Earthquake Motion of the 2011 off the Pacific Coast of Tohoku Earthquake and the Situation of Issuing Various Earthquake Alarms

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SUMMARY:
The 2011 off the Pacific coast of Tohoku Earthquake emerged various phenomena. This paper describes the distribution and the propagation of the real-time seismic intensity. Although Earthquake Early Warnings (EEW) by Japan Meteorological Agency (JMA) was issued for public at 14:46:49 on March 11, 2011 (JST), the area issued the alarm was restricted and a lot of damaged areas were not included. EEW for Shinkansen-line also failed to issue the P-wave alarm, and only a conventional alarm system worked by exceeding the trigger level of 120 Gal. In contrast, a simulation result of FREQL using the waveform of K-NET Kitakami station shows that FREQL detected the event at 14:46:40 and issued the P-wave alarm at 14:46:46. An actual working FREQL at a base of the Oshika Peninsula issued the P-wave alarm at 14:46:54 and estimated exact earthquake parameters without magnitude.

Keywords: Earthquake Early Warning, Realtime Intensity RI, FREQL

1. INTRODUCTION

The 2011 off the Pacific coast of Tohoku Earthquake (hereafter "the 3.11 earthquake") emerged various phenomena. This paper describes the distribution and the propagation of the real-time seismic intensity *RI* and the situation of issuing various earthquake alarms. And what is necessary for earthquake disaster prevention learning from the experiences of the 3.11 earthquake is discussed and the author proposes for national organization like JMA, Japan Meteorological Agency.

2. REAL-TIME INTENSITY RI

From a viewpoint of the vulnerability of various structures, a damage index *DI* was proposed, that is an earthquake motion index relating to the earthquake early warning (Nakamura, 1998). Then, in consideration of the close relationship between *DI* value and the instrumental seismic intensity of JMA, *Ijma*, *DI* is redefined as real-time intensity *RI* (Nakamura, 2003). *DI* and *RI* are defined from the power per unit mass of the earthquake motion, so it is characterized to be possible to grasp a physical value momentarily, unlike *Ijma* calculated as artificial value with 60 second-length earthquake motion after the event. *DI* and *RI* are defined as follows.

$$DI = log(|\mathrm{a} \cdot \mathrm{v}|) \tag{2.1}$$
$$RI = DI + 6.4 \tag{2.2}$$

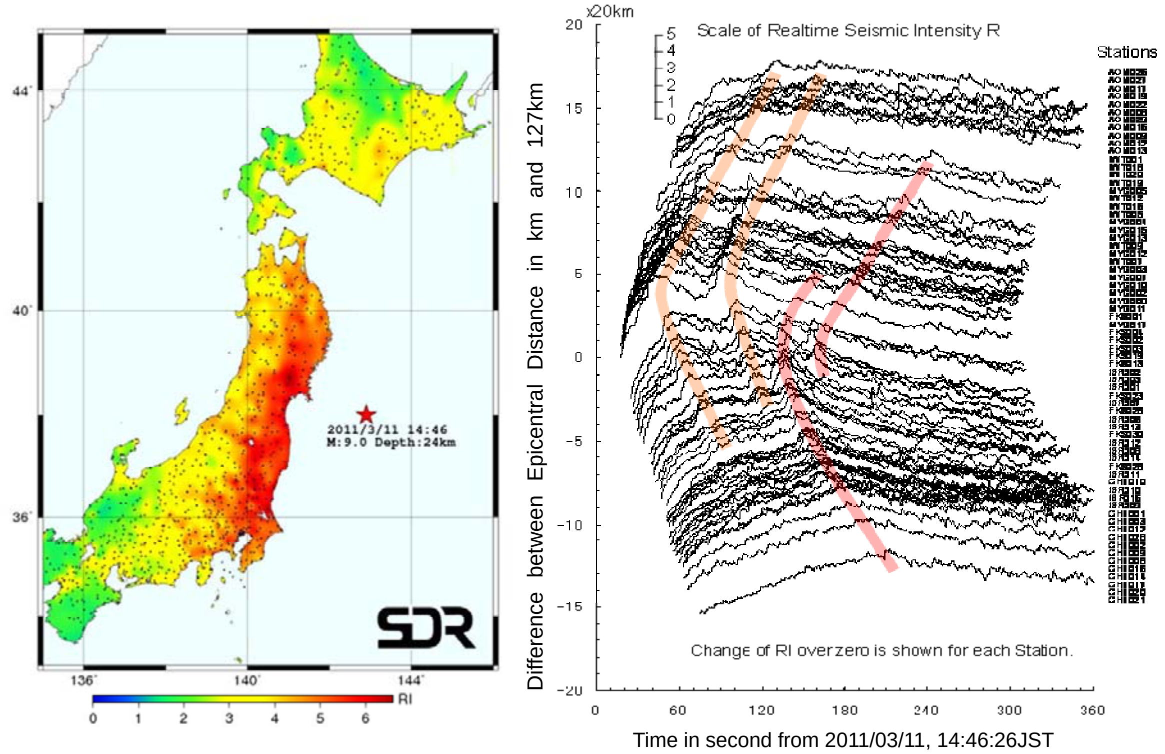
Here a is an acceleration vector (m/sec/sec) and v is a velocity vector (m/sec). An operator "·" of Equation 2.1 indicates an inner product. And the frequency range is limited to 0.5 to 5 Hz. Because *RI* can be calculated sequentially in realtime and can detect P wave, it is possible to utilize not only for the early warning for big earthquake but also assist proper countermeasures after an event by offering

the power of seismic strong motion accurately.
The relationship between *RI* and *MMI*, Modified Mercalli Intensity, is shown as follows.

$$MMI = (11/7)*RI + 0.5 \tag{2.3}$$

3. EARTHQUAKE MOTION VIEWED FROM RI

Figure 3.1 shows the change of *RI* more than zero of K-NET stations at Aomori, Miyagi, Fukushima, Ibaraki and Chiba prefectures corresponding to the difference of the epicentral distance between the epicentral distance of each station and the shortest epicentral distance (127km), separated to the north and south part for the rupture point of the 3.11 earthquake. This figure shows the situation properly of the earthquake motion propagation from some sources with time difference. In southern side, *RI* grew gradually and reached its maximum value more than intensity 5 taking a lot time, while *RI* in case of northern side reached its maximum value relatively early.
Taking advantage of the features of *RI* to be able to shows the intensity of the earthquake motion in real-time, it is possible to draw a propagation of the earthquake motion with distribution of *RI* of each station instantly. The motion picture is opened on our website (http://www.sdr.co.jp). The motion picture shows the situation that the earthquake motion reached wide area between far off Sendai and Sanriku area and spread at once, and then RI grew gradually. Because an area with large intensity spread increasingly toward to south side, the intensity slowly grew larger and reached its maximum value quite later than the epicentral area.



(1) Distribution of Maximum Realtime Intensity RI (2) Change of RI on Time Domain at Various Sites

Figure 3.1 Distribution of Maximum Realtime Intensity and Change of Realtime Intensity on Time Domain at Various Sites

4. OPERATING CONDITION OF VARIOUS WARNING SYSTEM

Figure 4.1 shows the variation of real-time intensity at eastern Japan using strong motion records of K-NET and other organization with alarm situation. Horizontal axis is a difference of the epicentral distance adding + or – corresponding to north and south to the epicentre and vertical axis is elapsed time from 14:46:26 on March 11, 2011, the start time of the waveform recording at K-NET Oshika station, the fastest detection station. Colored circles indicate the value of *RI*, peak and the time of maximum value as legend. Also circled number corresponds to the sequence number of the early earthquake information by JMA for the information based on the estimated intensity more than 3 or 4. From variation on time, an onset time of each intensity grade and maximum intensity delays roughly according to the difference of the epicentral distance in northern Tohoku area. On the other hand, although P wave arrived in advance in Kanto region, a time reaching each intensity grade increasingly

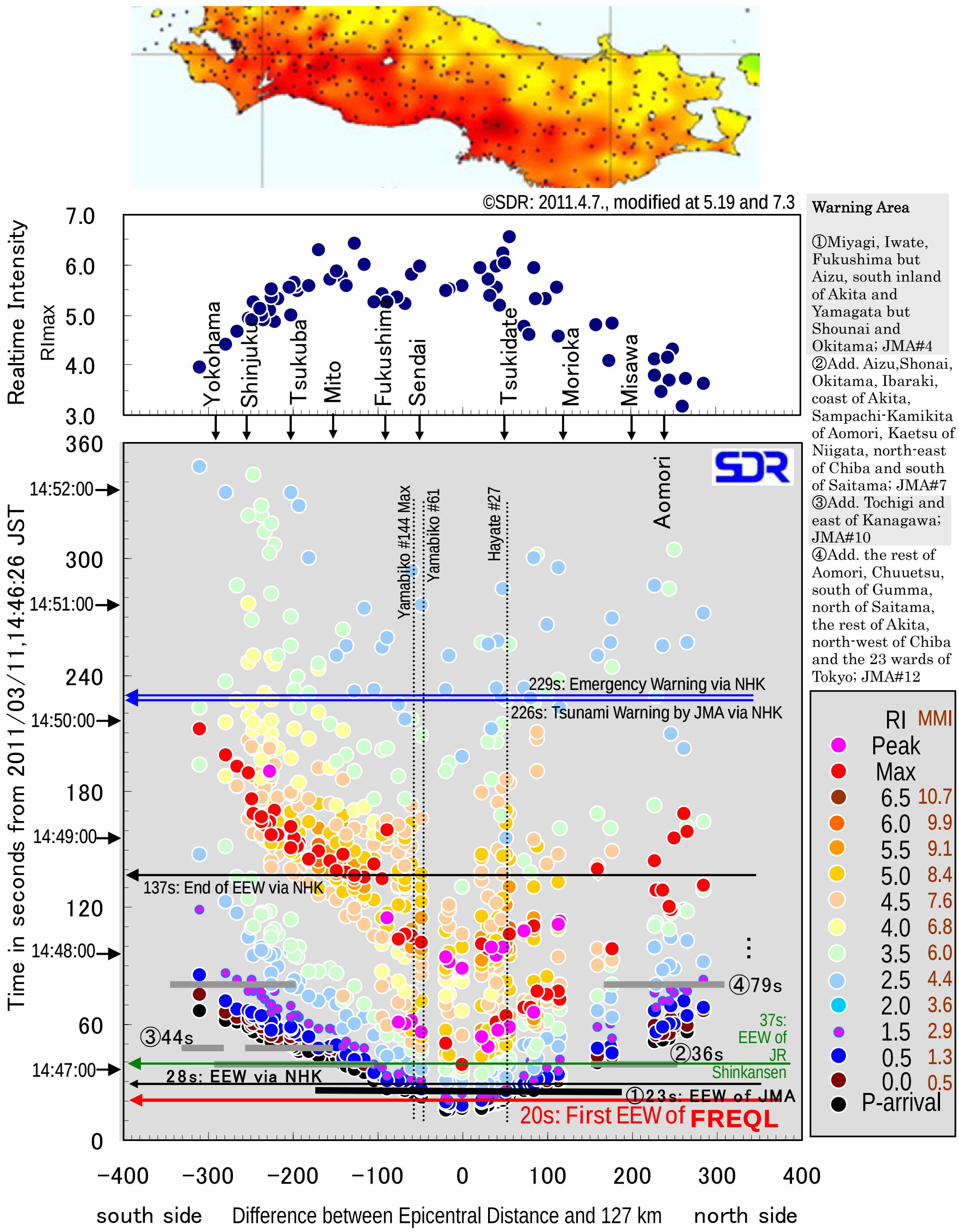


Figure 4.1 Variation of Realtime Intensity around the Eastern Japan using Strong Motion Records of K-NET and other Organization with Alarm Situation

slow and a time reaching maximum intensity is quite late.

While the earthquake early information by JMA was issued for public at 14:46:49 (23 seconds from start) on Figure 4.1, the issued area was restricted all part of Miyagi and Iwate prefecture, and restricted part of Fukushima, Akita and Yamagata prefecture. And it was not issued for the other damaged area with maximum intensity more than 5, so it must be said that the alarm is issued unreasonable. Meanwhile, because hypocentral distance is more than 120 km even in close area to epicentral region, a duration time of the initial motion estimated more than 15 seconds. So people in the area had enough time margins before suffering large earthquake motion after noticing the earthquake occurrence. However it seems to be possible for the earthquake early information by JMA to be valuable for earthquake disaster prevention, there is no report to help something specifically.

Earthquake alarm system for JR Shinkansen-line, the bullet train, also failed to issue the P-wave alarm, and a conventional alarm system just worked by exceeding the trigger level, 120 Gal (=cm/s/s) in 14:47:03. This time is later at least five seconds than initial system in 1985 with trigger level of 40 Gal. And if the system installed same system which issued P wave alarm successively at the time of the 2004 Niigataken-Chuetsu earthquake, the additional leading time is estimated 15 seconds or more. The current earthquake early alarm system that failed to issue the alarm in this time is similar system to that of JMA.

Figure 4.1 also shows the result of simulation of FREQL assuming installation close to epicenter. Here, FREQL is an earthquake early warning system essentially differs from that of JMA. FREQL is unique system characterized by its functions to distinguish P wave from ground motion, to determine the earthquake parameters independently at installed site. Also FREQL can issue P wave alarm based on the dangerousness of the detected earthquake motion with realtime data processing. FREQL has been operated as practical system for a disaster prevention system of railway companies or other organization. Please see the detail of FREQL in the paper (Nakamura, 2007). In this paper FREQL simulation is the realtime processing of the waveform data to judge its dangerousness for P wave alarm.

A simulation result of FREQL using the waveform K-NET Kitakami station shows that FREQL detected the event at 14:46:40 and issued the P-wave alarm at 14:46:46.

An actual working FREQL at a base of peninsula issued the P-wave alarm at 14:46:54 and estimated exact earthquake parameters, location and depth, without magnitude. The simulation results for this case agree with the actual situation. It shows the validity of the FREQL simulation.

On the other hand, tsunami warning was issued about three minutes after earthquake detection. It was enough early but that was underestimated and modified information was not accurately transferred for local people. Because organizations without JMA is restricted to issue these kinds of warnings as tsunami warning by low, local government could not start independently activity for evacuation although feeling large and long abnormal earthquake motion.

5. DISCUSSION

The 3.11 earthquake is abnormal earthquake with extremely long duration even for Japanese people used to feel earthquake motion commonly. Most of Japanese people including a people on vehicles noticed the earthquake motion by themselves before enlarged motion without any warnings. This situation can be understood easily by Figure 4.1. This abnormal motion started some tens seconds before the large motion. Since many people felt this abnormal earthquake motion as natural tsunami alert, there was only a few people started activity for evacuation immediately. Especially staffs of local government did not start any activities immediately and waited tsunami warning from JMA, although it is only a few minutes. This inactive approach seems to enlarge tsunami damage of this earthquake. However, people in Tohoku area, commonly hit by tsunami, had a legend to escape before anything else in case of large earthquake, there are many losses in this time. It is necessary to review in detail of the matter of this situation, but there are no signs to start review by third party. At least considering objectively, it must be thought that there were some problem on tsunami warning and countermeasures. It is possible to estimate that the people could not escape independently judging the dangerousness by choice, because of tsunami warning only issued by JMA under low and excessive sense of safety for huge coastal levee higher than estimated tsunami height by JMA. Moreover frequent excess tsunami warning based on over-estimation for foreshocks might cause crying wolf effect. Although the activity for evacuation must reflect local conditions, for instance, landform and vegetation, the activity is triggered by the warning from JMA of central bureaucracy. This situation seems to be abnormal. After the Kobe earthquake disaster, sixteen years ago, why does JMA amend a law to restrict issuing tsunami warning by judgment of local government? It may cause dependency for central bureaucracy and luck of decision on activity for disaster prevention, if local government could not judge by themselves. So although the author demands a correction at every opportunity, the situation continues still today without granted the request. Not only tsunami warning but also EEW, early earthquake warning, is also under same situation. Although EEW by JMA could not be issued before a large motion even in case of M7-class earthquake in damage area (within 30 to 50 km), public information continues saying the EEW by JMA is useful. Although the 3.11 earthquake was a rare chance that EEW by JMA can be useful, the system failed to issue the proper warning. As a result, EEW by JMA is protected by low but can not protect local people. The author thinks that JMA with nation wide observation network must focus to inform immediately exact earthquake parameters of main shock and aftershocks by parallel way and it must be possible for various organizations to issue earthquake warnings. This will enable to determine the severe damaged area quickly and help the rescue activity. As said before, both earthquake and tsunami warning must be realized by local organizations in their domain and the warning issued by central bureaucracy is meaningless. What is required for JMA is not warning, and they must provide the exact earthquake information for quick response. It is expected to realize rational correspondence just after the earthquake. Many observed data by JMA must be issued in realtime. If the offshore observatory of sea-wave height were distributed for coastal municipalities in realtime, the losses by tsunami will decrease drastically.

6. CONCLUSION

This paper shows that real-time intensity *RI* can comprehensibly express the distribution of the seismic intensity and the propagation of the earthquake motion of the 2011 off the Pacific coast of Tohoku Earthquake. EEW by JMA can gain only comparable or a little long time margin comparing with on-site FREQL or ordinary alarm seismometer, so the merit cannot be recognized. It has been also cleared that EEW by JMA is not applicable for the near-field earthquakes. Earthquake early warning by JMA is not a kind of a system operated under a low because it is feared adverse result from excessive expectation. It seems to be necessary to amend Meteorological Service Act as abolish the unnecessary restrict on earthquake early warning or tsunami warning, base on a view that such a kind of restrict causes the serious damage of the 3.11 earthquake. Finely-tuned responses are required for a disaster like epicentral earthquake or tsunami because of the strong reflection of the local conditions. It is desirable to change the centralized way of JMA and handle in close coordination and cooperation with local authorities specified familiar with local circumstances. A system to directly link the necessary information to the area must be established and the author expects JMA to support the system.

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