POLITECNICO DI MILANO





Il terremoto del Giappone dell'11 marzo 2011

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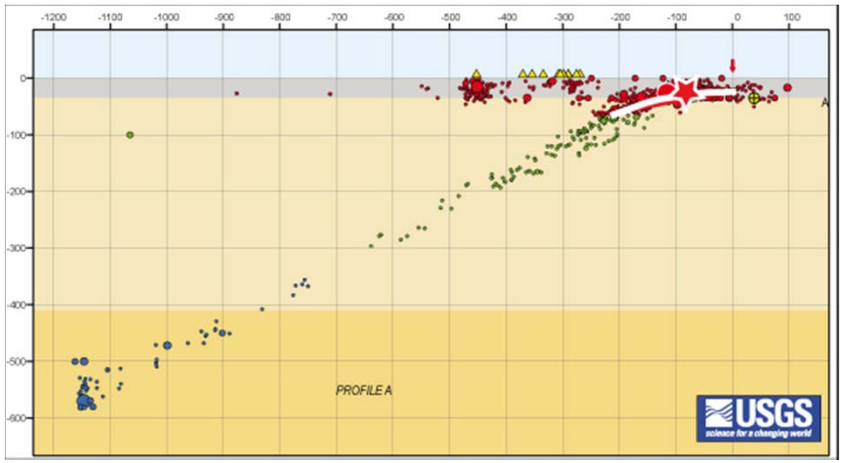
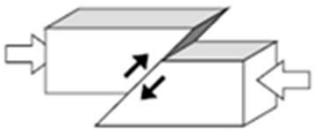
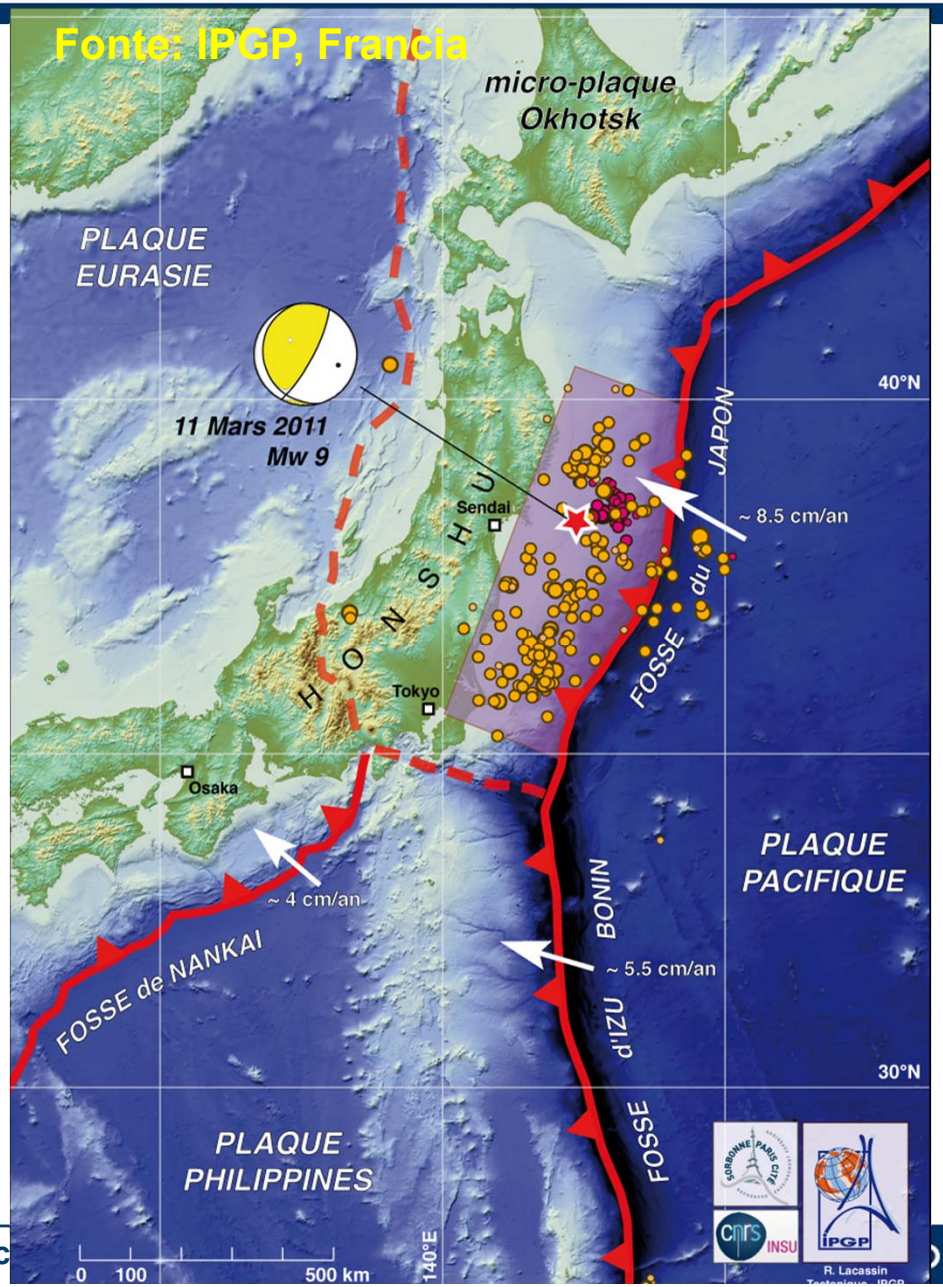
Che cosa è avvenuto?

Il mega-terremoto di Tohoku (11/3/2011, M_w 9.0)

Il terremoto ha avuto origine nella zona di subduzione della zolla pacifica al di sotto della zolla euroasiatica (fossa del Giappone). La velocità di subduzione è dell'ordine di ~ 10 cm/anno. La dimensione stimata per l'area di faglia è 500x250 km^2.

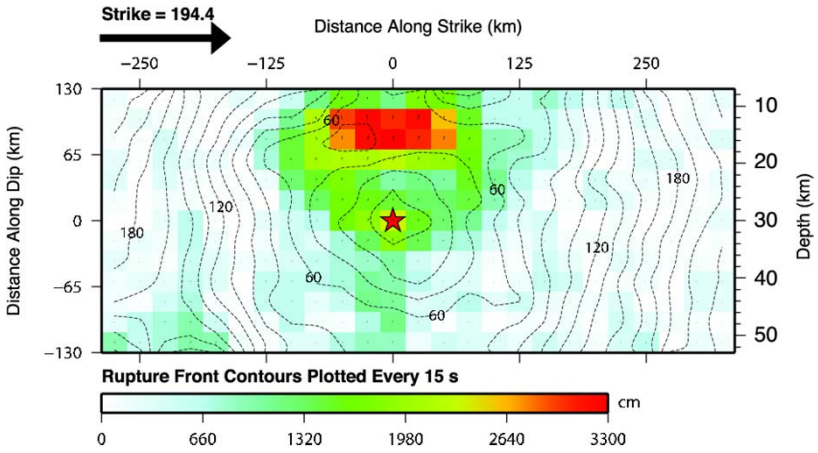


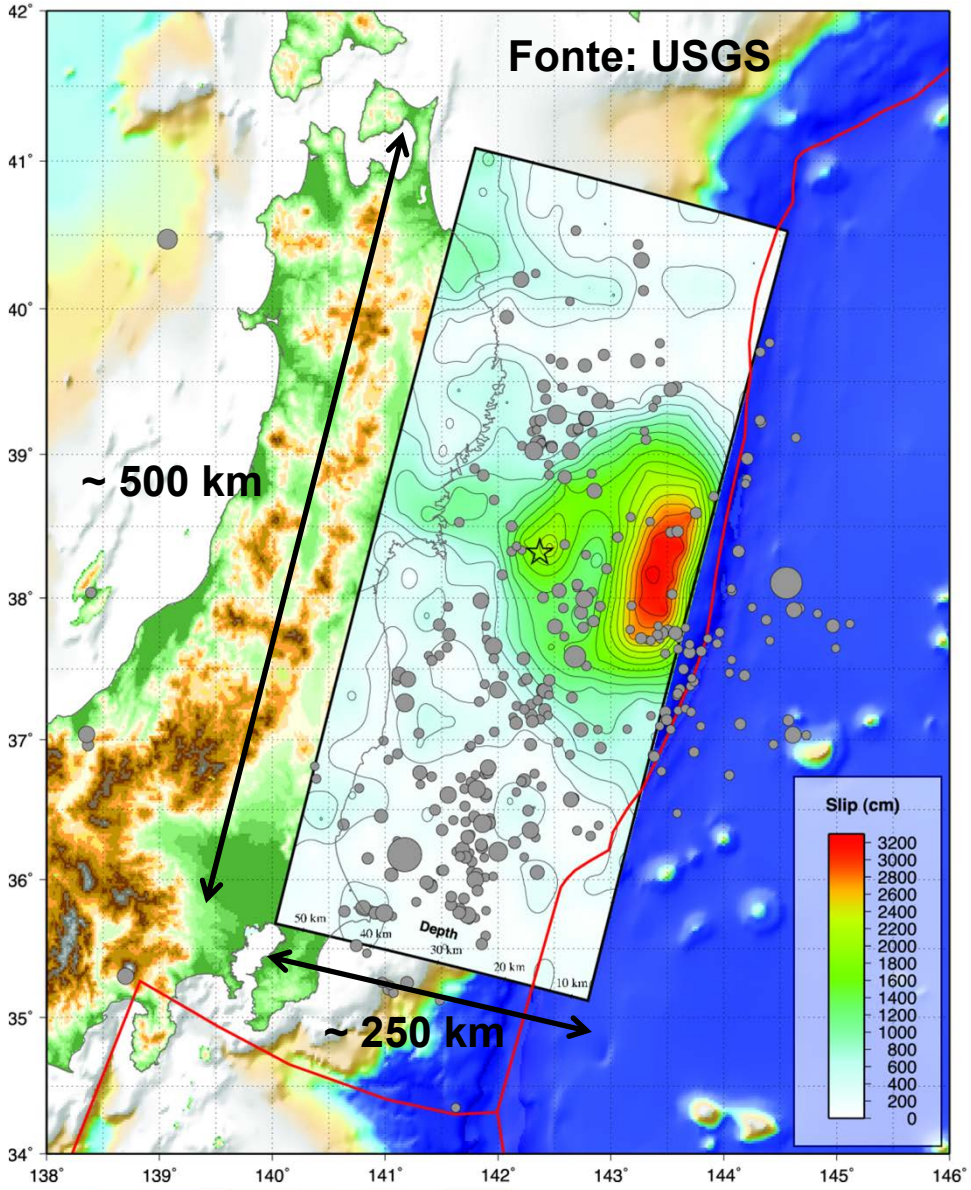




Il mega-terremoto di Tohoku (11/3/2011, M_w 9.0)

Modello della sorgente sismica (USGS)





Mega-terremoti dai grandi margini di subduzione

da Mc Caffrey, *Global frequency of magnitude 9 earthquakes*, Geology, 2008

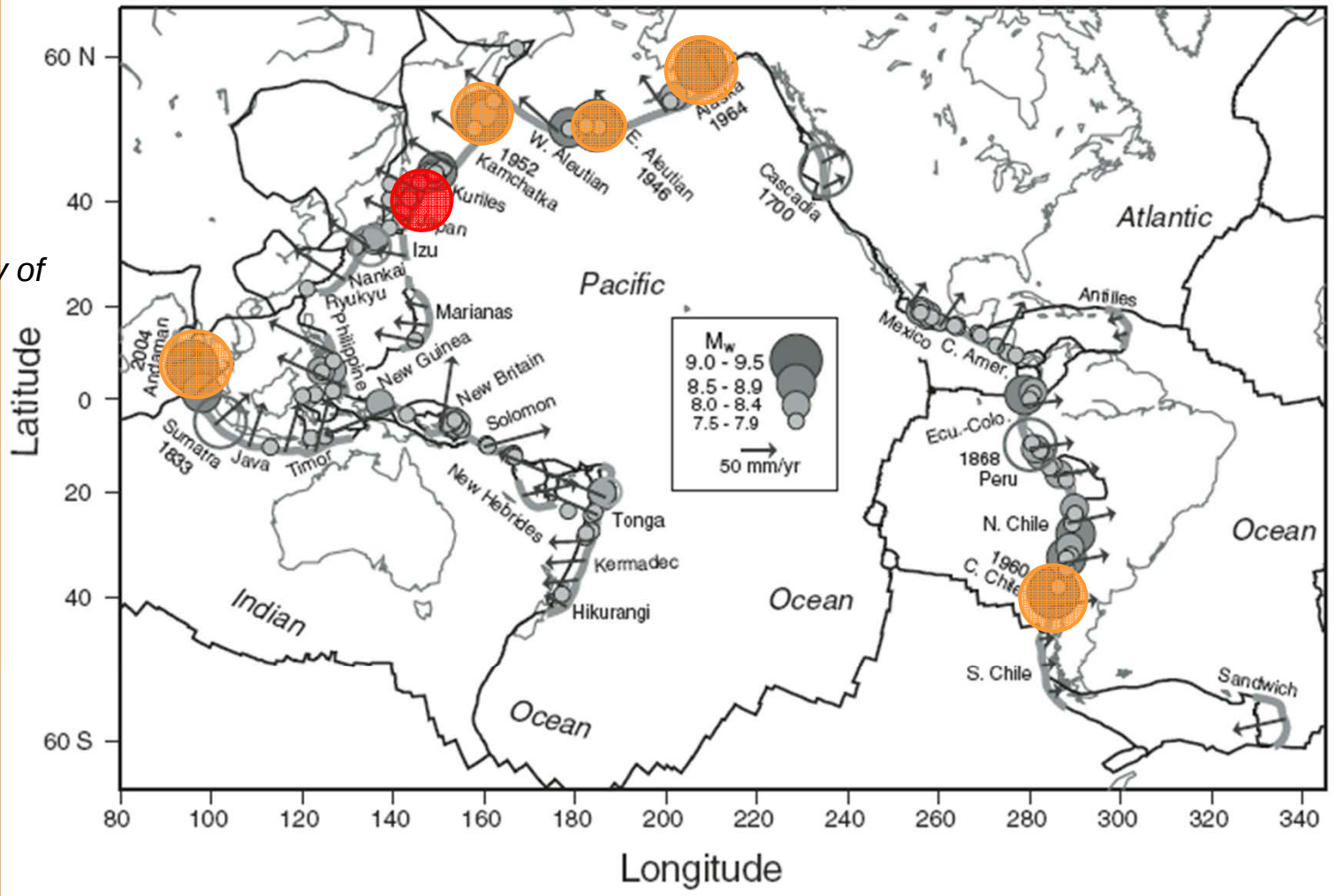
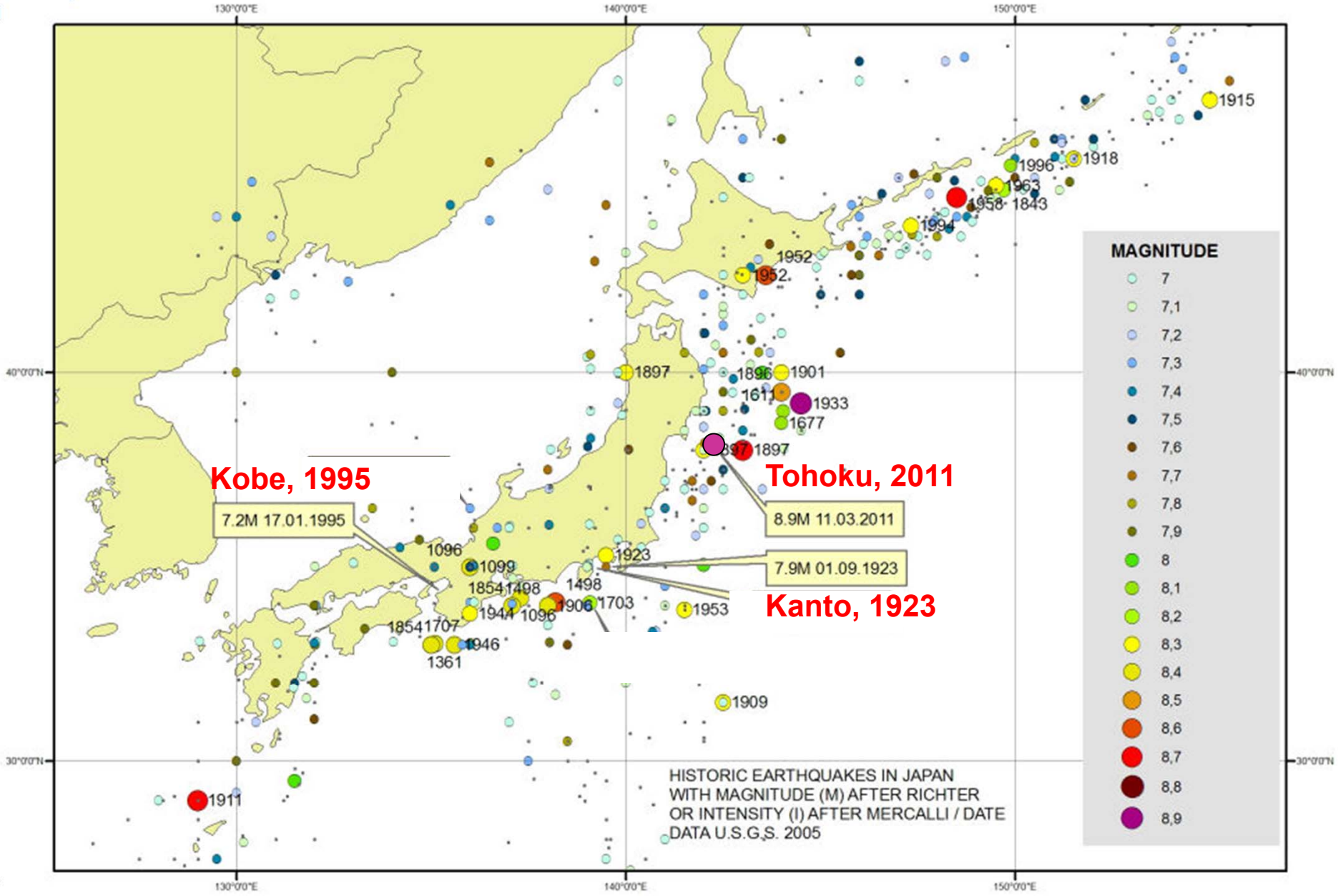


Figure 1. Map of world's major subduction zones (thick gray lines) and tectonic plate boundaries (Bird, 2003). Filled circles show locations of known earthquakes of $M_w \geq 7.5$ or greater since 1900 (circle radius and grayscaled by magnitude). Open circles are largest known earthquakes from A.D. 1700 to 1900 (compiled by Stein and Okal, 2007). Arrows show horizontal velocity of subducting plate relative to overriding plate. Dates are given for all M9 quakes.

Ci si attendeva un terremoto di questa magnitudo?

Sismicità storica in Giappone



Catalogo faglie sismogenetiche in Giappone, compilato da HERP, Headquarters for Earthquake Research Promotion, 2009)

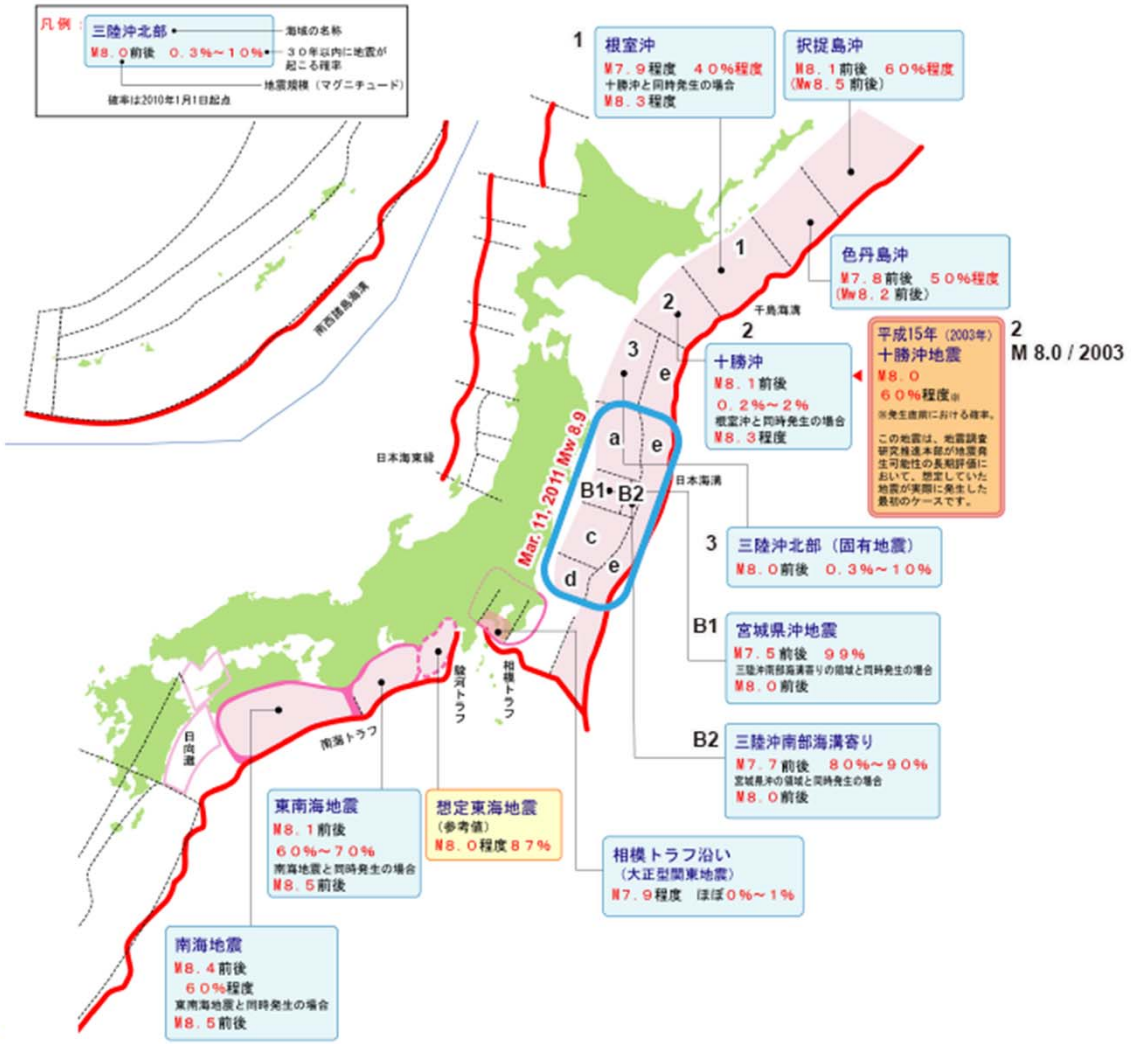
Faglie ben specificate, con probabilità di occorrenza in 100 anni

Japnaese Hazard Map category I: Eqrthquakes from SPECIFIC source with 100s year recurrence interval.
http://www.jishin.go.jp/main/chousa/10_yosokuchizu/k_jishincategory.pdf P. 28 with additional information
(Mar. 11, 2011 source area, segment 1, 2, 3, a, B1, B2, b, c, d, and e) by Koji.

解説：地震カテゴリー

カテゴリーⅠの地震の長期評価結果の概要

カテゴリーⅠの地震、すなわち、海溝型地震のうち震源断層を特定できる地震（震源断層を予め特定でき、再来間隔が数百年オーダーの地震）の長期評価結果の概要を以下に示す。



Japnaese Hazard Map category II: Eqrthquakes from UNSPECIFIED / HARD-to-SPECIFY sources.
http://www.jishin.go.jp/main/chousa/10_yosokuchizu/k_jishincategory.pdf P. 29 with additional information
(Mar. 11, 2011 source area, segment 1, 2, 3, a, B1, B2, b, c, d, and e) by Koji.

解説：地震カテゴリー

カテゴリーⅡの地震の長期評価結果の概要

カテゴリーⅡの地震、すなわち、海溝型地震のうち震源断層を特定しにくい地震（震源断層を予め特定しにくい地震のうち、プレート間地震とプレート内地震）の長期評価結果の概要を以下に示す。

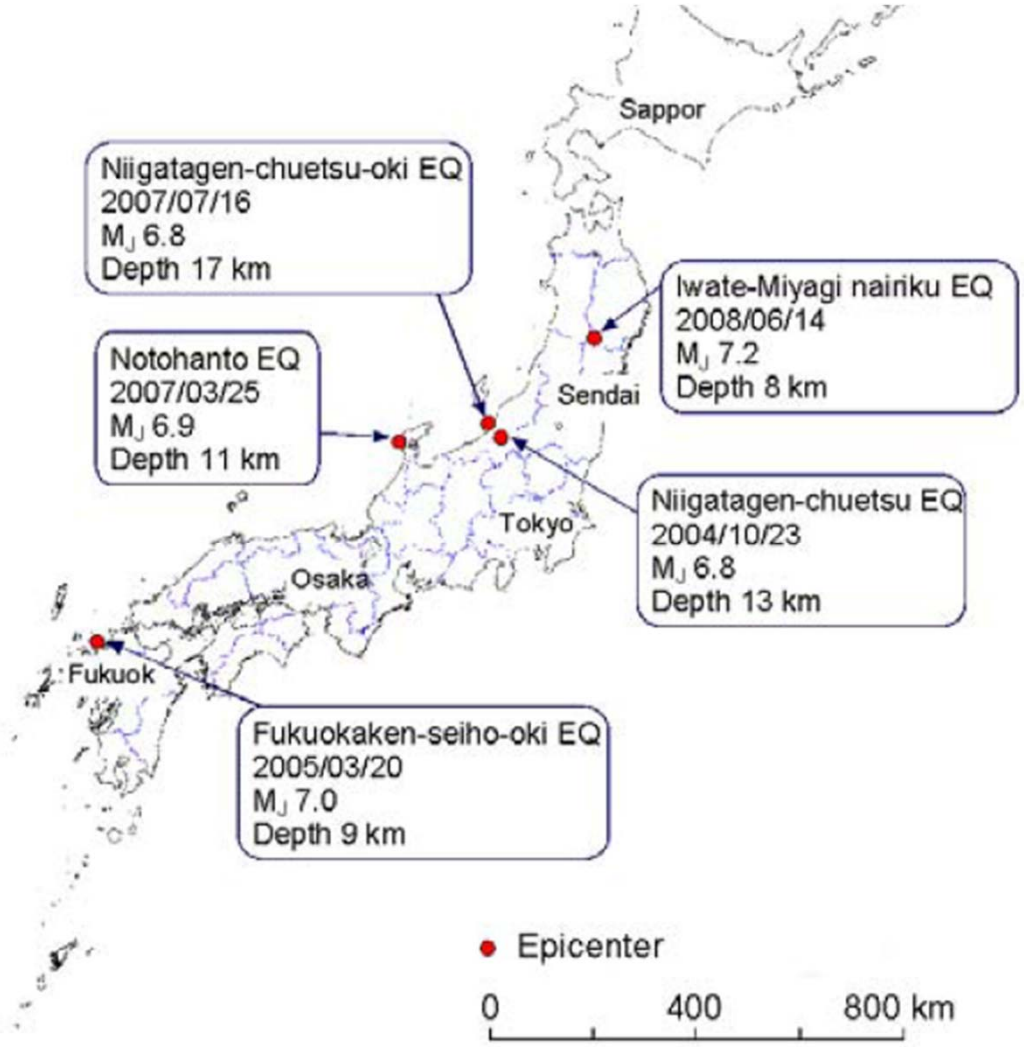
Catalogo faglie sismogenetiche in Giappone, compilato da HERP, Headquarters for Earthquake Research Promotion, 2009)

Faglie non ben specificate, con probabilità di occorrenza in 100 anni

Catalogo faglie sismogenetiche in Giappone, compilato da HERP, Headquarters for Earthquake Research Promotion, 2009)

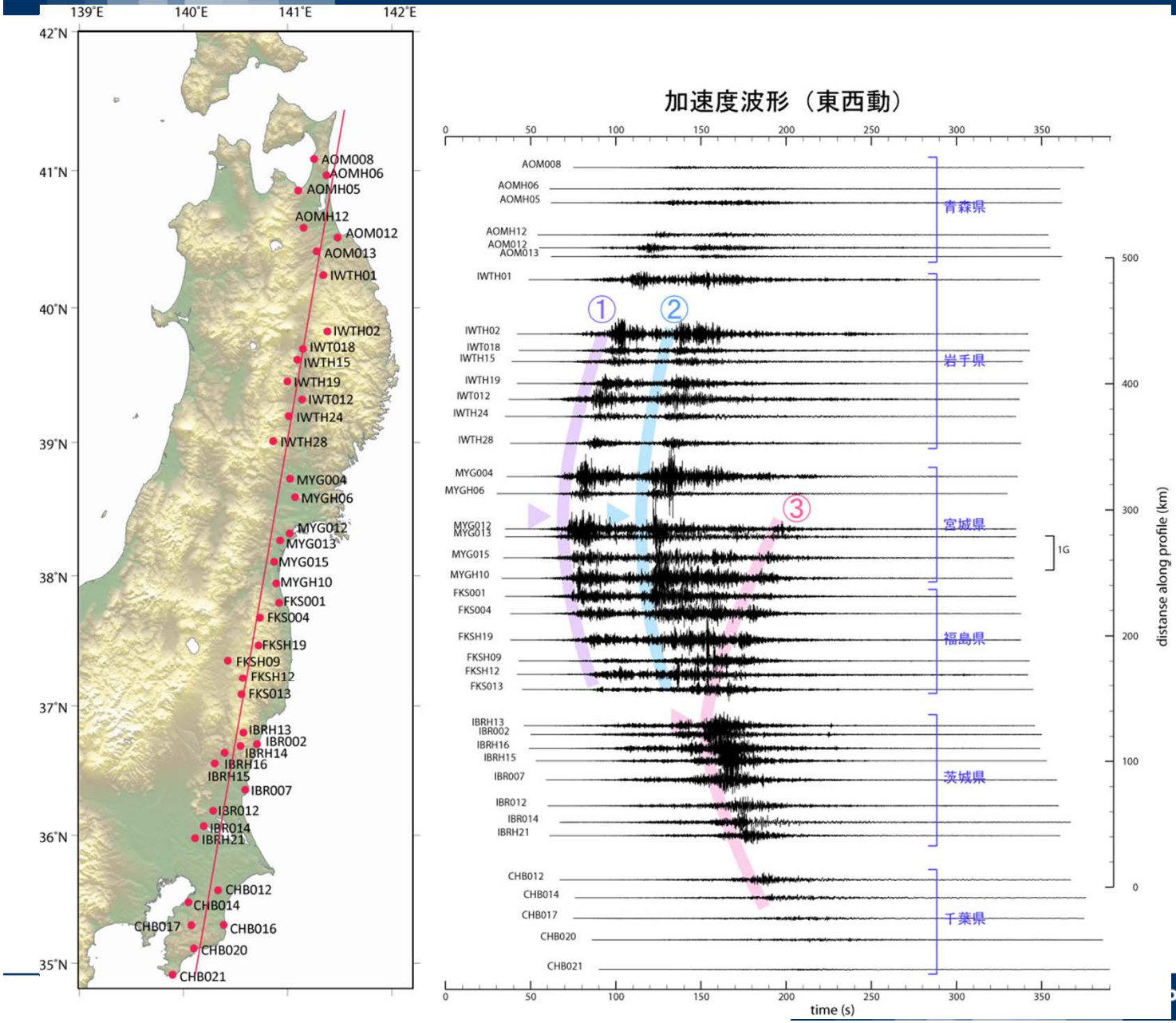
Faglie crostali, con probabilità di occorrenza in 100 anni

Recenti terremoti distruttivi in Giappone



Quale è stata la severità del moto sismico?

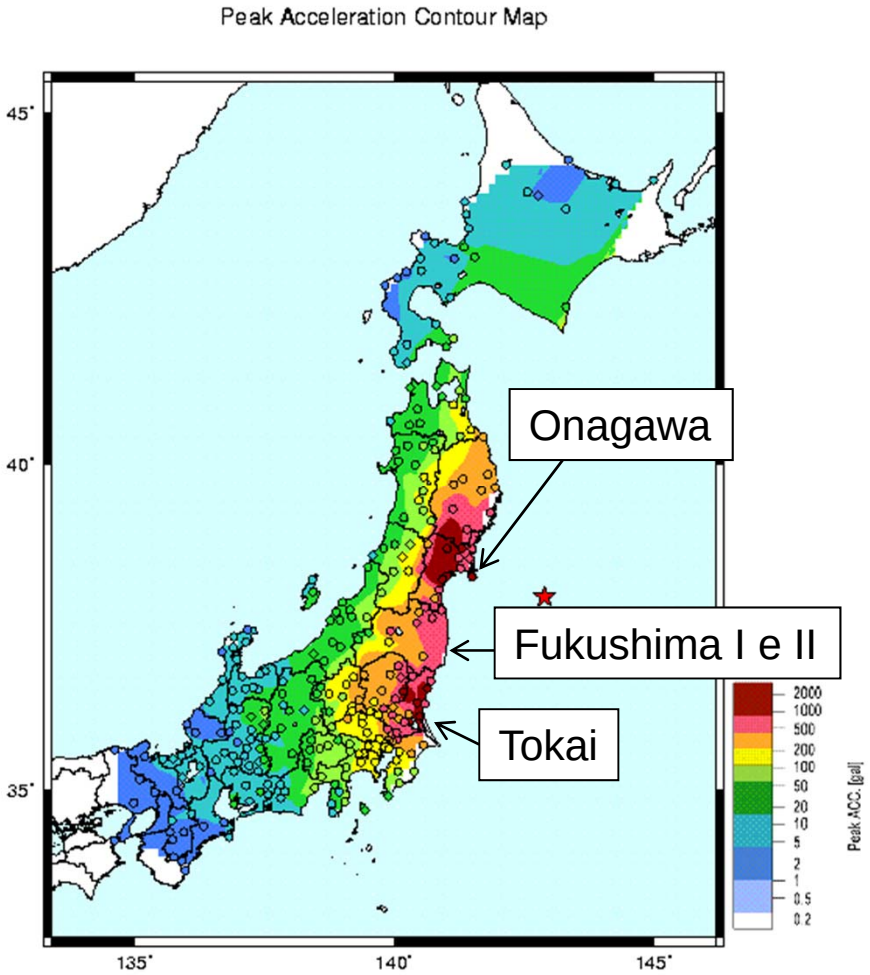
Le registrazioni del moto sismico dalle reti accelerometriche



Registrazioni accelerometriche dalle reti K-Net e KikNet, che mostrano le tre fasi del processo di rottura, le prime due al largo della prefettura Miyagi, la terza al largo della prefettura di Ibaraki.

Dal sito http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/eng

Valori di picco del moto sismico (http://www.k-net.bosai.go.jp)

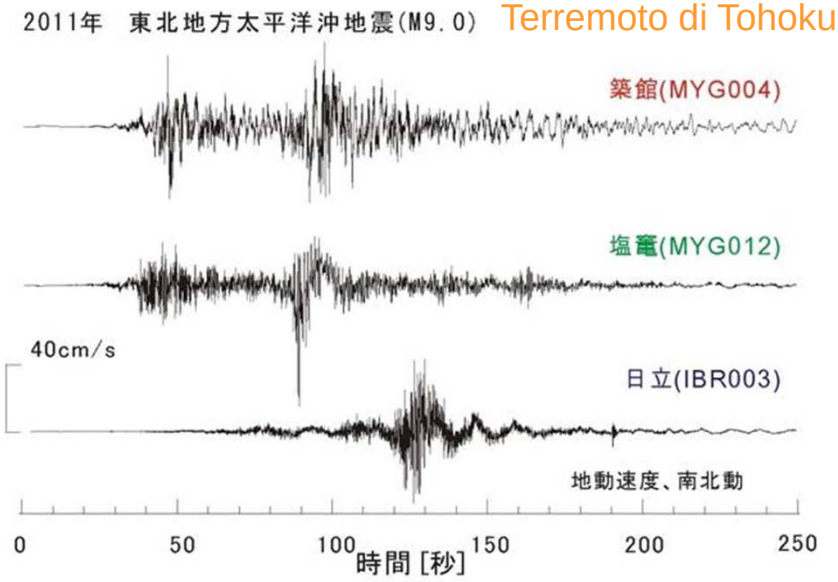


Nome impianto	Distanza epicentro (km)	pga stimata (g)	pga di progetto (g)
Onagawa	80	*0.81 (+116%)*	0.375
Fukushima Daiichi-2	145	*0.56 (+26%)*	0.44*
Fukushima Daiichi-3	145	*0.51 (+15%)*	0.44*
Fukushima Daiichi-5	145	*0.55 (+21%)*	0.44*
Fukushima Daiichi-1-4-6	145	*~0.44*	0.44*

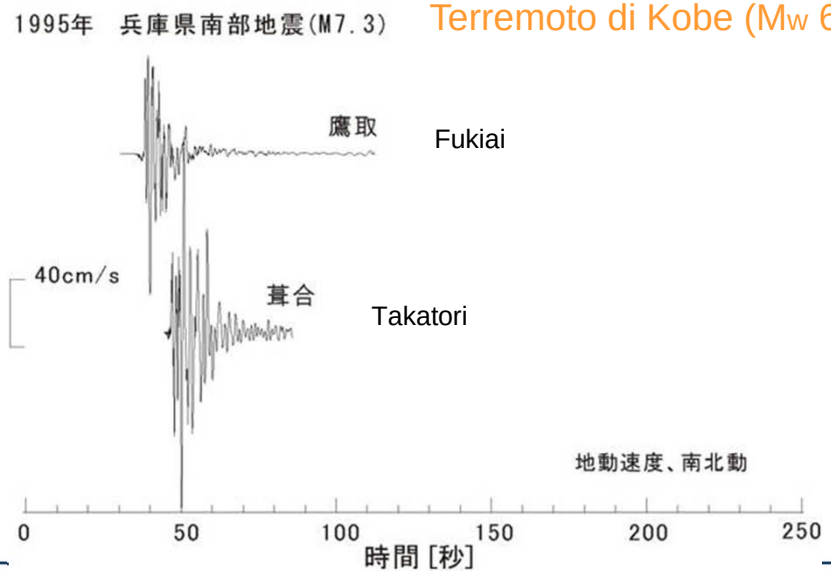
Dati JAIF (Japan Atomic Industrial Forum): horizontal ground acceleration

Unit 2: 550 gals (+26% design value) = 0.56 g
Unit 5: 548 gals (+21% design value) = 0.55 g
Unit 3: 507 gals (+15% design value) = 0.51 g
Unit 1-4-6: close to design limit
****Lavori per upgrade strutture a 600 gals (0.61 g) non erano ancora conclusi all'11 marzo***

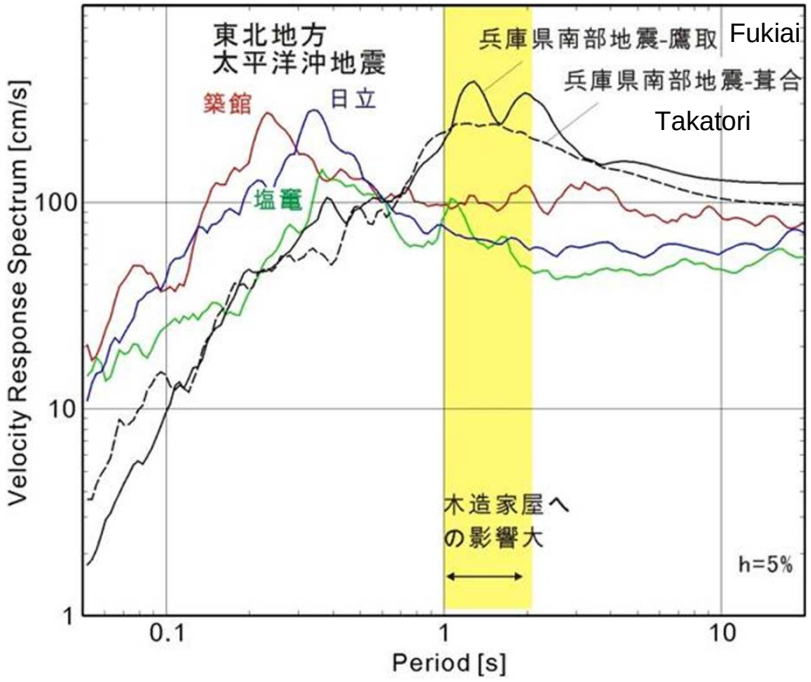
Severità del moto sismico: confronto con terremoto di Kobe



Terremoto di Tohoku (Mw 9.0)



Terremoto di Kobe (Mw 6.9)

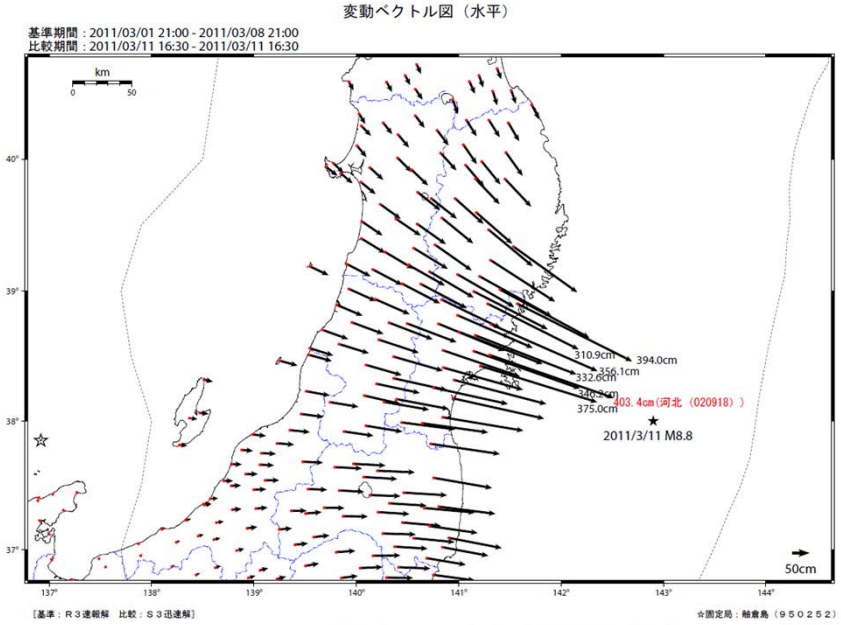


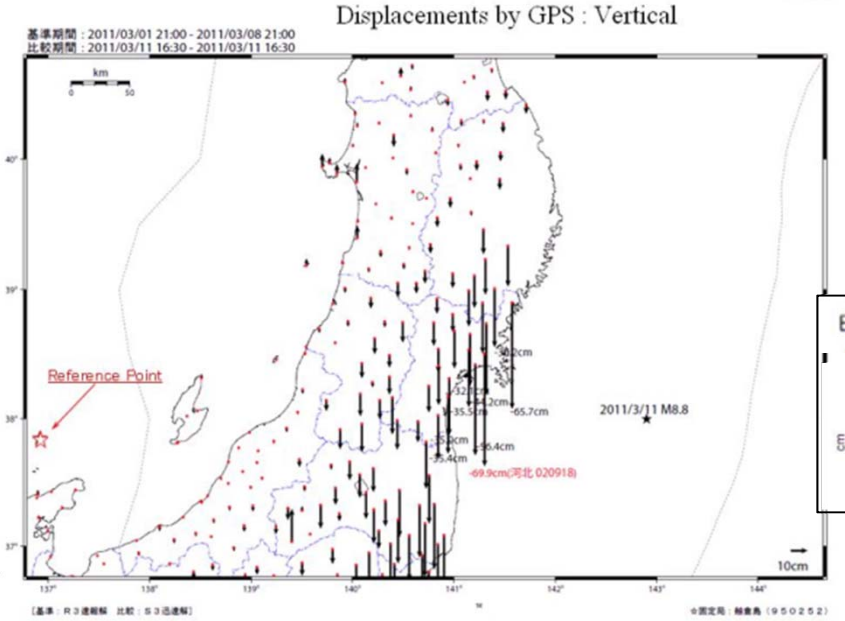
Strutture “rigide”

Strutture “ flessibili”

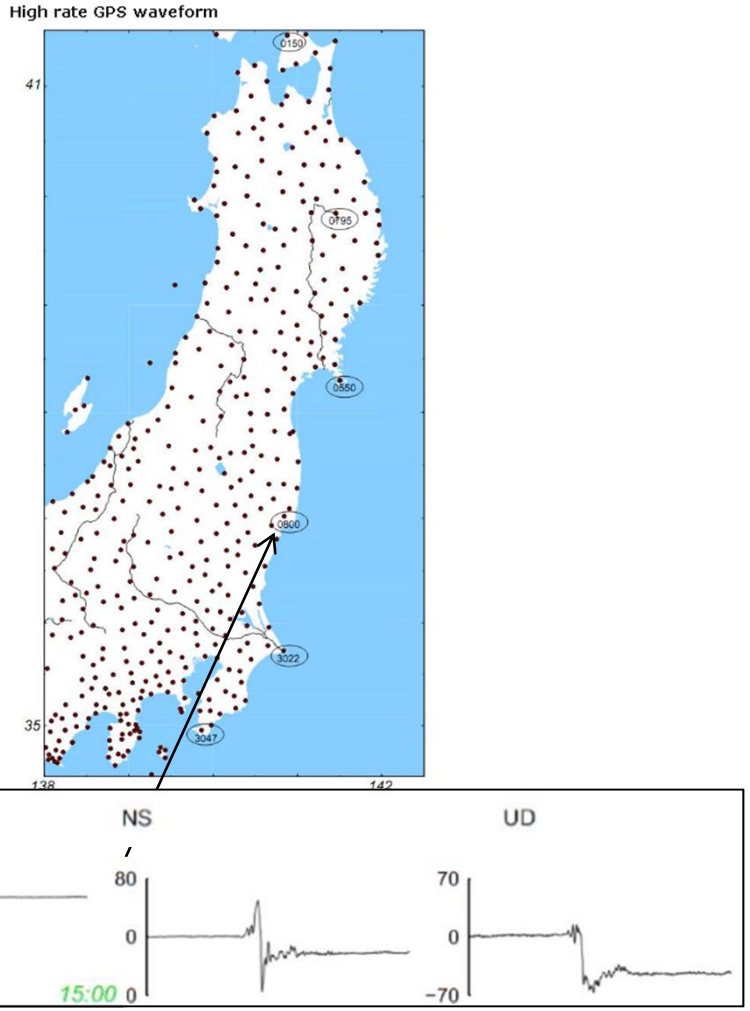
Dal sito http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/eng

Vettori spostamento da rete GPS





Fonte: JMA, Giappone



Come è avvenuto lo tsunami?

from "Inamura no hi", in Authorized Reading of Japanese for elementary school, vol. 10

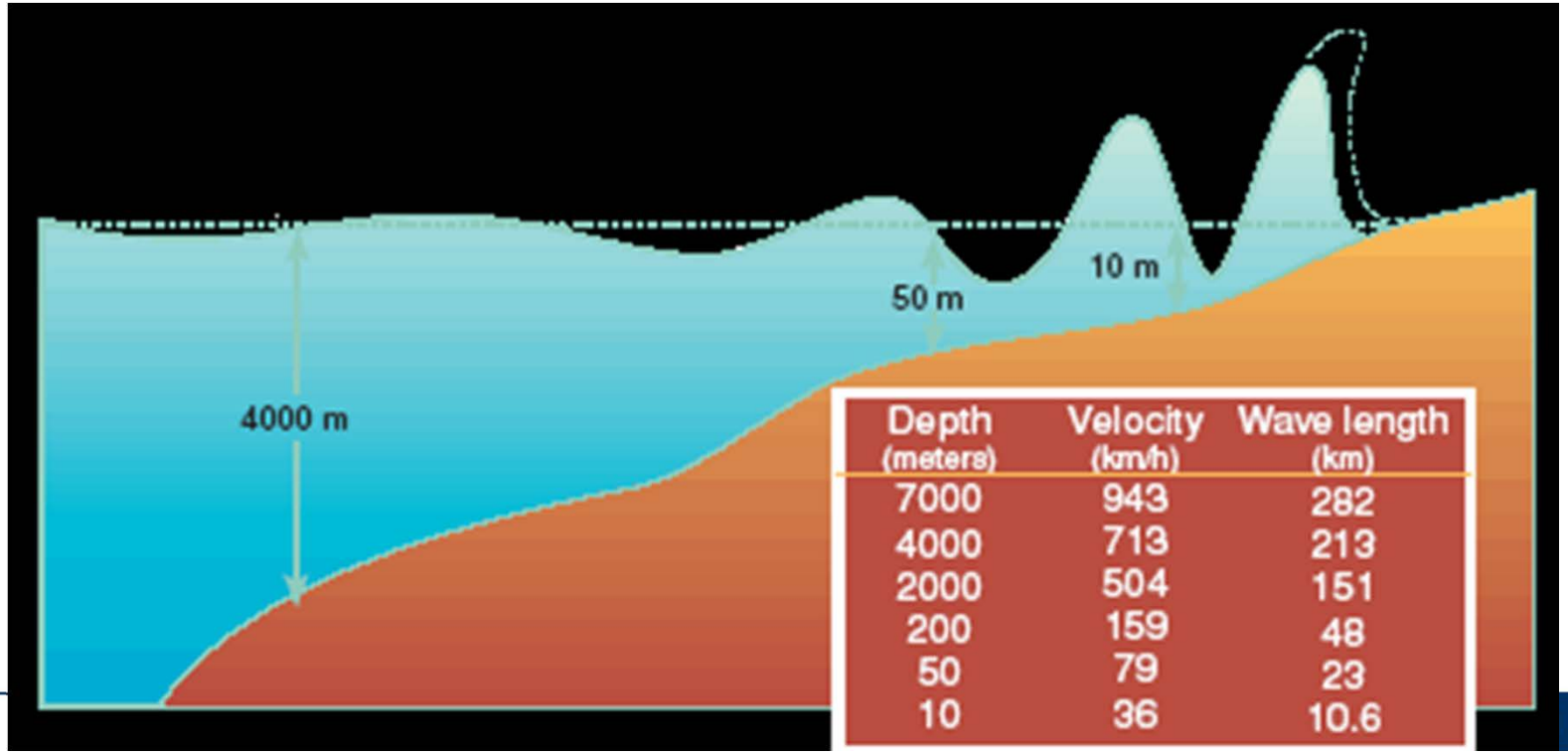
Tsunami (after Synolakis, 2003)

The term tsunami, also known as seismic sea wave or tidal wave, comes from the Japanese term meaning harbor wave. In Japan, historical documentation of tsunamis goes back almost 1000 years and suggests that **they attack Japan's shores, on average, about once every decade** (...)

In wind-generated waves, the orbital motion of the water particles decreases with depth from the water surface. As energy is transferred through the motion of the water particles, the energy of wind waves traveling through deep water is concentrated near the surface. **By contrast, the energy imparted to the water during tsunami formation sets the entire water column in motion.** Orbital velocities do not decrease significantly with depth, and although the wave height at the surface is relatively small, the energy contained throughout the entire water column is substantial. Furthermore, the rate at which water waves lose energy is inversely proportional to their wavelength. **So tsunamis not only contain a lot of energy, and move at high speeds, but they can also travel great distances with little energy loss**.

Tsunami (after Synolakis, 2003)

The speed or wave velocity or celerity, c, is calculated by dividing the wavelength L by its period T . The speed of deep-water waves does not depend on the depth, and the waves are dispersive, as each component frequency of a complex spectrum propagates at its own frequency-dependent speed. **Shallow-water waves travel at a speed c = √gd, where d is the local depth**, hence all frequencies in the spectrum of a tsunami travel at the same velocity. It is for this reason that tsunamis do not alter their shape substantially as they propagate over fairly constant depth. **In typical ocean depths of 4 km, a tsunami travels at a speed of nearly 200 m/sec, or almost 700 km/h. When tsunamis enter shallower water they slow down; at a depth of 30 m, an SW wave travels at only 59 km/h.**

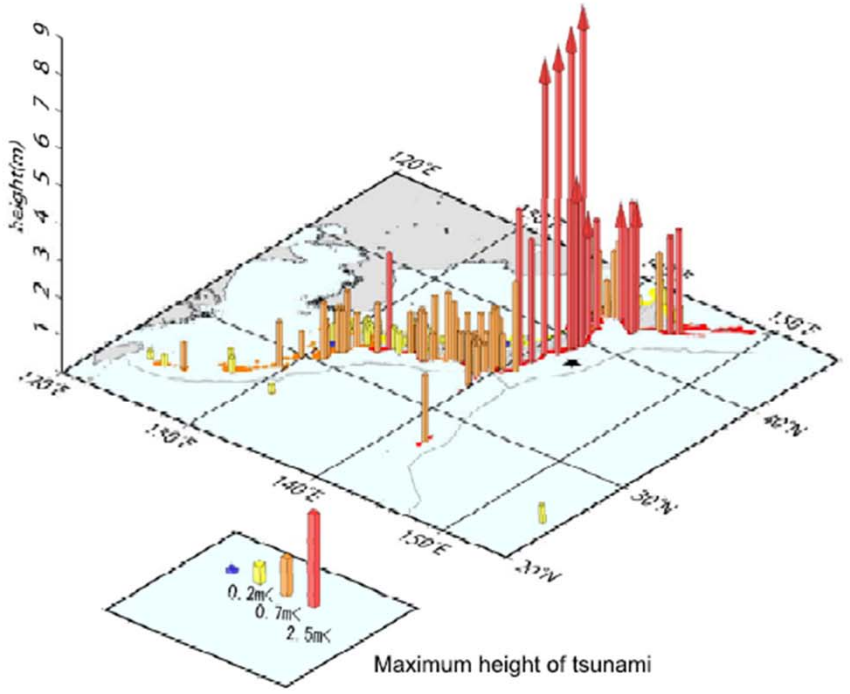


L'ampiezza d'onda di tsunami generata dal sisma del Giappone

Observed Tsunami (time and height)

	First tsunami	Maximum height of tsunami
Miyako (Iwate)*	March 11, 14:48 JST +0.2m	March 11, 15:26 JST +8.5m<=
Ofunato (Iwate)*	March 11, 14:46 JST -0.2m	March 11, 15:18 JST +8.0m<=
Ishinomaki (Miyagi)*	March 11, 14:46 JST +0.1m	March 11, 15:25 JST +7.6m<=
Soma (Fukushima)*	March 11, 14:55 JST +0.3m	March 11, 15:50 JST +7.3m<=
Oarai (Ibaraki)	March 11, 15:15 JST +1.8m	March 11, 16:52 JST +4.2m
Kamaishi (Iwate)*	March 11, 14:45 JST -0.1m	March 11, 15:21 JST +4.1m<=
Mutsu (Aomori)	March 11, 15:20 JST -0.1m	March 11, 18:16 JST +2.9m
Nemuro (Hokkaido)	March 11, 15:34 JST slight	March 11, 15:57 JST +2.8m
Tokachi (Hokkaido)*	March 11, 15:26 JST -0.2m	March 11, 15:57 JST +2.8m<=
Urakawa (Hokkaido)	March 11, 15:19 JST -0.2m	March 11, 16:42 JST +2.7m

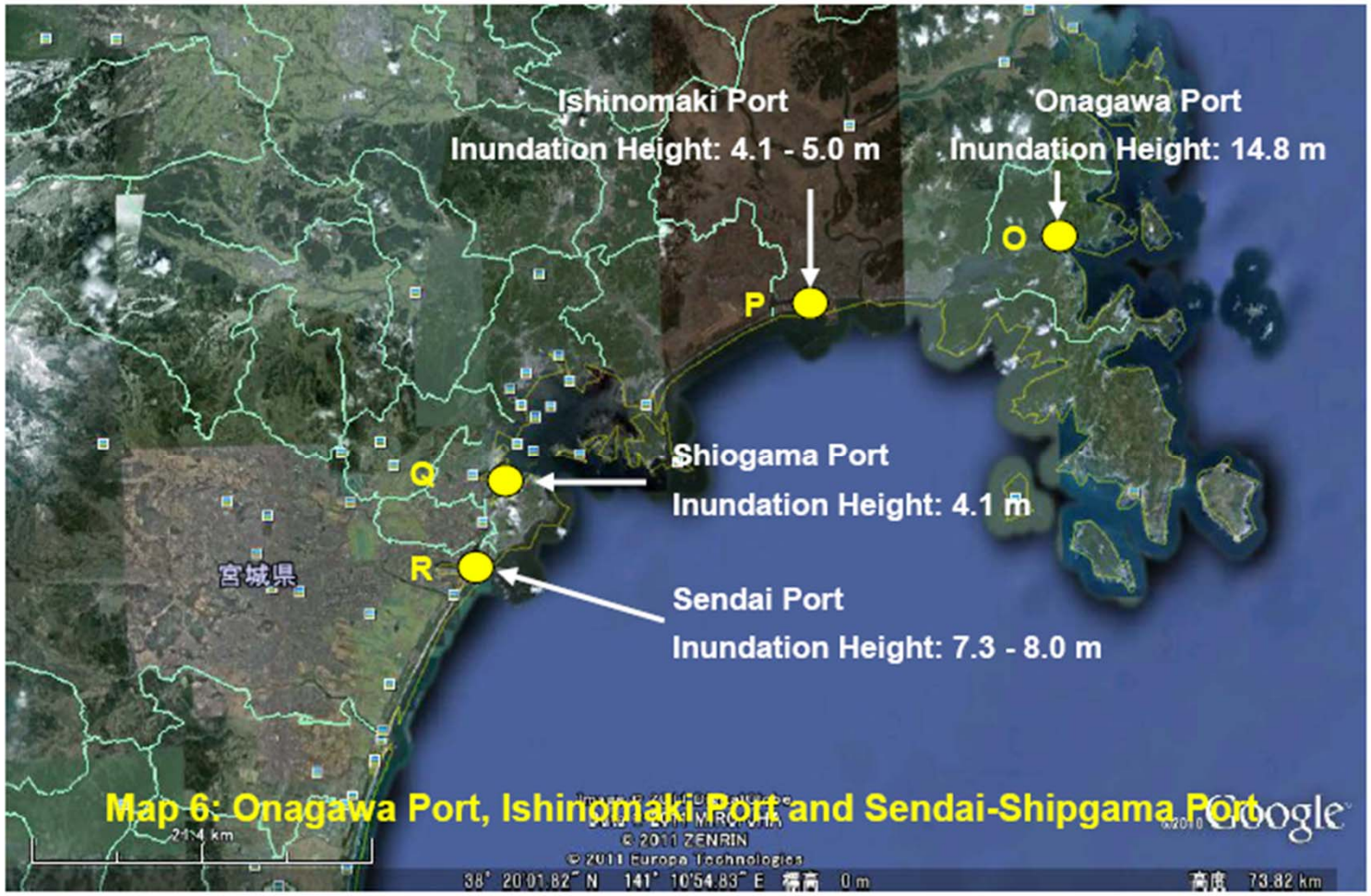
* Maximum height of tsumami cannot be retrieved so far due to the troubles. Actual maximum height might be higher.



Maximum height of tsunami

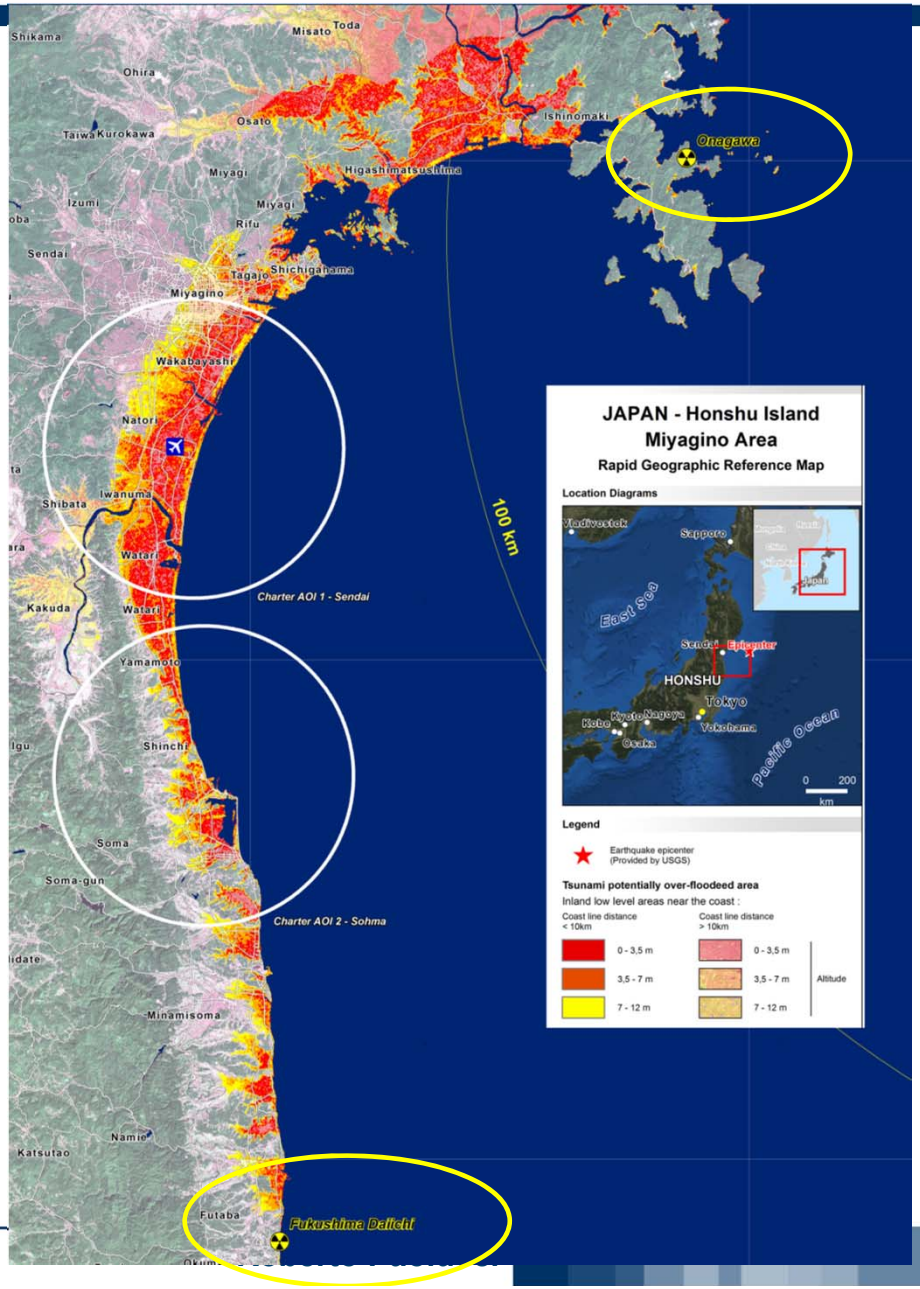
Fonte: JMA, Giappone

L’ampiezza d’onda di tsunami generata dal sisma del Giappone



fonte: Port and Airport Research Institute www. pari.go.jp

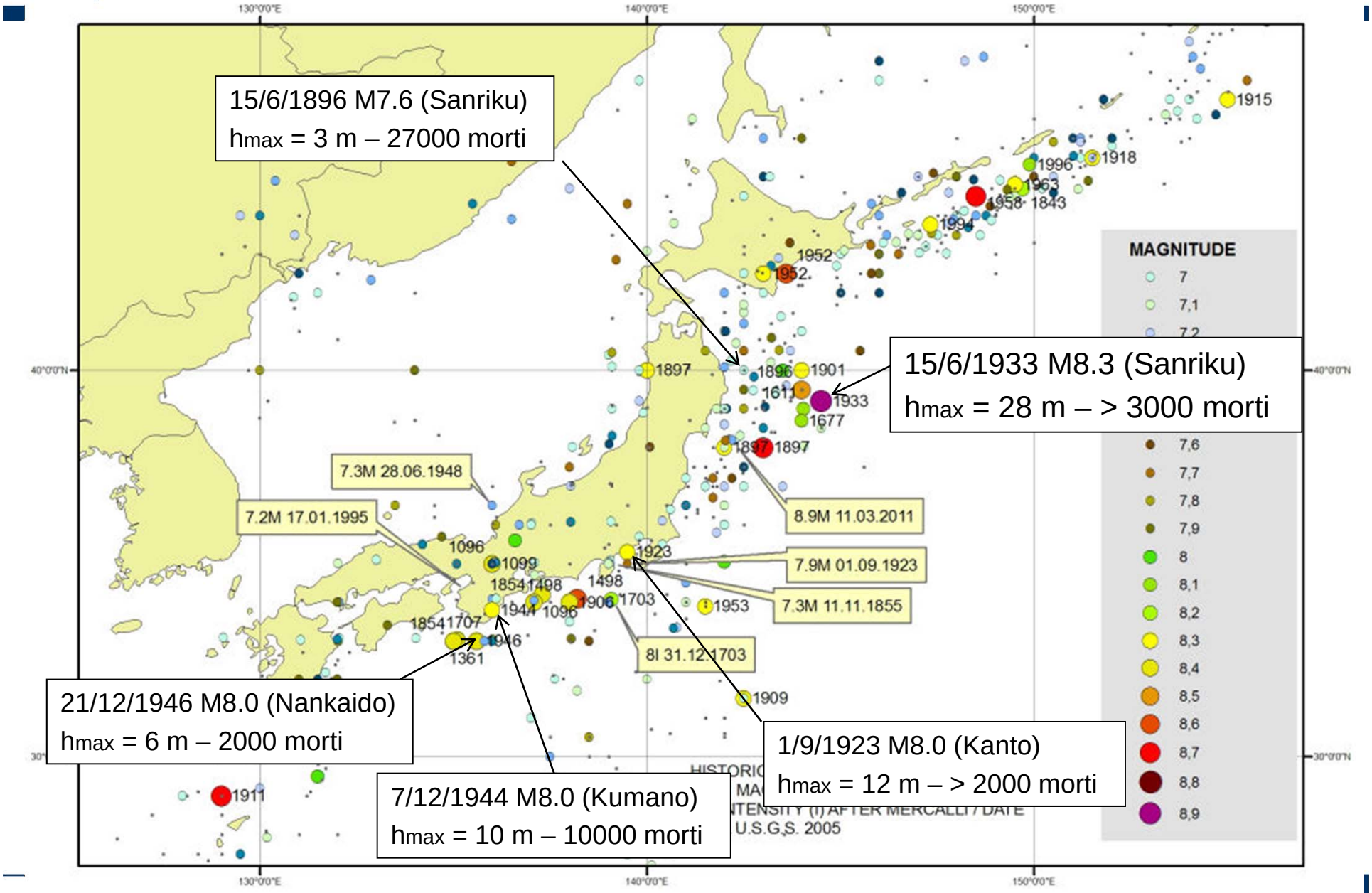
Aree inondate dallo tsunami (da www.dlr.de)



Alla centrale di Fukushima, l'onda di tsunami è stata stimata di altezza pari a 14 m. La stima è basata sull'inondazione di un parcheggio sopraelevato a quell'altezza

Ci si poteva attendere uno tsunami di questa entità?

Tsunami catastrofici in Giappone (da Synolakis, 2003)

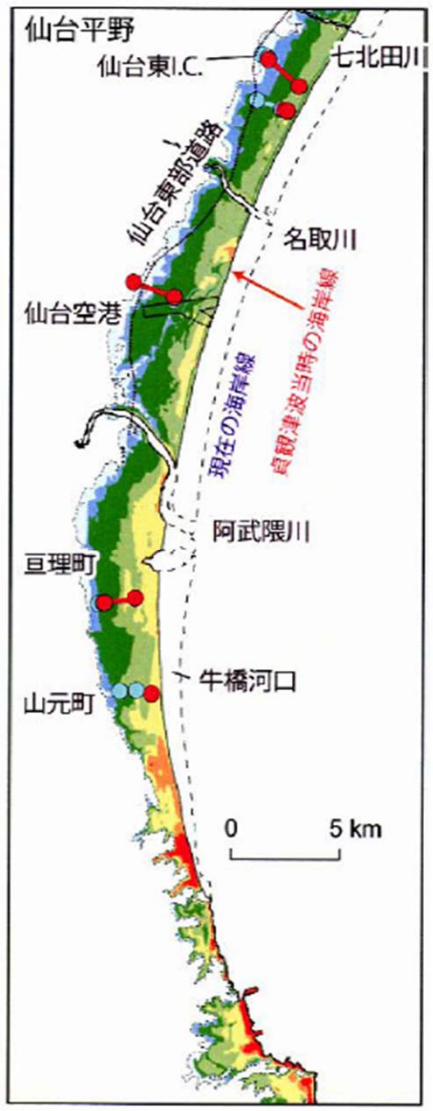


Il terremoto di Jogan, AD 869 (M_w stimata 8.4)

Ricostruzione dell'area inondata dallo tsunami nella baia di Sendai, stimata da Sakate nel 2008 per il terremoto di Jogan dell'869 e osservata da satellite dopo il terremoto del 2011

Minoura et al., 2001:

"More than 1100 years have passed since the Jogan tsunami and, given the recurrence interval, estimated between 800 to 1100 years from paleoseismology studies, the possibility of a large tsunami striking the Sendai plain is high".

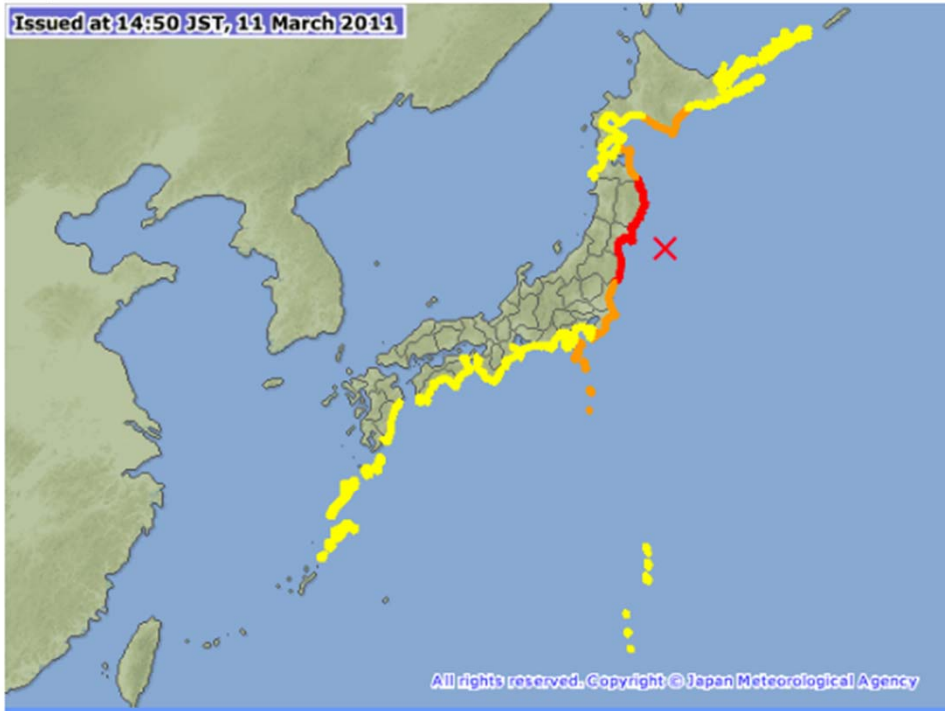


Ci si può difendere da uno tsunami ?

L’allarme tsunami alle 14:50 dell’11 marzo 2011

Occurred at 14:46 JST 11 Mar 2011
Region name Sanriku Oki
Depth about 10 km
Magnitude 7.9

Click the map to zoom in



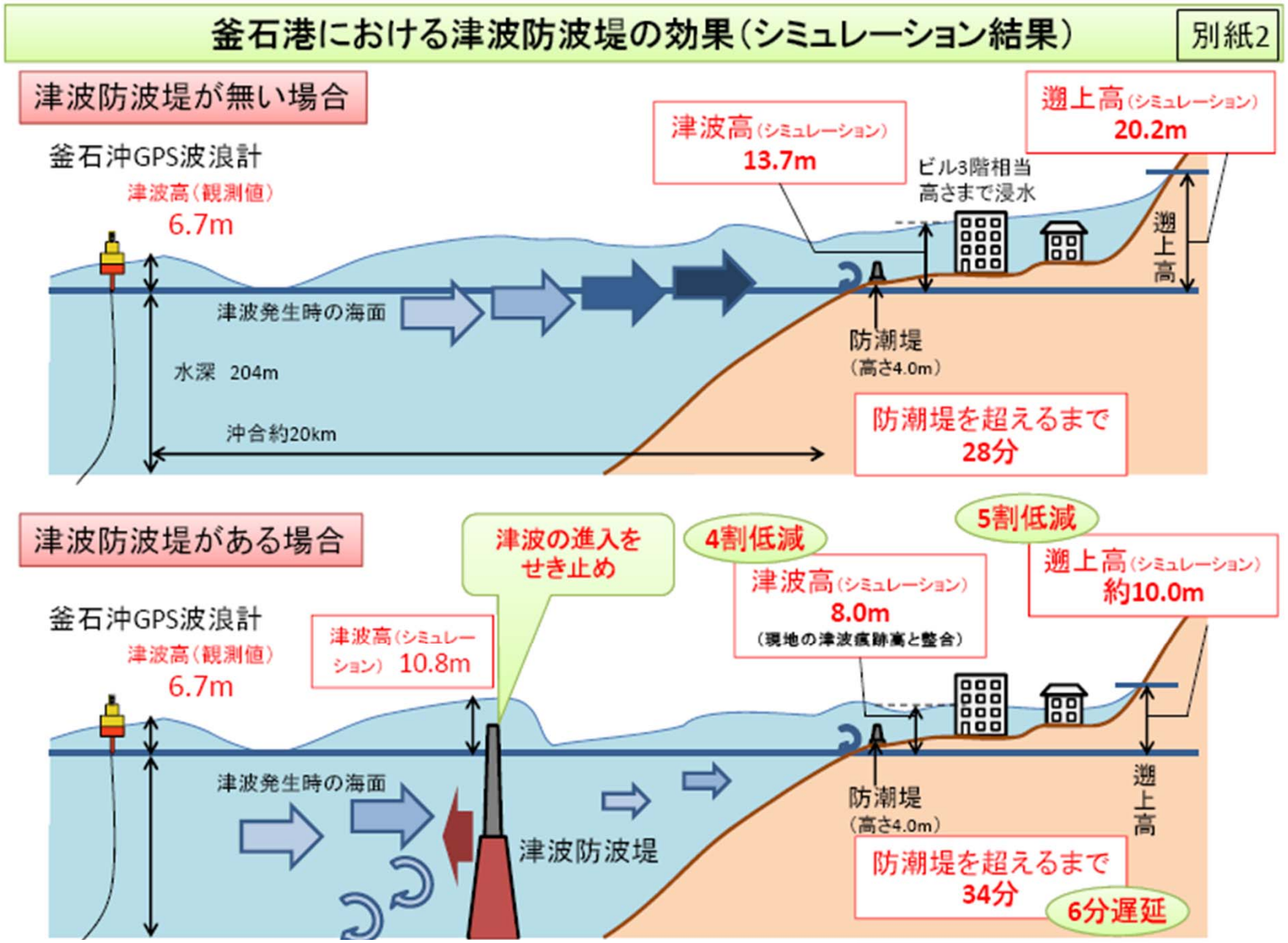
Tsunami Forecast Region	Estimated Tsunami Arrival Time	Estimated Tsunami Height
IWATE PREF.	(*1)	3 m
MIYAGI PREF.	15:00 JST 11 Mar	6 m
FUKUSHIMA PREF.	15:10 JST 11 Mar	3 m
CENTRAL PART OF PACIFIC COAST OF HOKKAIDO	15:30 JST 11 Mar	1 m
PACIFIC COAST OF AOMORI PREF.	15:30 JST 11 Mar	1 m
IBARAKI PREF.	15:30 JST 11 Mar	2 m
KUJUKURI AND SOTOBO AREA, CHIBA PREF.	15:20 JST 11 Mar	2 m

fonte:
http://www.jma.go.jp/en/tsunami

World's Deepest Breakwater (Kamaishi, Iwate prefecture, 2009)

Il breakwater costruito a Kamaishi era stato incluso nel 2009 nel Guinness dei primati come l'opera di protezione litoranea più profonda al mondo (63 metri)

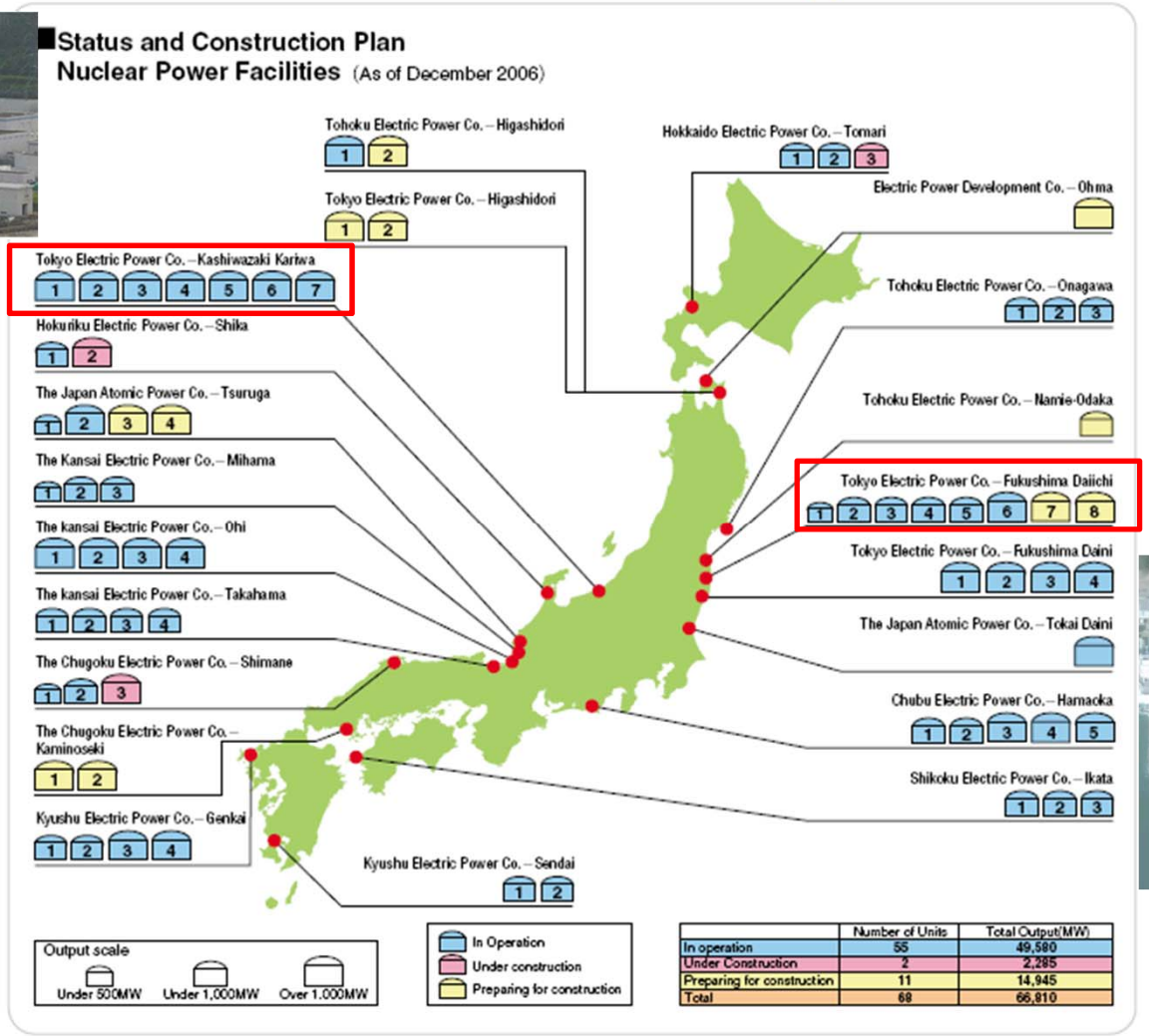
L’effetto stimato dello sbarramento di Kamaishi



fonte: Port and Airport Research Institute www. pari.go.jp

Il terremoto del Giappone dell'11 marzo 2011

Qual è il livello di protezione sismica delle centrali nucleari in Giappone?



fonte: Nuclear Safety Commission of Japan, 2007