稠密地震観測網に基づく関東地方における地震の発震機構解（2008年-2015年）

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

*石辺 岳男[1]、中川 茂樹[1]、酒井 慎一[1]、鶴岡 弘[1]、平田 直[1]、村岸 純[1]、佐竹 健治[1]
*Takeo Ishibe[1], Shigeki Nakagawa[1], Shin'ichi Sakai[1], Hiroshi Tsuruoka[1], Naoshi Hirata[1], Jun Muragishi[1], Kenji Satake[1]

1.東京大学地震研究所
1.Earthquake Research Institute, Univ. of Tokyo

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≧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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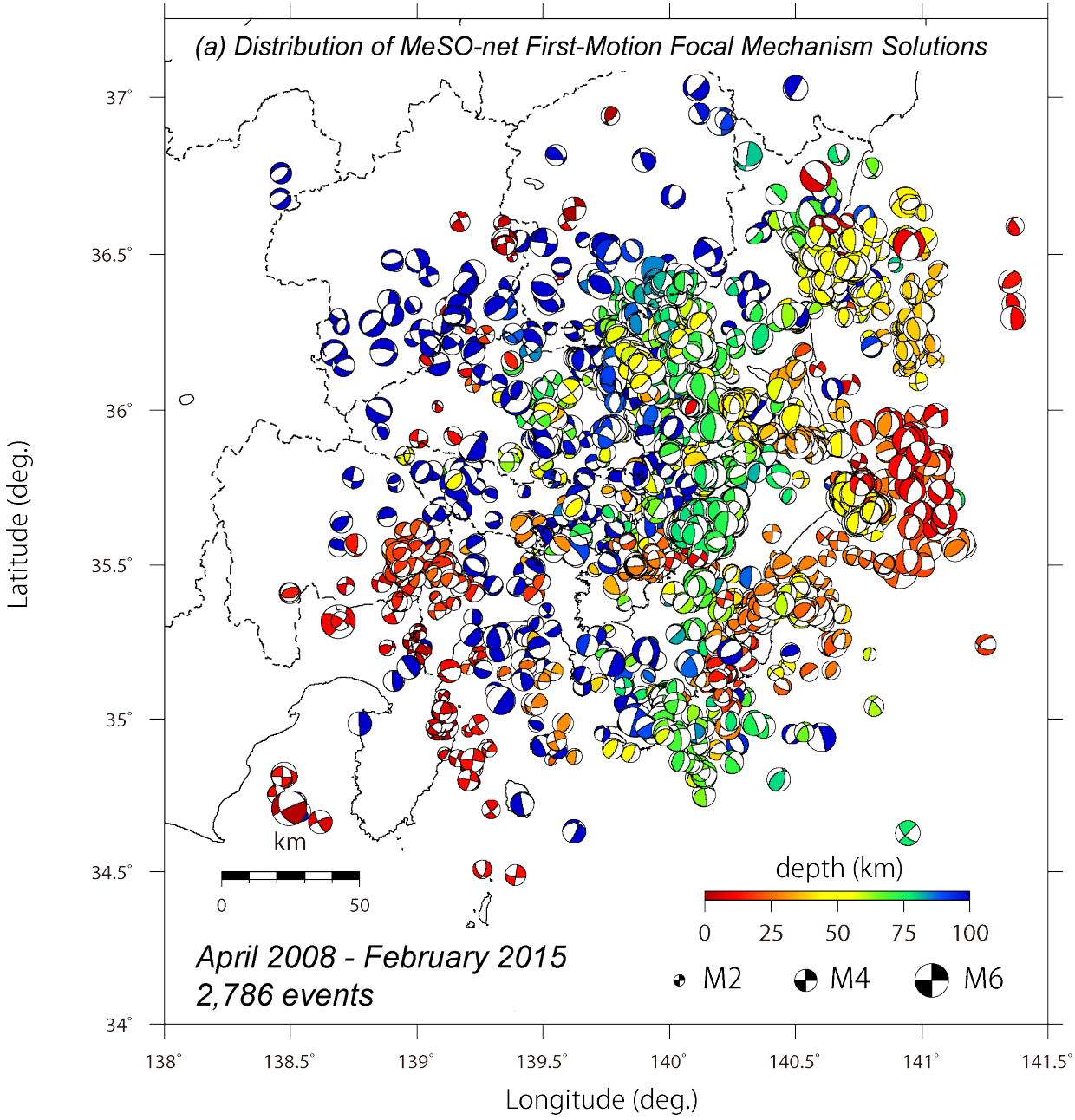
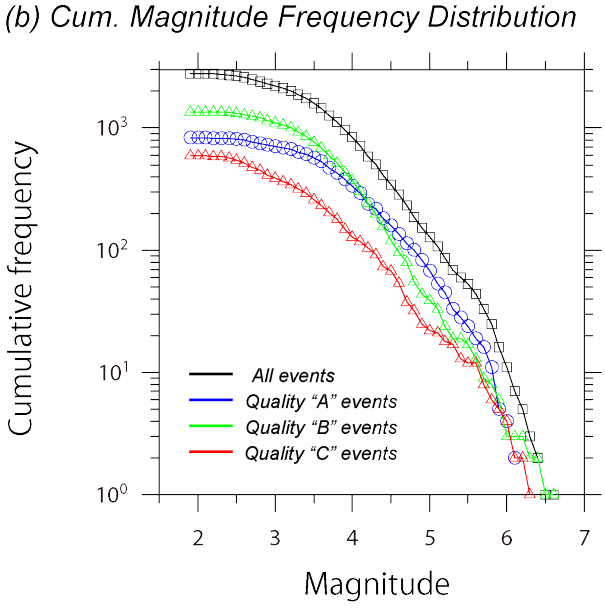
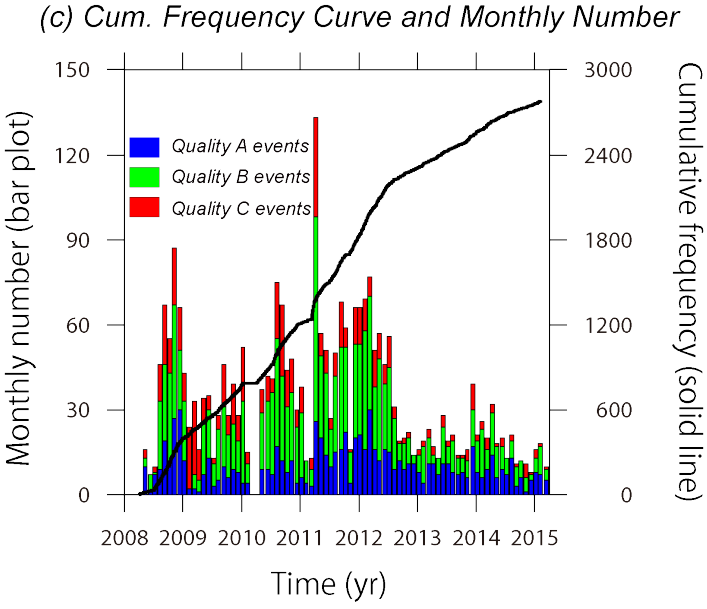
キーワード：Focal mechanism solution、Metropolitan Seismic Observation Network (MeSO-net)
Keywords: Focal mechanism solution, Metropolitan Seismic Observation Network (MeSO-net)







レプリカ交換モンテカルロ法を用いた首都圏地震動イメージング
Seismic wave field imaging based on the replica exchange Monte Carlo

*加納 将行[1]、長尾 大道[1,2]、石川 大智[2]、酒井 慎一[1]、中川 茂樹[1]、堀 宗朗[1]、平田 直[1]
*Masayuki Kano[1], Hiromichi Nagao[1,2], Daichi Ishikawa[2], Shin'ichi Sakai[1], Shigeki Nakagawa[1], Muneo Hori[1], Naoshi Hirata[1]

1.東京大学地震研究所、2.東京大学情報理工学系研究科
1.Earthquake Research Institute, the University of Tokyo, 2.Graduate School of Information Science and Technology, the University of Tokyo

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.

キーワード：マルコフ連鎖モンテカルロ法、MeSO-net、波動場、地震動
Keywords: MCMC, MeSO-net, seismic wave field, earthquake ground motion

首都圏の地震発生予測モデルの構築に向けて：プロスペクティブテスト3ヶ月予測の経過報告

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

*横井 佐代子[1]、鶴岡 弘[1]、平田 直[1]
*Sayoko Yokoi[1], Hiroshi Tsuruoka[1], Naoshi Hirata[1]

1.東京大学地震研究所
1.Earthquake Research Institute, The University of Tokyo

関東地方は本州弧の地殻内からフィリピン海スラブ、太平洋スラブに関連した浅発および稍深発地震の活動が活発であり、地震発生頻度の高い「深さ」が存在する。そこで私達は、地震活動の評価に基づく地震発生予測検証実験の「関東領域」と比較可能な予測領域で発生する地震の経度・緯度・深さを精度よく予測する三次元地震発生予測モデルを構築することを目的として2012年から研究を開始した。Relative Intensityモデル（以下、RIモデルとする。Nanjo, 2011 [EPS, 63 (3) 261-274]）を三次元地震発生予測モデルの土台とし、名前を3D-RIモデルとした。レトロスペクティブテスト（遡及的予測実験）によって3D-RIモデルのパラメータを2011年東北地方太平洋沖地震前の地震活動に最適化した。次に、3D-RIモデルが2015年2月以降の地震をどの程度予測できるかを評価するために2015年2月1日からプロスペクティブテスト（事前予測実験）を開始した。予測実験の予測対象は、3ヶ月間のM 4.0以上の地震とした。学習条件は、M 2.5以上、平滑化半径は7.5、10、20、50 kmとし、期間は以下の3種とした。期間1）1998年1月1日－2011年1月1日：2011年東北地方太平洋沖地震前の気象庁一元化地震カタログの確定値。期間2）1998年1月1日－予測期間の前の日：2011年東北地方太平洋沖地震前と後の気象庁一元化地震カタログ。期間3）2012年1月1日－予測期間の前の日：2011年東北地方太平洋沖地震後の気象庁一元化地震カタログ。予測は、予測期間終了後に『地震活動の評価に基づく地震発生予測検証実験』（三次元地震発生予測モデル用に改良したもの）と同様の方法で評価した。3回分の予測実験の期間中の地震活動度は、地震数は2011年東北地方太平洋沖地震の前の平均±2σ程度に、空間分布は、銚子沖深さ10 –50 kmの領域で2011年東北沖地震の余震が観測された。検証の結果、期間1)を学習した3D-RIモデルは、地震数を過小評価した。同時に、東北沖地震の余震を学習できなかったために空間予測は3つの期間の中で1番悪くなった。この結果から、期間1)を学習した3D-RIモデルは現在の首都圏の地震活動を予測するには力不足であることが示された。また、期間2)を学習した3D-RIモデルは、3つの期間を学習したモデルの中で地震数、空間分布の予測共に1番良い成績を示した。期間3)を学習した3D-RIモデルは、空間分布の予測は2番目に良かったが、地震数をいつも過大評価し数のテストで棄却された。地震数の予測について、大森宇津則と3D-RIモデルで学習期間（期間4）2013年8月1日から予測期間の前日までにする）を変える方法でさらに良くなるか検討したところ、3D-RIモデルの期間2)より改善したので、今後の予測実験でさらに検証を進めモデルの高度化につなげる。
本研究において、気象庁地震カタログを使用しました。記して感謝します。なお本研究は文部科学省受託研究「都市の脆弱性が引き起こす激甚災害の軽減化プロジェクト」の一環として行われています。

キーワード：三次元地震発生予測モデル、関東地方、プロスペクティブテスト、地震活動の評価に基づく地震発生予測検証実験
Keywords: Three-dimensional forecasting model, Kanto district, Prospective forecasting, Collaboratory for the Study of Earthquake Predictability

