Focal Mechanism Solutions of Earthquakes in the Kanto Region during 2008-2015 Obtained from Highly Dense Seismic Array

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A highly dense seismic array observation network in and around Tokyo, called MeSO-net (Kasahara *et al.*, 2009; Sakai and Hirata, 2009), has been constructed and maintained. We determined 2,786 focal mechanism solutions of earthquakes in the Kanto region from April 1st, 2008 to February 9th, 2015 by using first-motion polarities observed by the MeSO-net, and compiled them as the MeSO-net First-Motion Focal Mechanism catalog (MeSO-FM^2) (Fig.). This catalog includes reliable and accurate focal mechanism solutions for small-magnitude ($M \geq 1.9$) earthquakes which are not determined by other networks. The quality of focal mechanism solutions is generally better for earthquakes which occurred near the center of network and worse for earthquakes near the edge or outside the network. MeSO-FM^2 will be useful in investigating temporal changes following the occurrence of the 2011 Tohoku-Oki earthquake in detail, as well as spatial and temporal heterogeneity of stress fields in this region. Following the 2011 Tohoku-Oki earthquake, in the shallow depths, strike-slip and normal fault types with the T-axes striking roughly NE-SW or E-W directions have been increased. On the other hand, thrust-faulting earthquakes, which can be correlated with subductions of two oceanic plates beneath the Tokyo Metropolitan area, were typically activated in the intermediate depths.

We compared the focal mechanism solutions obtained in this study and those from JMA, for 862 pairs of earthquakes considered to be identical based on hypocenter information (i.e., origin time, longitude, latitude, depth, and magnitude). MeSO-net focal mechanism solutions basically showed good agreement with those provided by JMA, while some show significant discrepancies. In order to quantify the similarity between the focal mechanism solutions determined in this study and those from JMA, we used the Kagan angles, a three-dimensional rotation angle by which one double-couple earthquake source can be rotated into another arbitrary double-couple earthquake source (Kagan, 1991). The average and median Kagan angles between MeSO-FM^2 and JMA were 21.2°and 17.3°, respectively.

We first determined the hypocenters by using HYPOMH (Hirata and Matsu’ura, 1987) with the seismic velocity structure which is routinely used by the Earthquake Research Institute, the University of Tokyo. Then, we determined the focal mechanism solutions by using the first-motion polarities and a modified algorithm of HASH v.1.2 (Hardebeck and Shearer, 2002), a method of determining focal mechanisms taking into consideration possible errors in hypocenters, seismic velocity structures, and reported polarities. We omitted earthquakes with the ≤8 reported polarities from the analyses because the reliability and stability are considered to be low. We conducted grid searches for strike, dip, and rake angles at 2° intervals. The quality of focal mechanism solutions were classified as A, B, C, or D considering various criteria (see Hardebeck and Shearer, 2002 for the definition of qualities), and excluded the D quality events from the catalog.

The catalog can be also utilized to investigate plausible fault models generating strong ground motions and tsunamis in the Tokyo Metropolitan area. Precise determinations of both hypocenters and focal mechanism solutions of earthquakes from dense array are also important to evaluate the thickness of seismogenic zones and possible source regions of semi-historical earthquakes using recently-developed template matching technique (Ishibe *et al.*, 2015).

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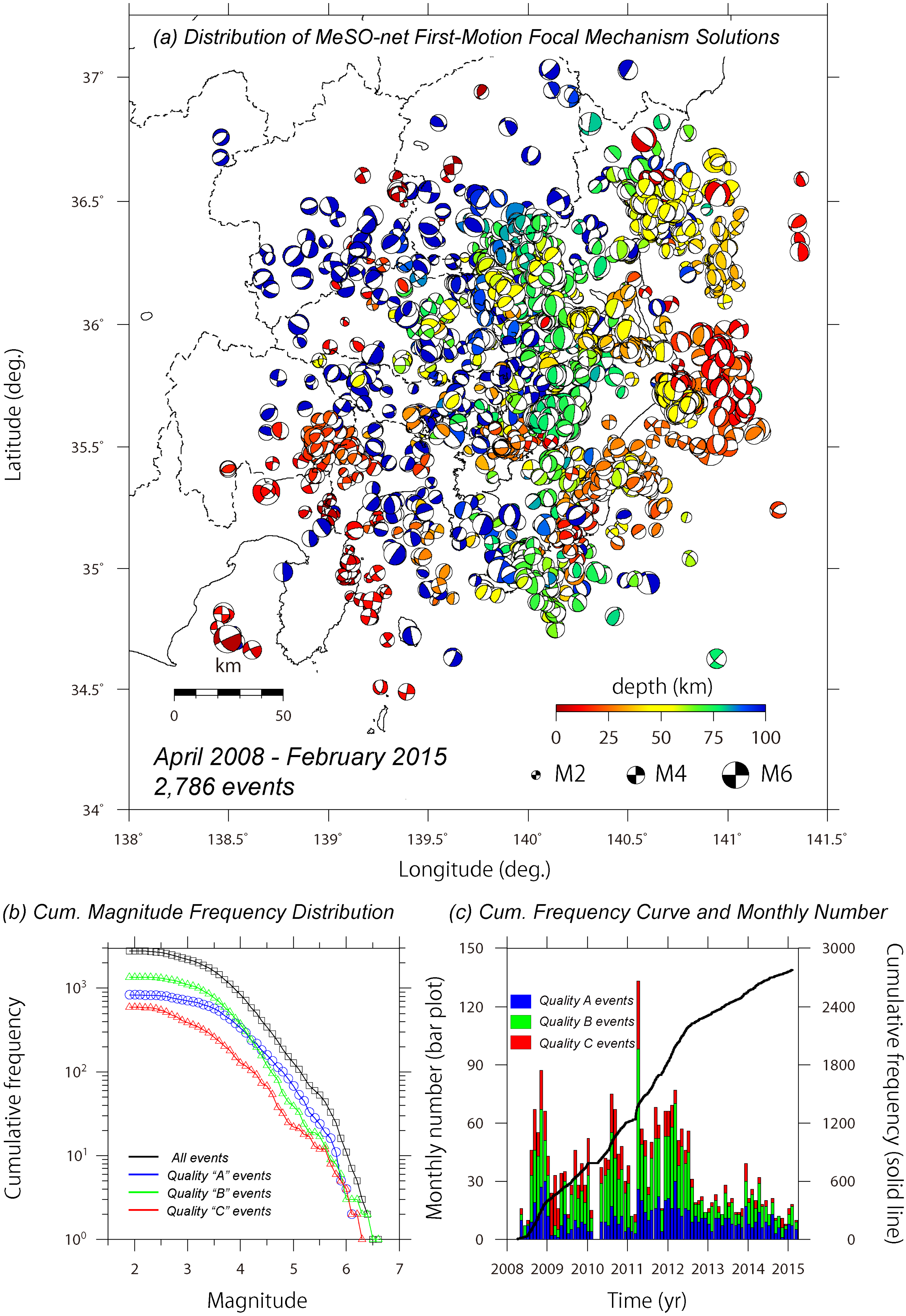
Keywords: Focal mechanism solution, Metropolitan Seismic Observation Network (MeSO-net)


(a) Distribution of MeSO-net First-Motion Focal Mechanism Solutions
Latitude (deg.)
37°
36.5°
36°
35.5°
35°
34.5°
34°
138°
138.5°
139°
139.5°
140°
140.5°
141°
141.5°
Longitude (deg.)
km
0
50
depth (km)
0
25
50
75
100
M2
M4
M6
April 2008 - February 2015
2,786 events
(b) Cum. Magnitude Frequency Distribution
Cumulative frequency
Magnitude
All events
Quality "A" events
Quality "B" events
Quality "C" events
(c) Cum. Frequency Curve and Monthly Number
Monthly number (bar plot)
Cumulative frequency (solid line)
Time (yr)
Quality A events
Quality B events
Quality C events
2008
2009
2010
2011
2012
2013
2014
2015

Seismic wave field imaging based on the replica exchange Monte Carlo

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Earthquakes sometimes cause serious disasters not only directly by ground motion itself but also secondarily by damage of infrastructures, especially in the case of metropolitan areas that have numerous populations and capital functions in the country. For reducing such the secondary disasters, it is potent to evaluate seismic hazards rapidly by analyzing seismic response of each structure due to ground motion input from the bottom. In this study, we propose a methodology that consists of physics-based and data-driven approaches, in order to obtain seismic wave field as an input for seismic response analysis of structures. One of the Markov chain Monte Carlo (MCMC) methods, the replica exchange Monte Carlo, is adopted for the estimation of seismic wave field together with local crustal structure. Two numerical tests are conducted to examine the feasibility of the proposed method using the analytical solution with a horizontally layered crustal structure. The geometry of observation sites is referred to dense seismological network, Metropolitan seismic observation network (MeSO-net). It is confirmed that 1) the proposed method is possible to search the parameters related to the local crustal structure in broader space compared to a fundamental MCMC method, Metropolis method and 2) the seismic wave field estimated by the proposed method is almost coincident with the true wave field even if the local crustal structures are not so well estimated around the assumed values. On the other hand, the wave field estimated by the ordinary kriging, a classical interpolation method for spatial data, is hardly possible to reproduce the wave propagation and is much different from the true one even in low frequencies. This indicates that the proposed combined method taking both physics-based and data-driven approaches into consideration is essential for the seismic wave field imaging utilizing a dense observation network like MeSO-net. Acknowledgments: This research is supported by the Special project for reducing vulnerability for urban mega earthquake disasters from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

Keywords: MCMC, MeSO-net, seismic wave field, earthquake ground motion

Three-dimensional earthquake forecasting model for the Kanto district: Progress reports of prospective tests for 3-month forecasting

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We constructed a 3-dimensional (3D) earthquake forecasting model for the Kanto district in Japan under the Special Project for Reducing Vulnerability for Urban Mega Earthquake Disasters. Because seismicity in this area ranges from 0 to 80 km in depth due to subducting Philippine-Sea and Pacific plates, we need to study the effect of earthquake depth distribution. We constructed a prototype of 3D earthquake forecasting model (3D-RI model) for the area based on the Relative Intensity (RI) model (Nanjo, 2011 [EPS, 63 (3) 261-274]) which forecasts earthquake probabilities using historical data. Parameters of the 3D-RI model were optimized for past seismicity of the area by retrospective tests. Next, the model also was applied to prospective test which was already implemented with 3 rounds for the 3-month forecasting class. Forecasting period in the 1st round was started from 1 February in 2015. Expectations of the models were calculated using past events at the following time periods: Period 1) From 1 January 1998 to 1 January 2011: before the 2011 Tohoku earthquake, Period 2) From 1 January 1998 to a day before the forecasting period: before and after the 2011 Tohoku earthquake, and Period 3) From 1 January 2012 to a day before the forecasting period: after the 2011 Tohoku earthquake. These models were evaluated by a statistical method based on the Collaboratory for the Study of Earthquake Predictability (CSEP) experiments. Number of earthquakes during all of the rounds were observed within the average ±2σof that before the 2011 Tohoku earthquake. Also, observed earthquakes located around off Choshi at the depth of 10 –50 km due to aftershocks of the Tohoku earthquake. Results of the evaluations for the all rounds are summarized as follows; the 3D-RI model based on the Period 1) underestimated number of earthquakes and also showed the lowest log-likelihoods in the space test in all models because the model could not consider seismicity of the aftershocks. This result suggests that the data from Period 1) is insufficient to predict the current seismicity. The model based on the data of Period 2) showed the best forecasts for number of earthquakes and spatial distributions. The model based on the Period 3) failed to the number test of the CSEP tests due to overestimations. After these experiments, we tried to reconsider number of earthquakes using the Omori-Utsu law and the 3D-RI model based on novel periods from 1 January 2013 to a day before the forecasting period to improve forecasting performance retrospectively. Both estimations showed the better prediction than that of the 3D-RI models based on Period 2) .
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Keywords: Three-dimensional forecasting model, Kanto district, Prospective forecasting, Collaboratory for the Study of Earthquake Predictability

