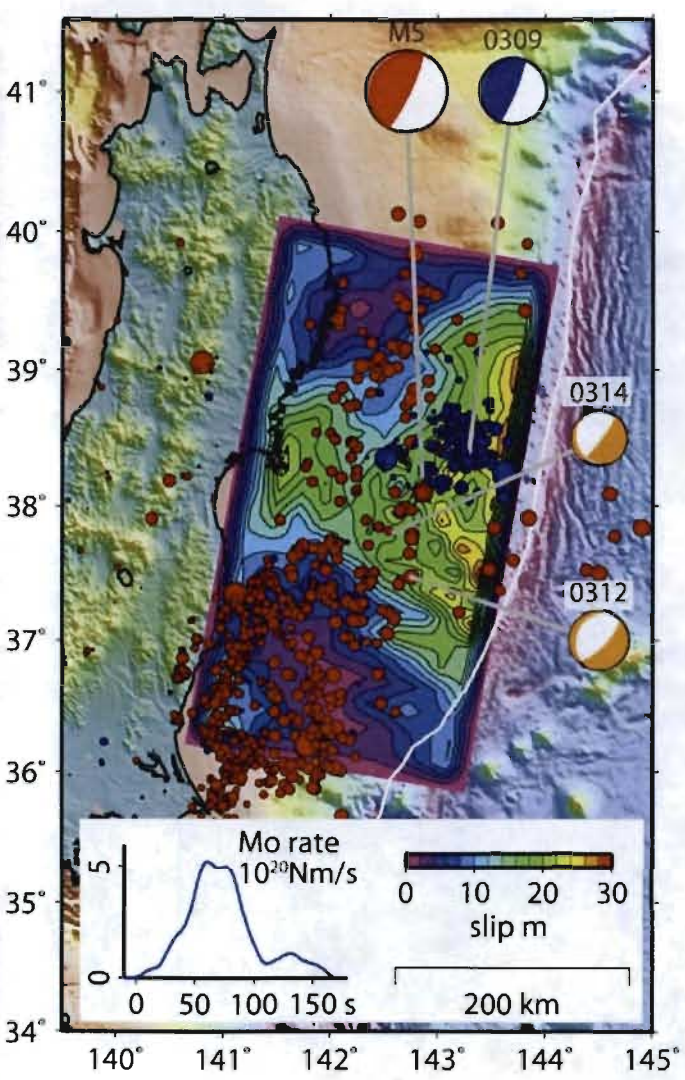
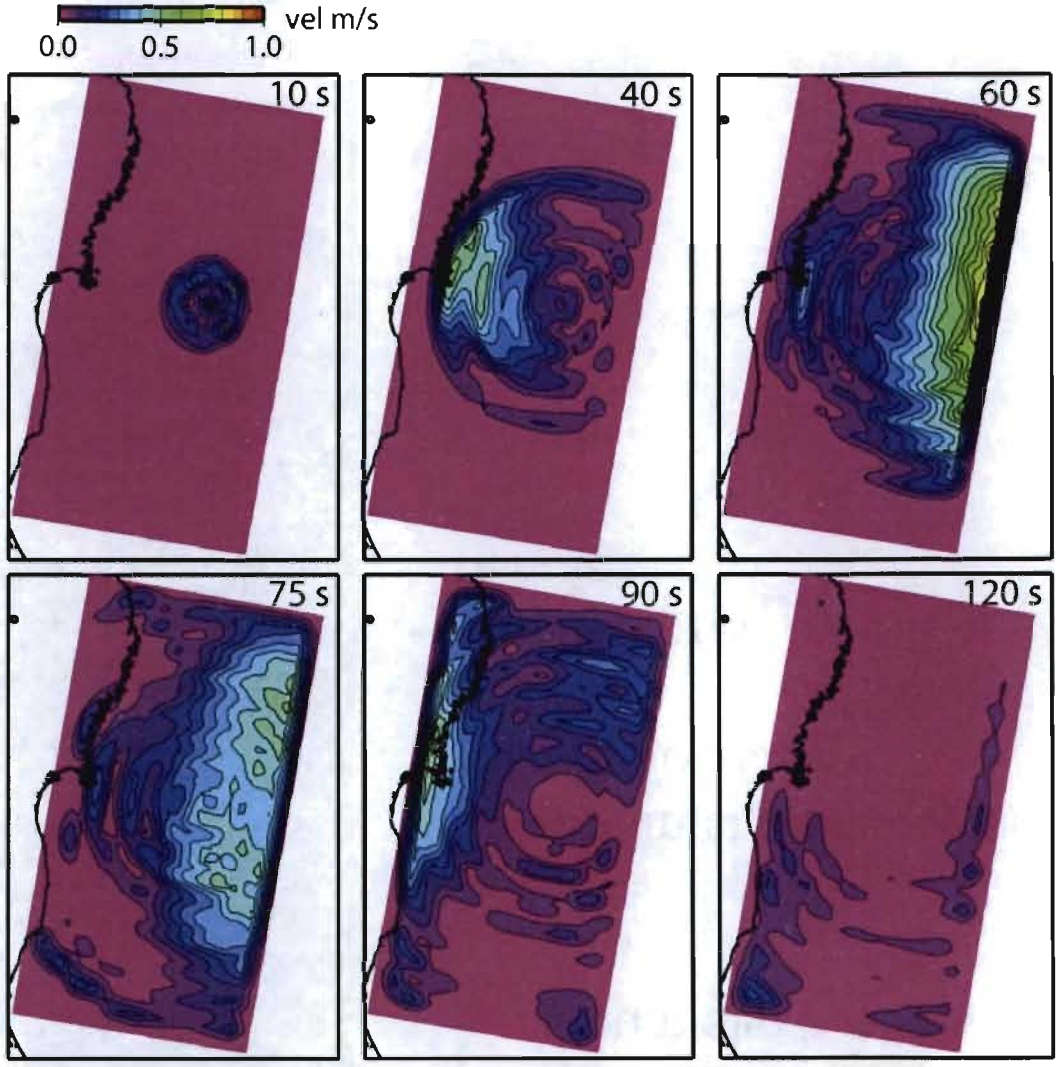


Final Slip Model

- Maximum slip > 45 m
- Maximum slip shallower than hypocenter
- Slip occurred over 3 minutes

Plate Tectonics and Earthquakes





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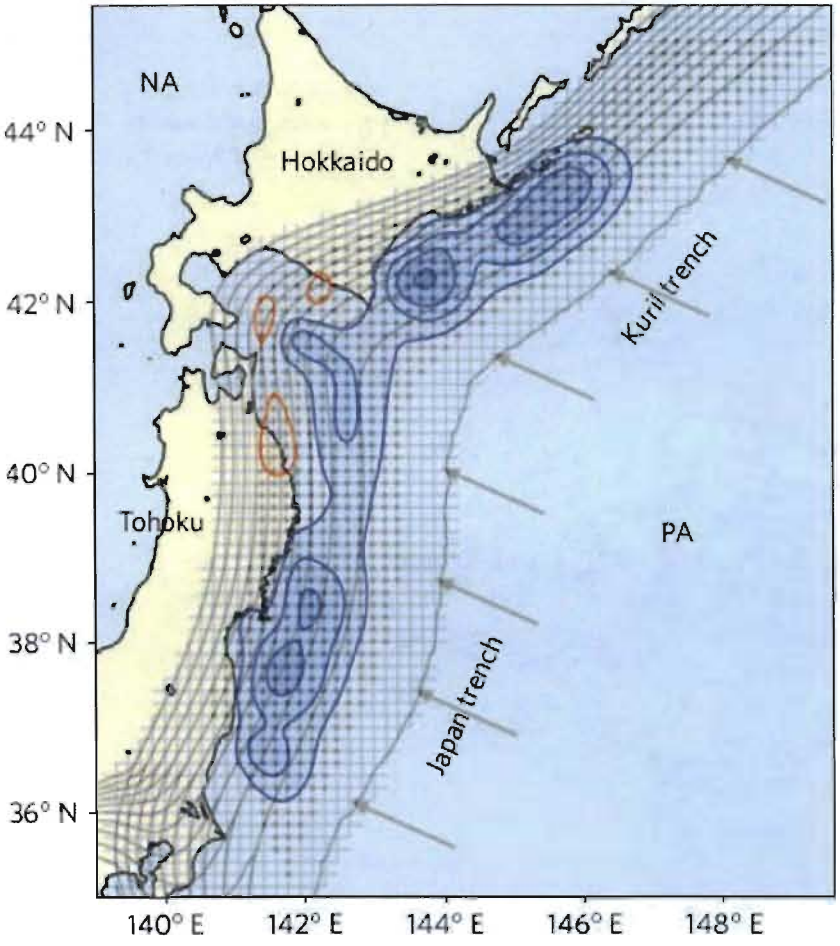
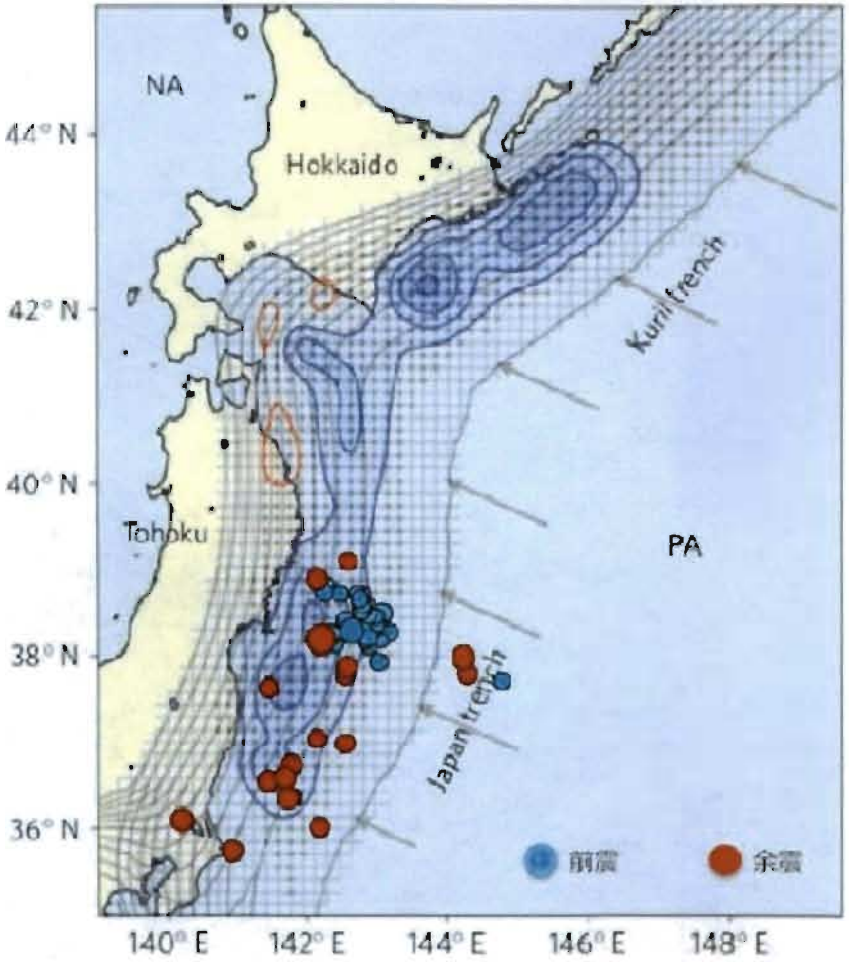
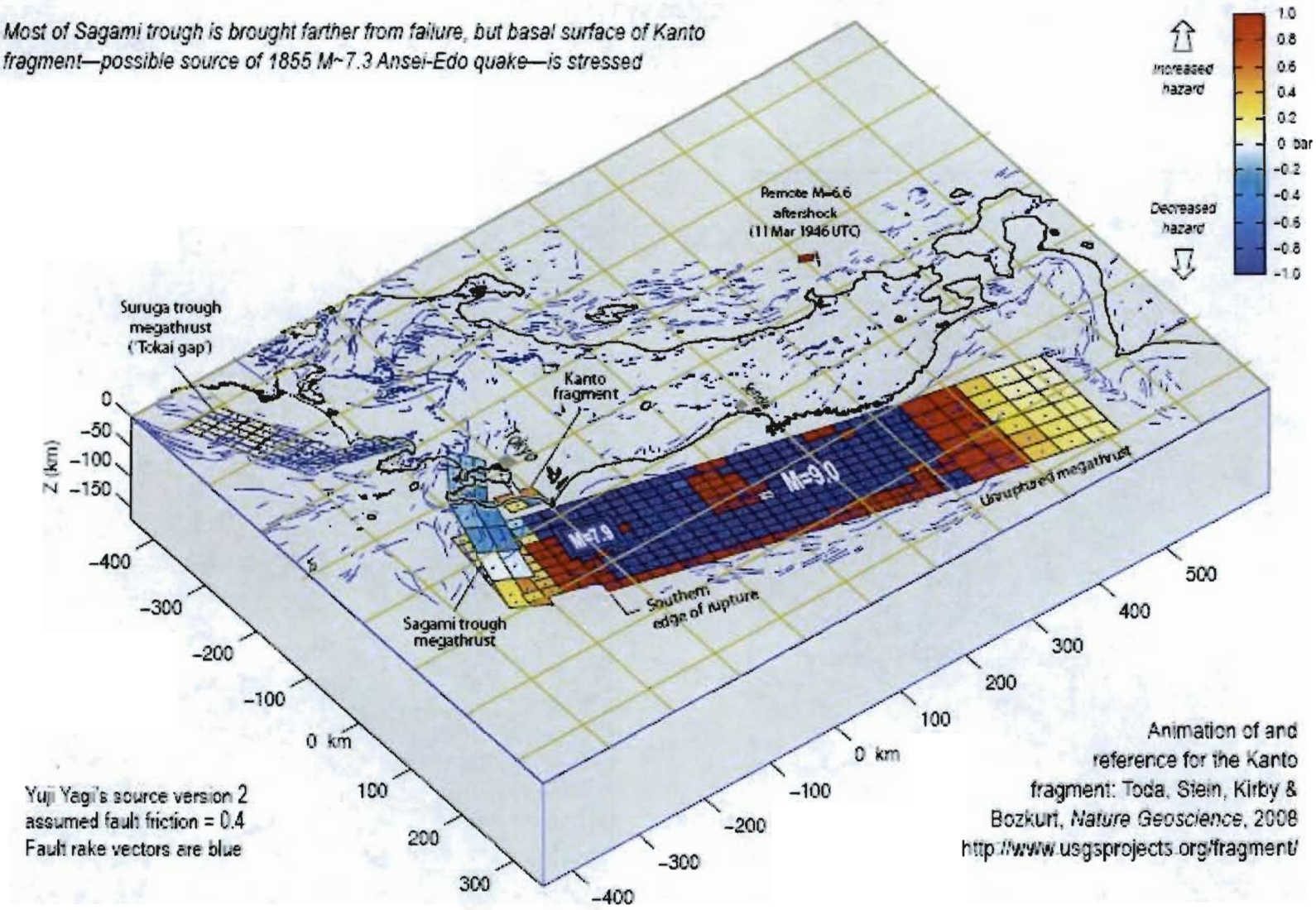
Earthquake is where it was predicted to be – but larger!





Coulomb stress imparted by the M=9.0 Off-Tohoku rupture and its M=7.9 aftershock to Japan Trench, Sagami Trough and Kanto Fragment



Ross Stein & Volkan Sevilgen (USGS) and Shinji Toda (DPRI, Kyoto Univ.) 18 Mar 2011 4:15 PM PDT

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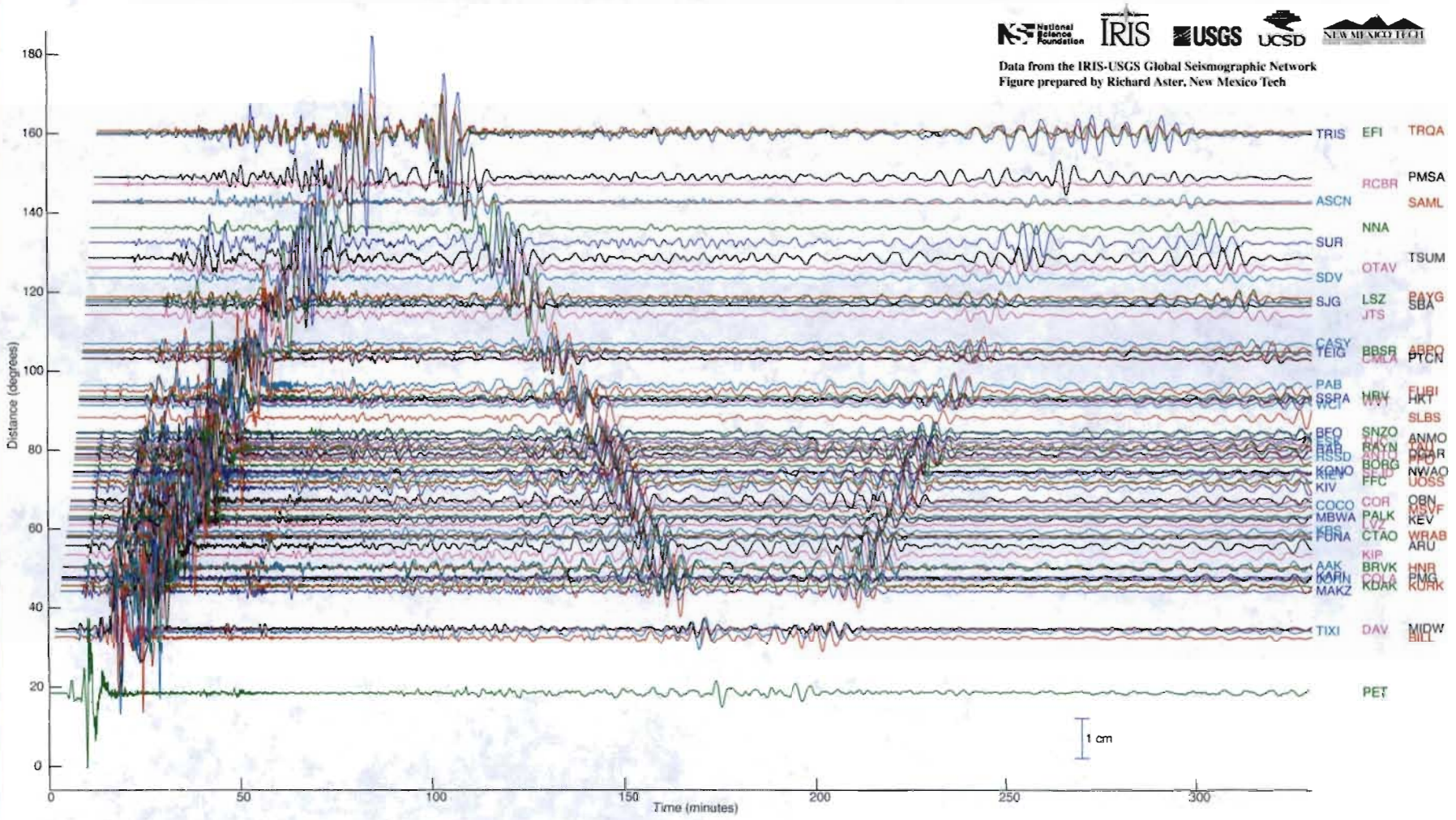
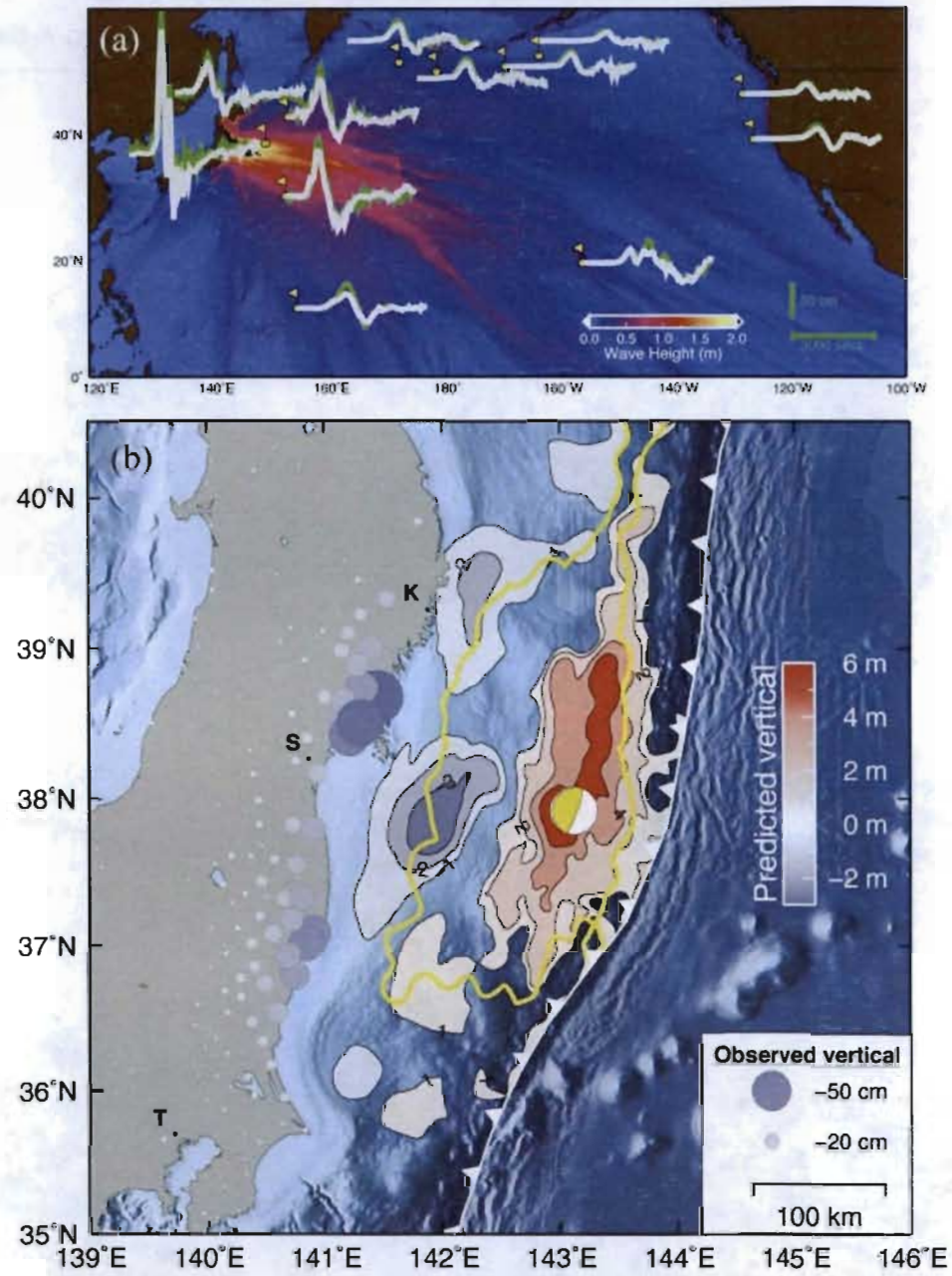
Earthquake

Japan Earthquake (M_w = 9.0), Global Displacement Wavefield



Tsunami strikes Sendai approximately 1 hr after the earthquake.

Tsunami



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Tsunami

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Tsunami

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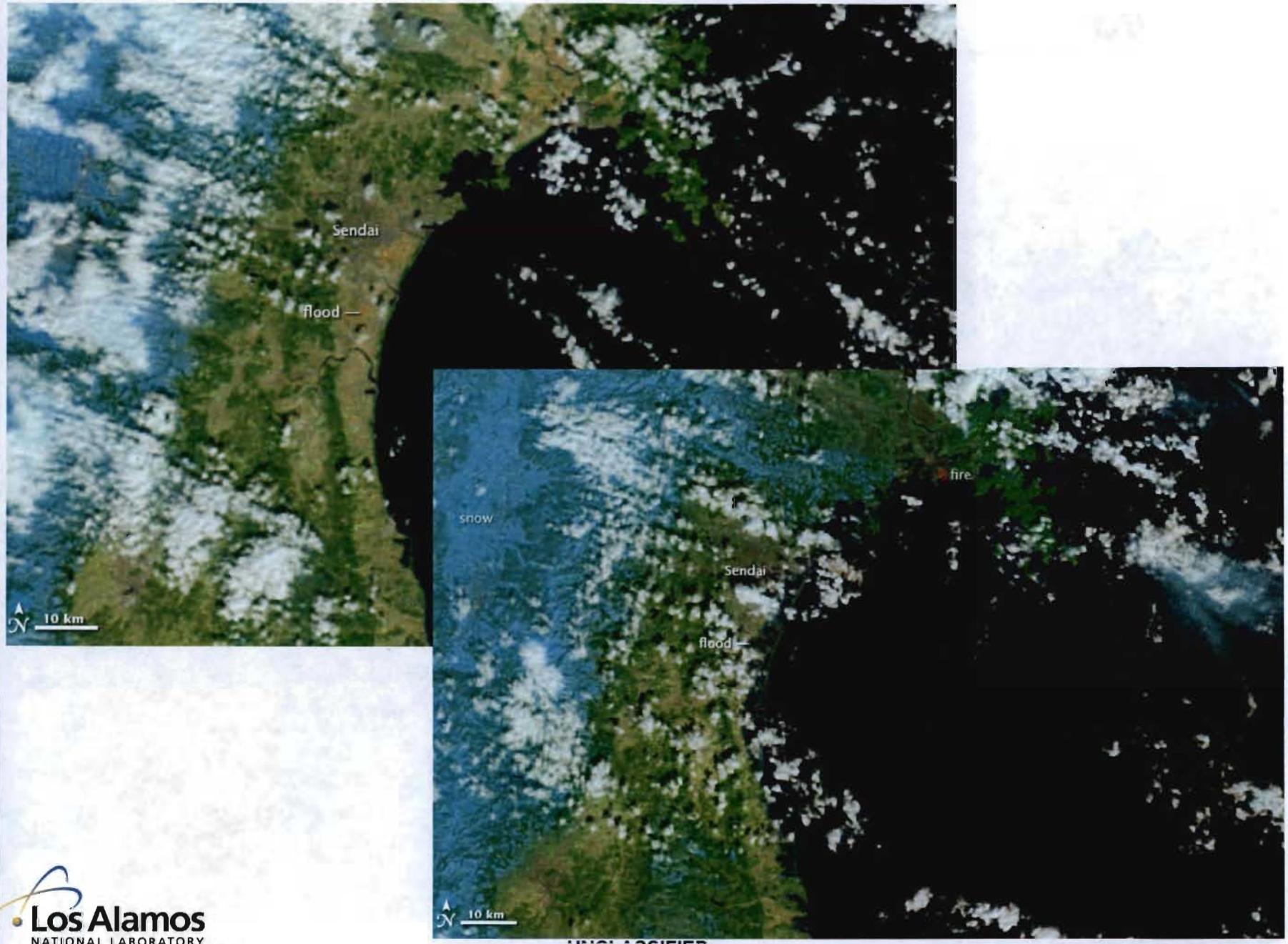
Looking NW from Epicenter of Main Quake
Sendai
Sendai 仙台
Matsushima 松島町
Shiogama
Tagajo 多賀城
Tagajō
Shichigahama
Natori 名取
Sendai Airport
© 2011 ZENRIN
© 2011 Geocentre Consulting
Data © 2011 MIRC/JHA
© 2011 Europa Technologies
©2010 Google
Imagery Date: 8/31/2008
lat 38.256358° lon 140.945011° elev 16 ft
Eye alt 49389 ft

Tsunami



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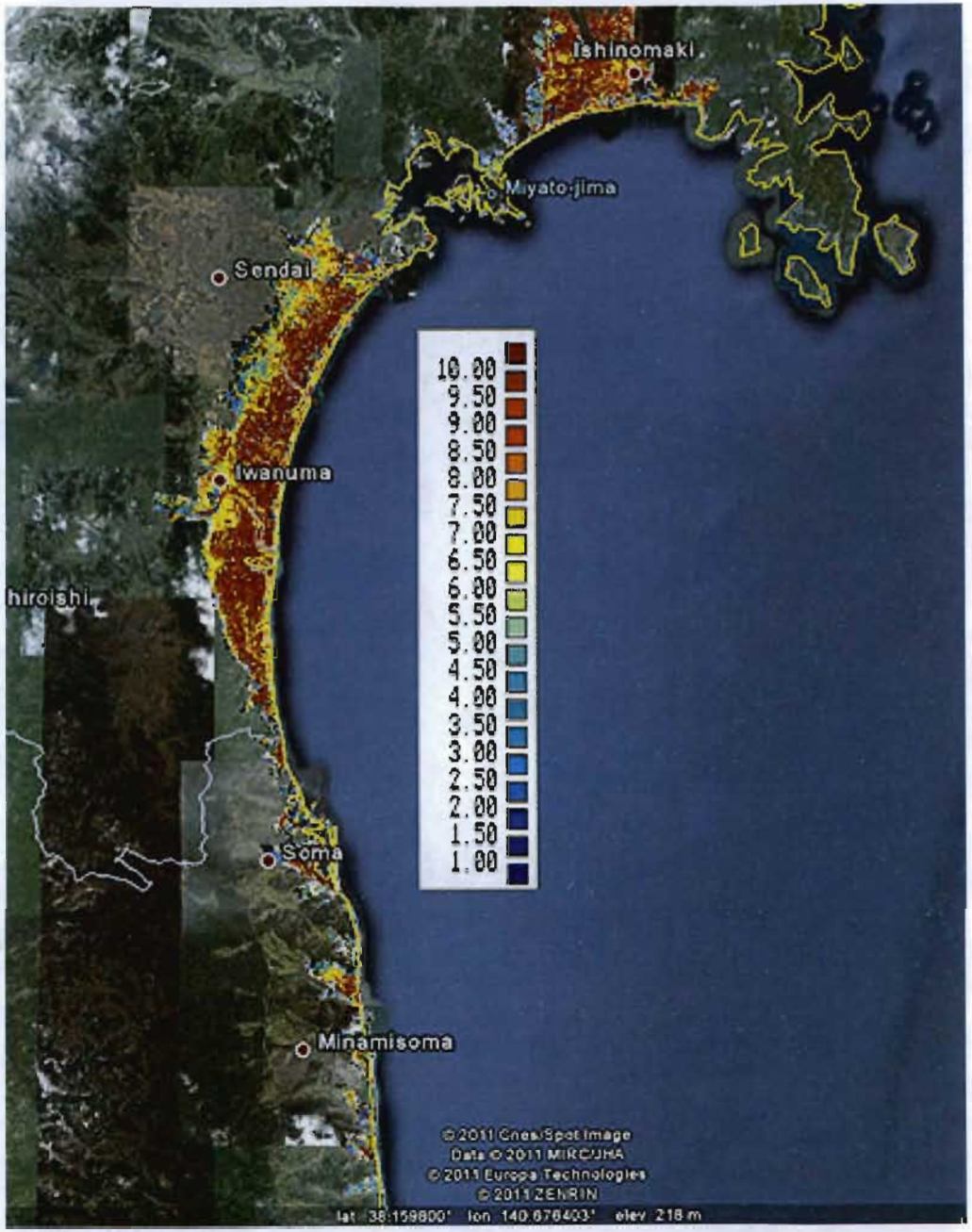
Tsunami

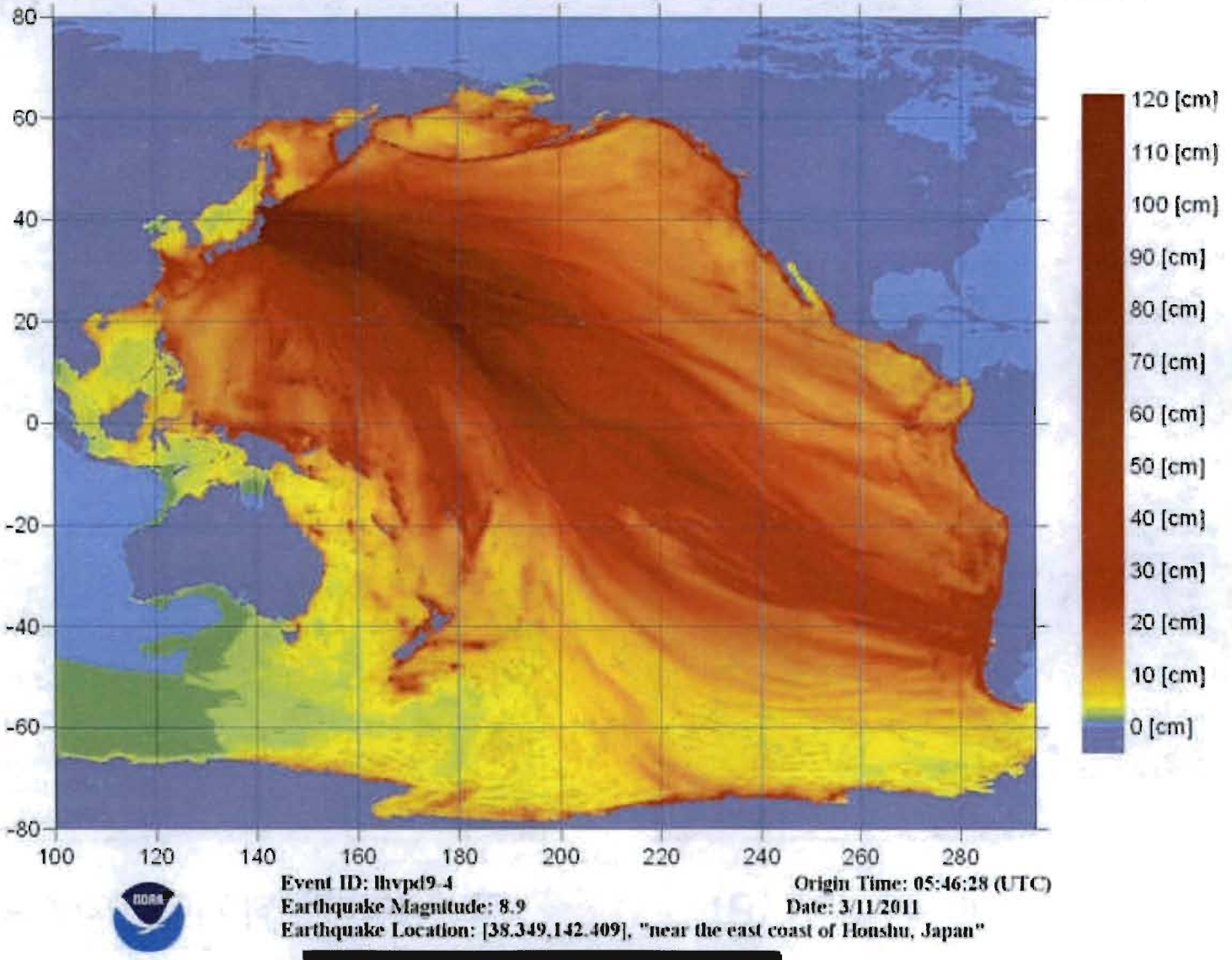
Tsunami

A model developed by Deepak Vatvani estimated the inundation (in meters) caused by the Tohoku tsunami.



Tsunami Propagation Forecast

Contours of forecasted maximum wave amplitude [cm], detailing tsunami energy propagation



West Coast and Alaska Tsunami Warning Center

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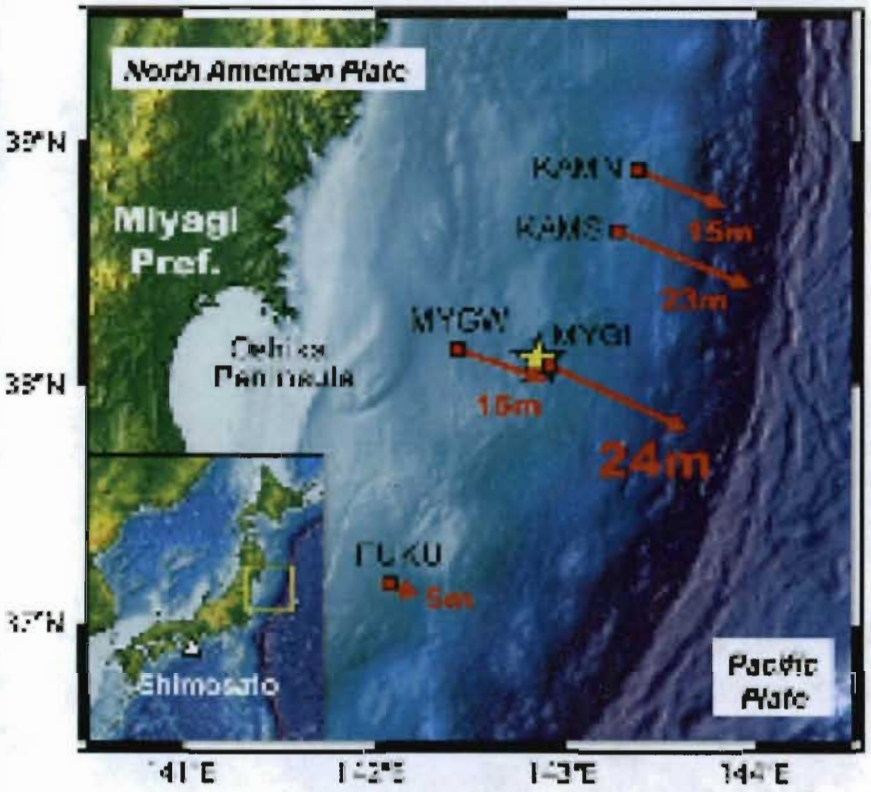
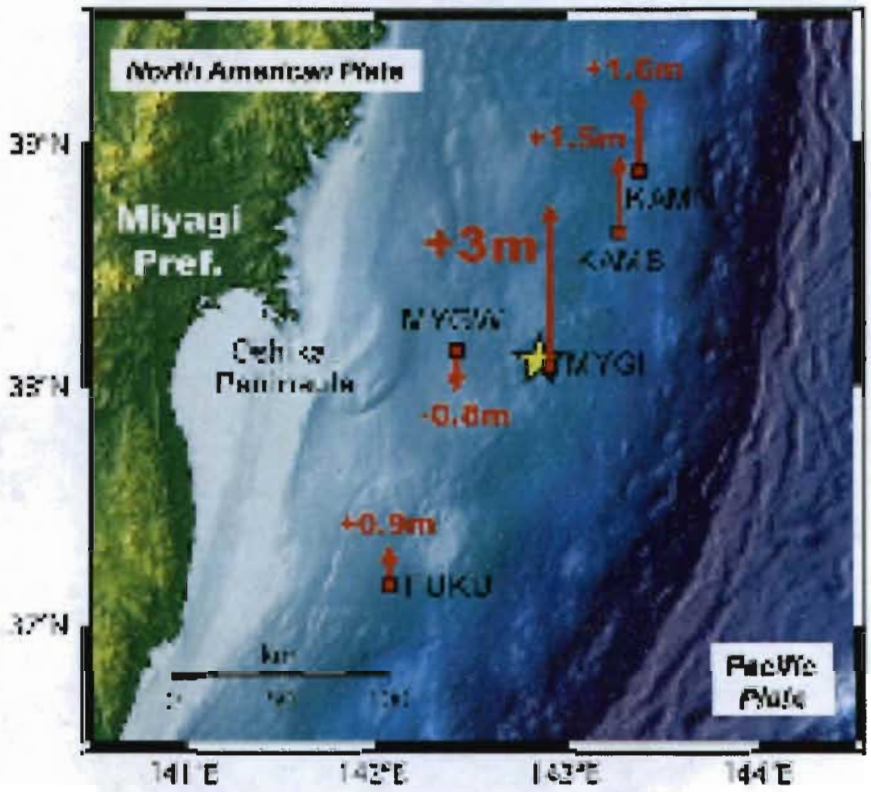
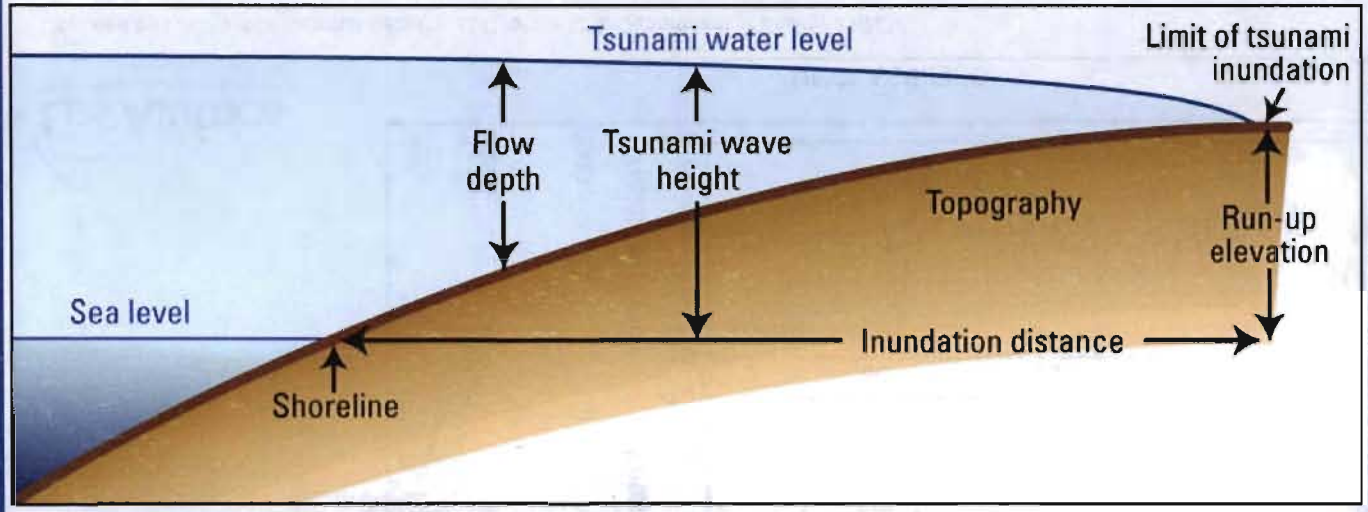
(A) Horizontal displacements



(B) Vertical displacements

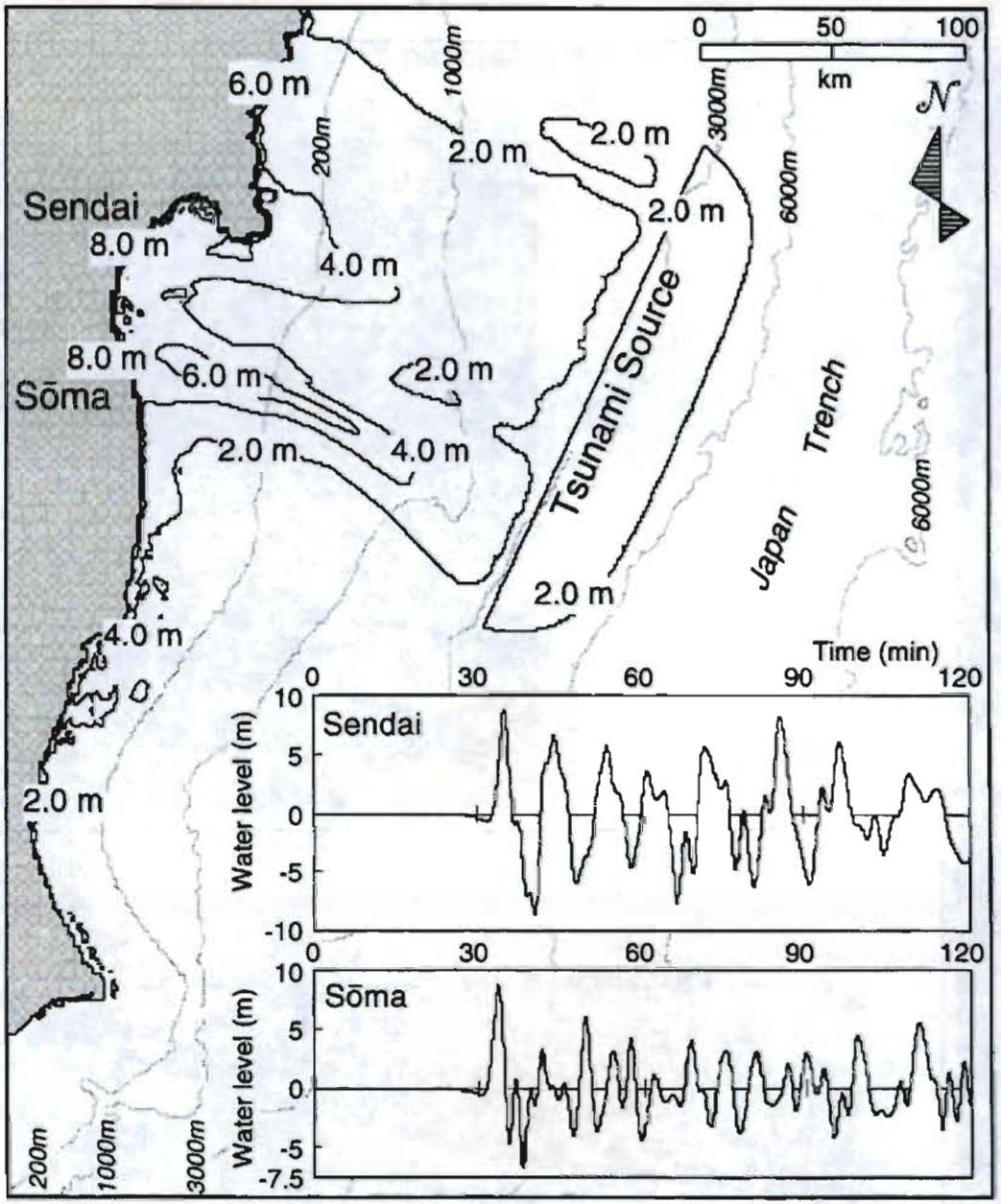




3 cm

March 11, 2011 tsunami

A.D. 869 Jōgan tsunami



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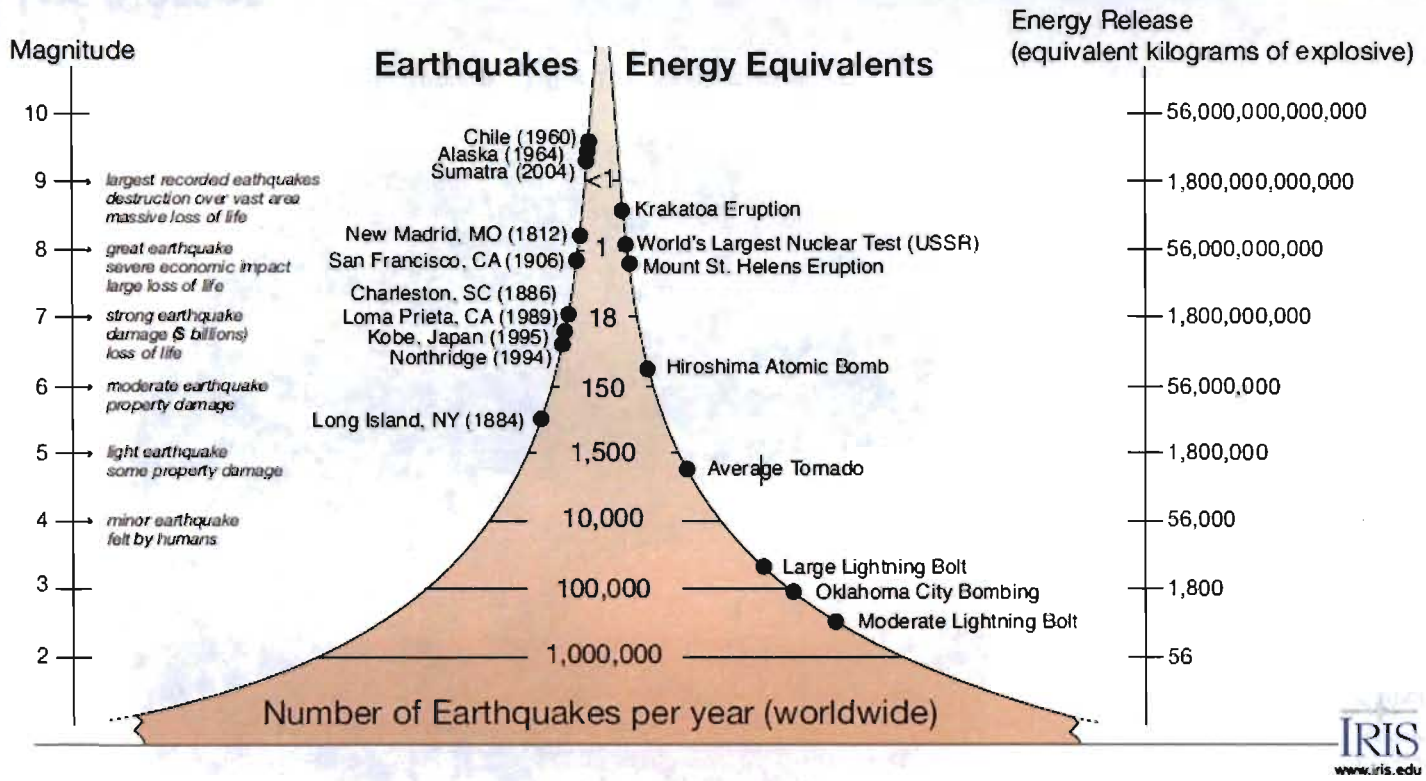
The Global Earthquake Cycle: Frequency, Magnitude and Energy

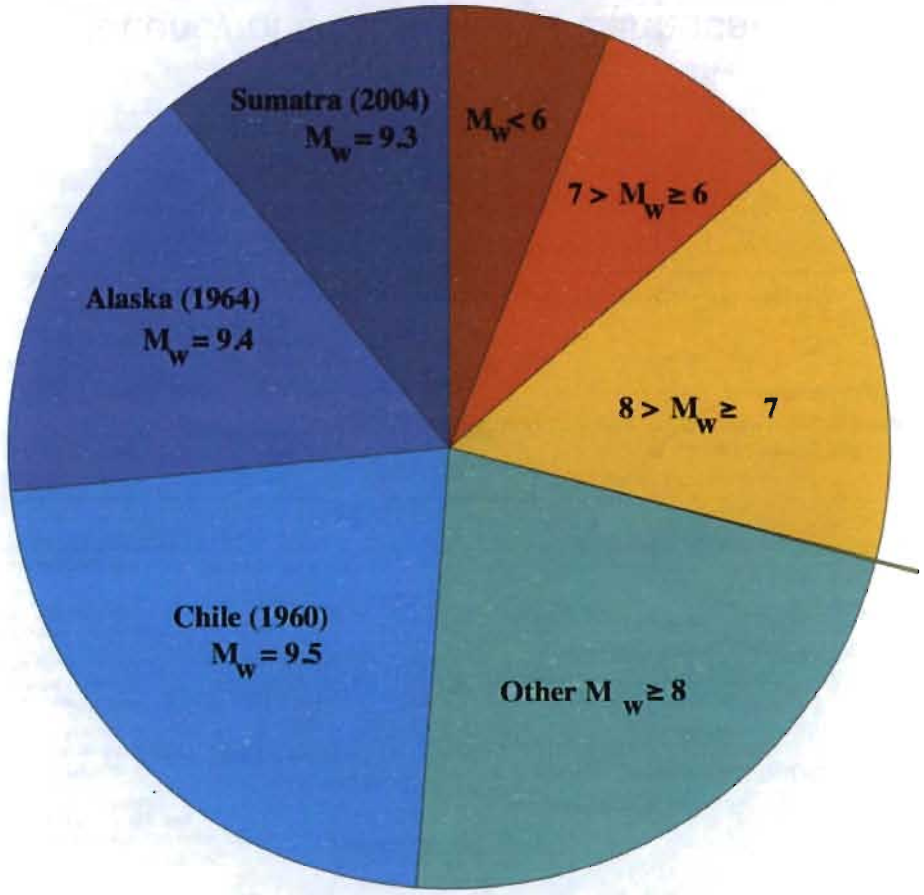


Frequency of Occurrence of Earthquakes

Magnitude	Average Annually
8 and higher	1 [1]
7 - 7.9	15 [1]
6 - 6.9	134 [2]
5 - 5.9	1319 [2]
4 - 4.9	13,000 (estimated)
3 - 3.9	130,000 (estimated)
2 - 2.9	1,300,000 (estimated)

Before Tohoku, the seismic moment and energy was dominated by 3 earthquakes.

Global Seismic Moment Release January 1906 - December 2005



Total Moment: 1.0×10^{24} Newton-meters

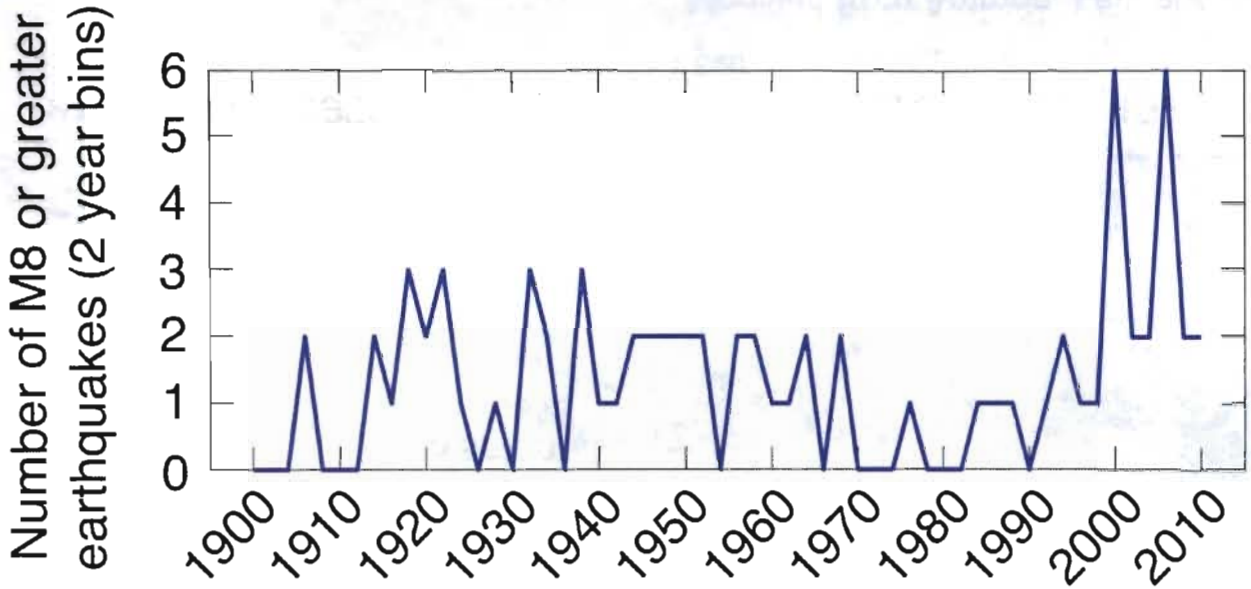
Largest quakes

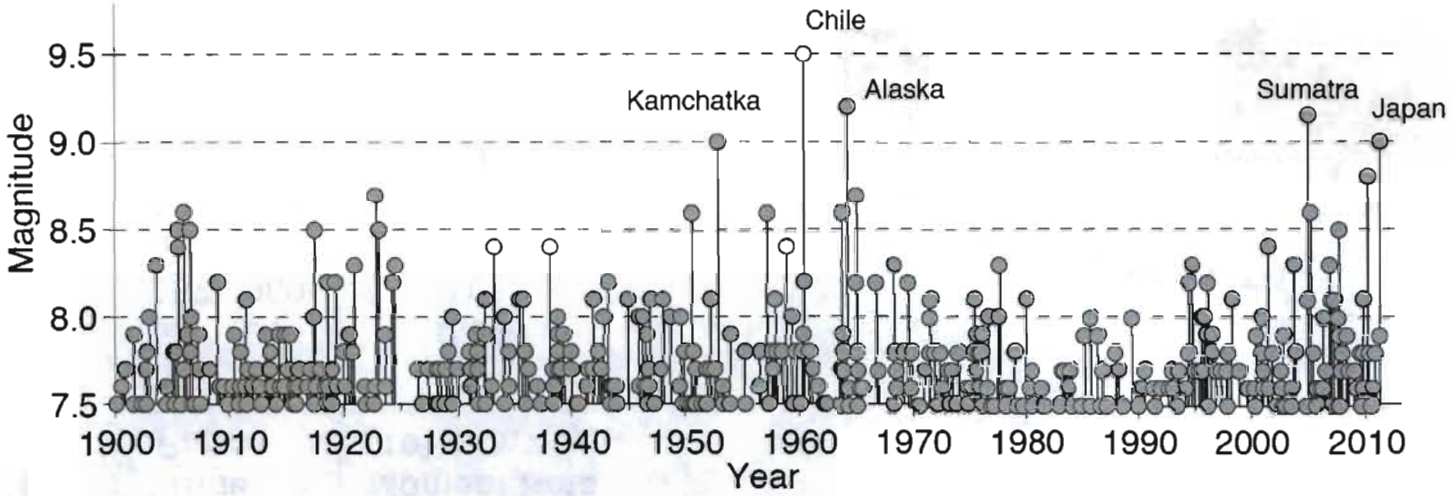
The world's highest-magnitude earthquakes since 1900:

Location	Year	Mag.
Chile	1960	9.5
Prince William Sound, Alaska	1964	9.2
Off coast of Northern Sumatra	2004	9.1
Kamchatka, Russia	1952	9.0
Honshu Coast, Japan	2011	8.9
Off coast of Ecuador	1906	8.8
Chile	2010	8.8
Rat Islands, Alaska	1965	8.7
Northern Sumatra, Indonesia	2005	8.6
Assam, Tibet	1950	8.6
Andreanof Islands, Alaska	1957	8.6
Southern Sumatra, Indonesia	2007	8.5
Banda Sea, Indonesia	1938	8.5
Kamchatka, Russia	1923	8.5
Chile-Argentina border	1922	8.5

Source: U.S. Geological Survey

Earthquakes >M8 since 1900

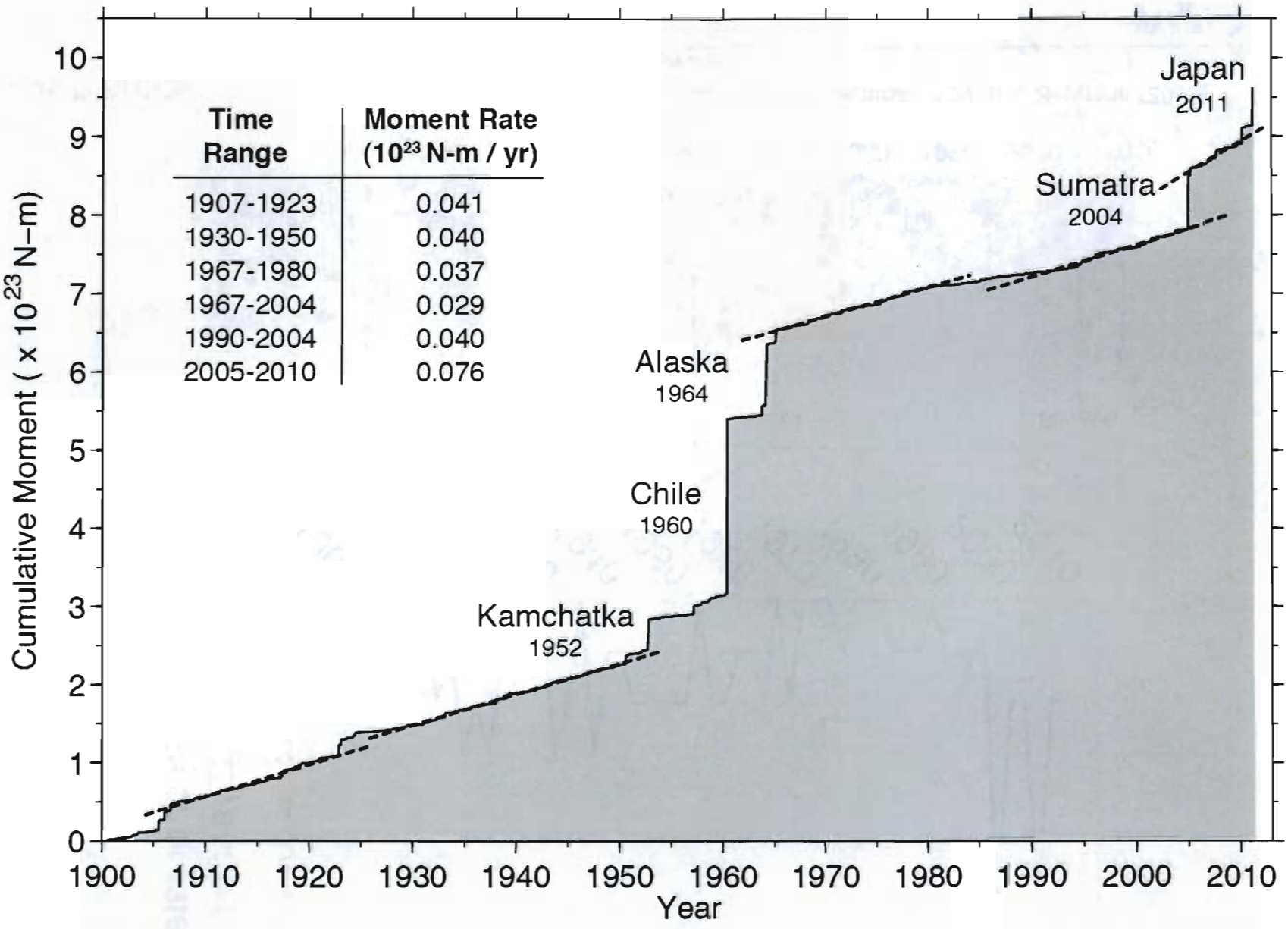




Modified from Ammon, Lay, and Simpson (2010)

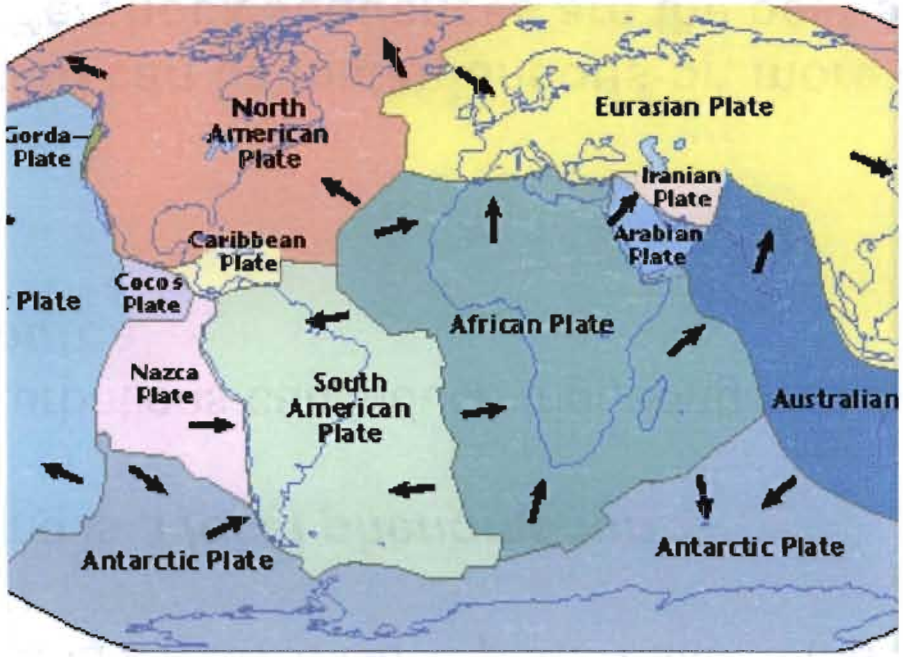
Global Earthquake Cycle

Time Range	Moment Rate (10^{23} N-m / yr)
1907-1923	0.041
1930-1950	0.040
1967-1980	0.037
1967-2004	0.029
1990-2004	0.040
2005-2010	0.076



Modified from Ammon, Lay, and Simpson (2010)

The plate-tectonic paradigm of Earth is based on plates sliding past each other driven by mantle processes. Stress builds up and Coulomb failure creates and earthquake.



The new paradigm is based on long range interactions between faults – Earth as elastic system. An earthquake can affect faults far away.

Earthquake Triggering

- Earthquakes and other types of slip events can be triggered by static stress changes (earthquake, tides, reservoir filling, fluid pumping into boreholes…) and dynamic wave perturbations (seismic waves).
- Static triggering is a ***local phenomenon***.
- Dynamic perturbations can induce triggering ***nearby or far from the triggering source***.

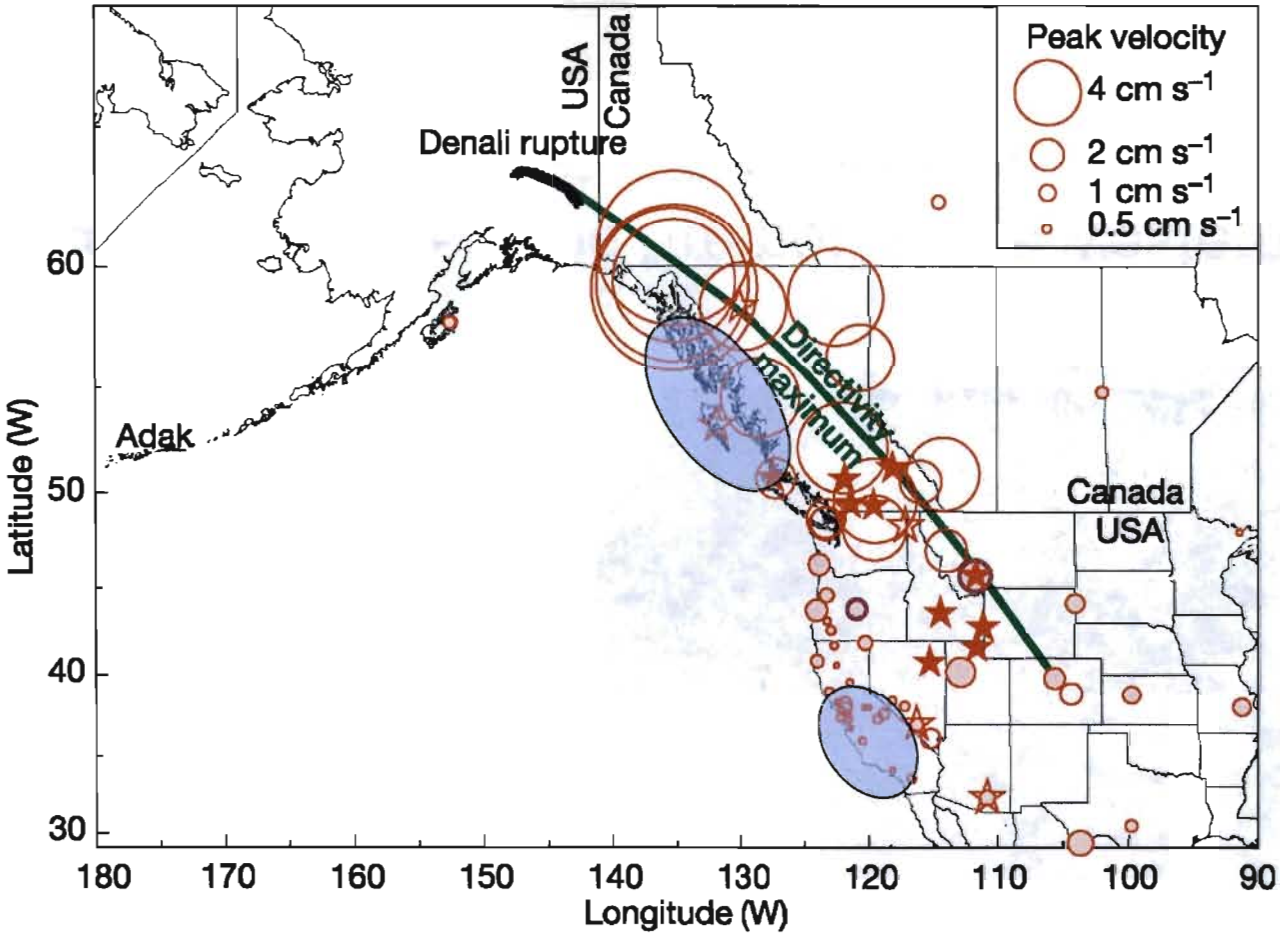
All triggering can be instantaneous or, more often delayed – aftershock sequences are the best example.

A Dynamic Earthquake Triggering Scenario

2002 M = 7.4 Denali earthquake

Triggered tremor

Triggered earthquake



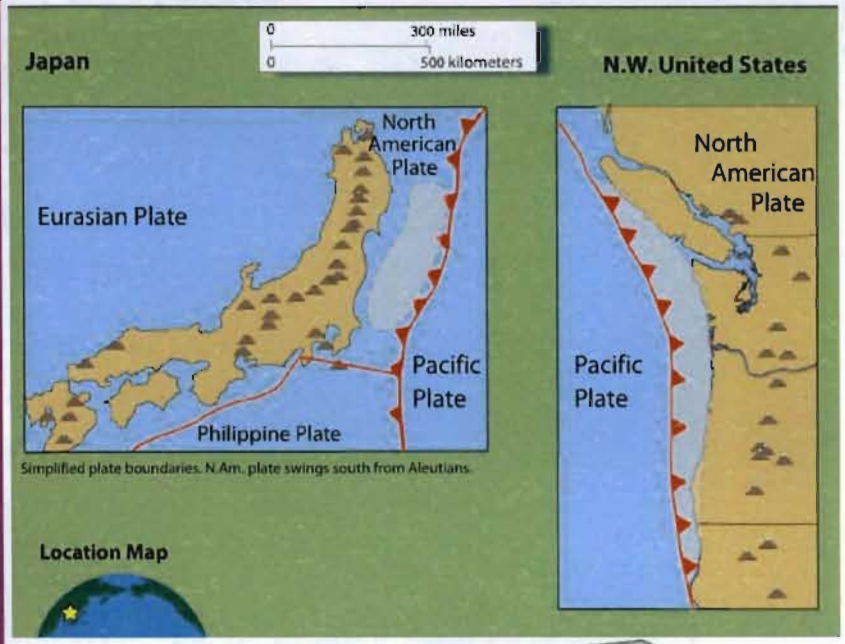
Modified from Gomberg et al., ***Nature*** (2004) + Gomberg et al., ***Nature*** (2008)

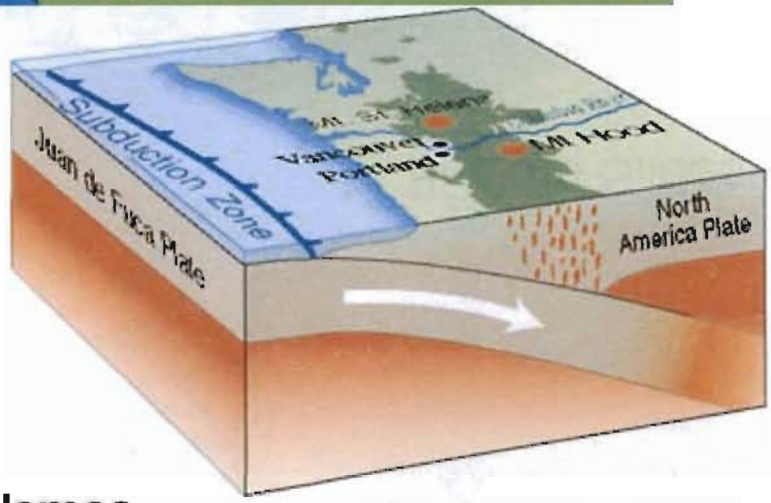
Dynamic Wave Triggering of other Natural Phenomena

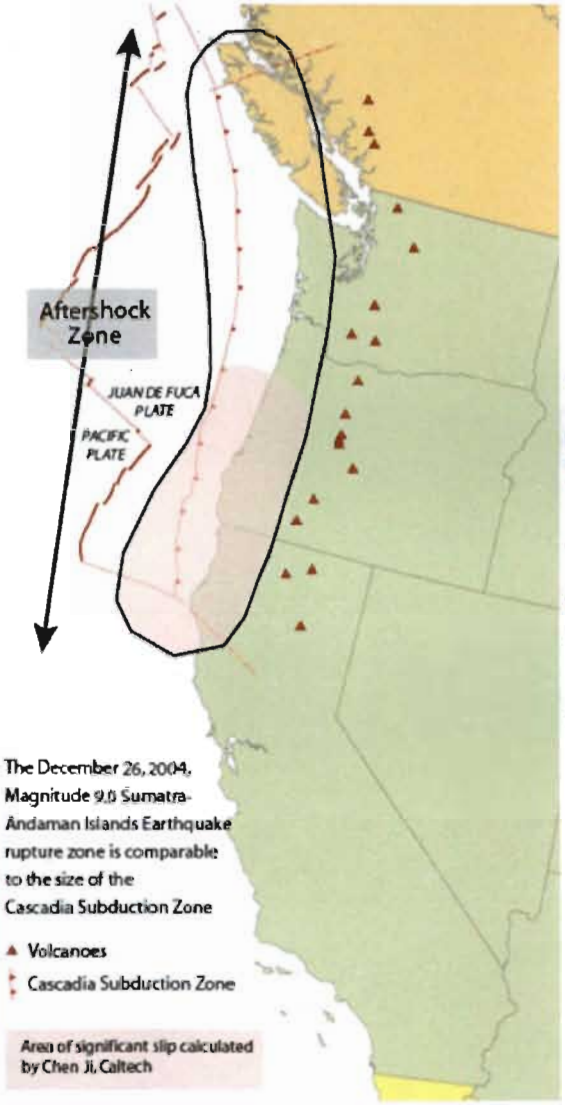
- Japan earthquake triggered volcano eruption In Russia? (*as yet unsubstantiated*)

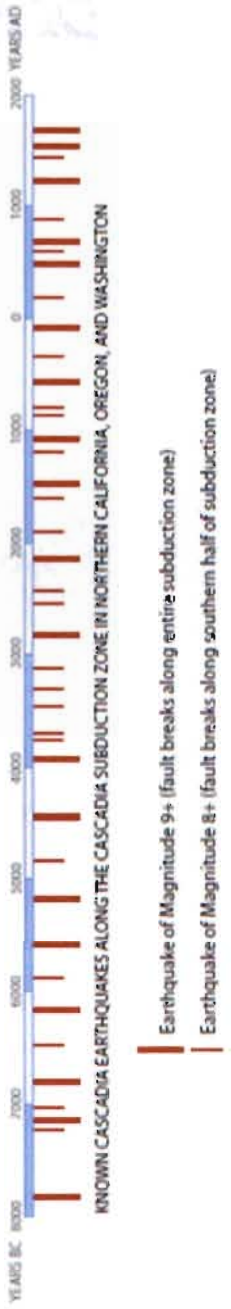
- Triggering of small earthquakes and "tremor" in the western US reported, but details are not yet available (Joan Gomberg, USGS Seattle Office).

Similar Characteristics in the Pacific Northwest



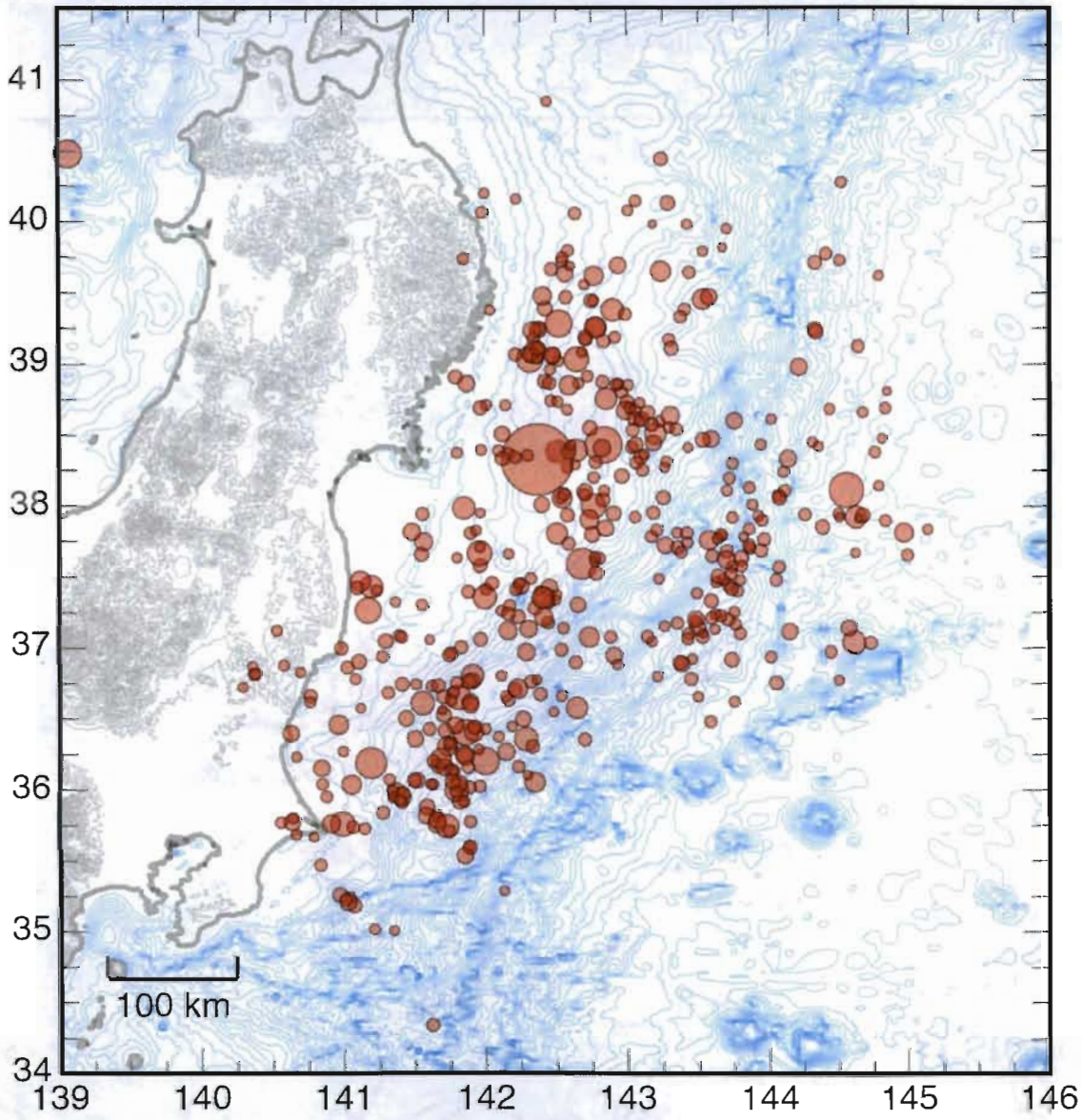






Backup Slides

Aftershocks: March 11-15



Credit: C. Ammon

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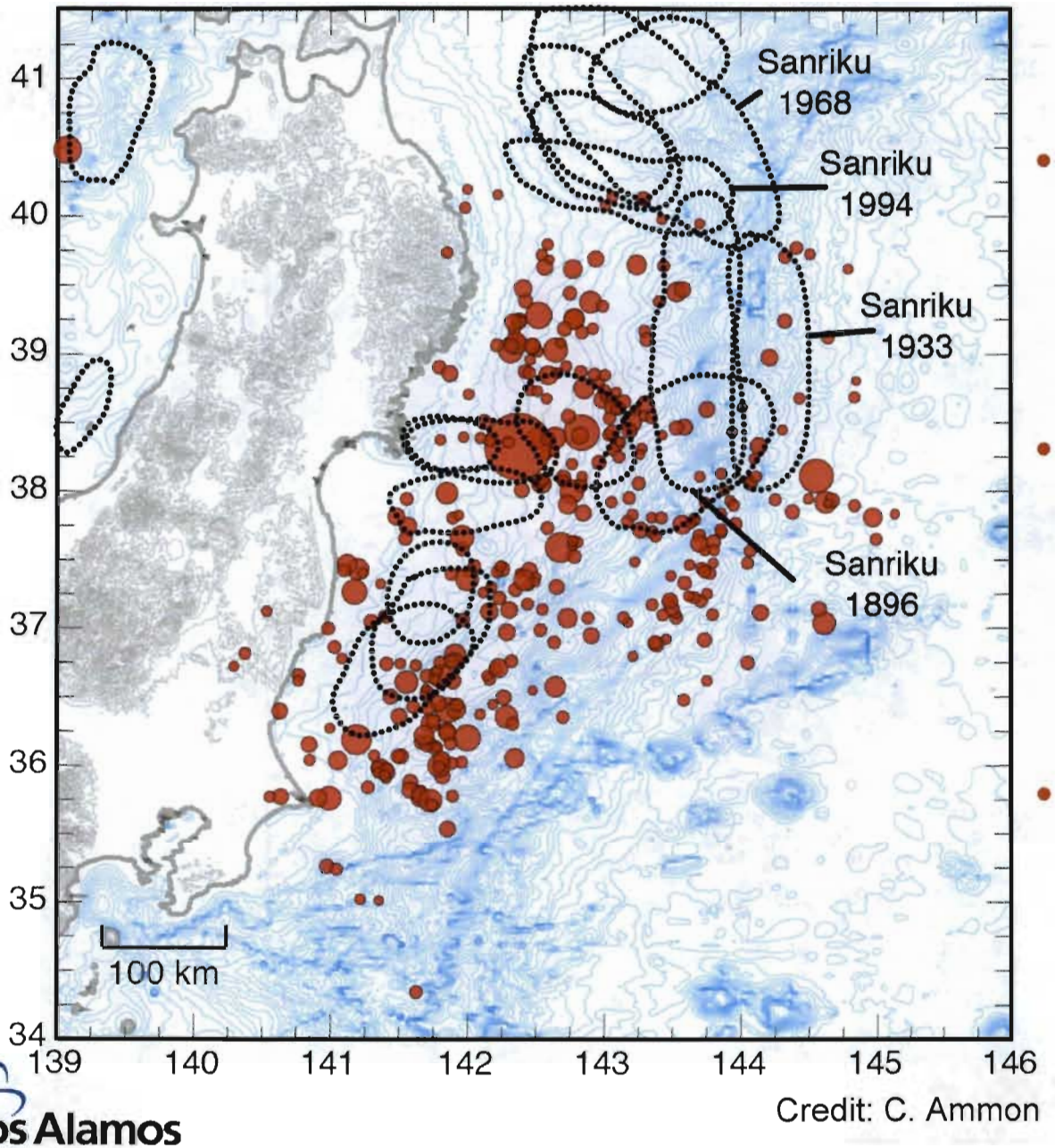
Earthquakes



Credit: C. Ammon

- Historic seismicity has been been magnitude 7.
- Larger earthquakes (> 8.0) have occurred to the north.
- This earthquake is a repeat of one in 869 AD.

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