Moment tensor inversion of near source seismograms

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ABSTRACT

We construct a program set for estimating moment tensor solution using near source seismograms. We take the effect of the source time function into account, which have been neglected in predominant program sets of the moment tensor analysis with near source seismograms. In our program set, we approximate the horizontal location of centroid to be epicenter, and then estimate a seismic source duration and depth of centroid in the moment tensor inversion procedure. To evaluate our program set, we applied it to three earthquake: aftershock (M_{JMA} 6.4) of the 2003 Tokachi-oki great earthquake, the 2004 Nemuro-oki earthquake (M_{JMA} 7.1) and its aftershock (M_{JMA} 4.2). The results show that the obtained moment tensor solutions for large earthquake are well consistent with results in other studies. We also found that the neglect of the source time function will results in an underestimation of the seismic moment.

INTRODUCTION

Moment tensor solution is one of most important information of earthquakes. From the moment tensor solutions; we can obtain seismic moment (M_0), moment magnitude (Mw) and faulting type of an earthquakes. The moment tensor solution is also necessary information for investigation of a detailed seismic source process.

The moment tensor solution has been estimated by inversion analysis of seismic waveform observed by local and global seismic networks (e.g. Dziewonski et al., 1981; Kikuchi and Kanamori, 1991; Kawakatsu, 1995). For example, U.S. Geological Survey (USGS) and Global Centroid Moment Tensor Project have estimated the moment tensor solution for earthquake M > 5.5 using global seismic network, and created a catalog of earthquake. The moment tensor information can be downloaded from their web site: USGS web-site (http://earthquake.usgs.gov/earthquakes) and GCMT web-site (http://www.globalcmt.org). Using local seismic network, many institute estimated moment tensor solution for earthquake M > 3 and a created catalog of earthquake (e.g. Dreger and Helmberger, 1993; Pasyanos et al. 1996). In Japan, the National Institute of Earth Disaster Prevention (NIED) has estimated the moment tensor solution using a broadband seismic observation network (F-net) since 1997 (Fukuyama et al., 1998).

Since the occurrence rate of middle-size earthquake is higher than that of large-size earthquake, it is important to estimate moment tensor solution of middle-size earthquake for understanding stress field and faulting system in local regions. So far, a broadband seismic network have been established in developing countries, we can estimate moment tenser solutions for earthquakes M > 3.5 in the developing countries and construct a catalog of moment tensor solution. The program set of moment tensor inversion and its lecture become important for seismologist in the developing countries.

In general, the effect of source time function has been neglected in predominant program sets of the moment tensor inversion with near source seismograms, for simplicity (e.g. Dreger and Helmberger, 1993; Ito et al., 2006). The neglect of the effect of seismic source duration should result in an underestimation of the seismic moment. In this study, we constructed a formulation to estimate moment tensor solution based on a point source model and a simple source time function, and then we applied it to local seismic data for evaluating our program set. Through application of new program set, we confirmed that the seismic moment is underestimated if we neglect the effect of the source duration. Our program set is introduced in lecture provided by International Institute of Seismology and Earthquake Engineering, Building Research Institute.

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METHODOLOGY

In general, observed seismic waveform of c component at a station j due to seismic moment release in a source volume V is given by

$$u_{cj}(t)=\sum_{q=1}^{6}\iiint_{v}\tilde{G}_{cjq}(t,\boldsymbol{\xi})*\tilde{M}_q(t,\boldsymbol{\xi})d\boldsymbol{\xi}+e'_{cj}(t), \tag{1}$$

where $\tilde{G}$ is the Green's function of basis moment tensor (Kikuchi and Kanamori, 1991), $\tilde{M}$ is a spatio-temporal moment release function, and e' is observed error. Since the volume change during earthquake is too small to detect, we can neglect volume change component $\tilde{M}_6$. To estimate stable moment tensor solution, we should assume a simple source model such as the point source model, in which we assume the seismic waveform to be radiated from one point. Following the point source model, we rewrite eq. (1) as

$$u_{cj}(t)=\sum_{q=1}^{5}\tilde{G}_{cjq}(t,\boldsymbol{\xi}_c)*M_q(t)+e_{cj}(t), \tag{2}$$

with

$$M_q(t)=\iiint_{V}\tilde{M}_q(t,\boldsymbol{\xi})d\boldsymbol{\xi}. \tag{3}$$

Where $\boldsymbol{\xi}_c$ is the location of the centroid, and e contains observed and modeling error. We assumed that the focal mechanism is kept constant during earthquake, and approximated the shape of the source time function to be an isosceles triangle with half duration of t_r. Based on the assumption of the constant focal mechanism and the simple source time function, we can rewrite eq. (2) as

$$u_{cj}(t)=\sum_{q=1}^{5}m_q\times G_{cjq}(t,t_r,\boldsymbol{\xi}_c)+e_{cj}(t), \tag{4}$$

with

$$G_{cjq}(t,t_r,\boldsymbol{\xi}_c)=\tilde{G}_{cjq}(t,\boldsymbol{\xi}_c)*T(t,t_r). \tag{5}$$

In general, we apply low-pass filter to observed data for mitigating the aliasing effect in re-sampling procedure, the effect of the complicated seismic source process and the effect of the heterogeneity of the local velocity structure. Therefore, relationship between the observed seismic waveform and data waveform is represented by

$$d_{cj}(t)=B(t)*u_{cj}(t). \tag{6}$$

where, B is the function of the low-pass filter. Substituting eq. (4) into (6), and then we rewrite in the following simple vector form:

$$\mathbf{d}=\mathbf{A}(t_r,\boldsymbol{\xi}_c)\mathbf{m}+\mathbf{e} \tag{7}$$

where $\mathbf{d}$ and $\mathbf{e}$ are N-dimensional data and error vectors, respectively; $\mathbf{m}$ is a 5-dimensional model

parameter vector; **A** is a N x 5 coefficient matrix. The solution of the above matrix equation is obtained by least square approach if we assume the duration of the source time function t_r and the centroid location $\boldsymbol{\xi}_c$. In the study, we assumed that horizontal location of centroid can be approximated to the epicenter, and estimated optimal depth of the centroid and half duration using the grid-search method, which minimizes normalized L2-norm as $\left\|\mathbf{d}-\mathbf{A}\left(t_r,\boldsymbol{\xi}_0\right)\mathbf{m}\right\| / \left\|\mathbf{d}\right\|$.

APPLICATION

We performed a moment tensor inversion of one large earthquake and two medium earthquakes for examining the validity of our program set.

Data and the Green's Function

Fig. 1 shows the epicenters of three earthquakes and locations of stations, which are used in this study. Two aftershocks of the 2003 Tokachi-oki great earthquake were selected for the evaluation of our program set. We retrieved near source data observed by broadband seismograph F-NET station, NIED. 9 components at 3 stations were used to estimate moment tensor solution. The observed raw data were corrected for seismometer responses and converted to ground velocity motion. The data was filtered in the bandpass to mitigate the effect of the heterogeneity of the local velocity structure, and re-sampled with 1 Hz. Following the NIED moment tensor analysis (Fukuyama et al., 1998), we selected filtering range 20 – 100 sec for event A and B, and 20 – 50 sec for event C. We did not integrate observed waveform to avoid the increase of off-diagram of the data covariance components (Yagi and Fukahata, 2008). Green's function was calculated by the discrete wave number method developed by Kohketsu (1985) with the simple J-B structure.

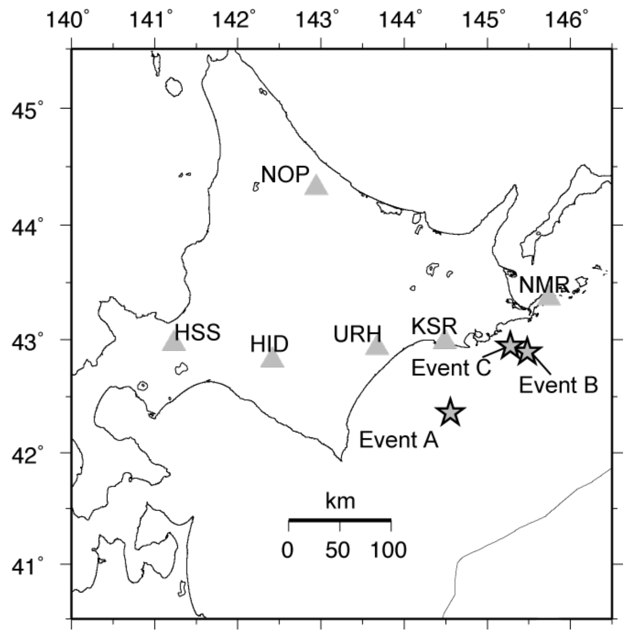

Fig. 1 Location map of F-net broadband stations and earthquakes used in our analysis. The triangles and the star represent the location of stations and the epicenter, respectively.

Results

Now, we apply our program to an aftershock (M_{JMA} 7.1; origin time: 29 Sep 2003 11:37 JST) of the 2003 Tokachi-oki great earthquake, the 2004 Nemuro-oki earthquake (M_{JMA} 7.1; origin time: 29 Nov

2004 03:32 JST) and its aftershock (M_{JMA} 4.2; origin time: 30 Nov 2004 13:02 JST), which are labeled event A, B and C, respectively. We approximate the horizontal location of centroid to be the epicenter determined by Japan Meteorological Agency (JMA). Figure 2 shows the focal mechanism and the comparison between the observed waveform (black line) and the synthetic waveform (red line) for each event. As can be seen from the focal mechanism, three earthquakes are typical thrust earthquakes along plate boundary. The estimated focal mechanisms, depths and seismic moments of three events are consistent with the F-NET MT solution.

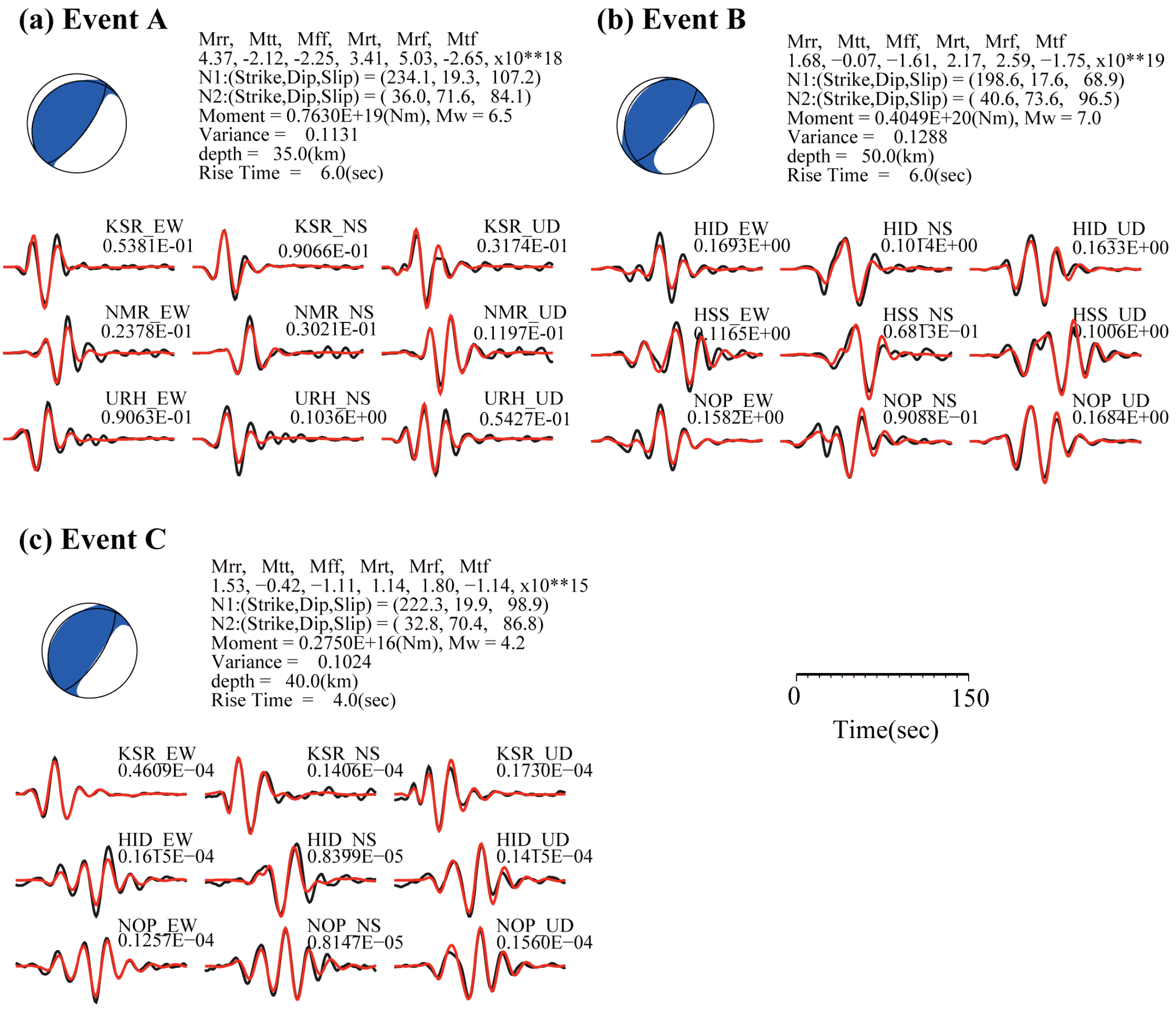

Fig. 2 Results of moment tensor inversion for the event A (a), the event B (b) and the event C (c). For each case, the focal mechanism (top left-hand graph), the information of source parameters (top right-hand graph), and observed and synthetic waveforms (black lines and red lines, respectively; bottom graph) are shown. The numbers bellow the station code indicate the maximum amplitude (in unit of cm/sec).

Table 1 shows the depth of centroid, the seismic moment, the half duration of source time function, and the normalized L2 norm for each event with our formulation and a conventional formulation that neglects the effect of source time function. As can be seen from values of the normalized L2 norm in table 1, the waveform fitting is improved by our formulation. It should be noted that the seismic moment estimated by our formulation is always larger than that estimated by the conventional formulation. This gap should increase with the seismic moment. This result shows that the neglect of source time function is inappropriate assumption for analysis of large earthquake, because the duration

of the source time function increased with the seismic moment. In fact, moment magnitude (*Mw*) of the 2003 Tokachi-oki earthquake estimated by NIED (Ito et al., 2004) is 7.9, which is meaningfully smaller than *Mw* 8.1 estimated by seismic source analysis (e.g. Yagi, 2004).

Table 1 Comparison between the source parameters obtained by our formulation and the conventional formulation.

(a) Event A

	Seismic moment (Nm)	Depth (km)	Half duration (sec)	Normalized L2 norm
Our formulation	7.63×10^{18}	35	6.0	0.113
Conventional formulation	5.54×10^{18}	35	N/A	0.140

(b) Event B

	Seismic moment (Nm)	Depth (km)	Half duration (sec)	Normalized L2 norm
Our formulation	4.05×10^{19}	50	6.0	0.129
Conventional formulation	3.18×10^{19}	50	N/A	0.139

(c) Event C

	Seismic moment (Nm)	Depth (km)	Half duration (sec)	Normalized L2 norm
Our formulation	2.75×10^{15}	40	4.0	0.102
Conventional formulation	2.46×10^{15}	40	N/A	0.104

CONCLUSIONS

We construct a program set for estimating moment tensor solution using near source seismograms, which will be introduced in the lecture provided by International Institute of Seismology and Earthquake Engineering, Building Research Institute. We applied our program set to real data, and confirmed that the obtained moment tensor solutions for large earthquakes are well consistent with results with the F-NET MT solution. We found that the neglect of the effect of seismic source duration will result in an underestimation of the seismic moment, since the neglect of source time function is inappropriate assumption for analysis of large earthquake

ACKNOWLEDGMENT

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