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(May 20-25 2012 at Makuhari, Chiba, Japan)

SSS40-01 Room:106 Time:May 21 15:30-15:45

Earthquake Early Warning of JMA - The 2011 off the Pacific coast of Tohoku Earthquake and its aftershocks -

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Japan Meteorological Agency (JMA) started to provide EEW to a limited number of users from August 2006 and to the public through TV and radio in October 2007. The Meteorological Service Act amended in December 2007 defined legally JMA EEW as "forecast" and "warning" of strong ground motions caused by an earthquake. "Warning" is issued when Seismic intensity of 5 or larger (on JMA scale) is expected.

The 2011 off the Pacific coast of Tohoku earthquake (Mw9.0) occurred of Match 11, 2011, caused strong ground motion around northeastern Japan. Before the strong ground motion hit cities, JMA issued EEW announcements to the general public of the Tohoku district. After the mainshock, JMA issued 96 warnings and 3751 forecasts from the mainshock to December 2011 (10 months) for its quite active aftershocks and induced earthquakes. (Note that, from October, 2007 to March, 2011 (41 months), JMA issued 17 warnings and 1928 forecasts).

On the other hand, some inaccurate "warnings" were issued after the mainshock. From March to December 2011, JMA issued 27 "false-alarms", caused by the active seismicity, in which seismic intensity did not exceed 3 everywhere in observation even when seismic intensity 5 lower (or larger) was expected.

The reason of the false-alarms is that multiple earthquakes sometimes occurred simultaneously over the wide source region during the period, the system became confused, and did not always determine the location and magnitude correctly,

In this presentation, we will present evaluation of the performance of EEW issuance, lessons learned from the earthquakes and various efforts and direction to improve EEW of JMA.

Keywords: Earthquake Early Warning, Warning event, The 2011 off the Pacific coast of Tohoku Earthquake

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Prediction of ground motion using real time monitoring -for real time ground motion prediction -

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Earthquake Early Warning (EEW) aims at mitigation an earthquake disaster by giving people enough time to take appropriate safety measures in advance of strong ground shaking. EEW system of the Japan Meteorological Agency(JMA) determines quickly the hypocenter and magnitude (M) of the earthquake, and then predicts seismic intensity using empirical attenuation relation and site amplification factors. During the 2011 off the Pacific Coast of Tohoku Earthquake, the JMA EEW was issued to the Tohoku district as expected, but it was not issued to Kanto district because of the underestimation of seismic intensity. The underestimation can be attributed due to the large extent of the later fault rupture. For several weeks after the mainshock, when earthquakes sometimes occurred simultaneously over the wide source region, the system became confused, and did not always determine the location and magnitude correctly, which leaded to some false alarms.

To solve above problems, Hoshiba(2011) proposed a method for expectation of ground motion based on Kirchhoff Fresnel integral method, in which hypocenter and M are not required. In this method, real time monitoring and estimation of wavefield and propagation direction of the waves are important. The Green function is required beforehand.

In real applications for prediction of ground motion, site amplification factors are important. Though the site amplification factors are scalar values for current JMA EEW system, Iwakiri and Hoshiba(2011) concluded that the preciseness will be improved by 20% when frequency dependency is introduced into the site amplification correction. When the correction can be applied in real time manner, it become possible to synthesize the waveform by combining the application of the Kirchhoff Fresnel integral method, which leads us to real time ground motion prediction.

For ground motion prediction for scenario earthquakes, source parameters such as the location of initial rupture and asperities are assumed and then waveforms are synthesized from the information. For real time ground motion prediction, waveforms are observed in real time manner and then predict based on the information. The real time ground motion prediction is expected to apply to the Earthquake Early Warning.

Keywords: Earthquake Early Warning, Real time, Monitoring, Ground motion prediction

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Real-time fault area location of a massive scale earthquake-Wenchuan Earthquake-

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1. Introduction It's difficult to estimate accurate tsunami heights at a time of a massive earthquake occurrence, since obtained magnitude by Japan meteorological agency are always less than the moment magnitude due to the problem of so-called Magnitude saturation. The Earthquake early warning uses a model of a point source to calculate seismic intensity, causing estimated intensities less than actual ones. Using data of real-time seismic intensity of every one seconds, Horiuchi et al. (2011) developed a method to determine time-and space distribution of fault area of the 2011 Off the Pacific coast of Tohoku Earthquake, and pointed out that these issues can be solved.

In 2008, a massive earthquake of M7.9 with a 280km fault length jolted Wenchuan County of Southwest China's Sichuan province. An estimated number of 80,000 people were found dead or missing in this catastrophic disaster. The length of the fault was so long that beyond the faulting, the destructive shake started 10 seconds after the initiation of the faulting. The development of the real-time location of fault area distribution will help people to effectively escape from the disaster in time, and it would also lighten the predicted damage. The report applied the Horiuchi etc. method to the Sichuan Wenchuan earthquake. An improvement to this method was made to make sure that it would be applicable in China.

2. Real-time location of fault area distribution Shi and Midorikawa(1999), Matsuzaki et al.(2006), showed that the seismic intensity is represented by the function of shortest distance from the seismic fault and determined empirical formulas. Shaking intensity by the empirical attenuation relation is put as,

S = S(M,D,H,C) (1)

where, D, H, and C are magnitude, fault distance, depth and site amplification. Assuming S of eq. (1) to be measured seismic intensity of every one seconds, time function of fault distance is

D(t) = D(S(t),M,H,C) (2)

Present study, similar with that of Horiuchi et al., determines real-time distribution of fault area by using equation (2) and projecting them onto the line connecting the epicenter and the observation point. We projected them only when calculated seismic intensities by the empirical attention are larger than the observed intensity.

3. Result Obtained direction of the fault is consistent with the result of the aftershock distribution or the results of waveform inversion when using the Shi and Midorikawa (1999)'s empirical equation, but the length of the fault was approximately doubled. The reason is caused by the data of large seismic intensities in a region 200km-500km northeast from the northeastern edge of the fault. There, empirical attenuation relation was changed for Chinese Mainland and was re-calculated. The source region of the results obtained the present study is in good agreement with the results estimated by data of aftershock distribution.

Since the present method is simple and can estimate nearly correct real-time distribution of fault, it can be used for an EEW system in China, which can provide information to eventually mitigate earthquake disaster at a time of a massive scale earthquake.

Keywords: Massive earthquake, Fault area, Real-time estimation, Fault, Seismic intensity, Empirical attenuation relation

SSS40-04 Room:106 Time:May 21 16:15-16:30

Classification of Simultaneous Multiple Earthquakes for the Earthquake Early Warning System

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The 2011 off the Pacific Coast of Tohoku Earthquake (Mw9.0) caused significant damage over a large area of northeastern Honshu. An earthquake early warning was issued to the public in the Tohoku region about 8 seconds after the first P-arrival, which is 31 seconds after the origin time. There was no blind zone, and warnings were received at all locations before S-wave arrivals, since the earthquake was fairly far offshore.

Over 70 early warnings for strong shaking were also broadcast during larger aftershocks. In general, the system worked well for these smaller events, but there were significant errors caused by event mislocations. Immediately following the earthquake, the waveforms of some large aftershocks were contaminated by long-period surface waves from the mainshock, which made it difficult to identify P-wave arrivals. Also, correctly distinguishing and locating later aftershocks was sometimes difficult, when multiple events occurred within a short period of time.

In this presentation, we propose a new approach to classify simultaneous multiple earthquakes in the current JMA system framework. We introduce a Particle Filter approach, also known as sequential Monte Carlo method, to estimate the most probable event parameter values, which include location, magnitude, and origin time. This approach provides a probabilistic solution to the problem of classifying multiple events. We formulate the likelihood function using the attenuation relationship in the current JMA system, and test the aftershock data of 2011 Tohoku earthquake. The results show that this approach can correctly classify multiple events occurred around the same time in several case studies.

Keywords: Earthquake Early Warning

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GRiD MT with W-phase monitoring system for tsunami early warnin

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The GRiD MT system (Tsuruoka et al., PEPI, 2009) is the real-time monitoring analysis system that continuously monitors long-period seismic wave field at a period of 20-50s recorded by broad-band seismometers. This analysis system automatically and simultaneously determines the origin time, location and moment tensor of seismic events within 3 min of their occurrence without earthquake information such as QED etc. This system has been in operation since April 2003 at the Earthquake Research Institute.

For tsunami early warning purposes, we have implemented a W-phase source inversion algorithm (Kanamori and Rivera, GJI, 2008) into the GRiD MT system (we call this system GRiD MT with W-phase monitoring system) using SeedLink software developed by GEOFON and later adopted by IRIS. W-phase is a very long-period (typically 200-1000s) phase starting after the P-wave arrival, and is suitable for fast source parameter determination for large (Mw>=7) earthquakes. When broad-band seismograms are available at distances (<=30 deg), we can detect seismic events and determine satisfactory mechanism solutions within 15 min after the earthquake occurrence.

We compared GRiD MT with W-phase monitoring results with W-phase source inversion results for events (Mw>=7) occurred from 2005 to 2011 in the World. From the results, (1) this system detects earthquakes and determines the source parameters with a high level of precision and complete automation within 15 min of the earthquake occurrence. (2) The origin time and locations are similar to those of PDE catalogue or GCMT catalogue. (3) The focal mechanism and moment magnitude obtained by two systems are very similar. The preliminary results suggest that this system provides rapid and reliable source parameters useful for tsunami warning purposes.

Keywords: realtime, earthquake analysis system, W-phase, Tsunami

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Improvement of MT/CMT analyses in the AQUA (Accurate and QUick Analysis System for Source Parameters) system

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Quick determination of hypocentral parameters and its transmission to the public are very valuable in the viewoint of disaster mitigation. We have operated an automatic system called the Accurate and QUick Analysis System for Source Parameters (AQUA system) since 2005 (Matsumura et al., 2006). In this system, the moment tensor (MT) and centroind moment tensor (CMT) solutions have been automatically estimated after determination of an initial hypocenter. However, after the 2011 Off the Pacific coast of Tohoku Earthquake, several limitations have been recognized. So, we improved the AQUA system to solve these problems.

The AQUA system could not determine the MT/CMT solutions of the 2011 Off the Pacific coast of Tohoku Earthquake. This is because NIED F-net broadband seismometers were saturated due to large amplitude excited from this earthquake. Furthremore, size of the initial hypocenter was underestimated at the initial stage of rupture process due to short processing time. On the other hand, numerous aftershocks occurred around the outer rise far from the inland seismographic network. Their initial hypocentral depths have large uncertainties and their MT/CMT solutions were not determined accurately.

To solve these problems, we used records from NIED F-net velocity type strong motion seismograph. These types of seismographs provide unsaturated records not only for the mainshock, but also for M>7 earthquakes at closer stations. In the AQUA system, proper parameters are selected according to event size and MT/CMT analyses are repeated at larger stage when larger size is estimated at some stage. We increased maximum number of this repetition of analysis from 1 to 10. We modified parameters such as search range of centroid time, to analyze M9-class earthquake accurately. We used 0.005-0.02 Hz records for M>8 earthquakes, in contrast to 0.01-0.05 Hz records in the original system. We broadened search range of centroid depth for earthquakes far from the seismographic network to process aftershocks around the outer rise.

After above improvement, we re-analyzed the mainshock with the M5-class initial hypocenter and obtained result with moment magnitude Mw of 8.6 after repetition of analyses at each stage. We also re-analyzed M>7 aftershocks. Comparing these results with GlobalCMT (Global CMT Web Page), focal mechanisms, sizes, and centroid depths show good coincidence. Sizes are consistent with those of GlobalCMT within Mw difference of 0.1 except the mainshock. However, difference is large for the mainshock compared to Mw9.1 of GlobalCMT. This might be because a passband of analysis is not adequate for an M9-class earthquake. So, we used 0.0025-0.01 Hz records and obtained result of Mw8.9. This result shows good coincidence with GlobalCMT (Mw9.1) and other results (e.g., Ozawa et al., 2011; Suzuki et al., 2011; Mw9.0). Further improvement is necessary to shorten analyzing time.

Keywords: Centroid moment tensor, Earthquake Early Warning, the 2011 Off the Pacific coast of Tohoku earthquake, outer rise earthquake