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

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

SSS28-02 Room:312 Time:May 2 10:15-10:30

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

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

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

Japan Geoscience Union Meeting 2014
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SSS28-04 Room:312 Time:May 2 11:00-11:15

Automatic arrival time picking compared to manual picking (6)

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[1]Home Seismometer Corporation, [2]Disaster Prevention Research Institute Kyoto University, [3]Association for the Development of Earthquake Prediction, [4]Research Center for Prediction of Earthquake and Volcanic Eruptions, [5]Earthquake Research Institute, The University of Tokyo, [6]Japan Agency for Marine-Earth Science and Technology

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

AOKI, Shigeki[1*] ; HOSHIBA, Mitsuyuki[1]

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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

SSS28-06 Room:312 Time:May 2 11:30-11:45

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

Japan Geoscience Union Meeting 2014
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SSS28-07 Room:312 Time:May 2 11:45-12:00

Investigation for earthquake early warnings of long-period ground motion

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[1]JMA

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

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

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

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

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

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

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

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

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SSS28-09 Room:312 Time:May 2 12:15-12:30

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

SSS28-P01 Room:Poster Time:May 2 14:00-15:15

New-development of real-time seismic waveform viewing system feeding from DONET

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Jamstec-Ocean seismological database-Integrated byNetwork data (team JOIN) is started since 2012, with the purpose of developing an earthquake research information database through the integration of discrete database, such as real-time earthquake study and lithosphere structure research catalogue. JOIN is consist of three divisions, 1) seismological study using DONET (Dense Ocean-floor Network for Earthquake and Tsunamis) data, 2) sub-structural study for nankai-tonankai earthquake area, and 3) data-management and opent to public for oceanographic data acquired JAMSTEC equipment. These can lead not only scientific but practical outreach, consequently, disaster prevention of each local government.

We have developed web-based real-time monitoring system of strong motion and pressure sensor of DONET observatory network, this is user-friendly tool for servant service of disaster prevention department.

Trial operation with the monitoring system is undergoing for a few government close to nankai-tonankai area, aiming full-scale operation which will start from April 2014.

Technical summary of this system will be introduced.

Keywords: DONET, database, real-time trace view, outreach for local government

Japan Geoscience Union Meeting 2014
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SSS28-P02 Room:Poster Time:May 2 14:00-15:15

Examination of the relative site amplification factor of OBS and their real-time correction: examples of Sagami Bay OBS

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Hoshiba (2013, JGR) proposed a method for real-time prediction of ground motion based on real-time monitoring as the next-generation EEW, in which detection of hypocenter and Magnitude are not required. In this method, site amplification is one of the important factors. Therefore, relative site amplification factor have been evaluated at KiK-net (Iwakiri and Hoshiba, 2011) and at JMA seismic intensity stations (Aoki and Hoshiba, 2013) in the frequency domain. Ocean Bottom Seismograph (OBS) will provide valuable information to grasp ground motion propagation from ocean area. However, it is necessary to correct the site amplification factor of OBS for applying real-time monitoring method. Hayashimoto and Hoshiba (2013, SSJ) reported relative site amplification factor of OBSs at Tonankai region (Tonankai OBS (JMA) and DONET (JAMSTEC)) as a preliminary result. In this study, we evaluate relative site amplification factor of Sagami Bay OBS (NIED, Eguchi *et al*., 1998, MGR) which is close to land stations, and examine the effects of real-time correction to predict ground motion of land station from OBS.

The averaged spectral ratio of a station-pair from many events can be regarded as the relative site factor when the hypocentral distances to station-pair are much larger than the distance of those stations. In this study, we use the waveform data from the Sagami Bay OBSs and adjacent land stations (K-NET and KiK-net, NIED), and select the dataset with the hypocentral distance which is greater than 100km. We compare Fourier spectra from the waveforms of S-wave portion (20s) on OBSs with those on adjacent land stations as the relative site factors. In examples of the relative site factors of OBSs to KNGH23 (KiK-net borehole station), the amplification factor of the horizontal component is greater than that of the vertical component for frequencies 1-10Hz. We conclude that the site effects of OBSs characterized by such a low velocity sediment layers causes those amplification factors.

In order to examine the effect of frequency-dependent relative site amplification factor, we compare the accuracies of predicted seismic intensity using the spectral ratio with those using the average of seismic intensity (frequency-independent factor). We design the causal digital filter (Hoshiba, 2013, BSSA) having similar amplitude property to relative site factor for the station pair. The filter parameters are estimated and applied for both horizontal and vertical components. And we use the real-time processing of seismic intensity (Kunugi *et al*., 2008, Zisin 2) to estimate seismic intensity from observed and predicted waveforms. Both of the techniques are applicable in real-time. We consider the RMS of residual between observed and predicted seismic intensities as the accuracy of site correction of each station pair. In the case of prediction of seismic intensities from OBSs data to land stations, the average RMS of frequency-dependent method are smaller than that of frequency-independent method. Similar results are also obtained at pairs of land station. These results indicate that the frequency-dependent site factor is crucial factor to predict seismic intensity from OBS data, and also show that OBS can be used as front stations in the method for prediction of ground motion based on the real-time monitoring.

Acknowledgments: Strong motion acceleration waveform data were obtained from K-NET and KiK-net of NIED.

Keywords: Earthquake Early Warning, Ocean Bottom Seismograph, Real-time prediction of ground motion, Site amplification factor

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

SSS28-P03 Room:Poster Time:May 2 14:00-15:15

Improvement of earthquake early warning system using the extrapolation of wavefield with apparent velocity and direction

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The present early warning system in Japan utilizes the epicenter information preliminary estimated by P-wave arrival times at stations near an event. The present system is still not effective in the following cases, for example, (a) more than one earthquakes occur nearly simultaneously, (b) a deep event whose wave front propagates in a different manner from shallow ones, particularly with very high apparent velocity on the surface, and (c) a large event (M>8) whose finite fault area cannot be neglected. In order to deal with non-circular wave front expansion of these cases, we propose a new approach based on the extrapolation of the early observed wave field alone without determining an epicenter. The idea is similar to the migration method of exploration seismology. The conventional migration method utilizes the wave field on a given wavefront (e.g., Kirchhoff integral migration). In the early warning system, on the other hand, we can obtain the speed and direction of wave field expansion over the surface. Based on the standard representation theorem with a Green's function, we extrapolate wave field outwards or in the future with not only the observed waveform but also its spatial derivative (normal for the wavefront). This enhances the resolution and reliability in the extrapolated wave field in comparison with the conventional approach with the waveform only.

For the extrapolation of wave fields accurately and reliably, we need a reliable Green function in each case. Since the actual wave propagation of P or S waves is very complex or sensitive to details of 3-D velocity structure between a source to each target point on the surface, we shall consider it in a two dimensional manner only focusing on the practical use of the early warning system, that is, a wavefront propagates on the surface with an apparent velocity of P-wave. These apparent velocities vary for events of various depths in different regions. The velocity of shallow events in Hokkaido is about 7.1km/s while that in Nagano prefecture of central Honshuu island is about 5.5km/s. The velocity strongly depends on focal depth: 7.1km/s for the depth of 10km, and 8.9km/s for the depth 100km. The velocity also varies as a function of epicentral distance, particularly for a deep event. We make a table of apparent velocities in different depths, regions and epicenters so that we can pick up an appropriate Green function (apparent velocity) for the wave field extrapolation when an event takes place. We also explain how to estimate the apparent velocity and propagation direction with several early observed wave forms. One key to apply the wavefield extrapolation in the warning system is the good correlation among the seismograms that are observed early as input data. Nevertheless, correlations are generally poor in high-frequency (about 1Hz) seismograms recorded in Japan such as Hi-net data. To enhance the correlation of P waveforms among adjacent stations, we need to correct the site response of each station promptly. Using both shallow and deep events, we first estimated site effect as a function of frequency for Hi-net stations in Hokkaido. We used a rock site station (ONPH) as a reference station for site correction terms for other stations.

For deep earthquakes, a region of anomalous seismic intensity is seen in the Pacific Ocean side of Japan called 'abnormal seismic intensity' , due to a subducting Pacific plate of high velocity and small attenuation. For the earthquake of 590 km deep beneath Vladivostok on 18 February 2010, we examined the direction of P waves propagating in Japan. The apparent velocity is highly anisotropic: fast along the islands but slow perpendicular to them. It is about 7.5km/s in the Souya district in the north of Hokkaido while about 13km/s in the Hidaka district in the south. In our extrapolation scheme, we can model the amplification of wavesin terms of abnormal seismic intensity.

Keywords: earthquake early warning system, extrapolation of seismic wave field, migration, apparent velocity, site effect, abnormal seismic intensity

SSS28-P04 Room:Poster Time:May 2 14:00-15:15

Early forecasting of aftershocks from seismic energy release rate immediately after the mainshock

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The detection completeness of earthquakes just after a large earthquake becomes very poor because their signals are overlapped each other in seismogram records and are hidden by the large amplitude of coda waves. Currently, the JMA starts to serve the aftershock forecasting at least 24 hrs after the mainshock because long lapse times are necessary before the catalog data becomes available for the forecasting with a certain reliability. Recently, Sawazaki and Enescu (under review) succeeded in estimating temporal change in energy release rate for the mainshock and the early aftershock sequence by using the Hi-net continuous records. In their method, the energy release is not determined for each discrete event, but is estimated as a continuous process like a source time function which sums up energies from all the earthquakes occurring at the same time. Therefore, theoretically there are no missing energies in the energy release rate even just after the mainshock. The estimated energy release rate follows a power-law temporal decay like the modified Omori law from about 40 s after the mainshock, and the deviation of the energy release rate with respect to the temporal regression curve distributes according to a power-law like the Gutenberg-Richter law. Since the current aftershock forecasting is conducted based on these two statistical laws, the energy release rate would be available for the early forecasting of the aftershocks.

We examine the statistical characteristics of energy release rate in the frequency range of 8-16 Hz for three crustal earthquakes took place in Japan. From the energy release rate obtained at the first 1 hr, 3 hrs, and 6 hrs after the mainshock, we estimate the number of energy release rate larger than 10^8 J/s (about M_W4/s) occurring within 24 hrs after the mainshock. For the 2008 Iwate-Miyagi Nairiku earthquake, the ratios of the estimated/observed numbers are 24/35, 12/20, and 20/10 for the forecasting at 1 hr, 3 hrs, and 6 hrs after the mainshock, respectively. Likewise, the ratios are 1524/223, 231/99, and 113/50 for the 2004 Niigata Chuetsu earthquake, and 17/59, 8/59, and 30/21 for the 2007 Niigata Chuetsu-oki earthquake. For the Niigata Chuetsu earthquake, M_J5.9, M_J5.8, and M_J6.3 aftershocks occurred in the first 1 hr, while there are no aftershocks larger than M_J5.5 in the lapse times from 1 to 24 hrs. For the Niigata Chuetsu-oki earthquake, there are no aftershocks larger than M_J5 in the first 3 hrs, while M_J5.7 aftershock occurred 5.4 hrs after the mainshock. Such large aftershocks and their secondary aftershocks may change the pattern of aftershock activity, and causes the over- and under-estimations in the forecasting.

Keywords: aftershocks, early forecasting, energy release rate, modified Omori law, Gutenberg-Richter law

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

SSS28-P05 Room:Poster Time:May 2 14:00-15:15

A method to remove non-seismic long-period pulses for improved estimations of automatic centroid moment tensor solutions

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Non-seismic long-period pulse-like waveforms appear in broadband seismic records when P or S waves arrive (e.g., Delorey et al, Bull. Seism. Soc. Am., 2008). The pulse-like waveforms affect centroid moment tensor (CMT) solutions estimated from waveform inversion, but a method to remove those pulse-like waveforms yet to be established. Broadband seismograph networks were installed in the Philippine and Indonesia region to monitor earthquakes and tsunamis. The pulse-like waveforms appear in those network data frequently. Those data are used for automatic estimations of CMT solutions by SWIFT (Source estimates based on Waveform Inversion of Fourier Transformed seismograms), which was developed by Nakano et al. (Geophys.J.Int, 2008). SWIFT estimates both the CMT and moment function by the use of long-period (50-100 s) waveform data, but sometimes the long-period pulse-like waveforms affect SWIFT solutions. To monitor earthquakes and tsunamis, we have to estimate source parameters rapidly and adequately. In this study, we propose a simple and rapid method to remove long-period pulse-like waveforms from broadband seismic records.

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SSS28-P06 Room:Poster Time:May 2 14:00-15:15

Japan Meteorological Agency information on long-period ground motion

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An earthquake generates seismic waves with various periods, and earthquakes with larger magnitudes generate stronger long-period ground motions. When the natural period of a high-rise building is close to the predominant period of ground motion, resonance happens and the building is severely shaken longer than surface of the Earth. Today, more and more people spend time in high-rise buildings especially in metropolitan areas. If great earthquake occurs, many people in high-rise buildings will be affected by long-period ground motion.

To notify people of such situations and facilitate effective countermeasures, JMA started to provide information on long-period ground motion from March 28th, 2013. Based on questionnaires to tenants of high-rise buildings, it has become clear that difficulty of people's activities depends on the velocity of floor movement, and we classified the intensity of long-period ground motion into four on the basis of velocity. To get the classification, we use wave forms observed by JMA seismic intensity meters on the surface of the Earth which are automatically sent to the JMA system. To estimate shaking at higher floors from wave forms on the surface of the Earth, we simulate the shaking of buildings by absolute velocity response spectrum of the period between 1.5 and 8.0 seconds which causes a significant resonance of buildings with 45 meters or higher. The information is available on the JMA website, with various kinds of contents such as absolute velocity and acceleration response spectrum.

Keywords: long-period ground motion, strong motion

SSS28-P07 Room:Poster Time:May 2 14:00-15:15

Prediction of long-period ground motion intensity for earthquake early warning

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The 2011 Mw 9.1 Tohoku-oki earthquake caused strong shakings of high rise buildings constructed on deep sedimentary basins in Japan. During the earthquake, many people got into difficulty with their movements inside the high rise buildings even on the Osaka basin located at distances as far as about 750 km from the epicentral area. Japan Meteorological Agency (JMA) has started to provide people with information on intensity of long-period ground motions based on the absolute velocity response spectra (1.6 to 7.8 s) of the observed records on the grounds (Aizawa et al., 2013). The intensity scale of long-period ground motions is classified into four: 1, 2, 3, and 4 having spectral values of 5 to 15 cm/s, 15 to 50 cm/s, 50 to 100 cm/s, and more than 100 cm/s, respectively. The spectra were computed at natural periods of 1.6 to 7.8 s using 5% of critical damping. The maximum value of the computed spectra among 1.6 to 7.8 s defines the class of intensity. We have recently constructed empirical prediction equations of absolute velocity response spectra in the period range of 1 to 10s aiming for earthquake early warning application (e.g., Dhakal et al., 2013). The equations use JMA displacement magnitude and hypocentral distance as basic parameters. Earthquakes having JMA magnitude 6.3 or larger and focal depths shallower than 50 km were used. One of the difficulties in empirical prediction of long-period ground motions is to effectively include the effects of local geological structure such as 3-D basin effects in the prediction equations. To simplify this problem, we obtained site correction factors at K-NET and KiK-net strong motion sites as the mean value of the logarithmic residuals. To make predictions possible at sites other than the strong motion observation sites, we derived correction coefficients based on the relationships between the average residuals and depths of deep sedimentary layers, which are available for whole Japan at Japan Seismic Hazard Information Station (J-SHIS). We found that the standard deviations are minimized by corrections using the depth of layer having Vs value of 1.4 km/s.

To define intensity at a site, we obtained the maximum value of the predicted spectra among T=1.6 to 7.8 s using the empirical prediction equations explained above. However, we found that the maximum predicted values were somewhat biased against the observed maximum values. Therefore, we applied an additional correction factor to the maximum predicted values to finally obtain the intensities. When a prediction equation was constructed using the maximum value of the observed spectra as the independent parameter, the additional correction factor was eliminated as the resulting residuals were normally distributed; also, the predicted intensities were almost identical to those obtained based on the regression analysis results for each natural period. In this study, we illustrate and discuss the application of empirical prediction equations for the prediction of JMA intensity of long-period ground motions for earthquake early warning application.

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Keywords: Long-period ground motion intensity, Earthquake early warning, Absolute velocity response spectra, Attenuation relations

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

SSS28-P08 Room:Poster Time:May 2 14:00-15:15

Regional Earthquake Early Warning Applications in Marmara Region Based on KOERI Seismic Network

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KOERI (Kandilli Observatory and Earthquake Research Institute) operates a seismic network in Marmara Sea region (NW Turkey) consisting of 40 broadband and 30 strong motion inland and OBS stations which has a good topology for regional EEW studies. Data transmission between the remote stations and the base station at KOERI is provided both with satellite and fiber optic cable systems. The continuous on-line data from these stations is used to provide real time warning for emerging potentially disastrous earthquakes.

The Virtual Seismologist in SeisComP3 and the PRESTo regional EEW (earthquake early warning) softwares are the two regional EEW algorithms that have been recently setup at KOERI data center to generate the EEW sygnal. Onsite EEW application are underway for more than a decade.

The early warning sygnal is communicated to the appropriate servo shut-down systems of the receipent facilities, that automatically decide proper action based on the alarm level. Istanbul Gas Distribution Corporation (IGDAS) is one of the end users of the EEW signal. IGDAS, the primary natural gas provider in Istanbul, operates an extensive system 9,867 km of gas lines with 550 district regulators and 474,000 service boxes. State of-the-art protection systems automatically cut natural gas flow when breaks in the pipelines are detected. IGDAS uses a sophisticated SCADA (supervisory control and data acquisition) system to monitor the state-of-health of its pipeline network. This system provides real-time information about quantities related to pipeline monitoring, including input-output pressure, drawing information, positions of station and RTU (remote terminal unit) gates, slum shut mechanism status at 581 district regulator sites. The SCADA system of IGDAS receives the EEW signal from KOERI and decide the proper actions according to the previously specified ground acceleration levels. Presently, KOERI sends EEW signal to the SCADA system of IGDAS Natural Gas Network of Istanbul.

The EEW signal of KOERI is also transmitted to the serve shut down system of the Marmaray Rail Tube Tunnel and Commuter Rail Mass Transit System in Istanbul. The Marmaray system includes an undersea railway tunnel under the Bosphorus Strait. Several strong motion instruments are installed within the tunnel for taking measures against strong ground shaking and early warning purposes. This system is integrated with the KOERI EEW System. KOERI sends the EEW signal to the command center of Marmaray. Having received the signal, the command center put into action the previously defined measures. For example, the trains within the tunnel will be stopped at the nearest station, no access to the tunnel will be allowed to the trains approaching the tunnel, water protective caps will be closed to protect flood closing the connection between the onshore and offshore tunnels.

Keywords: EEW sygnal, Virtual Seismologist, PRESTo, end users, IGDAS, Marmaray