Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

SSS28-01 Room:312 Time:May 2 10:00-10:15

The recent movement and the future plans of the JMA EEW

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We sometimes reported our efforts to improve the JMA EEW system and we will make a presentation about the recent movement of the JMA EEW and the future plan to improve the system.

In the case of the 2011 off the Pacific Coast of Tohoku Earthquake (Mw9.0), the warning of the EEW was disseminated 30 s after the Mw9.0 event occurrence, which was 8 s after the first detection. The estimated magnitude was 7.2 at the time and the warning was issued only for Tohoku. We could provide the warning before the arrival of S-waves for all warning areas. However, the actual magnitude was 9.0 and the wide area was ruptured. The under estimate of the magnitude and the extent of the source region caused the under estimate of intensities. Especially, in Kanto, we observed 6-upper, but we could not provide the warning for the public. The warning was provided for the public only once, but the updated information was provided only to the limited users. We issued the EEW totally 15 times for the event. Finally the EEW estimated M8.1 105 s after the first detection. Moreover, aftershocks sometimes occurred simultaneously over the wide region. Then, the system became confused and did not always determine the hypocenter parameters correctly. In 49 days after the main shock to April 28, 2011, 70 EEWs were announced to the public, but actual observed intensities did not exceed 2 at any stations in 17 cases.

To overcome those problems, we will introduce the real-time pseudo seismic intensity by Kunugi et al. (2008), by which we will be able to monitor the extent of the strong motion field (the simplest version of Hoshiba, 2013) and to evaluate the calculated hypocenter parameter. The current JMA EEW system is based on the calculated hypocenter parameter. We have the idea of a hybrid method using the conventional method and the real-time intensities (Kotera et al, 2014). Furthermore, Tamaribuchi et al. (2014) developed a new method to classify multiple concurrent events for EEW. Their approach used the particle filter method and the method estimated location, origin time and magnitude in the probabilistic framework, using trigger time, maximum amplitude, epicentral distance and incident angle of the waveform for the likelihood function. We have a plan to use the method additionally.

Moreover, JMA began to provide long period ground motion information, using the observed waveform at each station, on JMA web site March, 2013 (Aizawa et al., 2014). We have just begun to investigate the long period ground motion forecast aiming at establishing an earthquake early warning for long period ground motion (Ogami et al., 2014).

References: Aizawa et al., 2014, the abstruct of this meeting. Hoshiba, 2013, DOI: 10.1002/jgrb.50119. Kotera et al., 2014, the abstruct of this meeting. Ogami et al., 2014, the abstruct of this meeting. Tamaribuchi et al., 2014, Zisin 2, submitted.

Keywords: EEW, long-period ground motion, JMA, seismic intensity, intensity scale on long-period ground motion, hypocenter determination

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Earthquake Early Warning system combined with real-time ground motion prediction

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We introduce a hybrid method which is a combined method of the current JMA EEW system and the simplest version of real-time ground motion prediction method. We also report applications of the hybrid method to some cases in which the current JMA EEW system underestimates or overestimates seismic intensity.

The current JMA EEW system (the conventional method) forecasts seismic intensity on the basis of hypocenter parameters estimated from observed seismic waveform. When accurate hypocenter parameters are determined in an early phase, forecast values of seismic intensity in all areas are calculated quickly and long lead times are available in many areas. On the other hand, if estimated hypocenter parameters are inappropriate, the conventional method leads to underestimation or overestimation of forecast values of seismic intensity.

Hoshiba (2013) proposes real-time ground motion prediction method as a method of forecasting ground motion without the use of hypocenter parameters. The real-time ground motion prediction method predicts wave field directly from observed wave field by a boundary integral equation for displacement. This method is expected to robustly forecast accurate ground motion because it utilizes actual wave field information. Forecast of JMA seismic intensity based on the real-time ground motion prediction method can be performed easily by the following algorithm:

(1) Gather real-time pseudo seismic intensities (Kunugi et al., 2013) of observation stations within a radius R from a target station.

(2) Take the maximum value of the real-time pseudo seismic intensities as a forecasted seismic intensity of the target station.

This is the simplest version of real-time ground motion prediction method. The algorithm assumes that a ground motion which causes large seismic intensity propagates within a radius R without attenuation. In this method, a lead time tends to be short because the area where actual wave field information is available is limited to a radius R.

The conventional method and the simplest version of real-time ground motion prediction method have complementary features on earliness and robustness. Therefore, appropriate combination of these methods is expected to become a hybrid method which has both earliness and robustness. We propose a hybrid method as follows:

(1) Take the maximum forecasted value of two methods in ordinary circumstances.

(2) Reject a forecasted value of the conventional method when the conventional method is not consistent with the real-time ground motion prediction method.

We set input data as real-time pseudo seismic intensities of JMA observation stations, output data as forecasted values of seismic intensity meters in Japan and radius R as 30km and apply the hybrid method to some previous earthquake events. In the case of the 2011 off the Pacific coast of Tohoku Earthquake, whereas seismic intensity scales of Kanto region the conventional method estimates are more than one degree smaller than actual, the hybrid method estimates them appropriately with an accuracy of about one degree. In the case of multiple events on April 3, 2011, the hybrid method can avoid overestimation of seismic intensity the conventional method leads to by qualify control of estimated hypocenter parameters of the conventional method. In the case of an earthquake in the northern part of Tochigi prefecture on February 25, 2013, forecasted seismic intensities of the conventional method are one or two degrees larger than actual although the conventional method estimates hypocenter parameters appropriately. The hybrid method also overestimates seismic intensity in consequence of the overestimation of the conventional method.

Reference:

Hoshiba, M. (2013), *J. Geophys. Res. Solid Earth,* **118,** 1038-1050.

Kunugi, T., S. Aoi, H. Nakamura, W. Suzuki, N. Morikawa and H. Fujiwara (2013), *Zisin 2,* **65,** 223-230. (in Japanese)

Keywords: Earthquake Early Warning, Japan Meteorological Agency, seismic intensity

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SSS28-03 Room:312 Time:May 2 10:30-10:45

Achievement of Faster and More Accurate Earthquake Early Warning System - Combining JMA and Hi-net data -

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Earthquake Early Warning systems (EEWS) are designed to quickly determine locations and magnitudes of earthquakes and then provide predictive warnings about the arrival time and amplitude of the strong shaking. Current JMA EEWS uses data from two seismic networks: JMA accelerometer network and NIED high sensitive seismometer network (Hi-net). Currently, these two datasets are processed in the different scheme and the results are merged to issue a warning. Combining these two datasets and processing in the same framework should improve the accuracy and speed of the warning.

In this study, we tried to develop a method to use these two dataset in the same framework. A major barrier to do this is that the instrument responses are different in these networks. Hi-net seismometers are velocity-type sensor with the corner frequency of 1Hz, which means that the response of long-period components underestimates ground motions. It also saturates for very large ground motions. We need a special care to use this Hi-net data in the same framework.

We applied time-domain recursive filters to correct instrumental response of Hi-net sensors and adjust them to the response of mechanical seismometers. We successfully developed a method to produce records with the same response to the JMA acceleration data. We evaluated the saturation of the Hi-net data with the data in 2 month after the Tohoku earthquake, and found the effect of saturation was minor. Therefore, we can use Hi-net data and JMA acceleration data in the same scheme theoretically. Speed of the warning improved by 3 seconds in the average for the inland earthquake by combining these two networks.

Keywords: earthquake early warning, Hi-net, saturation, instrument response

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Automatic arrival time picking compared to manual picking (6)

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1. Introduction

Recent installation of many ocean bottom seismometers increases the number of P and S-wave arrival times to be measured. The number becomes more than the limit that we are able to conduct picking. We have started to develop an automatic system of hypocenter location which is able to locate hypocenter with accuracy compatible to manually picking. Our previous study introduced a method of using the evaluation equation composed of many parameters based on seismological knowledge about how to pick arrival times. We have showed that the method can pick reliable arrival times of P and S waves. We also have introduced the method of hypocenter location which is able to locate hypocenters even at a period of earthquake swarm. The method makes pseudo seismograms whose amplitude become large at P and S wave arrival times and locates hypocenter with applying the semblance technique to the pseudo seismograms. In this paper, we preset the accuracy of P and S wave picking by the automatic system.

2. Method

In general, the predominant frequency of S wave is lower than that of P wave. We added the data of time variations of predominant frequency for S wave picking. The predominant frequency is calculated by the similar manner of calculating τc, which is used widely to calculate magnitude in the EEW system. Firstly, we calculate differential and double differential of horizontal component observed seismograms as follows.

V (t) = (u(t)-u(t-dt))/dt

A (t) = (u(t)-2u(t-dt) + u(t+2dt))/dt2

Then we compute 0.1 second running mean of the absolute value of V(t),and A(t) and calculate the ratio of two running means. We get time variations in predominant frequency from the time change of the reciprocal value of the ratio, though it is required to multiply a constant value. We assume dt to be 0.02 seconds. We put values of time changes of predominant frequency in the evaluation equation, which is composed of many parameters showing characteristic of seismograms; correspond to the periods between the candidates of arrival times.

3. Results

1) Remarkable drop in predominant frequency are found in almost all seismographs at times of S wave arrivals, showing the effectiveness of its usage in the arrival time picking. Same drop is found at P wave arrivals but there are many cases of increase.

2) We copied all available continuous seismic waveform data in Japan for 24 hours on September 3, 2011, and computed hypocenter automatically. Our automatic system locates 1523 events and the number by JMA catalogue is 588 in the same period. The number of automatically picked P waves is 2.6 times larger than that of manually picking by JMA, and S wave 1.6 times larger.

3) We compared P and S wave arrival times picked automatically with those by manually picking. P and S wave time differences are 0.06 and 0.16 seconds, respectively. This value is close to the difference in a case when two operators conduct picking for the same data.

4) We compared origin times estimated by two closed stations both of which have P and S wave arrivals. We select all couple of two stations with station distance less than 30km and compared origin times estimated from P and S wave arrival times. The average origin time differences by the manually picked data and those by automatically are 0.26 and 0.27sec, respectively.

We can conclude from these comparisons that we already developed an automatic system compatible to manually picking.

Keywords: Hypocenter location, Automatic P and S wave picking, Evaluation equation, Senblance, Predominant frequency, compatible to manual picking

SSS28-05 Room:312 Time:May 2 11:15-11:30

Real-time site correction based on evaluating relative responses to common reference station for wide area network

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Hoshiba (2013a, JGR) proposed a method for prediction of ground motion based on real-time monitoring, in which hypocenter and M are not required. In this method, site amplification must be corrected in real-time manner. Aoki and Hoshiba (2013, AGU) designed the recursive filters for real-time site correction according to Hoshiba (2013b, BSSA), and predicted the JMA seismic intensity of a station by applying this filter to the observed record at the neighboring station, namely exchanging the site amplification factors with each other. In their experiments, in order to consider the effects of the source and propagation in the observed records at adjacent two sites to be identical, the events whose epicentral distances were greater than 100km were selected. Consequently, they show the accuracy of frequency-dependent site correction is better than that of frequency-independent correction using the scalar value, which indicates the average difference in observed intensities at both stations.

In this study, we regard the average spectral ratio, which can be evaluated from the strong motions simultaneously observed at adjacent two stations without the assumptions of attenuation function and source information, as the relative site amplification (RSF) between these two stations. The RSF between distant two stations are estimated by least squares method, combining RSFs of adjacent stations in the network which consists of adjacent station pairs in wide area (Ikeura and Kato, 2011, JAEE). The method is applied to JMA seismic intensity meter network and NIED strong motion seismograph network (K-net and KiK-net including borehole meters), and we can get the RSFs of the stations which almost cover Honshu and Shikoku islands to the common reference station (JMA Tokyo Chiyoda-ku).

The causal digital filters having similar amplitude property to the RSFs are designed according to Hoshiba (2013b, BSSA) and are applied to the waveforms observed in the 2011 Tohoku great earthquake and 2004 Chuetsu earthquake. Site-corrected waveforms can be regarded as the waveforms simulated observing on the sites having the same amplification factor as the reference station. We compare the distribution of seismic intensity with and without site correction. In the distribution of site-corrected intensity on the ground surface, small-scale heterogeneities found on the distribution without site correction vanish and the smooth attenuation of seismic intensity with distance becomes clearer. Before the site correction, the intensity observed in the borehole generally tends to become smaller than that on the ground surface. However the distributions of site-corrected intensities in the borehole are very similar to the distribution of site-corrected intensities on the ground surface. These results indicate that our site correction method applicable to real-time processing works well.

Acknowledgements: We make use of the recordings of NIED strong motion seismograph network (K-NET and KiK-net) and JMA seismic intensity meter network.

Keywords: Site amplification factor, Spectral ratio method, Real-time processing, Strong motion seismograph network in Japan, Prediction of the ground motion

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Real-time prediction of earthquake ground motion -application of data assimilation and its application to actual data-

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Aiming at improvement of prediction of seismic intensity in Earthquake Early Warning, we are investigating a new technique for real-time prediction of earthquake ground motion. We have proposed to use data assimilation technique for estimation of current wavefield of ground motion, and then predict future wavefield based on physics of wave propagation. In this presentation, we will show examples of application of the technique to the actual data, such as those from the 2011 Tohoku earthquake and the 2004 Mid-Niigata earthquake.

In the proposed technique, estimation of current wavefield is important. We correct site amplification factors using recursive filtering (Aoki and Hoshiba, 2014), apply band pass filter which is used for JMA seismic intensity (Kunugi et al., 2008), and then estimate envelope of 3-component vector summation of the filtered waveforms. We apply the data assimilation technique to the envelope and then estimate the spatial distribution of strength and propagation direction of ground motion.

The strength and the propagation direction are used as an initial condition, and then wave propagation is calculated. In this presentation, as the physics of wave propagation we will use Radiative Transfer Theory in which wave propagation is simulated by energy propagation based on high frequency approximation. The theory has been used for interpretation of seismogram envelope. We will indicate examples of predictions of 10 and 20s in this presentation.

For application to the 2011 Tohoku earthquake, this method reproduces the strong ground motion which were generated from multiple SMGA, and then propagated into many directions. Strong ground motion, generated at off Fukushima much later than the earthquake origin time, propagated into Kanto region, and then around Kofu and Nagoya. The prediction of 10 and 20s reflects the spatial distribution. In the conventional method based on hypocentral location and magnitude, it was not easy to predict the ground motion for the case of the late rupture.

For case of the 2004 Mid-Niigata earthquake, this method reproduces propagation of strong ground motion from repeated aftershocks. Especially at around epicenter region, strong ground motion repeatedly arrived even when the motion of earlier events still large. In the conventional method, the case of the repeated occurrence of aftershocks was not easy.

The proposed method is expected to be useful for improvement of prediction of seismic intensity in Earthquake Early Warning.

Keywords: Earthquake Early Warning, Data assimilation, Prediction of ground motion, Radiative transfer theory, 2011 Tohoku earthquake

Investigation for earthquake early warnings of long-period ground motion

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Sometimes seismic intensity cannot express difficulty of action and indoor situations in high rise buildings properly when severe long-period ground motion occurs. To notify people of such situations and facilitate effective countermeasures, JMA started to provide information on long-period ground motion from March 28th, 2013. And now, we are investigating for an earthquake early warning for long-period ground motion.

There are some techniques for prediction long-period ground motion, and we investigate attenuation relationships of response spectrum because it can calculate at any given seismic parameter and calculate fast.

We investigate following three relationships that they are used for governmental studies, we can get their coefficients and detail information on amplification factors, and they have different equation format or adjustment techniques.

-Sato et al.(2010) and Sato et al.(2012)
-Morikawa and Fujiwara(2013)
-Yokota et al.(2010)

We use earthquakes that earthquake early warnings were issued, their magnitudes are bigger than 5.5, and maximum seismic intensities are 3 or larger, and we calculate absolute velocity response spectrum for seismic parameters of each earthquake early warning information and JMA seismic catalog. Prediction points are JMA seismic stations, K-net stations and KiK-net stations, and prediction element is intensity scale of long-period ground motion.

As a result, every equation represent trend properly. Especially, the probability that intensity scales fall inside the error of +/-1 is 70 to 80 percent when we use seismic parameters of JMA seismic catalog. But there is a tendency that prediction intensity scale is bigger than one of calculated from real wave form near the epicenter because we use the shortest distance from source faults to observation stations which depend on Mw. In addition, calculated results are affected accuracy of seismic parameters of earthquake early warnings. Therefore there is need to discussion when we issue prediction information and what information number we should use.

Keywords: long-period ground motion, JMA, EEW, attenuation relationship, response spectrum

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Updating of Earthquake Early Warning for Long-Period Ground Motions

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Introduction: In the present EEW systems developed by the JMA, Japan, hypocenter and magnitude of an earthquake are determined quickly, after which ground shaking strengths such as seismic intensity are predicted based on a ground motion prediction equation and then earthquake warning are sent to public when the seismic intensity are beyond 5-lower. This method might underestimate ground motions for large earthquakes with wide rupture area because source extent produces error in estimating distance from source to site and the effects of rupture directivity prediction are not taken into account. Another problem is that the magnitude and source distance cannot be determined before the rupture terminate. Therefore, lead times of prediction become smaller in disastrous regions as earthquakes become larger. Long-period strong motions related to damage of skyscrapers and large oil-storage tanks are generated only from large earthquakes.such as mega-thrust earthquakes. It takes very long time before the rupture terminates. A new idea applying the Kirchhoff-Fresnel boundary integral equation proposed by Hoshiba (2013) will solve the above problem by predicting ground motions at front stations where ground motions do not arrive yet without estimating the hypocenter and magnitude of an earthquake. We attempt to examine the applicability of the front detection method to prediction of long-period strong motions.

Methodology: Ground motion u(P,t) in the wavefield at location P and time t inside a close region is approximated as Kirchhoff-Fresnel Integral.

Equation (1)

In the above equation, u(r,t) is ground motion at a reference point on S and G(P-r,t) is the Green's function between a reference point r and a target point P. The above equation is available for the case where the wave length is much smaller than the spatial fluctuation of absolute amplitude of u(r, t) and G(P, t?t, r , 0), i.e. in high-frequency motions.

When the distance to the source is much larger than |P ? r|, plane wave incidence can be assumed locally around P. Then, u(P,t) is approximated as a convolution between G(P-r,t) and u(r,t).

Equation (2)

When the target point is almost aligned along a line connecting the source to the reference point, the crosscorrelation of u(P,t) and u(r,t) is approximated as follows.

Equation (3)

T(P,r, t) is the transfer function between the reference point and the target point. S(t) is defined as the autocorrelation of the source time function s(t).

Equation (4)

We can estimate the transfer function when the ground motions from some small earthquakes are obtained at the target point and at the reference point at the same time from (3). The autocorrelation function of the source time function of the small earthquake is estimated in advance, e.g. from the waveform inversion of the source process. When large earthquakes such as mega-thrust earthquakes happen in the subduction zone, we can evaluate long-period ground motions at sites where large shakings do not arrive yet using ground motions at stations already observed closer to the source and the transfer functions calculated in advance.

Keywords: Earthquake Early Warning, Long-Period Ground Motions, the applicability of the front detection method

SSS28-08 Room:312 Time:May 2 12:00-12:15

$$u(\boldsymbol{P},t) = \int \frac{1}{v(\boldsymbol{r})} \cdot (\cos\theta + \cos\theta') \cdot G(\boldsymbol{P}-\boldsymbol{r},t) * \dot{u}(\boldsymbol{r},t)dS \quad (1)$$

$$u(\boldsymbol{P},t) = G(\boldsymbol{P},\boldsymbol{r},t) * u\left(\boldsymbol{r}, t - \frac{\boldsymbol{P}-\boldsymbol{r}}{v}\cos(\theta' - \theta)\right) \quad (2)$$

$$u(\boldsymbol{P},\boldsymbol{r_0},t) * u(\boldsymbol{r},\boldsymbol{r_0},-t) = T(\boldsymbol{P},\boldsymbol{r},t) * S(\boldsymbol{r_0},t) \quad (3)$$

$$S(\boldsymbol{r_0},t) = s(\boldsymbol{r_0},t) * s(\boldsymbol{r_0},-t) \quad (4)$$

Japan Geoscience Union Meeting 2014
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Current Status and Issues of the Broadcast Start Condition of Earthquake Early Warning

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In-site broadcasting system is widely used as a means of transmitting of earthquake early warning. But about the current situation of the broadcast start condition, it is determined by the user who introduced it in consultation with providers. For example, if there is a hazardous material in the building, it will be broadcast starting at predicted seismic intensity 3 or more. On the other hand, in the building with no less hazardous materials, it will be broadcast starting at predicted seismic intensity lower 5 or more. The current situation of the broadcast start condition is as described above; the users have determined in consideration of the user environment.

The document, which serves as a reference in the broadcast start condition to determine appropriate, did not exist until the JMA had published guidelines in April 2011. In this guideline, in particular, for the case of in-site broadcasting towards an unspecified number of people, it has been recommended to broadcast suited to the alarm condition of earthquake early warning of JMA.

The alarm condition of earthquake early warning in JMA is, "it is issued for areas predicted strong shaking (seismic intensity lower 5 or more) and for areas where seismic intensity 4 is predicted when if seismic wave were observed at more than two seismic stations and the seismic intensity was predicted to lower 5 or more". And to match in this, mobile phone companies and commercial televisions have broadcast the earthquake early warning in areas where JMA issued an alarm.

At the beginning, we also have set the broadcast start condition of our in-site broadcasting system to match to this alarm condition in JMA. Furthermore, we have operated by setting the "broadcast start condition for giant earthquakes" by using the combination of not only predicted seismic intensity but also predicted magnitude because from the fact that at the time of the Tohoku Giant Earthquake, the predicted seismic intensity at the alarm of earthquake early warning was much lower than the actual.

However in the period of one year from the start of the operation, there were three broadcasting occurred but in those case the real seismic intensity were 2 or 3 and as a result, these broadcasting became the excessive broadcast.

In this opportunity, I would like to report on the results of review for broadcast start condition of earthquake early warning. And I hope to discuss issues for better broadcast start condition and realizing it.

Keywords: Earthquake Early Warning, Broadcast Start Condition, Alarm Condition