Observation of Seismic intensity and Earthquake Early Warning of JMA - M_w9.0 Pacific Coast Tohoku Earthquake (Mar, 11, 2011)-

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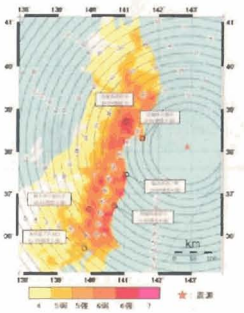
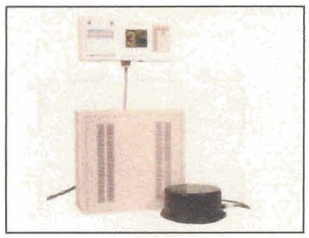
- Seismic Intensity (JMA intensity and its observation at M_w9.0 Pacific Coast Tohoku Earthquake , Mar, 11, 2011)
- Performance of JMA EEW for the M_w9.0 Earthquake
  - functioned as expected
  - malfunctioned
  - feedback from users, general public



Brief explanation of JMA instrumental seismic intensity

Instrumental JMA intensity

JMA introduced instrumental observation for Seismic Intensity *in 1996*.
(The first nation in the world)



- JMA intensity is measured from 3 comp. accelerogram.

It is easy to estimate JMA intensity, when you have 3 comp. digital acceleogram

- Derivation of the instrumental intensity is defined to keep the consistency with the intensity estimated from human feeling.

It is possible to compare with the data of intensities based on human feeling (old data)

Same scale with former one

Flow for estimation of JMA instrumental seismic Intensity

Accelerogram (in cm/s^2)(NS) | Accelerogram (in cm/s^2)(EW) | Accelerogram (in cm/s^2)(UD)

↓

Fourier Transform | Fourier Transform | Fourier Transform

↓

Filtering | Filtering | Filtering

↓

Inv. Fourier Transform | Inv. Fourier Transform | Inv. Fourier Transform

↓

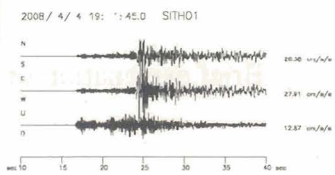
3 com. vector summation, $a(t)=\sqrt{(NS^2+EW^2+UD^2)}$

↓

Estimation of amplitude which satisfies the condition that total duration of $a(t) > a_0$ is 0.3s

↓

Instrumental Seismic Intensity, $I = 2 \log_{10} a_0 + 0.94$



a_0 is not PGA (Peak Ground Acceleration)

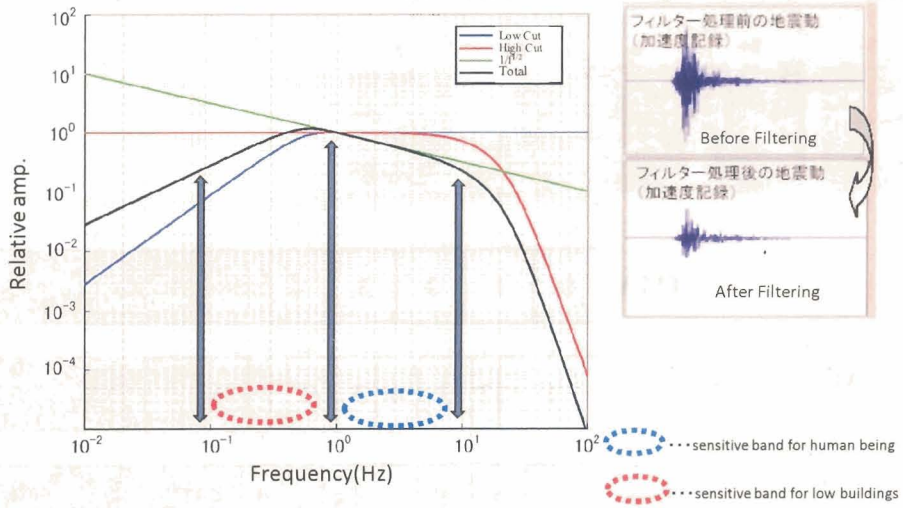
30th largest for 100 samples/s data
15th largest for 50 samples/s data

Filtering

1) Low-cut filtering: $(1-\exp(-(f/0.5)^3))^{1/2}$

2) High-cut filtering: $(1+0.694y^2+0.241y^4+0.0557y^6+0.009664y^8+0.00134y^{10}+0.000155y^{12})^{-1/2}$, where $y \equiv f/10$

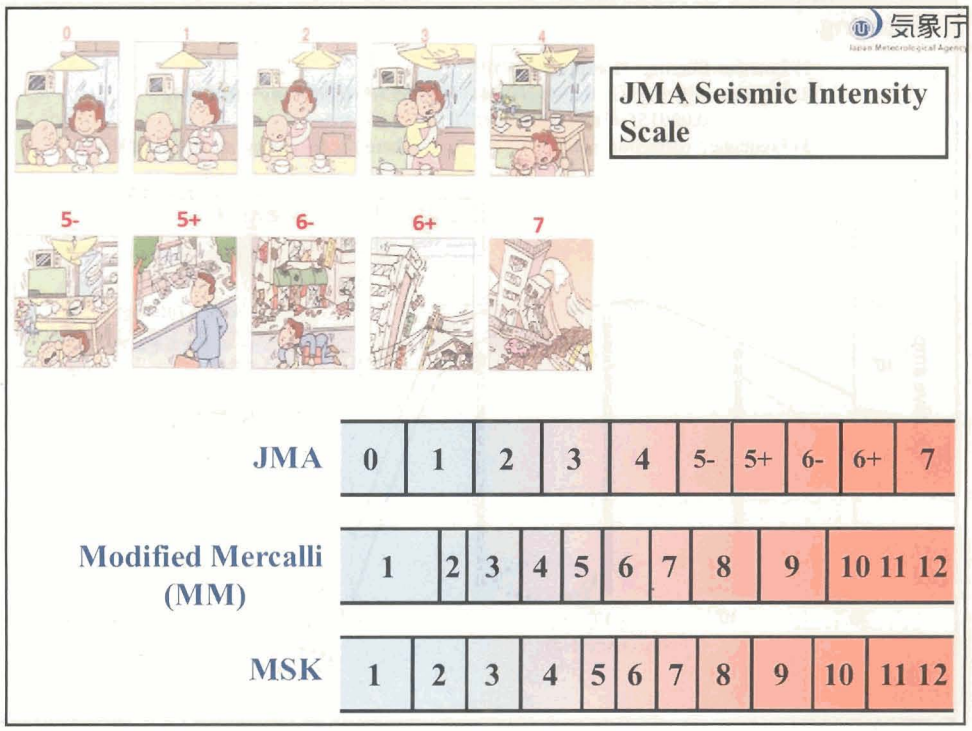
3) Frequency correction : $(1/f)^{1/2}$ where f is frequency measured in Hz

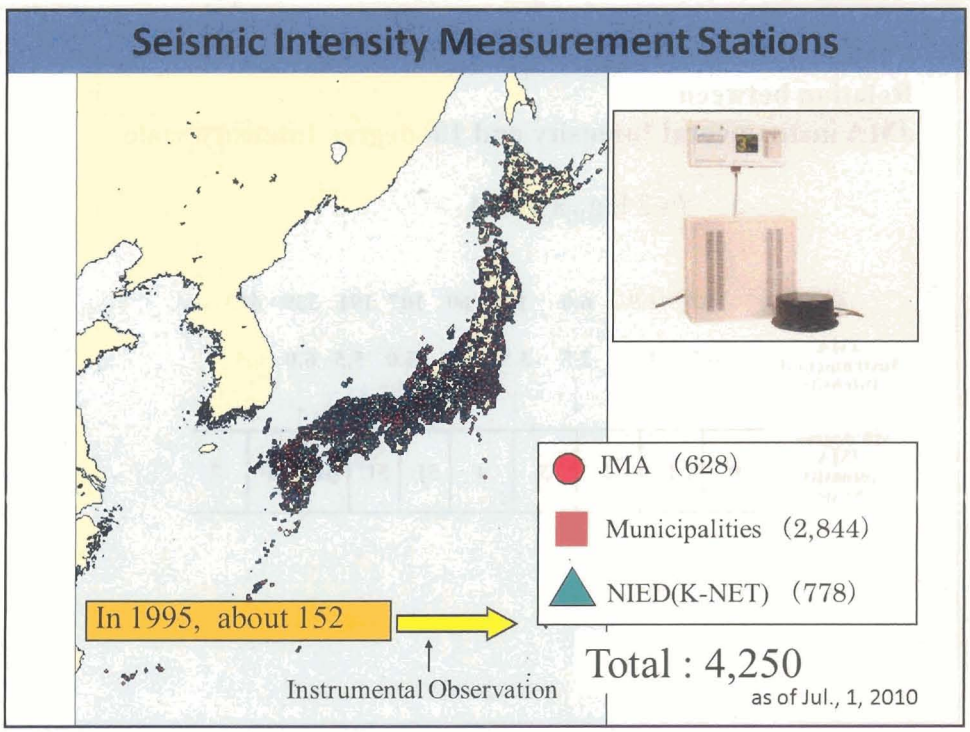


Relation between JMA instrumental Intensity and 10–degree Intensity scale

$$I = 2\log_{10}a_c + 0.94$$

a_c	0.6	1.9	6.0	19	60	107	191	339	603 cm/s²
JMA Instrumental Intensity	0.5	1.5	2.5	3.5	4.5	5.0	5.5	6.0	6.5
10-degree JMA Intensity Scale	0	1	2	3	4	5L	5U	6L	6U	7


気象庁
Japan Meteorological Agency
JMA Seismic Intensity Scale
0
1
2
3
4
5-
5+
6-
6+
7
JMA 0 1 2 3 4 5- 5+ 6- 6+ 7
Modified Mercalli (MM) 1 2 3 4 5 6 7 8 9 10 11 12
MSK 1 2 3 4 5 6 7 8 9 10 11 12


Seismic Intensity Measurement Stations
JMA (628)
Municipalities (2,844)
NIED(K-NET) (778)
In 1995, about 152
Instrumental Observation
Total : 4,250
as of Jul., 1, 2010

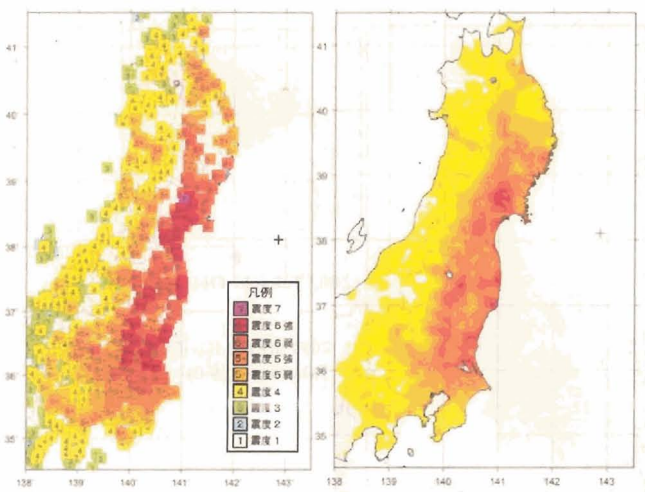
The 2011 off the Pacific coast of Tohoku Earthquake

OT: Mar., 11, 2011, 14:46:18.1 (JST)
Mag: 9.0(M_w: Moment magnitude), 8.4 (M_d: Displacement magnitude)

14,786 people were killed; 9,982 people were missing; 83,586 houses were damaged (as of May, 10)

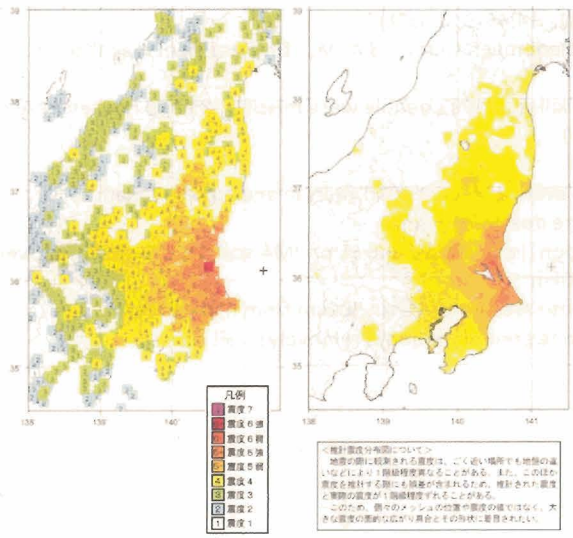
- Largest Magnitude event of recent 1000 years in and around Japan
- Most of fatality were due to Tsunami
- Strong ground motion (Intensity 6U and 6L on JMA scale) were observed over an wide area (400 x 100km.)
- Liquefactions at Kanto area (more than 300km from hypocenter)
- Damage due to strong ground motion is relatively small

M_w9.0 Pacific Coast Tohoku Earthquake , Mar, 11, 2011



Contour representation after taking site amplification factors into account

Largest aftershock (M_w: 7.7, Mar, 11, 2011, 15:15 JST)



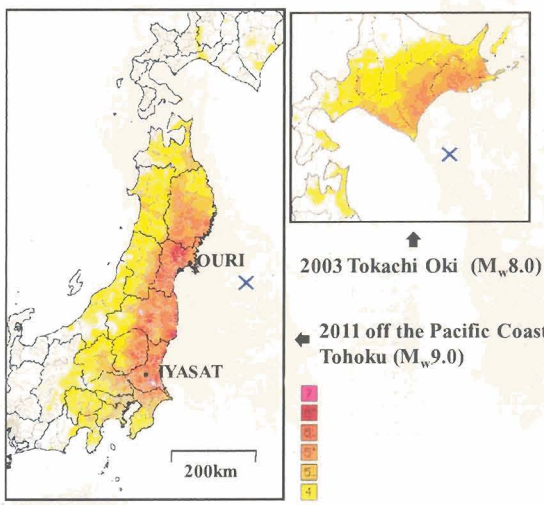


表３－４　３月 11 日 14 時 46 分に発生した本震（M9.0）の計測震度及び最大加速度（震度５弱以上）

※観測点名の＊印は、地方公共団体または独立行政法人防災科学技術研究所の震度観測点を示す。
※震度および最大加速度データは再調査後、修正することがある。

都道府県	市区町村	観測点名	震度	計測震度	最大加速度（gal=cm/s/s）				震央距離（km）
					合成	南北成分	東西成分	上下成分	
宮城県	栗原市	栗原市築館＊	7	6.6	2933.7	2699.1	1268.9	1879.7	174.3
茨城県	日立市	日立市助川小学校＊	6強	6.4	1843.4	1598.8	1184.6	1165.6	258.1
茨城県	鉾田市	鉾田市当間＊	6強	6.4	1761.5	1352.3	1071.6	811.1	301.7
宮城県	栗原市	栗原市若柳＊	6強	6.3	-	-	-	-	168.1
福島県	大熊町	大熊町下野上＊	6強	6.3	922.0	-	-	-	182.3
宮城県	登米市	登米市米山町＊	6強	6.2	542.2	372.6	487.2	264.0	156.7
宮城県	大崎市	大崎市古川三日町	6強	6.2	567.7	549.6	456.4	321.5	173.8
宮城県	川崎町	宮城川崎町前川＊	6強	6.2	2698.2	2691.9	962.1	727.1	193.8
宮城県	仙台市宮城野区	仙台宮城野区苦竹＊	6強	6.2	1402.5	1390.5	632.2	276.3	169.5
茨城県	那珂市	那珂市瓜連＊	6強	6.2	767.5	662.3	722.5	490.4	278.4
宮城県	大崎市	大崎市古川北町＊	6強	6.1	585.7	443.9	571.5	238.7	173.2
宮城県	名取市	名取市増田＊	6強	6.1	815.6	580.8	654.9	308.3	172.3
宮城県	東松島市	東松島市矢本＊	6強	6.1	650.9	412.4	648.6	489.9	148.2
福島県	白河市	白河市新白河＊	6強	6.1	1425.3	1295.2	841.7	427.5	259.1
福島県	双葉町	双葉町新山＊	6強	6.1	504.3	-	-	-	177.9

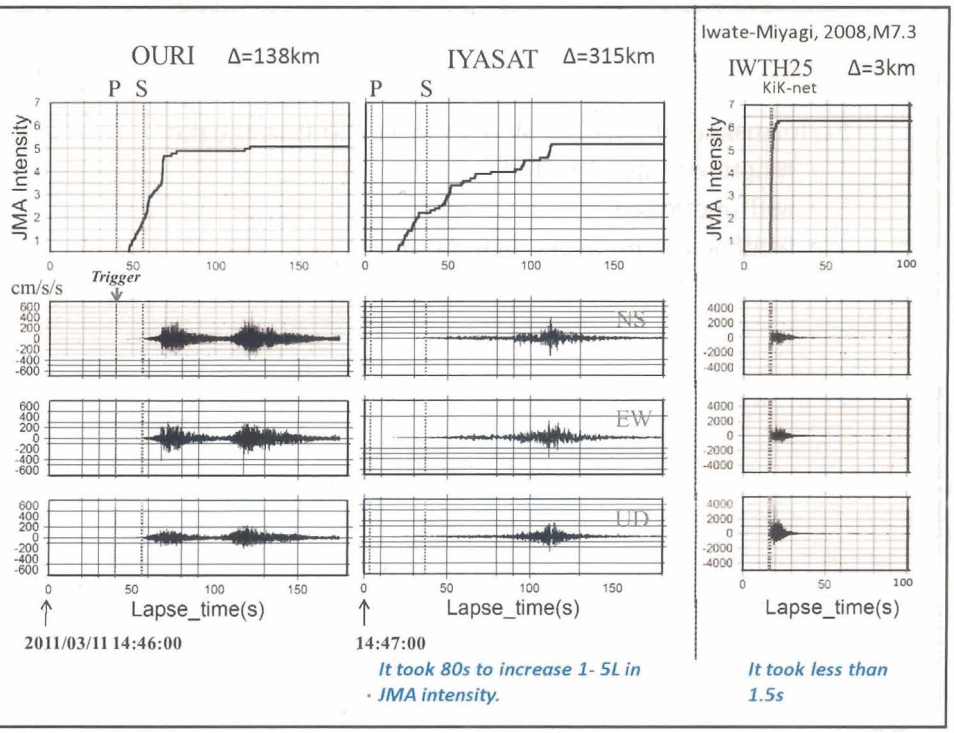
Location (Prefecture, city, site name)

10-degree intensity

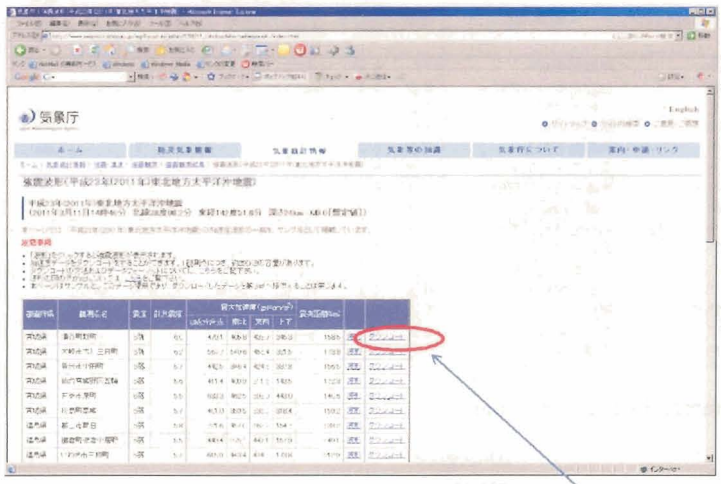
Instrumental Intensity

PGA (3com., NS, EW, UD)

Epicentral Distance



Some waveforms are at JMA home page;
http://www.seisvol.kishou.go.jp/eq/kyoshin/jishin/110311_tohokuchiho-taiheiyouoki/index.html



"download" of digital data

- Performance of JMA EEW for the M_w9.0 Earthquake
  - functioned as expected
  - malfunctioned
  - feedback from users, general public

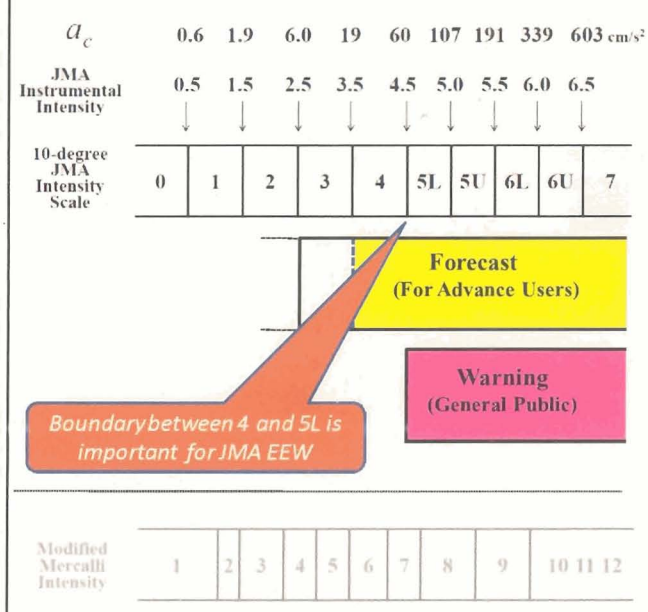
JMA EEW

- Fully operational in ***October, 2007***
  - **Nationwide**
  - **Issued to general public using TVs, radios, cell phone mails**
- More than 1100 stations are used for hypo. determination
- Combination of several techniques are used for hypo. determination
- Magnitude is determined from **maximum amplitude of ongoing waveform**
  (The growth of the rupture is monitored using the amplitude in real time)

M=1/0.72*{ log(Amp)+1.2*logR+5.0*10^{-4}*R-5.0*10^{-3}*D+0.46 (For P wave)
M=log(Amp)+log(Δ)+0.00110*Δ+0.0007*D+1.7613 (For S wave)

- Seismic Intensity is expected using Hypocenter, Magnitude, Attenuation relation, and Site amplification factors.
- JMA EEWs are issued depending on the expected intensity
- JMA EEWs are **updated repeatedly as available data increases with elapsed time (example: 15 EEWs were issued for the M9.0 earthquake, Mar., 11, 2011)**

2 grades for JMA EEW ("Forecast" and "Warning")



a_c
- filtered accelerogram
- 3 com. vector sum.
- 30th largest for 100 samples/s)
  (15th largest for 50 samples/s)

Forecast
- $I \geqq 3$ (or $M \geqq 3.5$)
- **Regions of $I \geqq 4$ are specified**

Warning
- **for the regions of $I \geqq 5L$**
- Broadcasted by TV, radios, cell phone mail

Grade is based on expected Intensity, not Magnitude

Two Grades of JMA EEW, depending on the strength of expected Intensity

Forecast

EEW receivers, dedicated systems, etc.
Provided through private companies

Predicted earthquake intensity
and the expected time of arrival at each point.
When I ≧3 is expected (or M>3.5).
Regions of I ≧4 are specified

TO ADVANCE USERS

For ***1880 events***
(Oct., 2007- Feb., 2011)

Warning

Using TV, radio, local-governmental radio, cellular phone, etc.

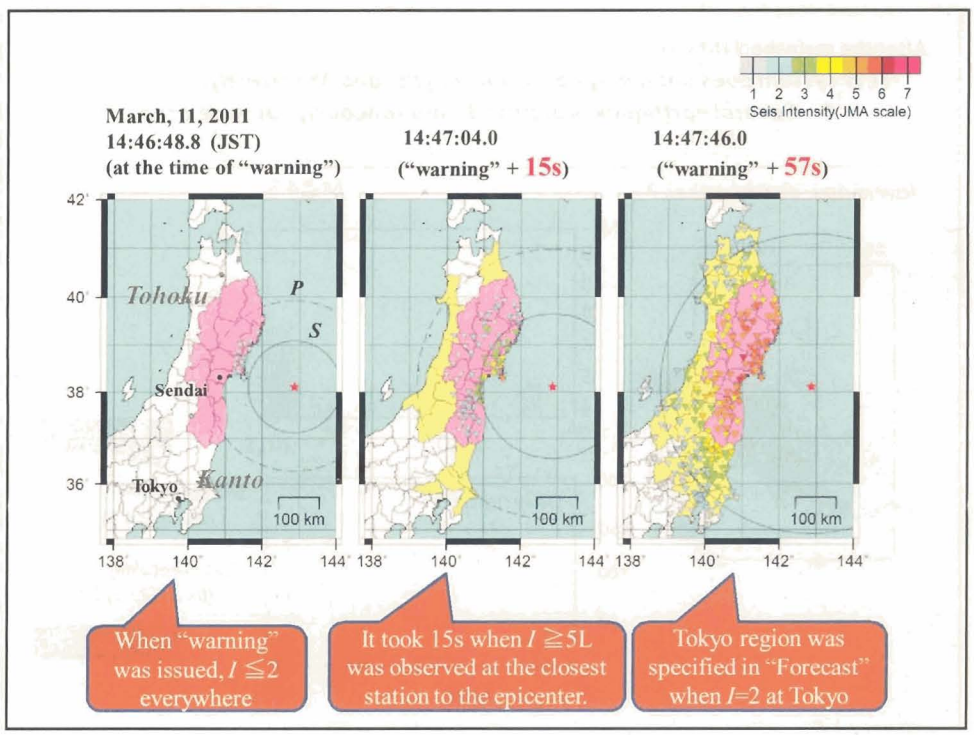
When I ≧5L is expected.

TO THE GENERAL PUBLIC

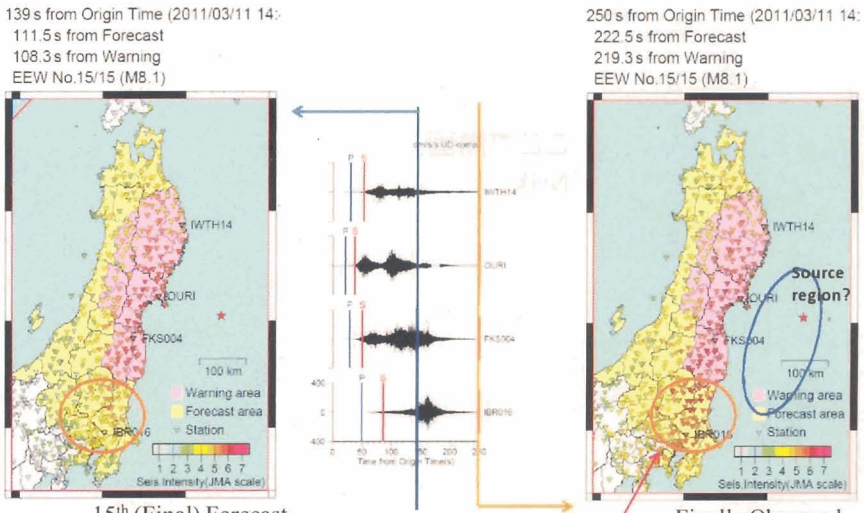
For ***17 earthquakes***
(Oct., 2007- Feb, 2011)

Movie

ここで動画,
NHK


1 2 3 4 5 6 7
Seis.Intensity(JMA scale)
March, 11, 2011
14:46:48.8 (JST)
(at the time of "warning")
14:47:04.0
("warning" + 15s)
14:47:46.0
("warning" + 57s)
42°
40°
38°
36°
Tohoku
P
S
Sendai
Tokyo
Kanto
100 km
138°
140°
142°
144°
When "warning" was issued, I ≦2 everywhere
It took 15s when I ≧5L was observed at the closest station to the epicenter.
Tokyo region was specified in "Forecast" when I=2 at Tokyo

Underestimation for Kanto region



15th (Final) Forecast

Finally Observed

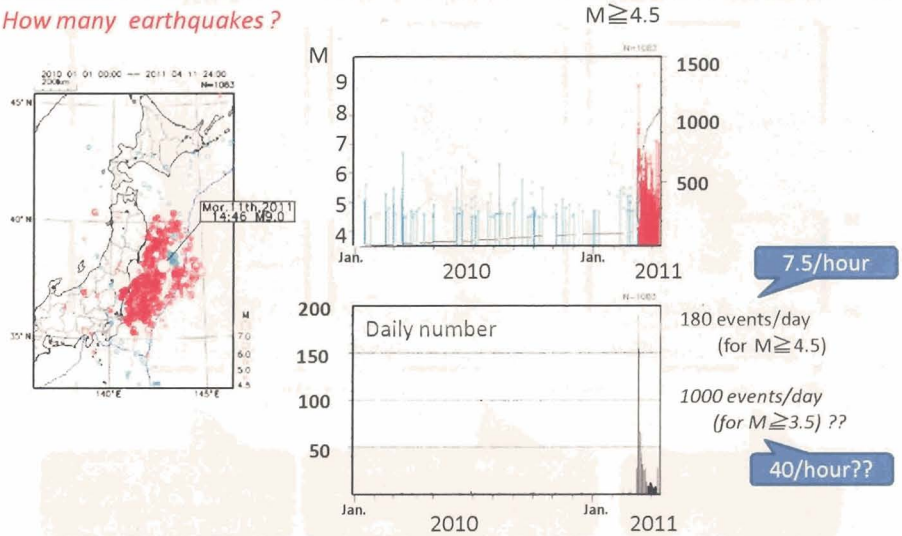
Strong motion was not yet for Kanto region

Intensity of 4 was expected,
but 5L-6U were observed as a result.

After the mainshock(Mw9.0)...

- ***EEW system does not always determine hypo. and M correctly.***
  - ← ***Several earthquakes occurred simultaneously at wide area.***

How many earthquakes ?



7.5/hour

180 events/day
(for M≧4.5)

1000 events/day
(for M≧3.5) ??

40/hour??

Movie,
Seismic Activity and Simultaneous events

In the 49 days (from the mainshock to April, 28, 2011)

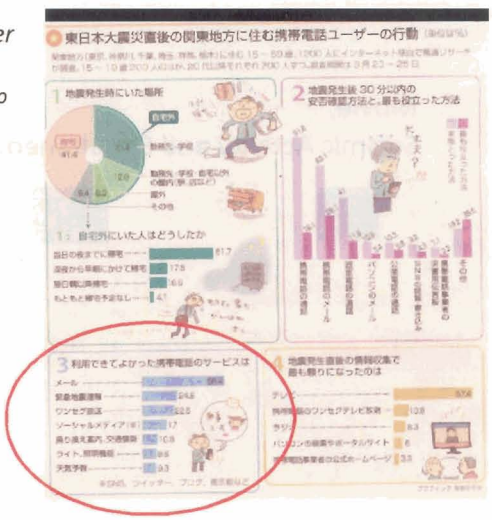
JMA appropriately issued EEW "warnings" for 26 of the 46 events for which seismic intensity 5-lower or greater was actually observed.
26/46 = 57%
(Before Mar., 11, 10/18=56 %)

On the other hand,
70 EEW "warnings" were issued, but actual intensities did not exceed 2 at any observation stations in 17 of the 70 events.
(Before Mar., 11, 1 /17 events)

Questionnaire to Cell Phone users after the Mw9.0 Tohoku earthquake
(answers were from 1200 people at Kanto region)

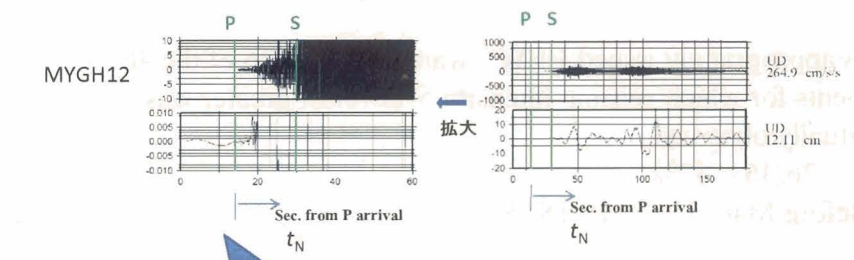
Question 3:
Which function is useful in your cell phone ?

Cell phone Mail:	58.4 %
Earthquake Early Warning:	24.8 %
Cell phone TV:	22.5 %
Twitter, Blog:	17.0%
Transportation information :	10.8%
Light :	9.6%
Weather Forecast:	9.3%

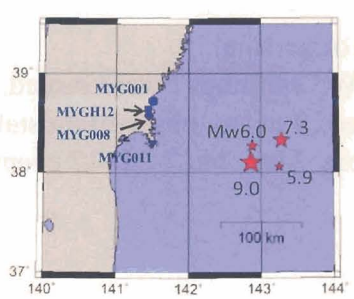


From Asahi Shinbun (Newspaper company)
June 4, 2011

Initial Several Seconds of the M9.0 Earthquake and its Foreshocks.



First several second,
・1cm/s² for acceleration.
・comparable to noise level for disp.



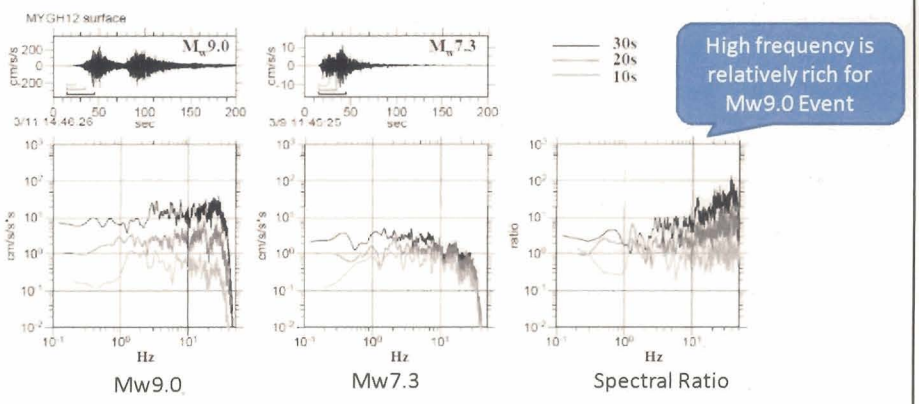
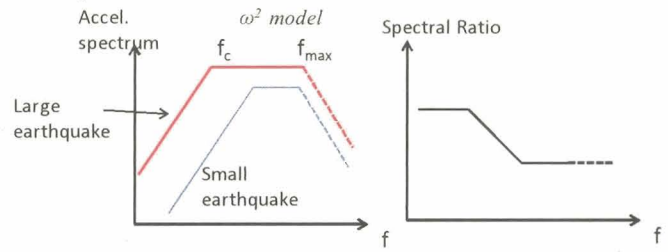


Image of many cases



Summary

The 2011 off the Pacific coast Tohoku earthquake (M_w 9.0) generated widespread strong ground motion, and seismic intensities of 6-lower and 6-upper were recorded in the Tohoku and Kanto districts over an area of approximately 400 × 100 km. The durations of strong ground motion were very long.

JMA EEW functioned as expected;

- The JMA EEW system issued one warning to the general public in the Tohoku district before the start of strong ground motion. It was earlier than the *S* wave arrival and 15 s earlier than strong ground motion (intensity 5-lower) at the closest station to the epicenter.

But it was not completely perfect;

- For Kanto region, JMA EEW expected to be *I*=4, which is understimation as compared with actual observation(5L-6U). This is probably due to the large extent of fault rupture.

- For aftershocks, JMA EEW did not always determine the location and magnitude correctly, because many earthquakes occurred simultaneously over an wide area and system was confused.