(2016/11/22)

Overview of Earthquake and Disaster

Earthquake and Seismic Waves

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OUTLINE

Earthquake information systems in Japan

Seismic wave observation

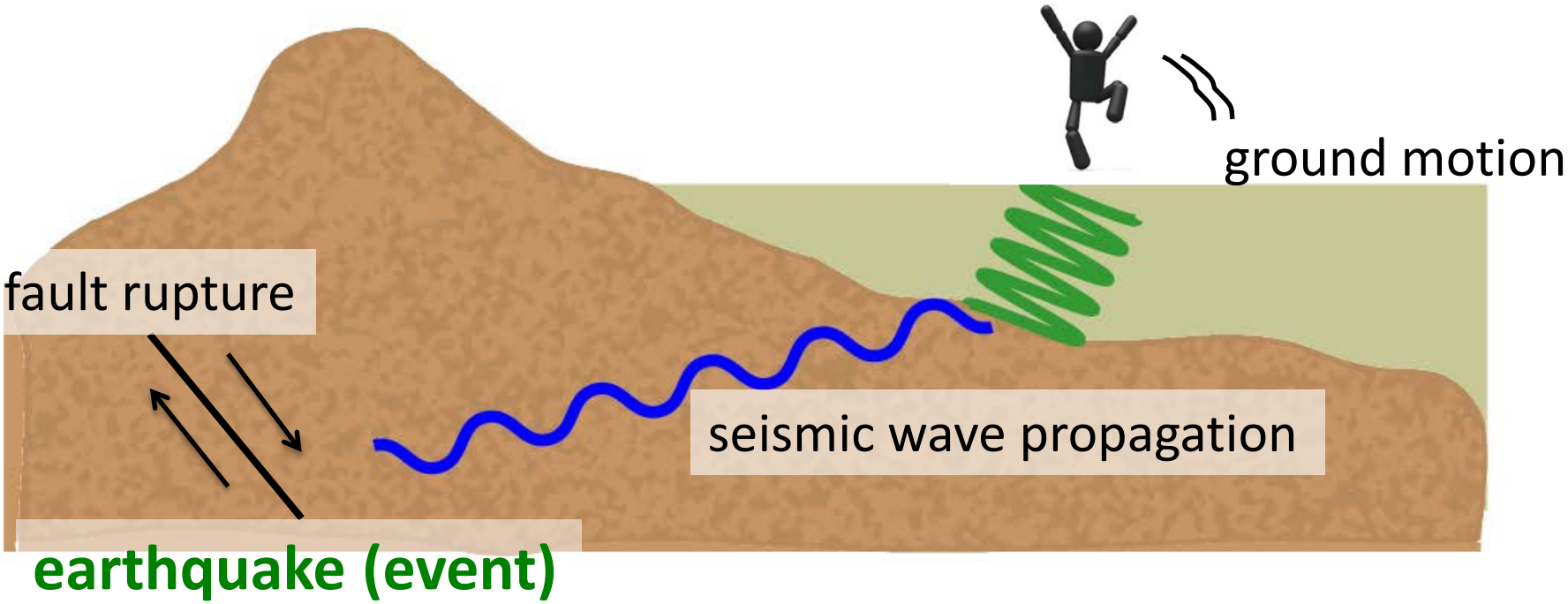
Seismic wave propagation

Ground motion indicators

Earthquake and Ground Motion

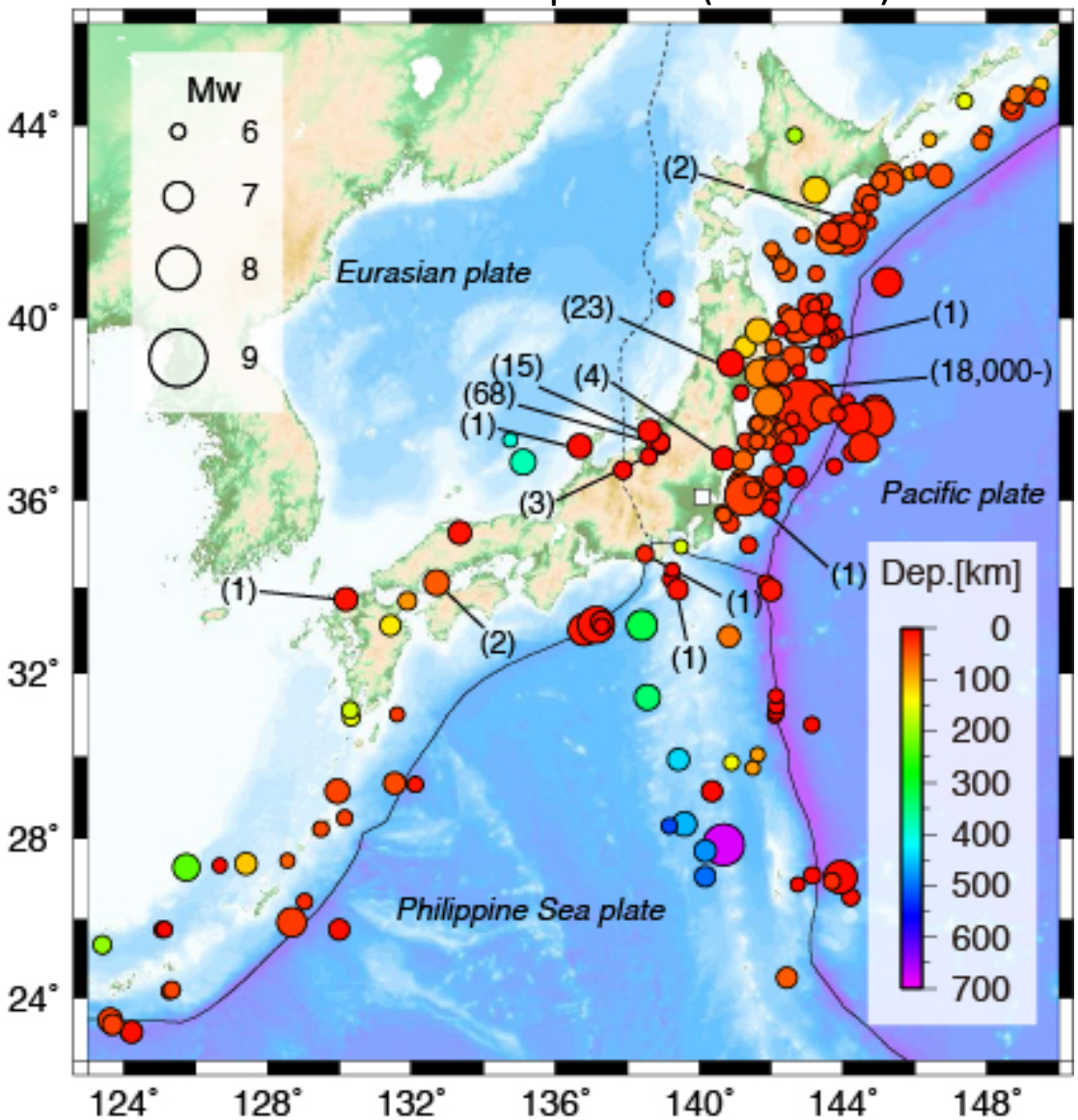
地 *ji* 震 *shin* 地 *ji* 震動 *shindou*

earth + quake ≠ ground motion (ground shaking)



Recent earthquakes in Japan

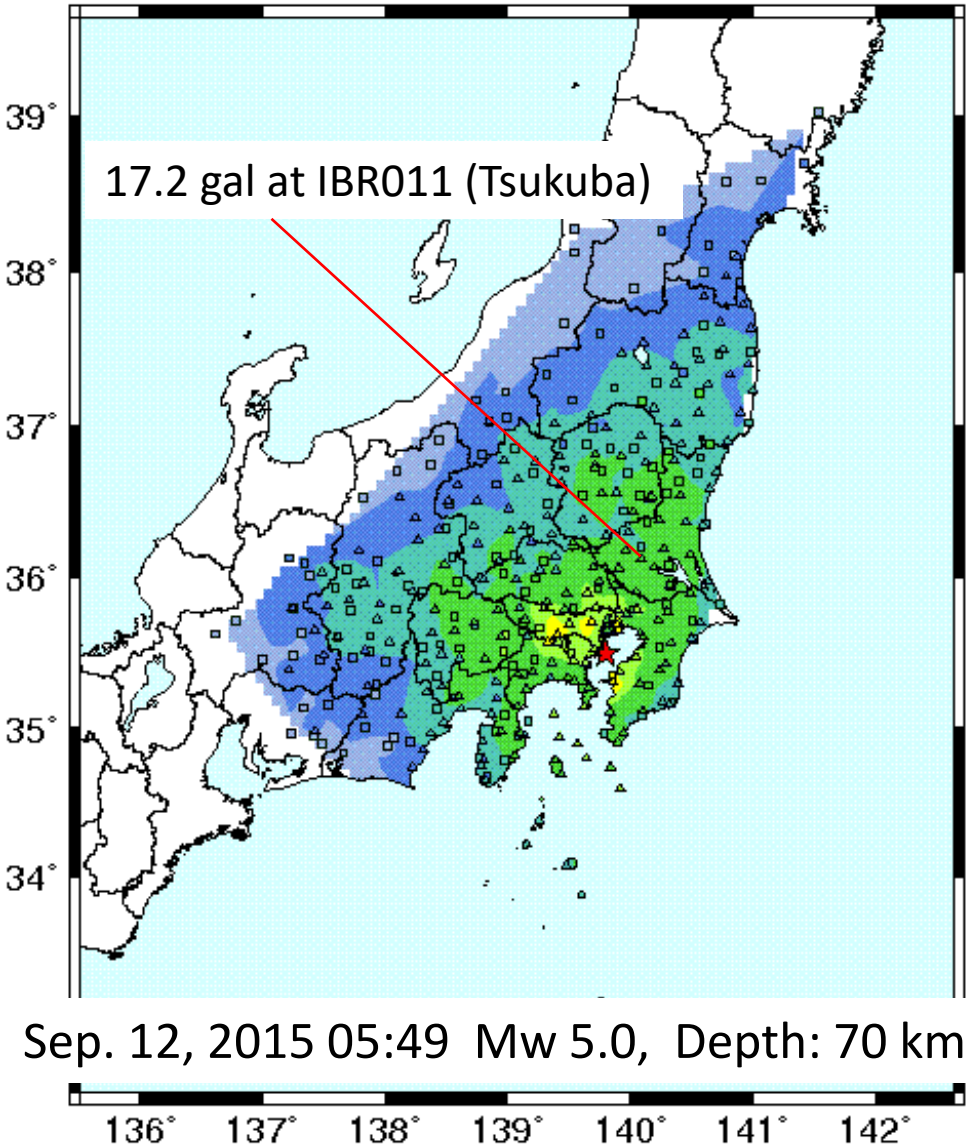
Jan. 2000 – Sep. 2015 (> Mw6.0)



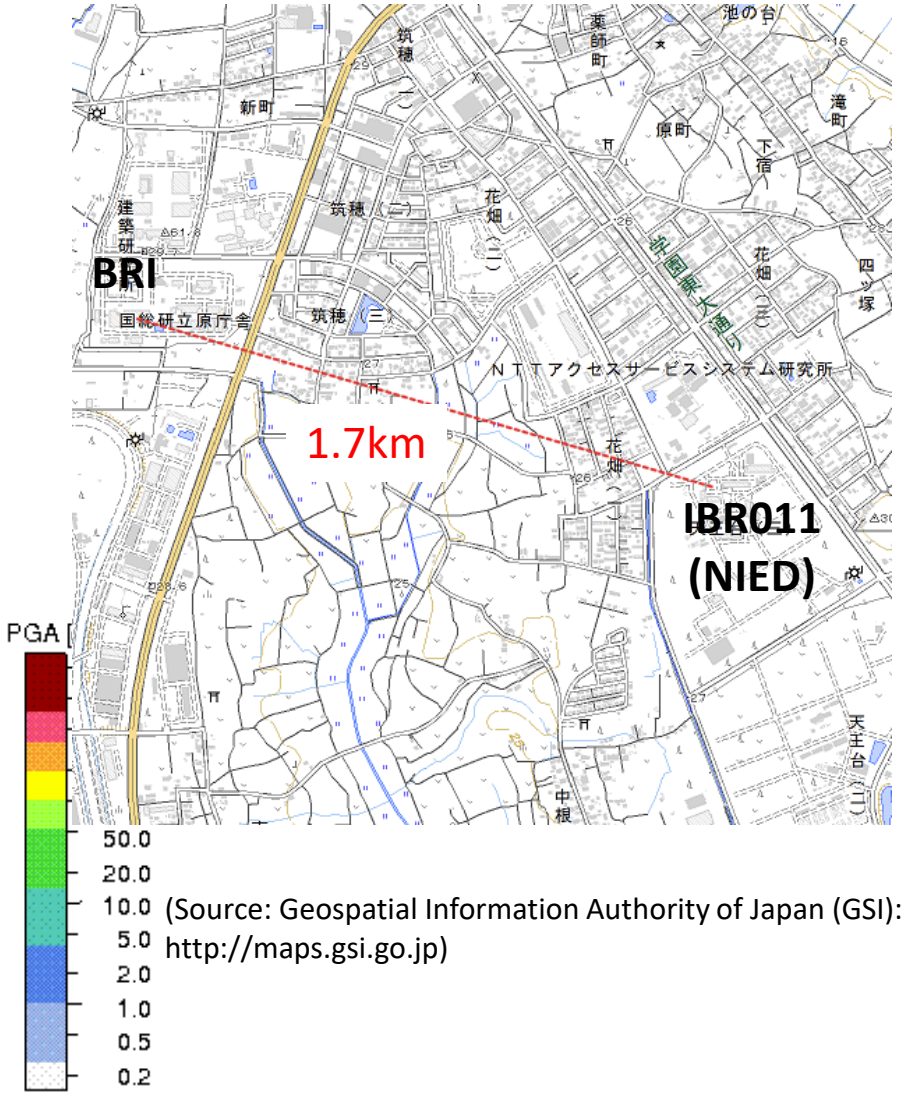
( ): number of deaths

Magnitude	2010	2011	2012	2013	2014
8.0 to 9.9	0	1	0	0	0
7.0 to 7.9	3	8	3	3	1
6.0 to 6.9	16	108	20	20	14
5.0 to 5.9	168	633	210	169	123
4.0 to 4.9	1254	4920	1543	1139	955
3.0 to 3.9	4863	19600	9272	6219	5384
2.0 to 2.9	16920	47163	28791	22254	20809
1.0 to 1.9	42181	82415	66675	46748	46271
0.1 to 0.9	55231	68197	62909	53545	52267

Recent felt earthquake in Tsukuba



Sep. 12, 2015 05:49 Mw 5.0, Depth: 70 km



(Source: Geospatial Information Authority of Japan (GSI): http://maps.gsi.go.jp)

Source: National Research Institute for Earth Science and Disaster Prevention (NIED) (http://www.kyoshin.bosai.go.jp/kyoshin/)

1. Earthquake Information System in Japan

If you feel earthquake in Japan…

0: earthquake occurrence

↓

within 1-2 minutes :

provisional information by JMA

-> information on television

↓

within 3 minutes :

earthquake information by JMA

(hypocenter location, intensities, and possibility of tsunami)

-> information on television

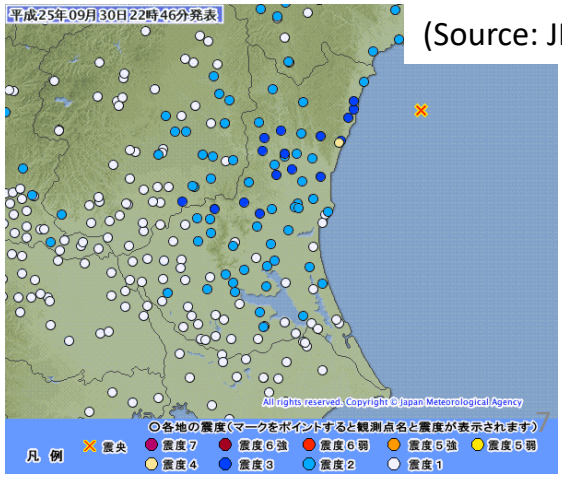
↓

after 4 minutes :

seismic intensity map

-> JMA web site

-> television (in case of a large EQ)



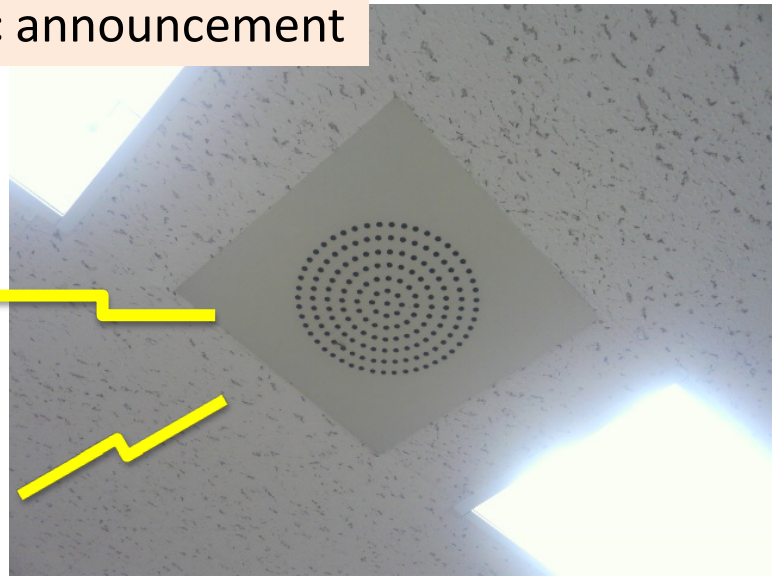
(Source: JMA)

(http://www.jma.go.jp/jp/quake/index.html)

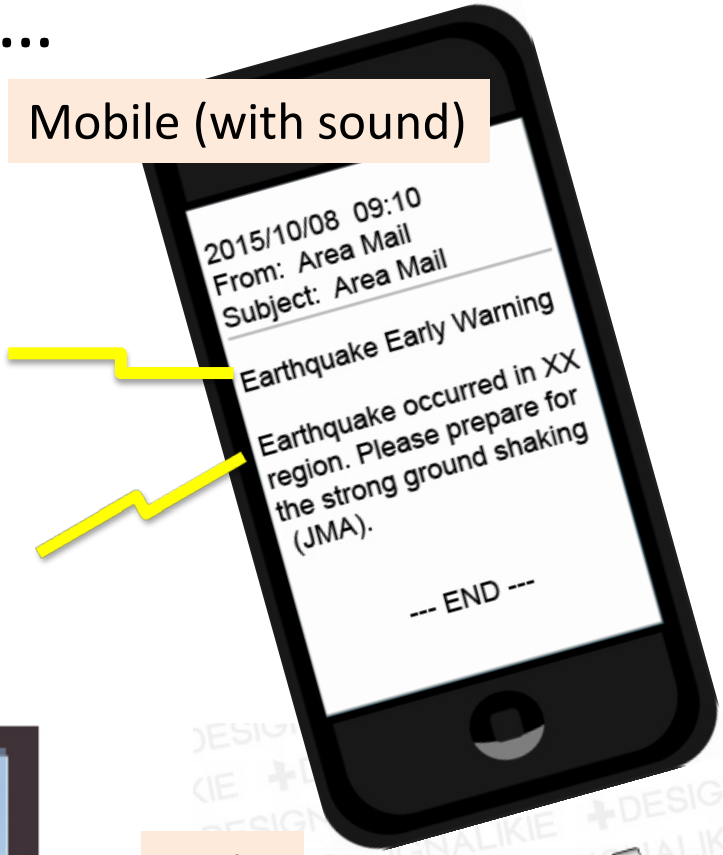
Related lecture: Study Tour of Earthquake Monitoring (JMA)

If a large earthquake occurs…

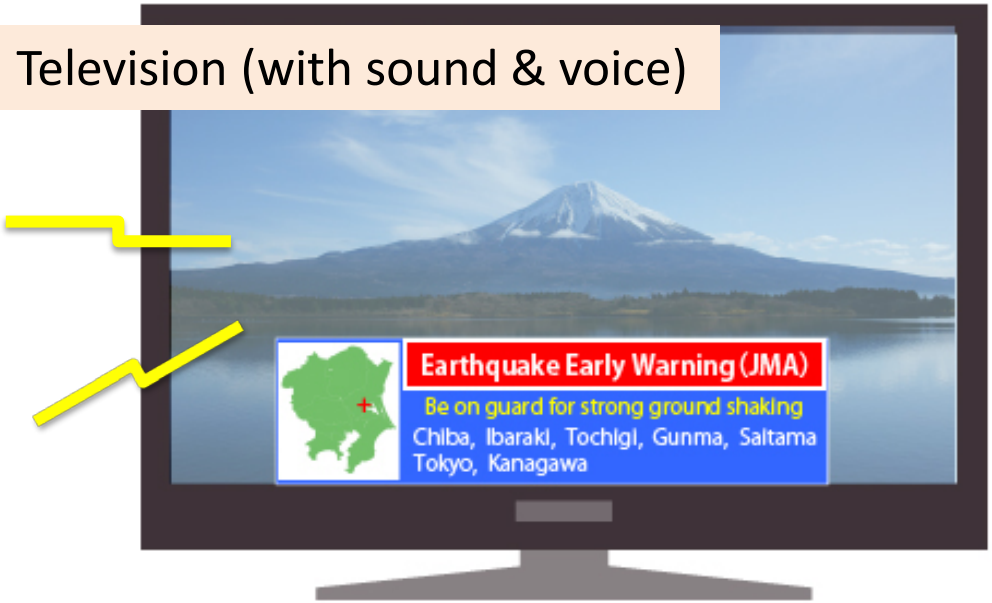
Public announcement



Mobile (with sound)



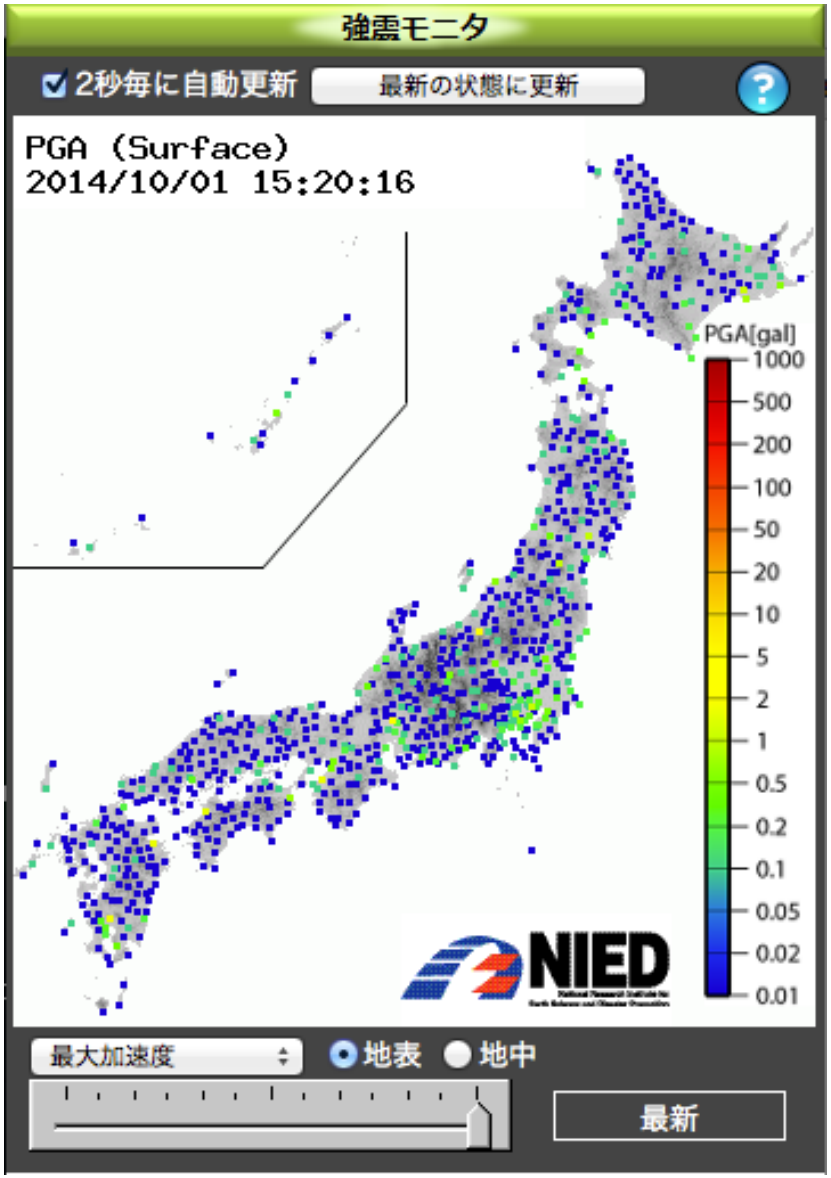
Television (with sound & voice)

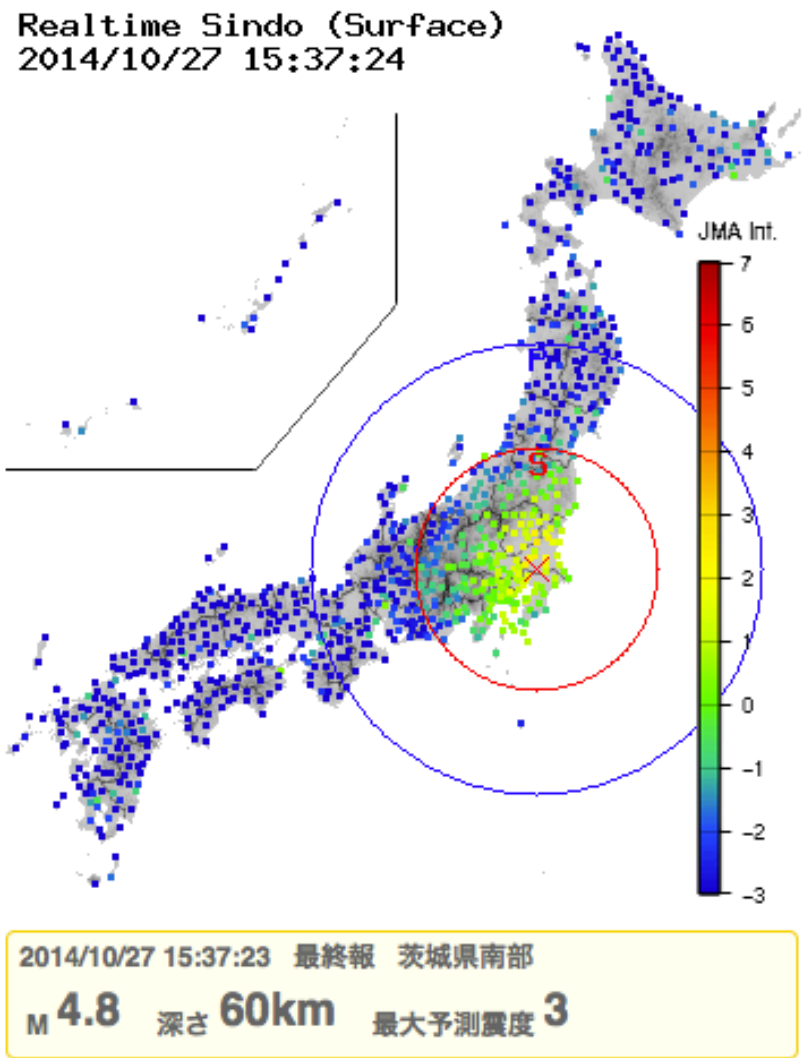


Radio

etc…

Kyoshin Monitor

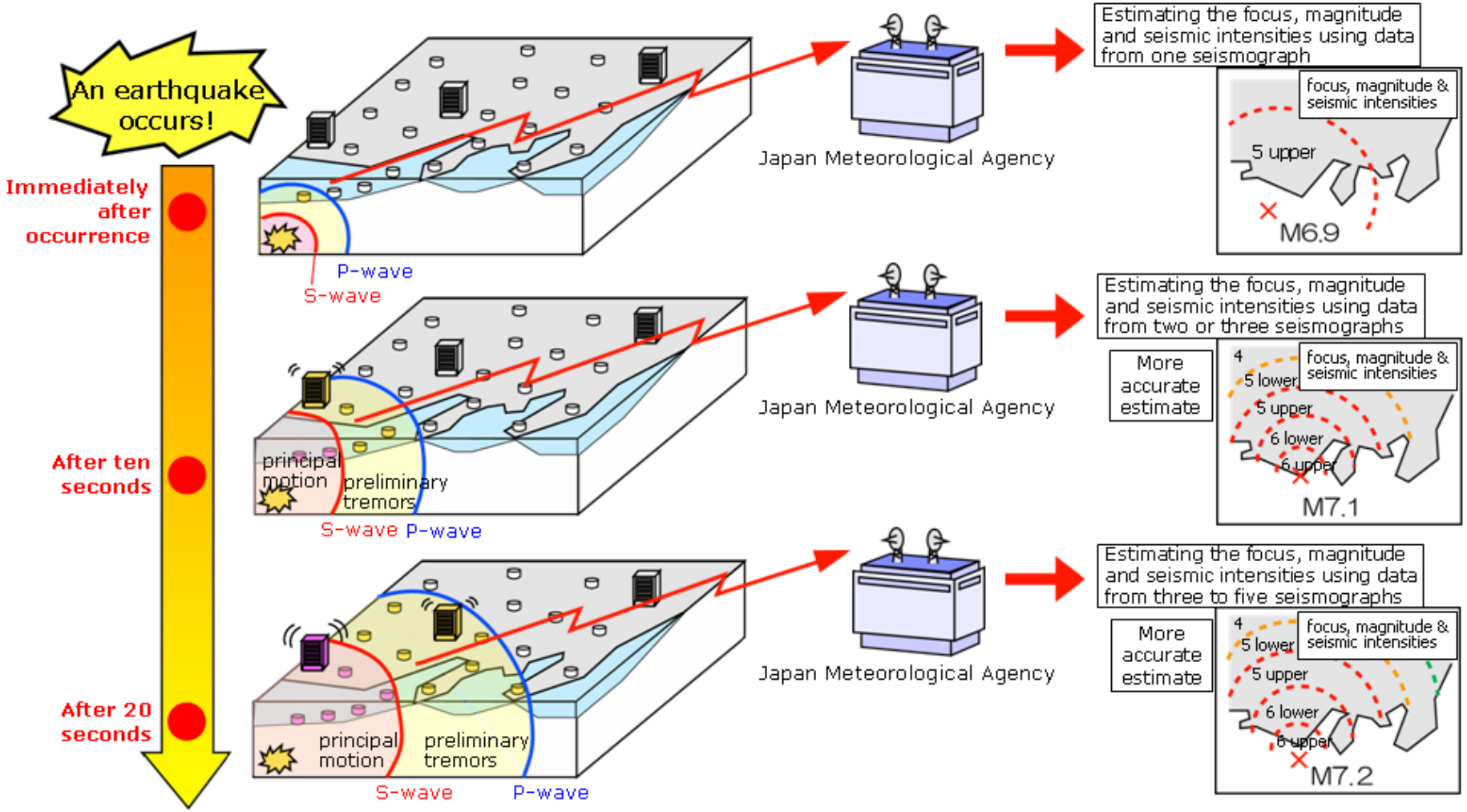




(Source: National Research Institute for Earth Science and Disaster Prevention (NIED): http://www.kyoshin.bosai.go.jp/)

Earthquake early warning (EEW) in Japan

(Source: Japan Meteorological Agency (JMA): http://www.jma.go.jp/jma/en/Activities/eew1.html)



Related lectures: Special lecture by Dr. Hoshiba (JMA)
Special lecture by Dr. Yamada (Kyoto Univ.)

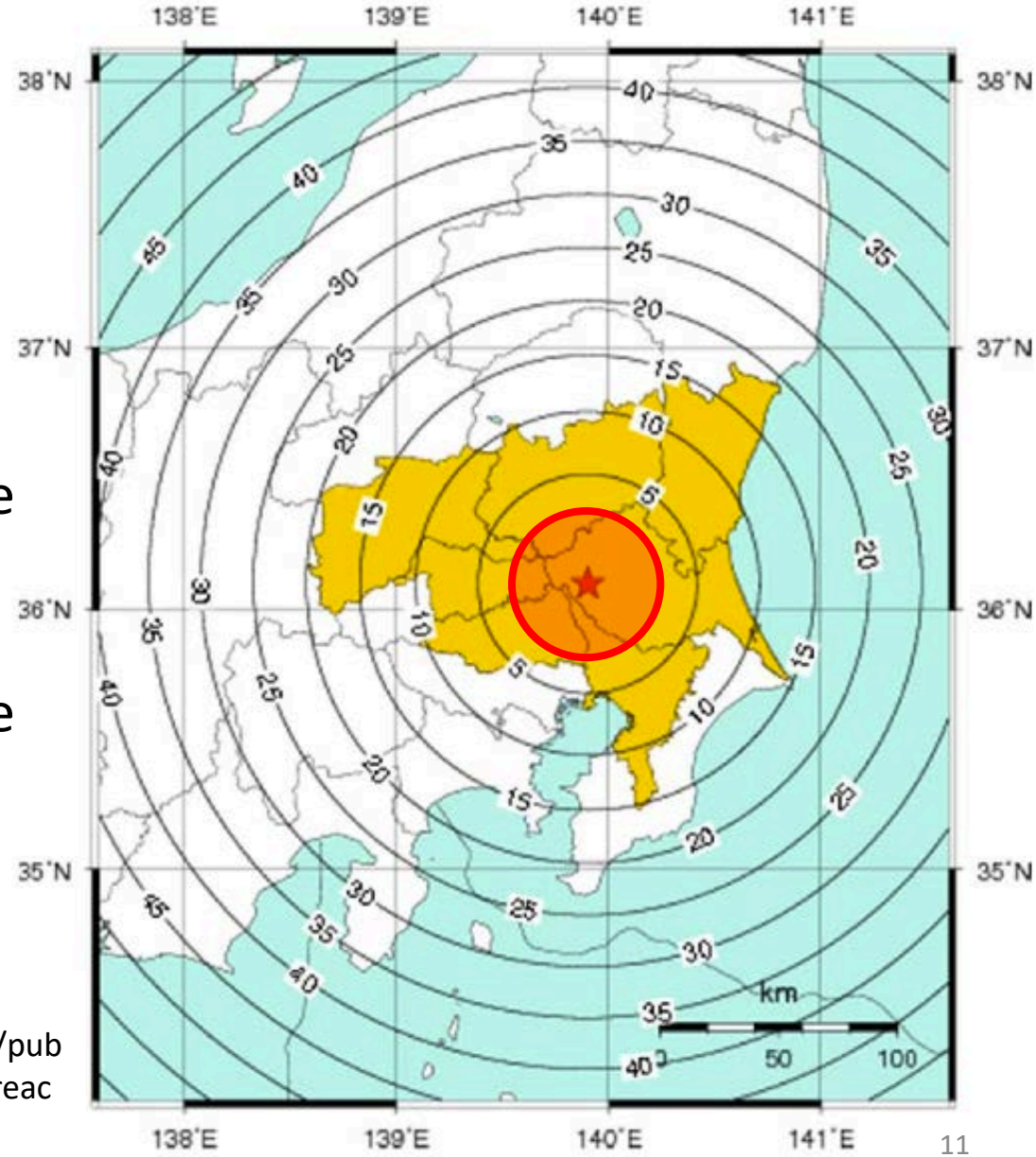
Sep. 16 2014 12:28:31 (Mw5.4, depth=46.5 km)

First detection:

3.4 sec after the origin time

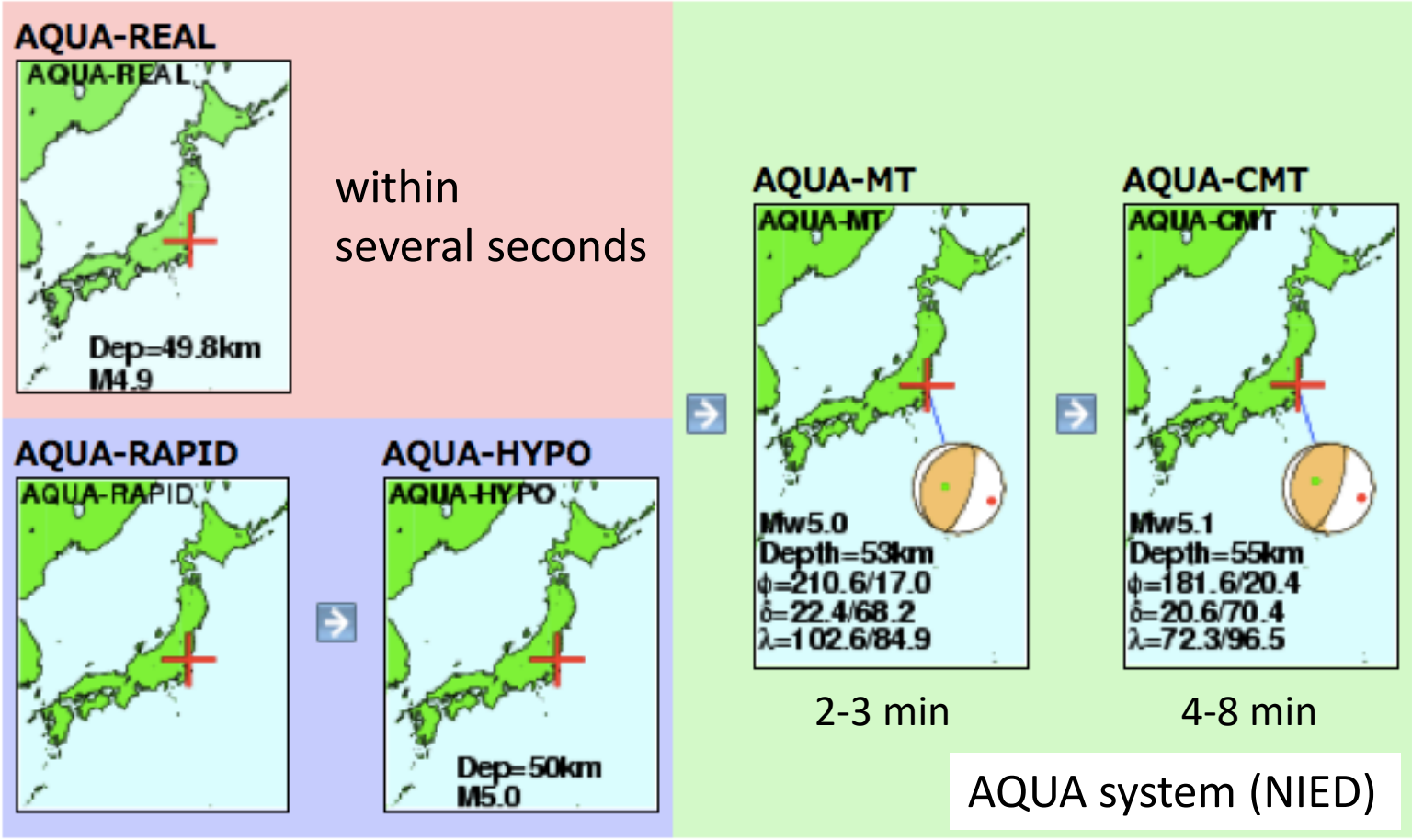
Earthquake Early Warning:

3.6 sec after the origin time



(Source: JMA: http://www.data.jma.go.jp/svd/eew/data/nc/pub_hist/2014/09/20140916122840/reachtime/reachtime.html)

Seismological Information

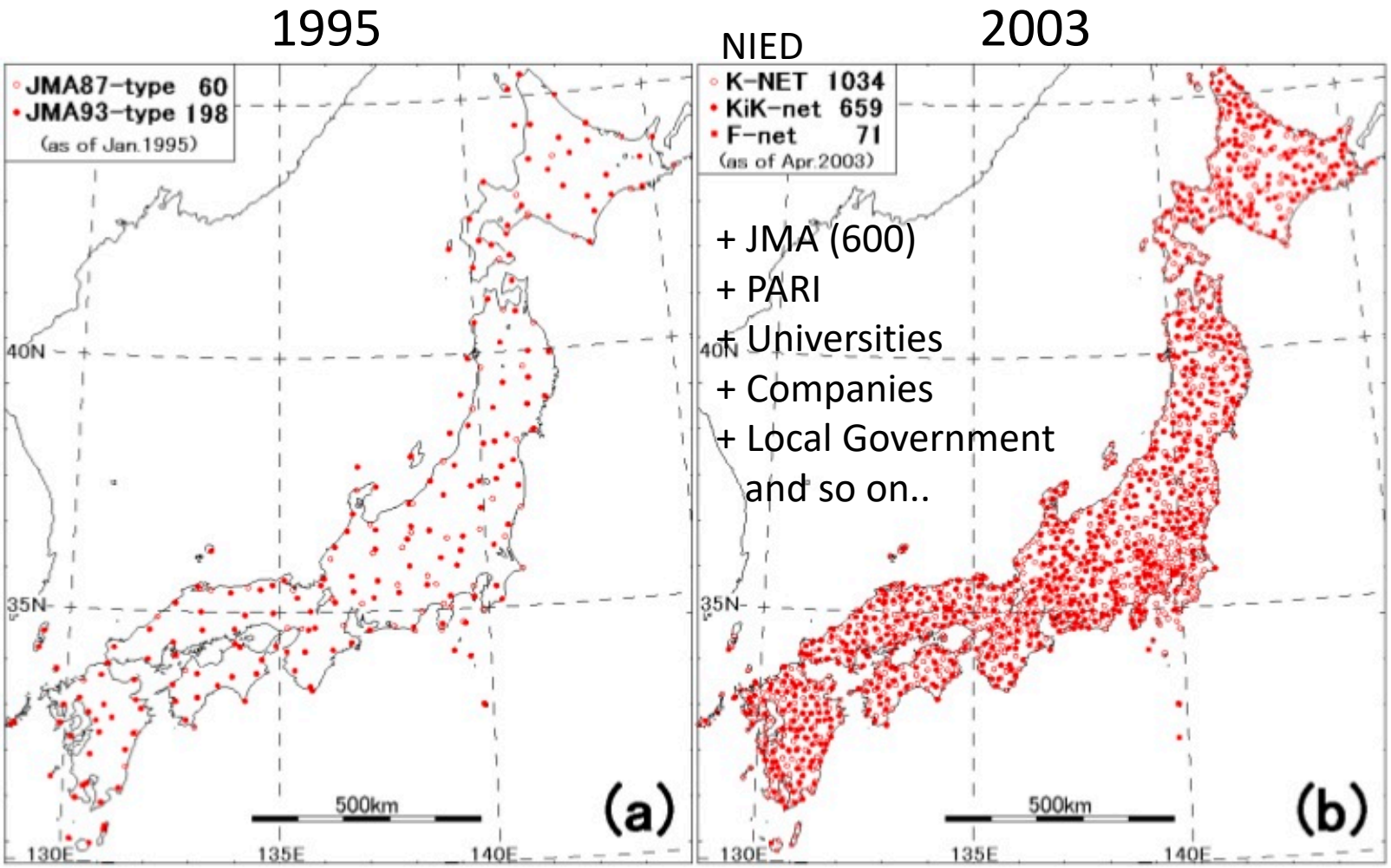


(Source: NIED: http://www.hinet.bosai.go.jp/?LANG=en
http://www.hinet.bosai.go.jp/AQUA/aqua_exp.php?LANG=en)

Related lectures: *Focal Mechanism , Local Earthquake Analysis, Moment Tensor Analysis*

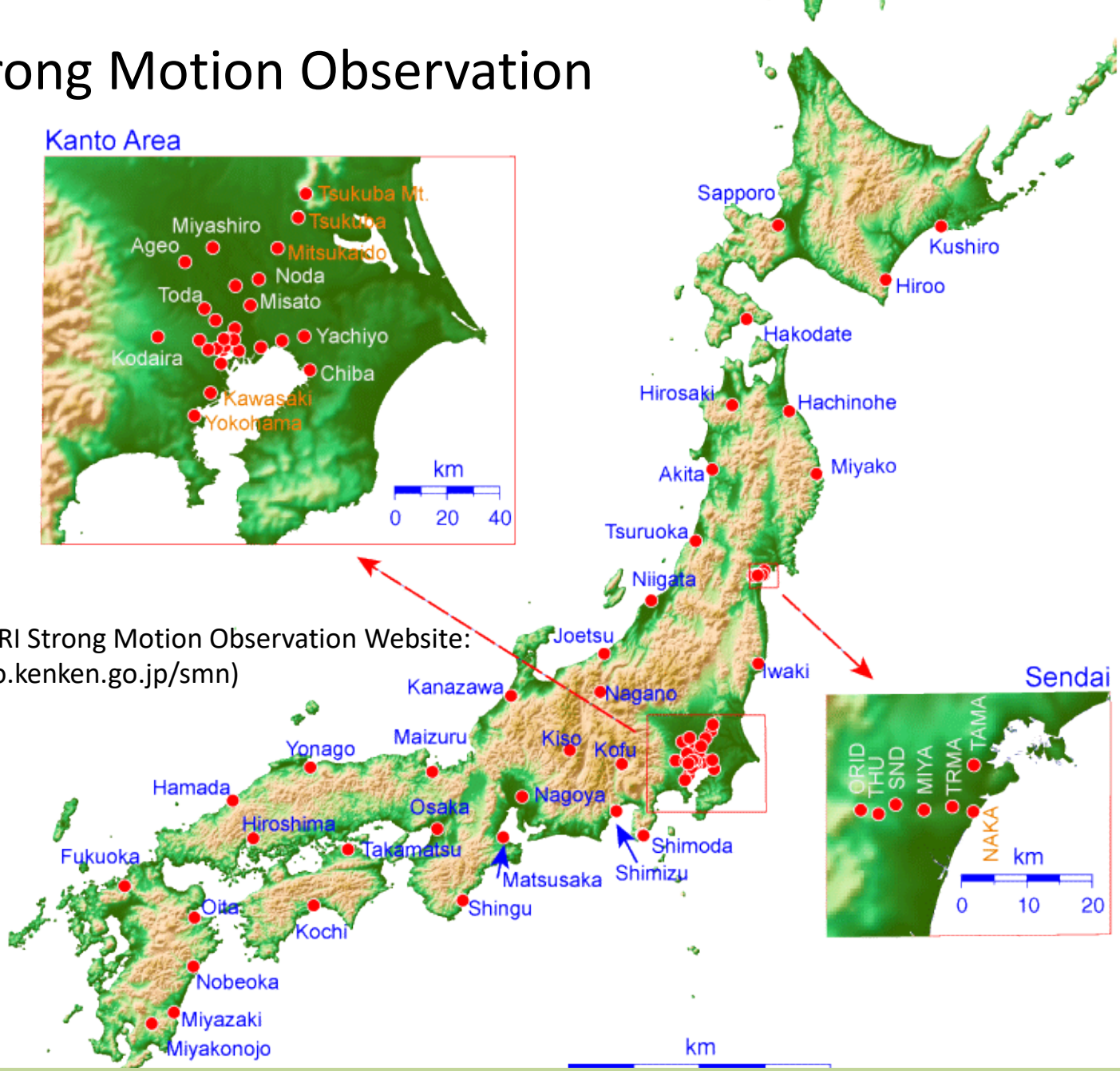
2. Seismic Wave Observation

“What made the earthquake information systems possible in Japan?”



(Okada et al., "Recent progress of seismic observation networks in Japan -Hi-net, F-net, K-NET and KiK-net-", Earth Planets Space, 56, xv-xxviii, 2004)

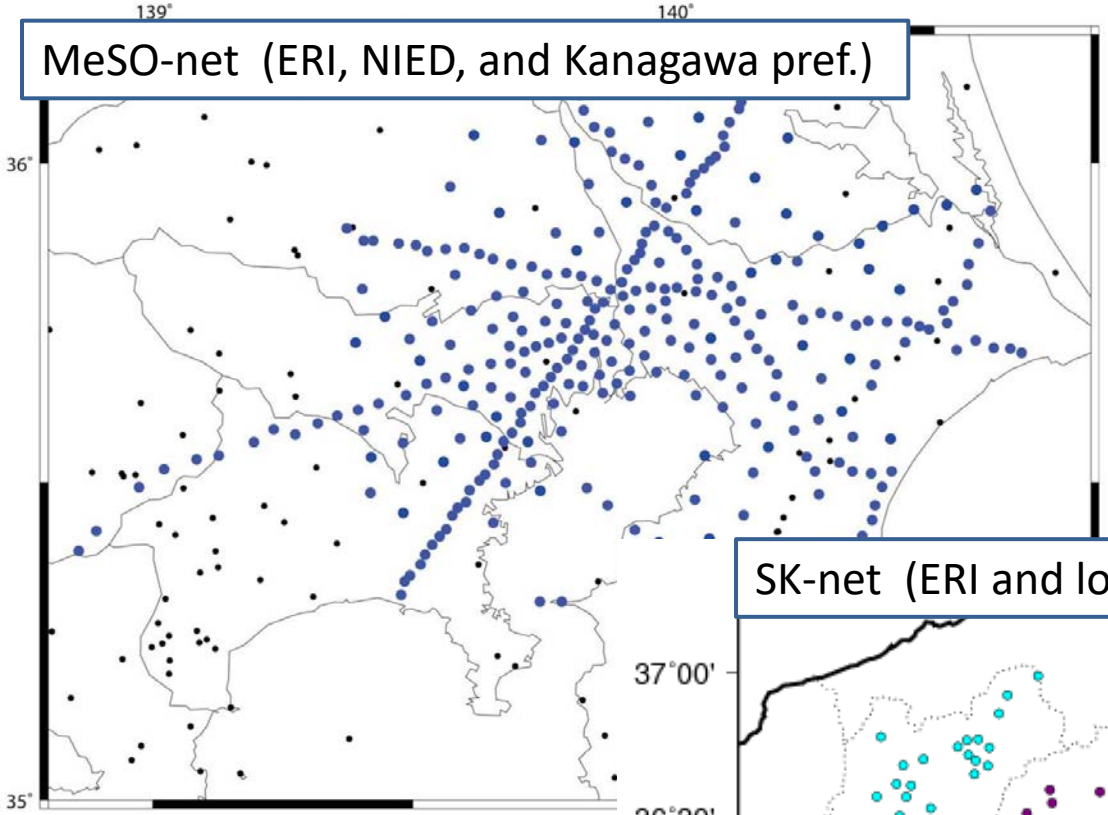
BRI Strong Motion Observation



(Source: BRI Strong Motion Observation Website: http://smo.kenken.go.jp/smn)

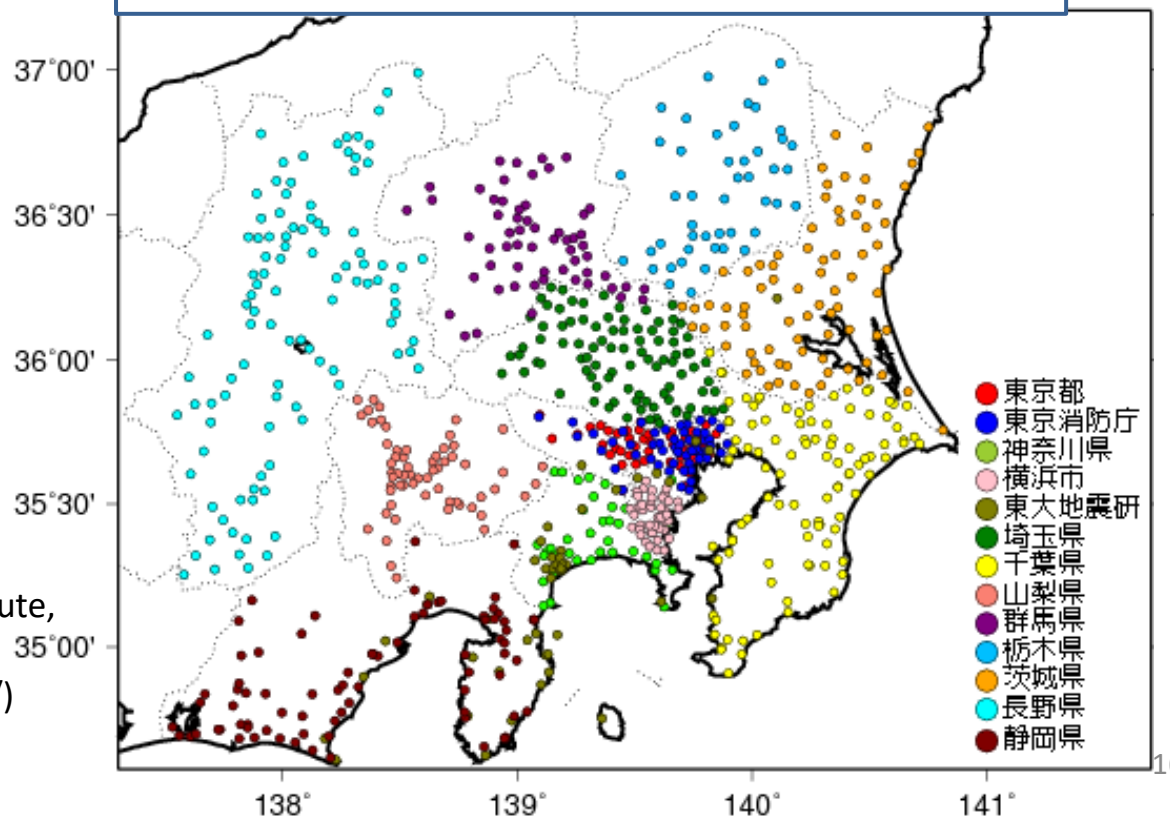
Related lecture: Strong Earthquake Motion Observation (for S course)

MeSO-net (ERI, NIED, and Kanagawa pref.)



(Source: Earthquake Research Institute, The University of Tokyo: http://www.eri.u-tokyo.ac.jp/KOHO/Nenpo2013/images/ch2.5/fig23.html)

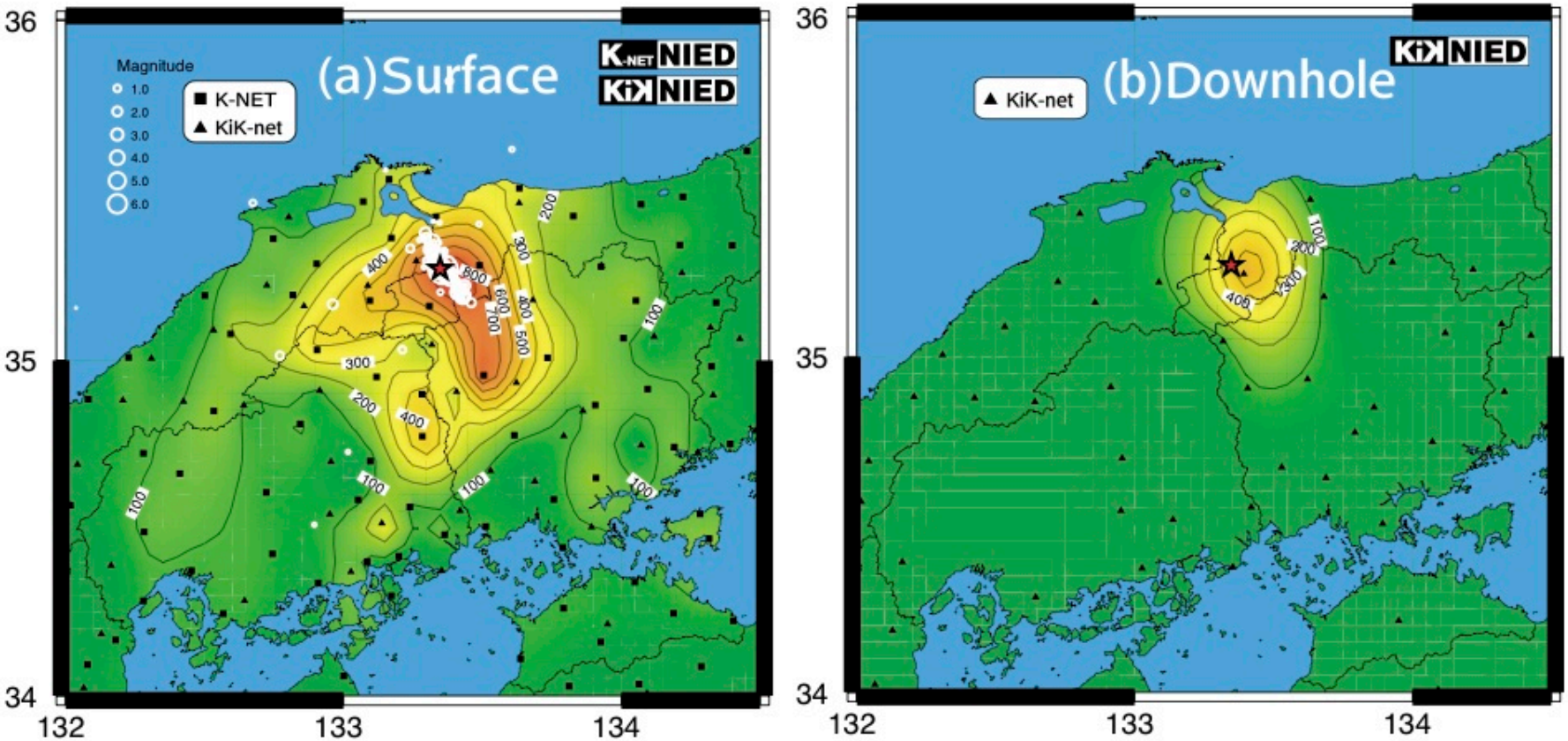
SK-net (ERI and local governments)



(Source: Earthquake Research Institute, The University of Tokyo: http://www.sknet.eri.u-tokyo.ac.jp/)

Findings from dense observation networks

(1) Variation of ground motions

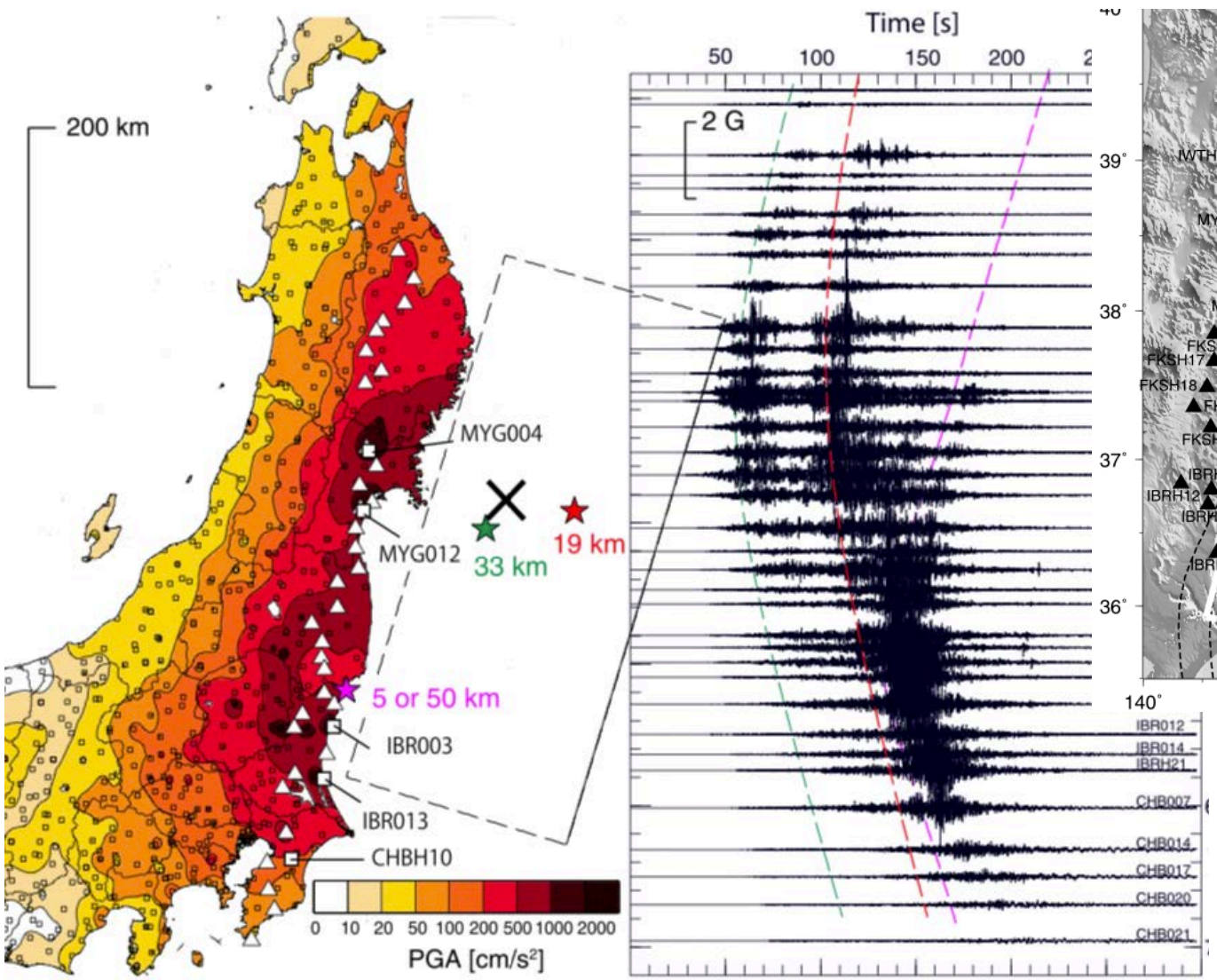


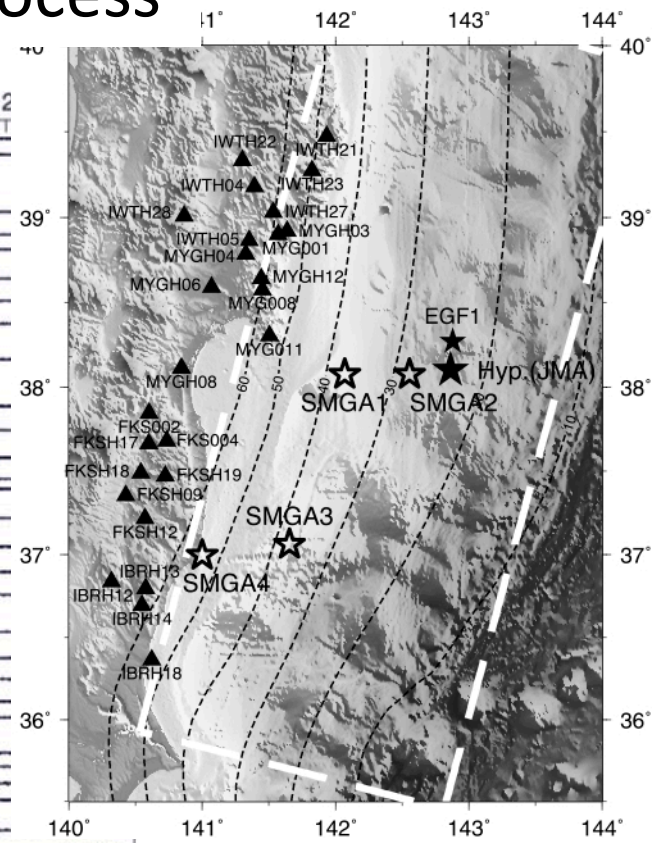
abnormal distribution of ground motion

-> local site effect?

(Okada et al., "Recent progress of seismic observation networks in Japan -Hi-net, F-net, K-NET and KiK-net-", Earth Planets Space, 56, xv-xxviii, 2004)

(2) Complicated earthquake rupture process



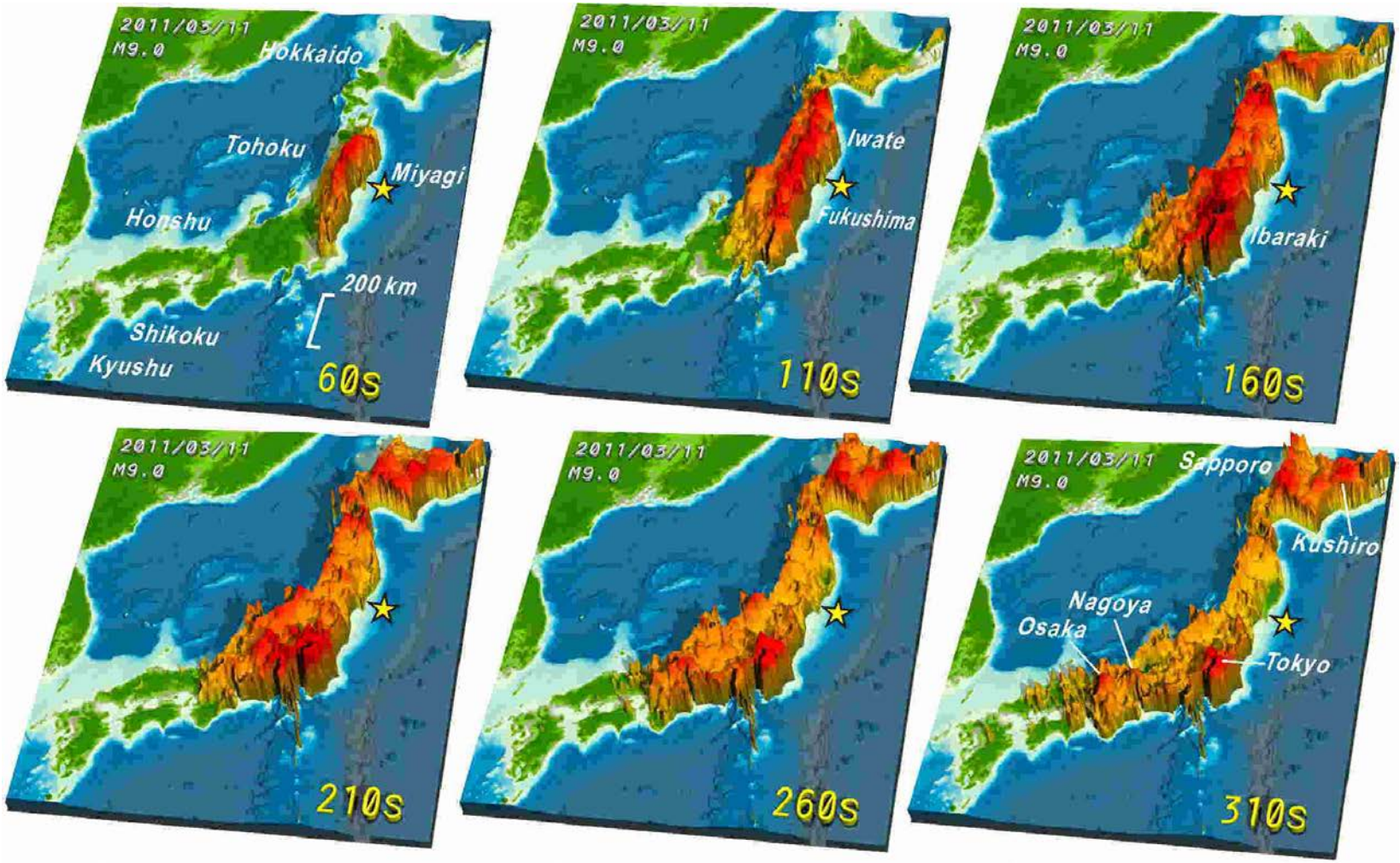


(Upper right: Asano and Iwata, "Source model for strong ground motion generation in the frequency range 0.1-10 Hz during the 2011 Tohoku earthquake", Earth Planets Space, 64, 1111-1123, 2012)

(Left: FURUMURA Takashi, et al., “Strong ground motions from the 2011 off-the Pacific-Coast-of-Tohoku, Japan(Mw=9.0) earthquake obtained from a dense nationwide seismic network, 2011”, The University of Tokyo website: http://www.eri.u-tokyo.ac.jp/people/furumura/pdf/2011ls.pdf)

(3) Visualization of seismic wave propagation

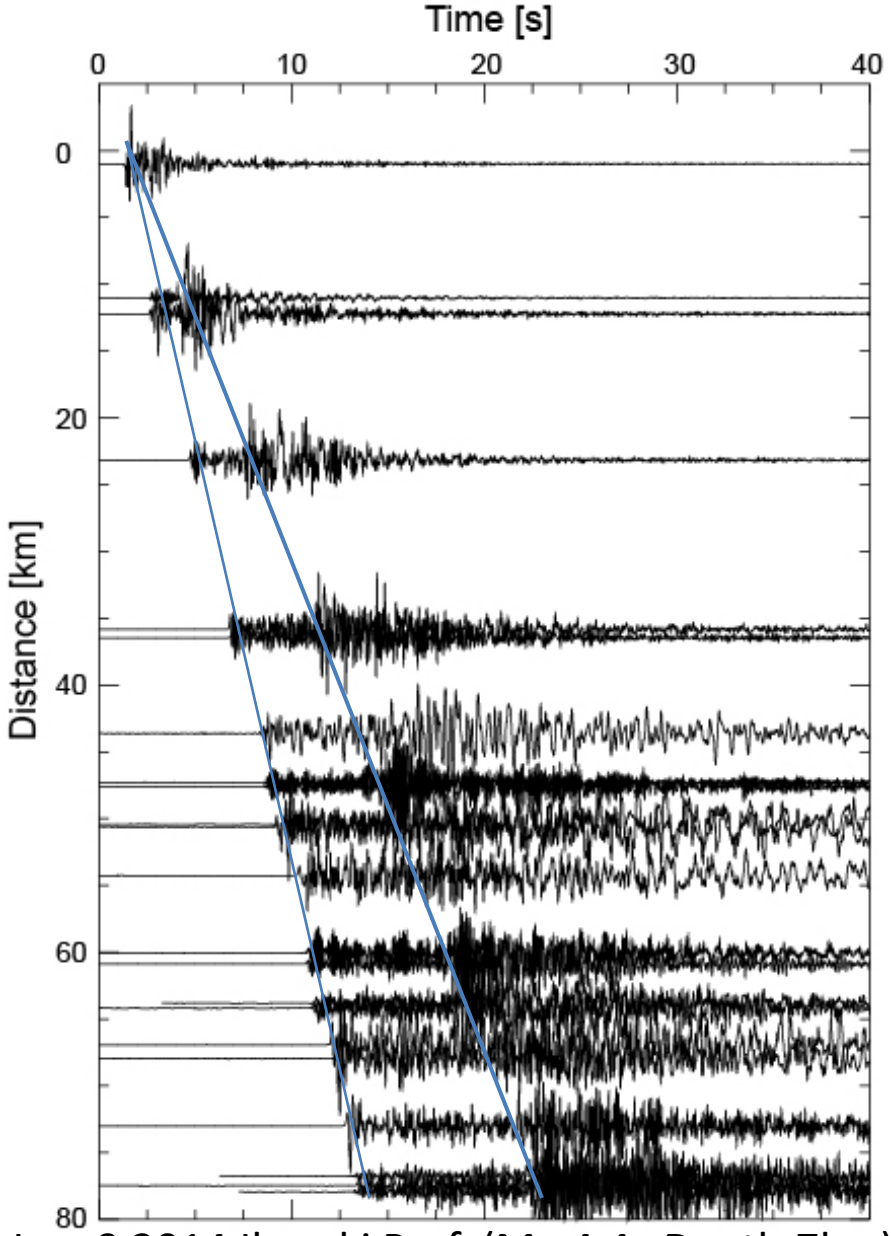
(Source: FURUMURA Takashi, et al., The University of Tokyo website: http://www.eri.u-tokyo.ac.jp/people/furumura/pdf/2011ls.pdf)



Related lecture: Theory of Seismic Waves

3. Seismic Wave Propagation

3.1 Body waves



Jan. 9 2014 Ibaraki Pref. (Mw4.4, Depth:7km)

Near field recordings:

- P- and S-waves are clearly seen

P wave (Primary wave or Pressure wave)
S wave (Secondary wave or Shear wave)
-> **Body wave**

- S-waves are slower than P-waves

- Generally body wave decrease in amplitude with increase in distance

P-wave: 25km(5s), 55km(10s)
S-wave: 10km(5s), 30km(10s)

Propagation velocities of body waves

Pitch (baseball) :	150 km/h	0.042 km/s
Bullet train :	300 km/h	0.084 km/s
Passenger jet :	900 km/h	0.250 km/s
Sound :	1,200 km/h	0.333 km/s
Concorde :	2,170 km/h	0.603 km/s
S-wave speed :	11,000-14,000 km/h	3.0-4.0 km/s
P-wave speed :	18,000-25,000 km/h	5.0-7.0 km/s
Space shuttle:	28,000 km/h	7.800 km/s
Earth's orbital speed:	107,218 km/h	29.78 km/s

This figure is masked
due to copyright problem.

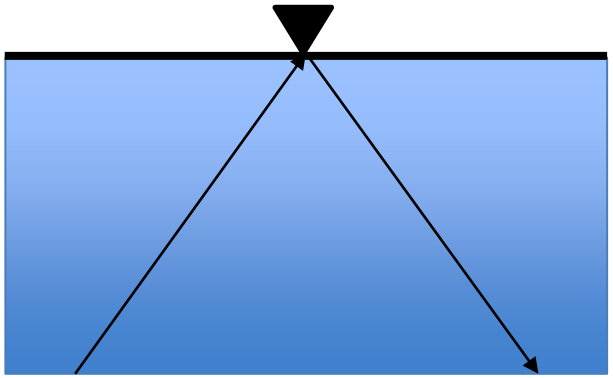
P-wave propagation : “involve both a volume change and shearing (change in shape) in the material”

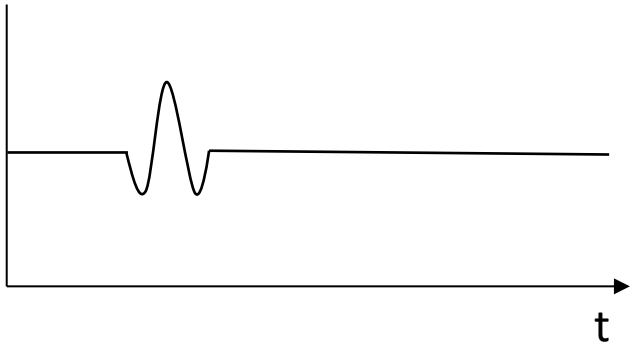
S-wave propagation : “pure shear with no volume change”

Related lecture: Theory of Seismic Waves

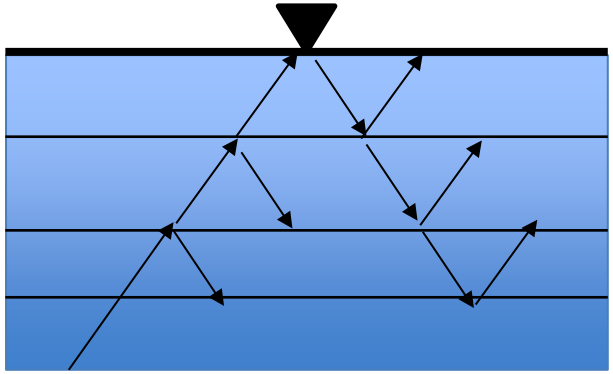
Wave propagation in multilayered structure

(a) Infinite homogeneous medium





(b) Inhomogeneous medium

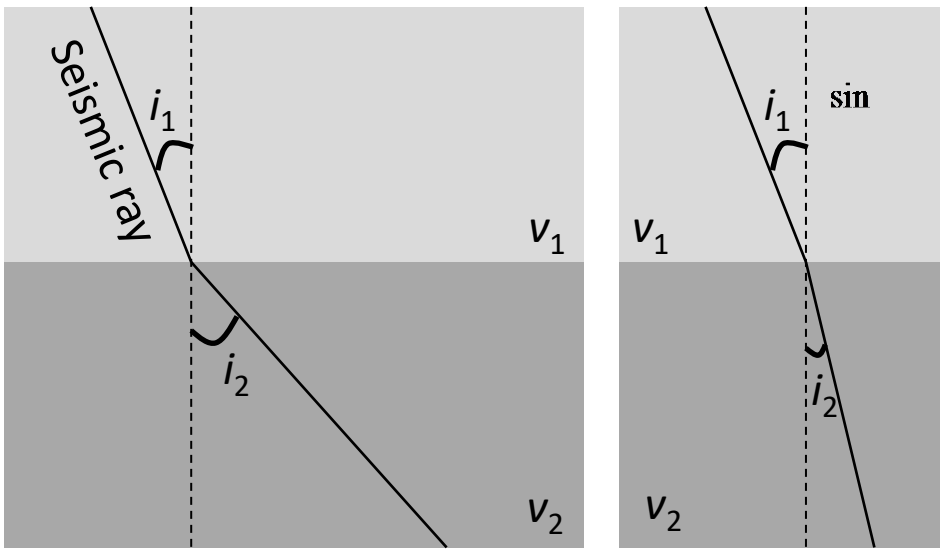


Reflections & refractions
→ long duration, amplification

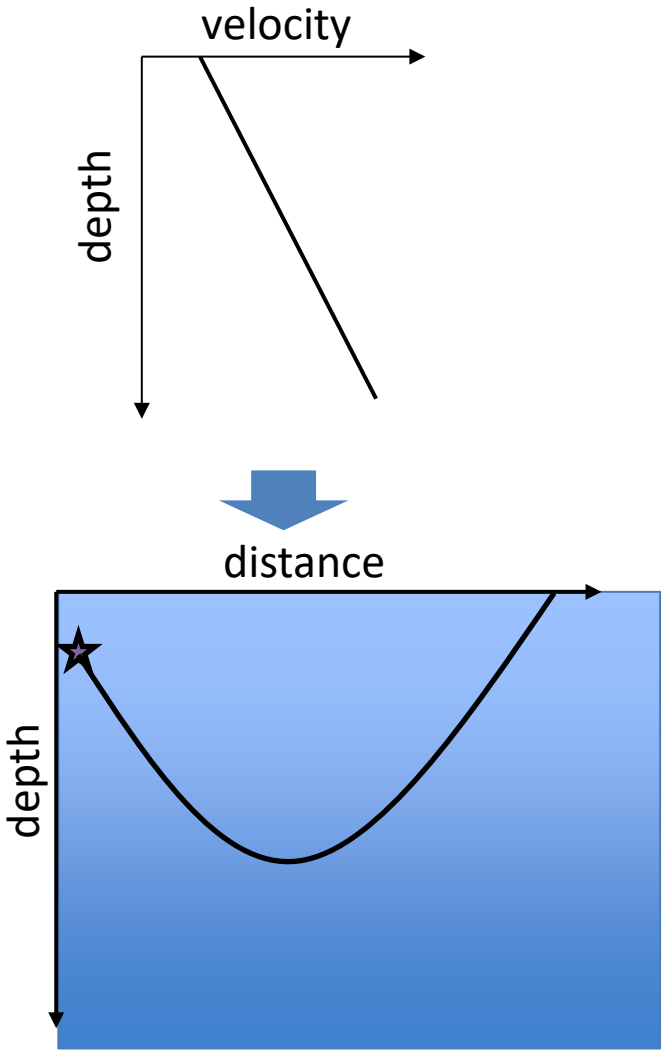
Snell's law

$$\frac{\sin i_1}{v_1} = \frac{\sin i_2}{v_2} = \frac{\sin i_n}{v_n} = p$$

i: angle, v: velocity, p: ray parameter

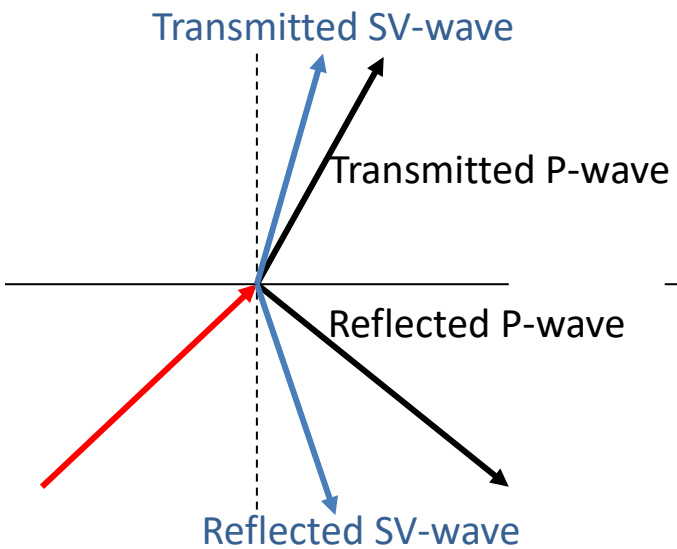


$v_1 < v_2$ $v_1 > v_2$

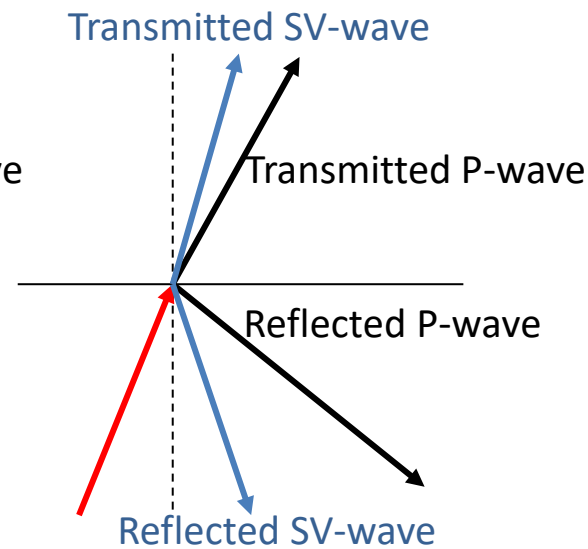


Mode conversions

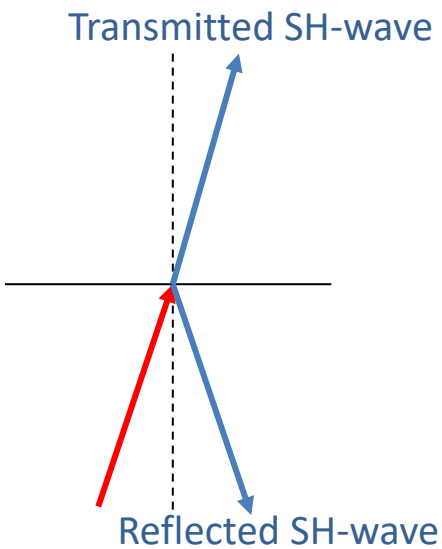
(a) Incident P wave



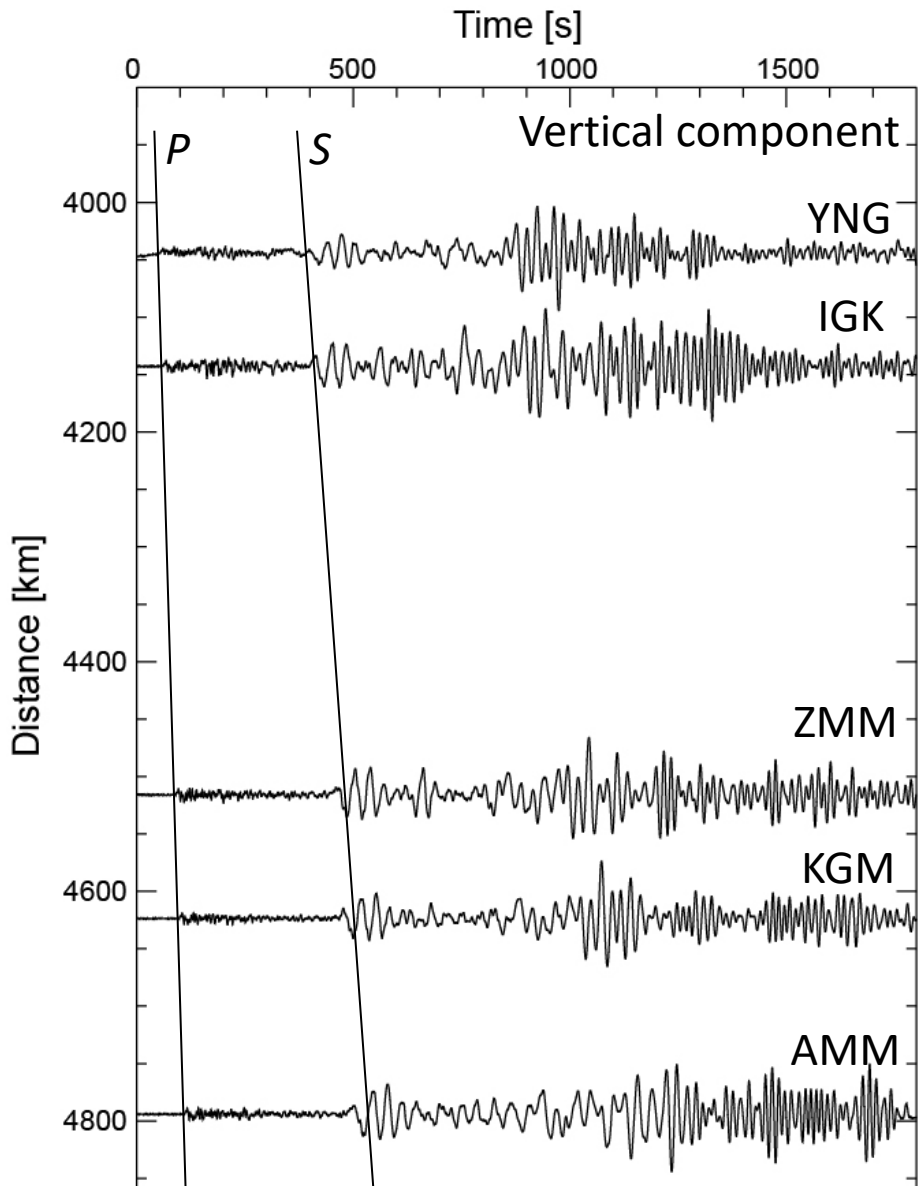
(b) Incident SV wave



(c) Incident SH wave



3.2 Surface waves



Far field recordings:

-Propagation velocity is slower than those of body waves.

- Have long duration and large amplitudes

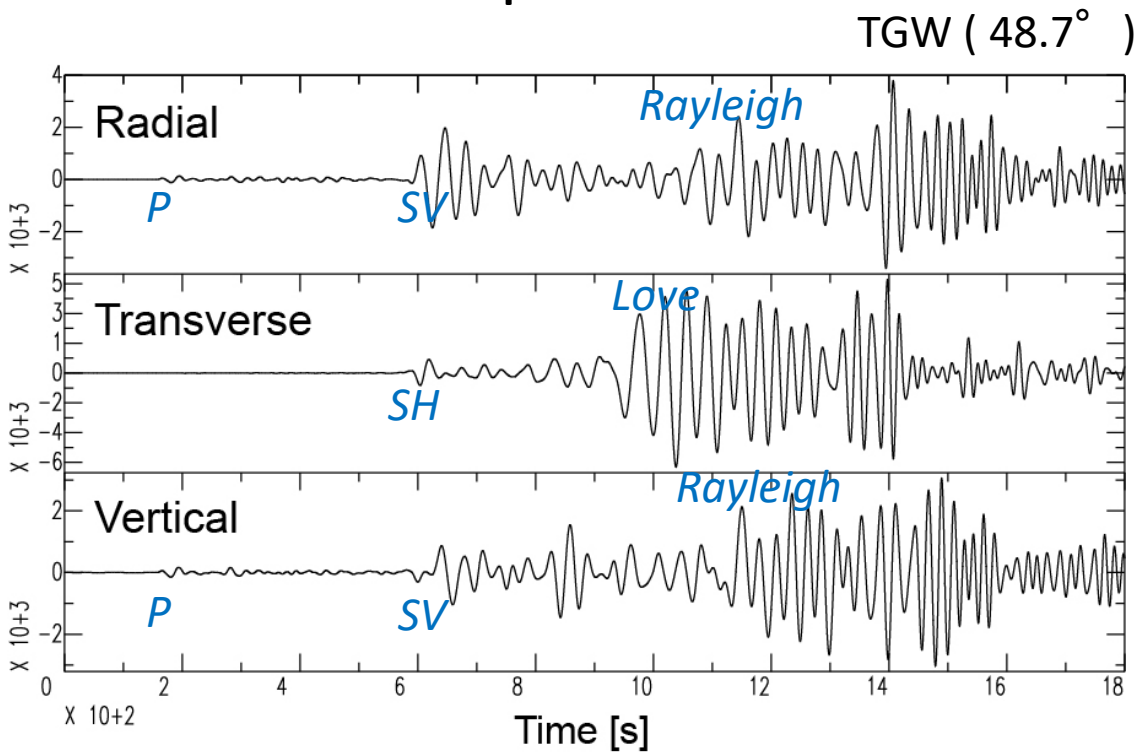
Related lecture: Surface Waves

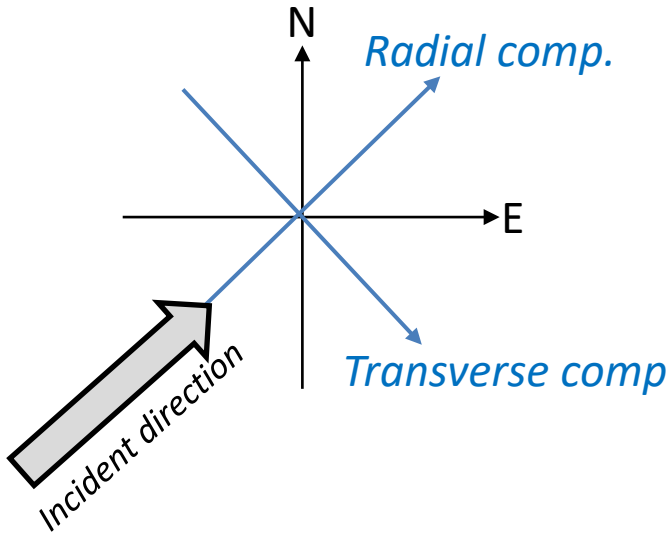
Apr. 11 2012 Northern Sumatra (Mw8.6, Depth:22.9km)

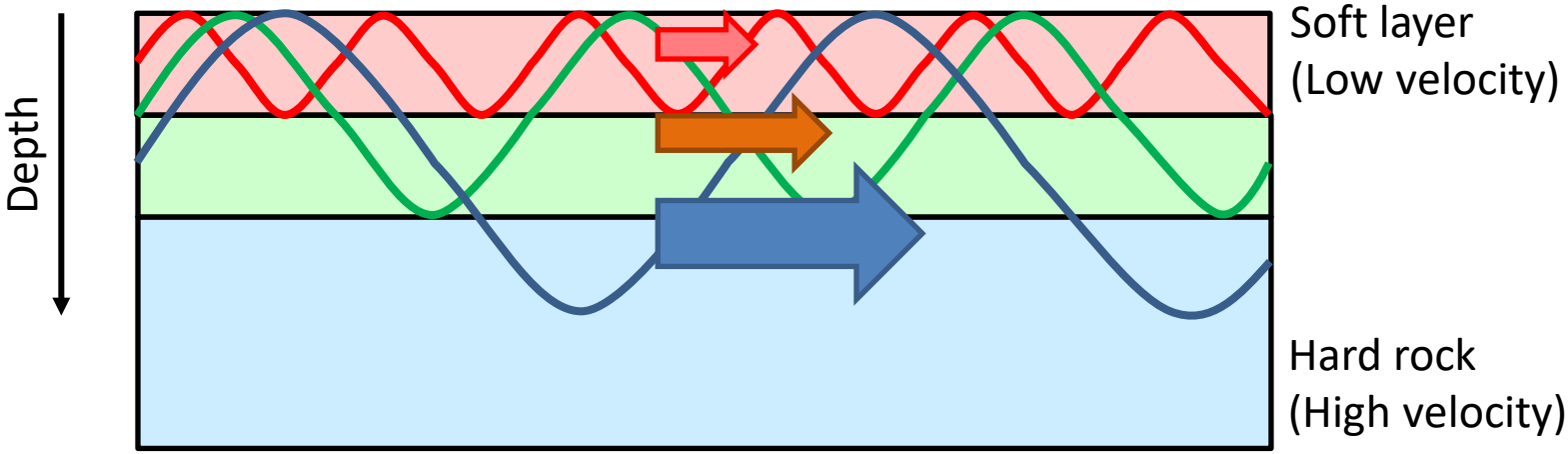
This figure is masked
due to copyright problem.

Surface wave amplitude decays strongly with depth.

Surface wave dispersion

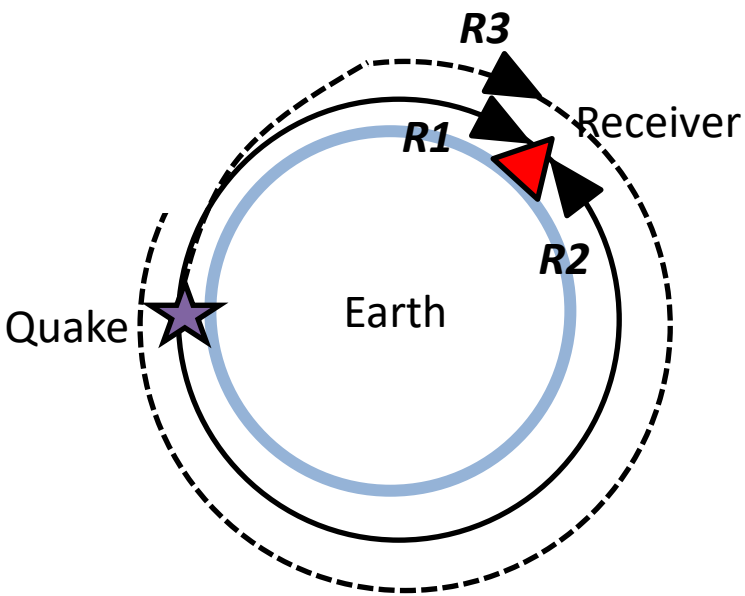


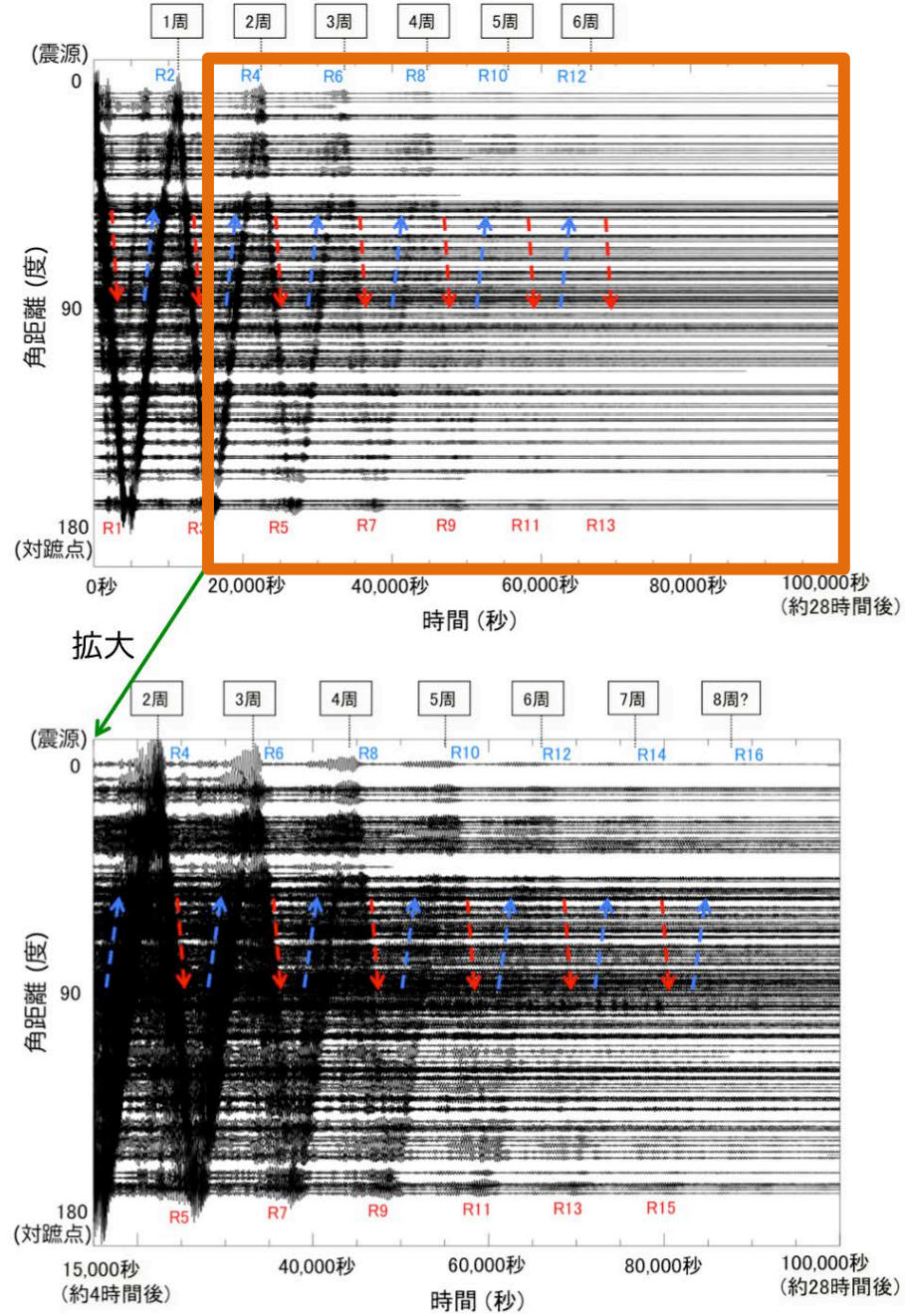




Global surface waves

Multiple orbit surface waves detected in the 2011 Tohoku earthquake (Mw9.0)

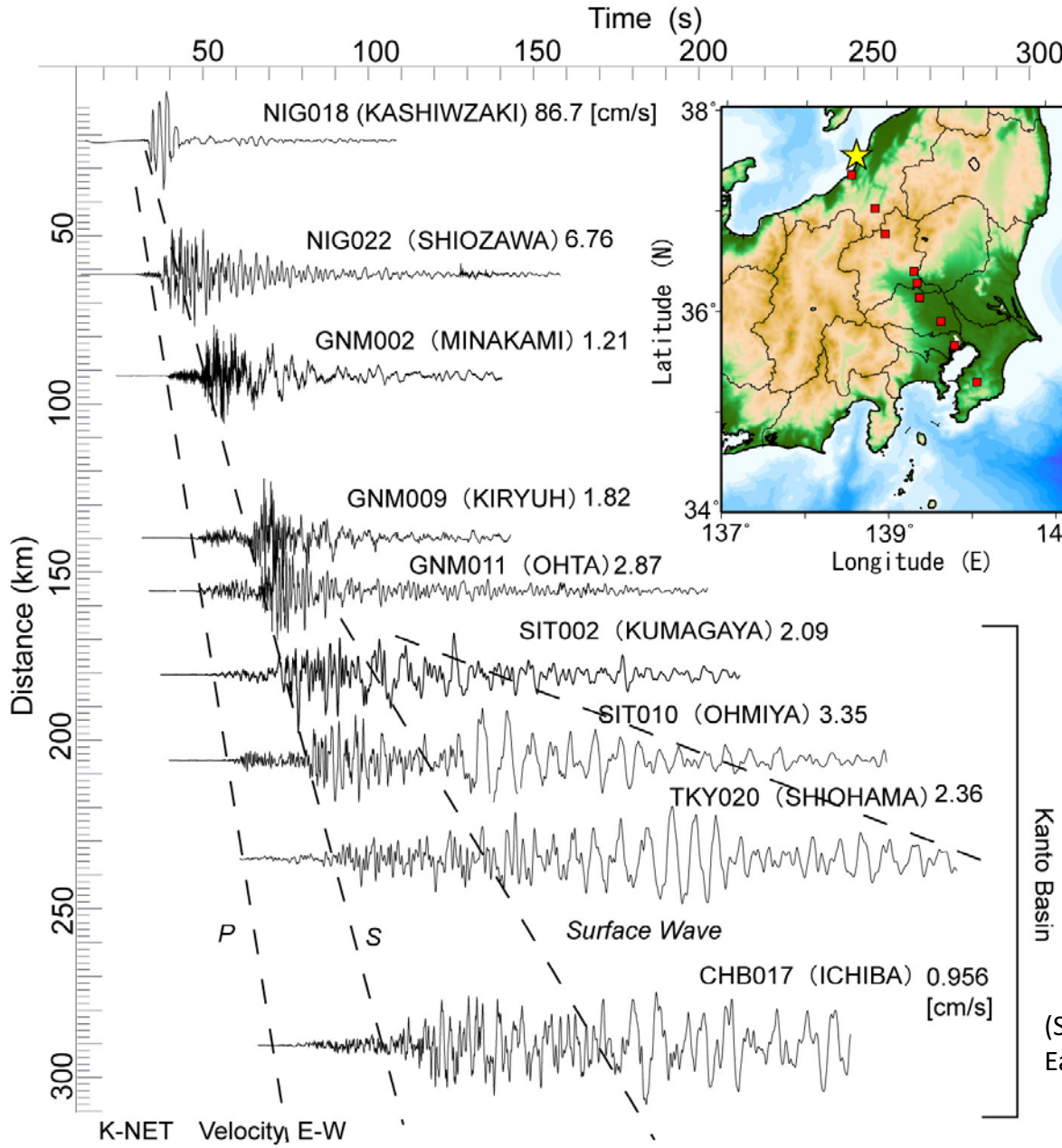


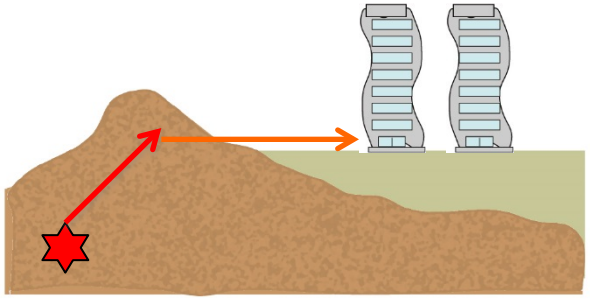


(Source: Yoshizawa, 2011, http://noreply.sci.hokudai.ac.jp/~seis/tohoku/)
(Original Waveform data: Global Seismographic Network, GEOSCOPE (provided by IRIS DMC))

Regional surface waves

The 2004 Chuetsu earthquake (Mw6.6)





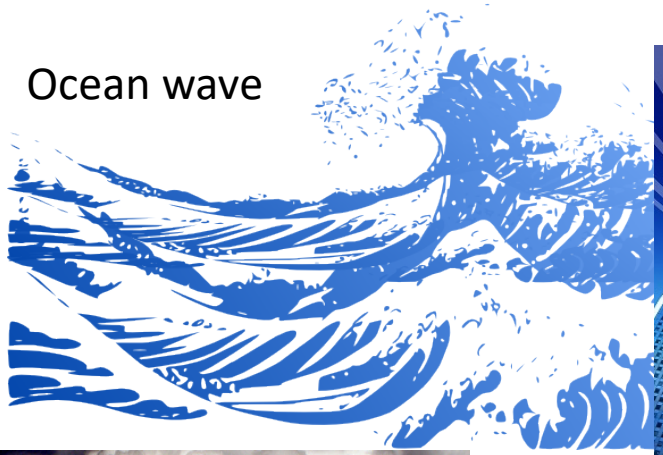
(Source: FURUMURA Takashi, 2007,
Earthquake Research Institute, University of Tokyo.

3.3 Microtremor (microseism, ambient vibration)

Global — Regional — Local — Nearby

Low frequency — 1Hz — High frequency

Ocean wave



Wind

Human activities

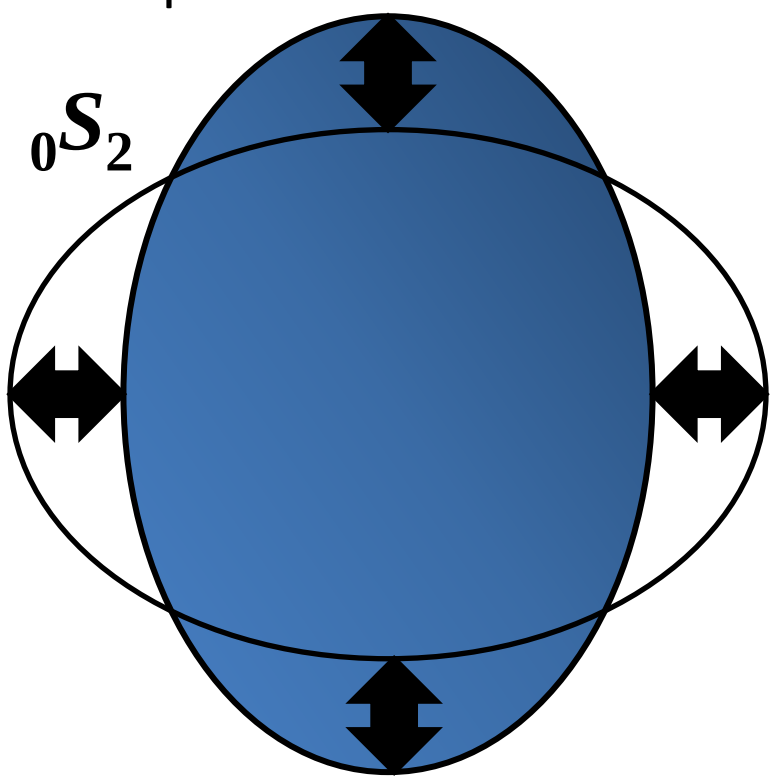
Storm

Related lecture: Effect of Surface Geology on Seismic Motion I & II (S+E)
Microtremor Observation I & II (S+E)

3.4 Free oscillations of the Earth

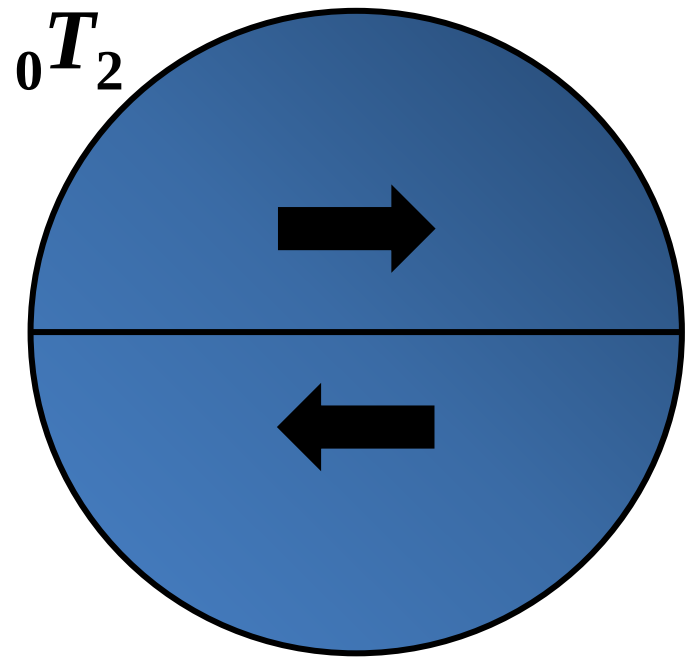
Large earthquakes make the Earth oscillate like a ringing bell for weeks, even months after the event.

Spheroidal oscillation



Period: about 54 minutes

Toroidal oscillation



Period: about 44 minutes

4. Ground Motion Indicators

What is “strong” ground motion and how to evaluate it?

4.1 Maximum amplitudes

(1) Peak Ground Acceleration (PGA: cm/s^2, gal)

(1) Peak Ground Velocity (PGV: cm/s, kine)

(1) Peak Ground Displacement (PGD: cm)

(1) Spectral Acceleration (SA: g)

4.2 Engineering ground-motion parameters

(1) Response Spectra

$$S_a(t,\xi), S_v(t,\xi), S_d(t,\xi)$$

(1) Housner Spectrum Intensity (SI, cm)

$$SI(\xi) = \int S_v(t,\xi)\,dT$$

(1) Arias Intensity (m/s)

$$I_A = \frac{\pi}{2g}\int_0^{Td} a(t)^2\,dt$$

$a(t)$: acceleration amplitude

(1) Cumulative Absolute Velocity (g-sec)

$$CAV = \int_o^{Td} |a(t)|\,dt$$

etc…

4.3 Seismic intensity scale

Seismic intensity quantifies the effects of ground motion on the humans, objects of nature (e.g. trees), and man-made structures

(a) Mercalli intensity (MM) scale

- 12 scales

INTENSITY	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Shaking	Not Felt	Weak	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme	Extreme	Extreme

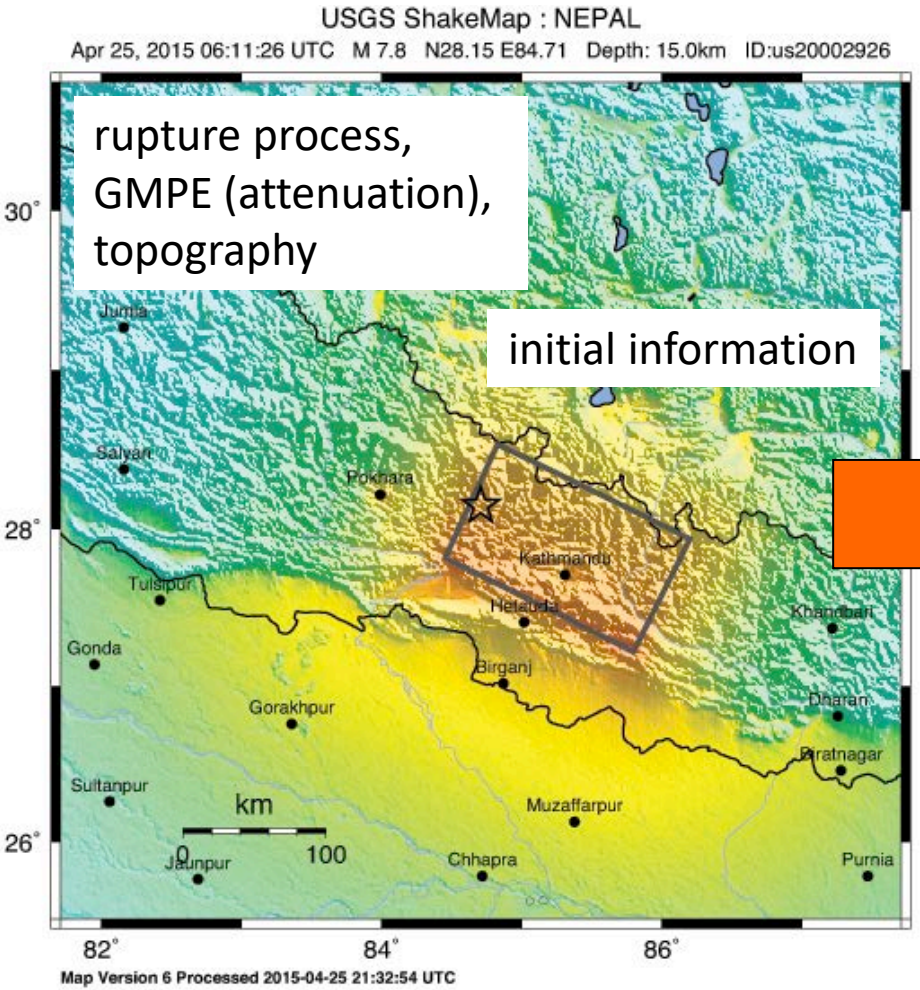
(b) Medvedev-Spouheuer-Karnik (MSK) intensity scale

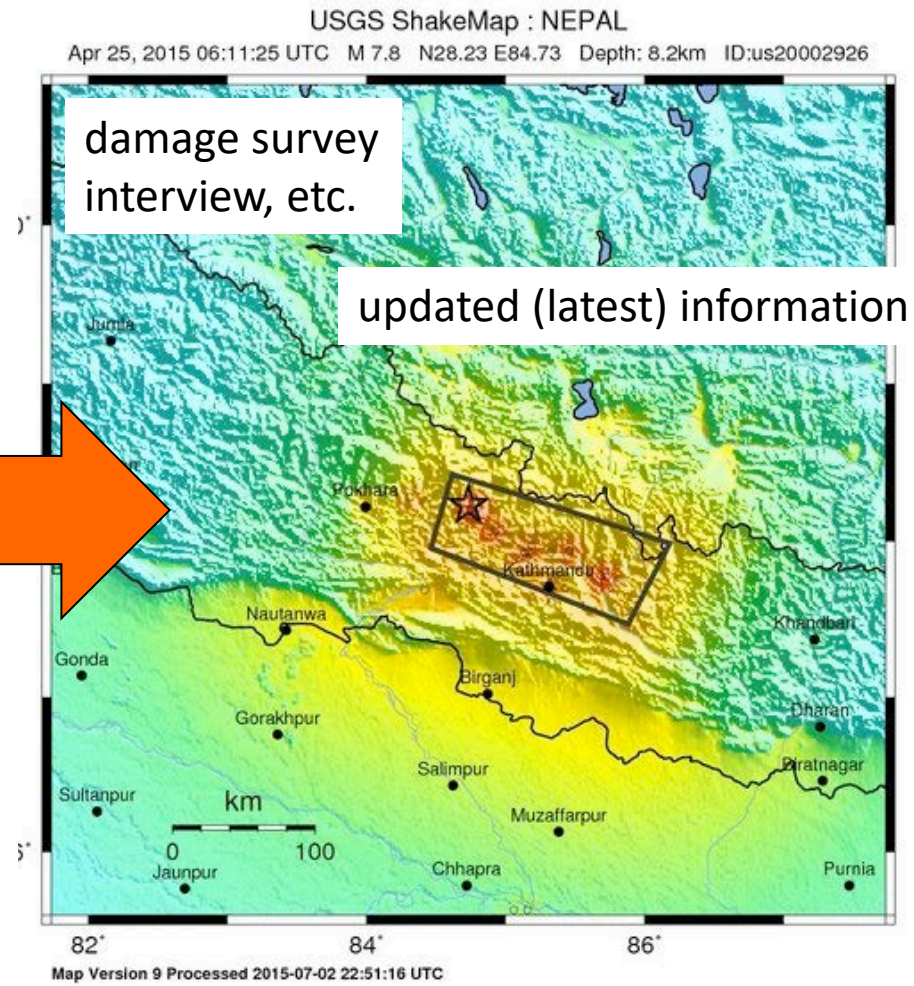
- India, Israel and CIS countries
- 12 scales

INTENSITY	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Shaking	Not Perceptible	Hardly Perceptible	Weak	Largely Observed	Fairly Strong	Strong	Very Strong	Damaging	Destructive	Devastating	Catastrophic	Very Catastrophic

2015 Nepal Gorkha earthquake (Mw7.8)

(Source: USGS Website)





PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	*<0.02*	*0.1*	*1.4*	*4.7*	*9.6*	*20*	*41*	*86*	*>178*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
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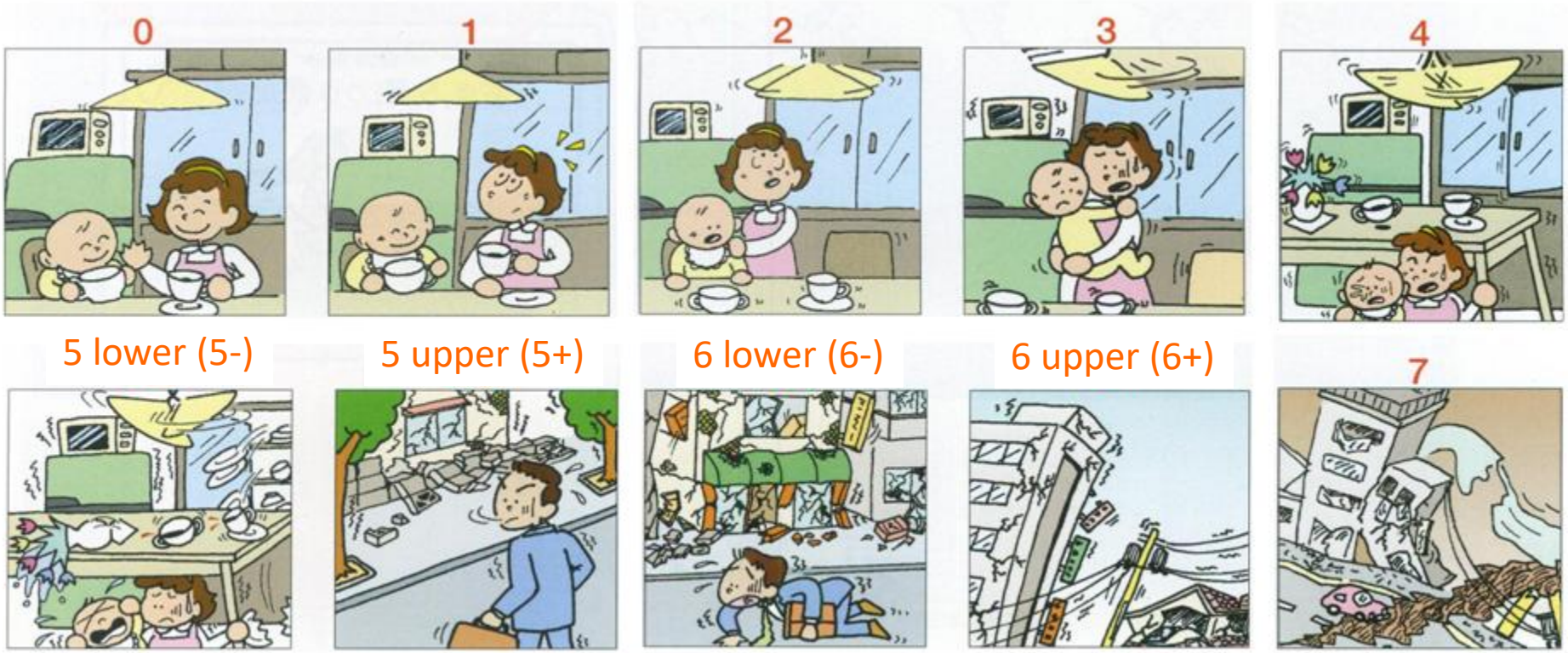
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

(c) JMA seismic intensity scale



(Source: JMA website: http://www.jma-net.go.jp/sapporo/tenki/calendar/today/1001.html)

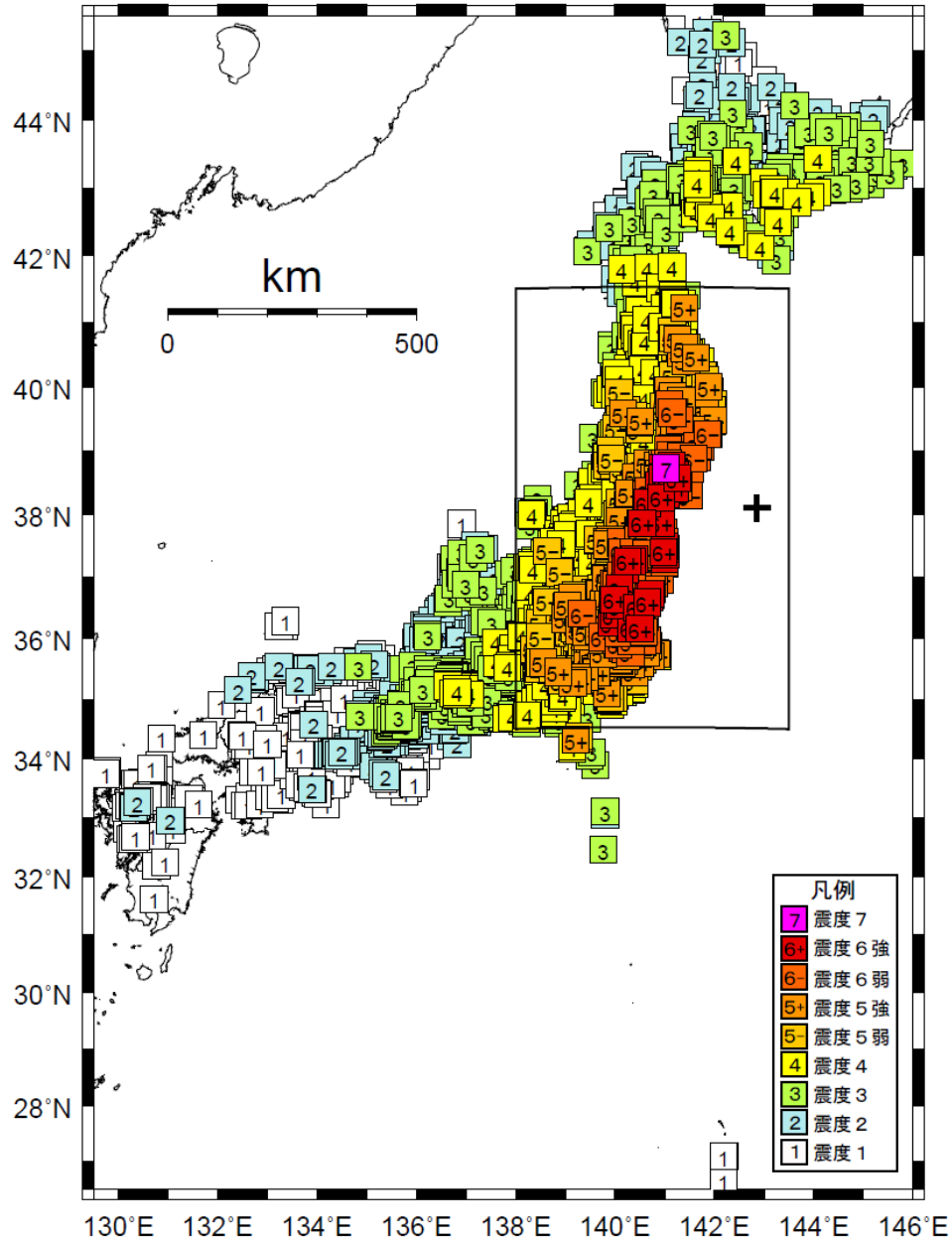
before April 1996 – judged by feelings and damages

処理部 STR-360

計測部 SAS-360

JMA intensities are now measured by purpose-built intensity meters (instrumental intensity)

2011 Tohoku Earthquake (Mw9.0)



(Source: JMA website: http://www.data.jma.go.jp/svd/eqev/data/2011_03_11_tohoku/201103111446_smap.png)

My lectures :

1. Overview of Earthquake and Disaster 1 h
2. Computer (Fortran programming) 6 days
3. Data Processing 2 days
4. Microtremor Observation II 1 day