

# EARTHQUAKE MOTION OF THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE AND THE SITUATION OF ISSUING VARIOUS EARTHQUAKE ALARMS

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**Abstract:** 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 and the situation of issuing various earthquake alarms. Real-time Intensity, RI, is a physical value defined from the power per unit mass of the earthquake motion, so it is characterized to be possible to grasp a physical value in realtime, unlike JMA intensity calculated as artificial value with 60 second-length earthquake motion after the event. Although Earthquake Early Warnings (EEW) by 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 of intensity 5+ were not included. Earthquake alarm system for JR Shinkansen-line also failed to issue the P-wave alarm, and a conventional alarm system as a backup system just worked by exceeding the trigger level of 120 Gal, issuing the alarm later than initial status (40 Gal of trigger level) at 1985. 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 as same as that obtained by simulation.

## 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 and the situation of issuing various earthquake alarms. And what is necessary for earthquake disaster prevention using the experiences from the 3.11 earthquake is discussed and propose 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.

$$DI = \log(|\mathbf{a} \cdot \mathbf{v}|) \quad (1)$$

$$RI = DI + 6.4 \quad (2)$$

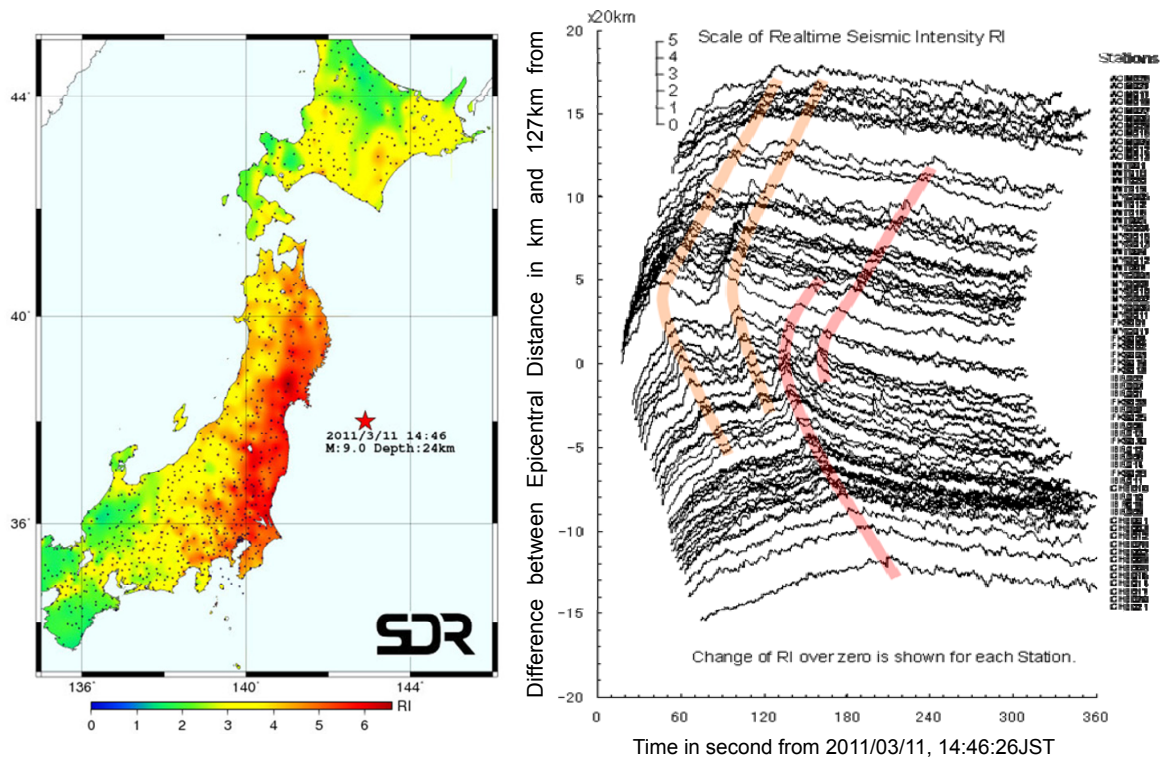
Here  $\mathbf{a}$  is an acceleration vector (m/sec/sec) and  $\mathbf{v}$  is a velocity vector (m/sec). An operator “ $\cdot$ ” of Equation (1) indicates an inner product. And the frequency range is limited to 0.5 to 5 Hz. Because RI can be calculated sequentially in realtime and can detect P wave, 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.

$$MMI = (11/7) \cdot RI + 0.5 \quad (3)$$

## 3. EARTHQUAKE MOTION VIEWED FROM RI

Figure 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



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

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.

#### 4. OPERATING CONDITION OF VARIOUS WARNING SYSTEM

Figure 2 shows the variation of real-time intensity around the nation 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 north and south to the epicenter and vertical axis is elapsed time from 14:46:26 on March 11, 2011, the start time of the waveform recording of 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 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 2, 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

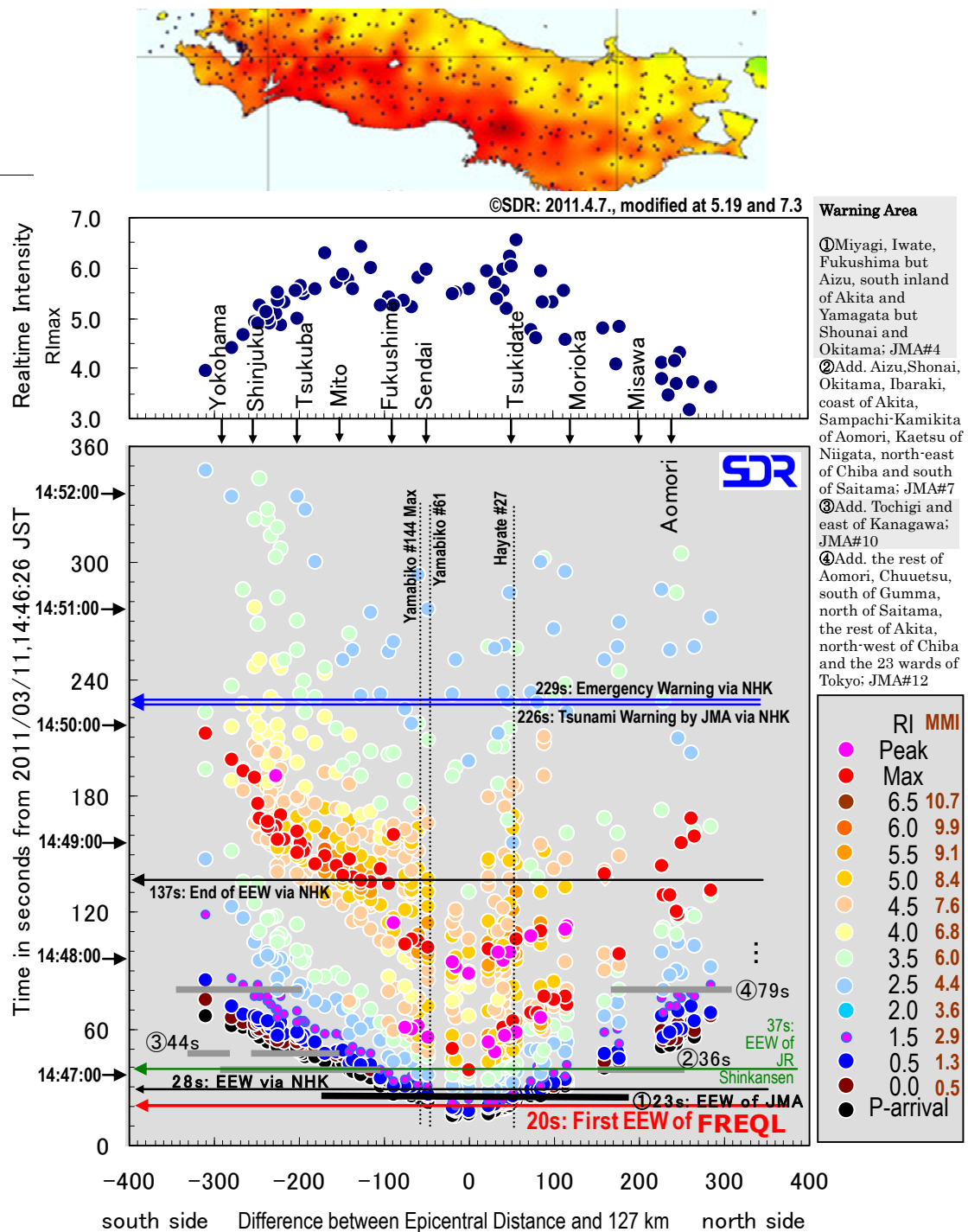


Figure 2 Variation of Realtime Intensity around the Nation using Strong Motion Records of K-NET and other Organization with Alarm Situation.

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 2 also shows the result of simulation of FREQL installed close to epicenter. Here, FREQL is an onsite earthquake alarm system practical used for private railway companies and other factories. 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.

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 law, 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 2. Relatively large 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 a few minutes. This inactive approach seems to enlarge tsunami damage of this earthquake. People in Tohoku area, commonly hit by tsunami, have a legend to escape before anything else in case of large earthquake. In spite of this legend, 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 and excessive sense of safety for huge coastal levee. Moreover frequent excess tsunami warning for foreshocks might cause crying wolf effect. Although the activity for evacuation must reflect local characteristics, the activity is triggered by the warning from JMA, central bureaucracy. This situation seems to be abnormal. After the Kobe earthquake disaster, sixteen years ago, why JMA amended a law to restrict issuing tsunami warning by judgment of local government? It may cause dependency for central bureaucracy and lack 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 today without granted the request. Not only tsunami warning but also EEW, early earthquake warning, is also under same situation. Even EEW by JMA could not be issued before a large motion in case of M7-class earthquake in damage area (within 30 to 50 km), public information continues saying

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 law 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, earthquake 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.

## 6. CONCLUSION

This paper shows that real-time intensity RI can comprehensively express the distribution of the seismic intensity and the propagation of the earthquake motion of the 2011 off the Pacific coast of Tohoku Earthquake. Earthquake early warning 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 Earthquake early warning 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 law 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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