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Centroid moment tensor inversions of offshore earthquakes using a three-dimensional velocity structure model: Slip distributions on the plate boundary along the Nankai Trough

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Running Title

3D CMT inversion along the Nankai Trough

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Summary

Due to complex three-dimensional (3D) heterogeneous structures, conventional one-dimensional (1D) analysis techniques using onshore seismograms can yield incorrect estimation of earthquake source parameters, especially dip angles and centroid depths of offshore earthquakes. Combining long-term onshore seismic observations and numerical simulations of seismic wave propagation in a 3D model, we conducted centroid moment tensor (CMT) inversions of earthquakes along the Nankai Trough between April 2004 and August 2019 to evaluate decade-scale seismicity. Green's functions for CMT inversions of earthquakes with moment magnitudes of 4.3–6.5 were evaluated using finite-difference method simulations of seismic wave propagation in the regional 3D velocity structure model. Significant differences of focal mechanisms and centroid depths between previous 1D and our 3D catalogues were found in the solutions of offshore earthquakes. By introducing the 3D structures of the low-velocity accretionary prism and the Philippine Sea Plate, dip angles and centroid depths for offshore earthquakes were well-constrained. Teleseismic CMT also provides robust solutions but our regional 3D CMT could provide better constraints of dip angles. Our 3D CMT catalogue and published slow earthquake catalogues depicted spatial distributions of slip behaviours on the plate boundary along the Nankai Trough. The regular and slow interplate earthquakes were separately distributed, with these distributions reflecting the heterogeneous distribution of effective strengths along the Nankai Trough plate boundary. By comparing the spatial distribution of seismic slip on the plate boundary with the slip-deficit rate distribution, regions with strong coupling were clearly identified.

Keywords:

Computational seismology, earthquake ground motions, earthquake source observations, seismicity and tectonics, wave propagation

1. Introduction

Focal mechanisms of earthquakes and their spatial distributions are important for evaluating tectonic/local stress and strain fields (e.g. Saito *et al.* 2018, Terakawa & Matsu'ura 2010, Townend & Zoback 2006). To determine focal mechanisms, first-*P* or *S* polarisation inversion (e.g. Hardebeck & Shearer 2002, Shelly *et al.* 2016) and waveform-based centroid moment tensor (CMT) inversion (e.g. Dziewonski *et al.* 1981, Ekström *et al.* 2012, Kanamori & Rivera 2008) techniques have been widely used around the world. One-dimensional (1D) Earth models are assumed in typical focal mechanism determination methods. In regions with complex three-dimensional (3D) heterogeneous structures, first-motion solutions using the 1D Earth model systematically show mis-estimations (e.g. Takemura *et al.* 2016). Although CMT methods based on long-period (> 10 s) waveforms can be applied only for moderate-to-large earthquakes due to signal-to-noise problems for long-period components, their evaluations of source parameters are generally robust against structural heterogeneities in comparison to first-motion solutions.

Along the Nankai Trough, megathrust earthquakes have repeatedly occurred at intervals of 100–150 years (e.g. Ando 1975). Evaluating seismicity around this region is important for contributing to the understanding of megathrust earthquakes, such as evaluating stress accumulation/release processes on plate boundaries. In Japan, regular and slow earthquakes have been systematically monitored by the seismic networks of the Monitoring of Waves on Land and Seafloor (MOWLAS; https://doi.org/10.17598/NIED.0009) operated by the National Research Institute for Earth Science and Disaster Resilience (NIED; Okada *et al.* 2004). According to the combined earthquake catalogues of the International Seismological Centre-Global Earthquake Model (ISC-GEM; Storchak *et al.* 2013), the Japan Meteorological Agency (JMA), and the NIED F-net (Fukuyama *et al.* 1998, Kubo *et al.* 2002), the seismicity of regular earthquakes along the Nankai Trough, especially interplate earthquakes, is quite low. Figure 1 shows the spatial distribution of regular earthquakes with moment magnitudes (*Mw*) of 4.3–6.5 that occurred from April 2004 to August 2019, as listed in the F-net moment tensor (F-net MT) catalogue. The regional moment tensor inversion can be applied to earthquakes with *Mw* > about 4, which is smaller than a lower limit of teleseismic moment tensor inversion (e.g., Figure 5 of Ekström *et al.* 2012). This is an advantage for discussing detail seismicity in a certain region. A few shallow offshore earthquakes occurred in the Tonankai and Nankai regions and their focal mechanisms in the F-net catalogue were not characterised by low-angle thrust faulting. In other words, no earthquakes suggesting faulting on the plate boundary around the Tonankai and Nankai regions are listed in the F-net MT catalogue.

On 1 April 2016, the *Mw* 5.8 earthquake, called “2016 southeast off the Kii Peninsula earthquake”, occurred in the Tonankai region (marked A in Figure 1). The F-net MT solution of this earthquake was characterised by high-angle (38°) reverse faulting below the upper surface of the Philippine Sea Plate, indicating it was an intraslab earthquake. However, a detailed analysis of this earthquake revealed that it could be modelled by low-angle thrust faulting at a depth of approximately 10 km, suggesting seismic slip along the plate boundary (e.g. Nakano *et al.* 2018a, Takemura *et al.* 2018a, Wallace *et al.* 2016). Source models suggested in these studies were also consistent with a model based on observed tsunami data (Kubota *et al.* 2018). In regions with a thick accretionary prism, characteristics of surface wave propagation are significantly affected by a low-velocity accretionary prism (e.g. Gomberg 2018, Kaneko *et al.* 2019, Shapiro *et al.* 1998). Thus, the focal mechanisms of other offshore earthquakes along the Nankai Trough could be incorrectly estimated using conventional 1D regional MT inversion, even for long-period displacements. Indeed, shallow very low frequency earthquakes along the Nankai Trough have been interpreted as low-angle thrust faulting on the plate boundary by using offshore seismic observations (e.g. Nakano *et al.* 2018b), but their focal mechanisms based on 1D analysis of onshore observations were high-angle reverse faulting mechanisms within the accretionary prism (e.g., Ito & Obara 2006). To evaluate seismic activity along the Nankai Trough more precisely, offshore earthquakes listed in the previous 1D catalogues require re-analysis.

Parallel simulation codes of seismic wave propagation (e.g. Gokhberg & Fichtner 2016, Maeda *et al.* 2017) and 3D seismic velocity structure models (e.g. Eberhart-Phillips *et al.* 2010, Koketsu *et al.* 2012) enable the simulation of Green’s functions propagating through realistic 3D Earth models (hereafter called ‘3D Green’s functions’), which have been used to develop CMT inversions (e.g. Hejrani *et al.* 2017, Lee *et al.* 2013, Okamoto *et al.* 2018, Ramos-Martínez & McMechan 2001, Takemura, *et al.* 2018ab, 2019, Wang & Zhan 2020). Although the resolution of detailed source characteristics for offshore earthquakes derived using the 3D CMT method and onshore seismograms is limited compared to those using offshore observations, these methods provide similar focal mechanisms and centroid locations (see Figure 2 of Takemura *et al.* 2018b). Thus, offshore seismic activity, including earthquakes before offshore seismic observations, can be effectively evaluated.

To investigate the decade-scale seismicity of offshore earthquakes along the Nankai

Trough, we re-evaluated focal mechanisms based on CMT inversion using 3D Green's function datasets, which were evaluated by numerical simulations of seismic wave propagation in a regional 3D velocity structure model. Then, to investigate spatial variation in slip behaviours on the plate boundary along the Nankai Trough, we compared the spatial distribution of focal mechanisms based on the 3D CMT technique with the spatial distribution of slip-deficit rates (Noda *et al.* 2018), slow slip events (SSEs; Kobayashi 2014, Miyazaki *et al.* 2006, Nishimura *et al.* 2013, Takagi *et al.* 2016, 2019, Yokota & Ishikawa 2020), shallow low-frequency tremors (LFTs; Yamashita *et al.* 2015), shallow very low-frequency earthquakes (VLFEs; Takemura *et al.* 2019b), and the 1968 Hyuga-nada earthquake (Yagi *et al.* 1998).

2. Data and Methods

We used three-component (NS, EW, and UD) velocity seismograms from F-net (NIED 2019), for which the performance of the sensors have been systematically monitored (Kimura *et al.* 2015). To conduct CMT inversion of the target earthquakes, we applied a band-pass filter with passed periods of 25–100 s. We selected a 25–100 s period band because ground motions for periods of 8–20 s are significantly affected by internal structures of the accretionary prism along the Nankai Trough (e.g. Takemura *et al.* 2019a). The selected period band is enough longer than corner periods of source spectra for target earthquakes. In our CMT inversions, we used 10-min F-net velocity seismograms from three minutes before the initial origin minute to conduct pre-processing (filter and integration) stably. We obtained displacement waveforms by calculating time integration of each filtered velocity record. The target earthquakes occurred within the region of assumed source grids (grey crosses in Figure 2) between April 2004 and August 2019, and values of *Mw* in the F-net catalogue ranging from 4.3 to 6.5. According to the signal-to-noise ratios for the target period band, the magnitude range of the analysed earthquake was determined by trial and error. Source grids were uniformly distributed at horizontal intervals of 0.1°. Depths of source grids ranged from 6 to 50 km at an interval of 2 km. The total number of source grids was 61,433.

Green's functions were evaluated by solving equations of motion in the 3D viscoelastic medium model based on the finite-difference method (FDM) simulations. The 3D simulation model covered an area of $900 \times 1{,}000 \times 100$ km^3, which was discretised by grid intervals of 0.5 km in the horizontal direction and 0.2 km in the vertical direction. We used a parallel simulation code of OpenSWPC (Maeda *et al.* 2017), which includes the reciprocal calculation mode for effectively evaluating Green's functions. The reciprocal calculation has proved very useful in the case that the number of seismic source grids is significantly larger than the number of seismic stations (e.g. Eisner & Clayton 2001, Hejrani *et al.* 2017, Okamoto *et al.* 2018). We obtained a total of approximately 35,000,000 Green's function SAC files from 61,433 source grids to 32 F-net stations (black and blue filled triangles in Figure 2) via 96 reciprocal FDM calculations. The source time function of each Green's function was the Küpper wavelet with a duration of 1 s.

The 3D velocity model of Koketsu *et al.* (2012) was used, as it has been widely applied in studies of seismic ground motions across Japan. The configurations of the subducting oceanic plate and the Moho discontinuity are consistent with other models (e.g., Hirose *et al.* 2008, Shiomi *et al.* 2006). The oceanic crust of the model of Koketsu *et al.* (2012) has approximately 7 km thickness, which correspond to those by seismic surveys (e.g., Nakanishi *et al.* 2002). The topography model in our simulations was the ETOPO1 model (Amante & Eakins 2009). The *P*- and *S*-wave velocities and density (V_P, V_S and ρ) in the seawater layer were 1.5 km/s, 0.0 km/s and 1.04 g/cm^3, respectively. The air column was modelled as a vacuum with V_P of 0.0 km/s, V_S of 0.0 km/s and ρ of 0.001 g/cm^3. The minimum V_S in the solid column of 1.5 km/s was assumed. The accretionary prism is important for constraining centroid depth but detail velocity structure within the accretionary prism has limited effects on long-period (> 20 s) seismograms (Figures 5 and 6 of Takemura *et al.* 2019a).

Simulations were conducted using the computer system of the Earthquake and Volcano Information Center at the Earthquake Research Institute, the University of Tokyo. Each simulation required 385 GBytes of computer memory and a wall-clock time of 2.5 hours and was performed using parallel computing with 432 cores to evaluate seismic wave propagation of 200 s with 20,000 time-step calculations. According to our grid and model settings, our FDM simulation can precisely evaluate long-period (> 10 s) seismic wave propagation.

Examples of Green's functions are illustrated in the right panels of Figure 2. The source (red star) was located at a depth of 10 km, near the plate boundary. We employed the Cartesian coordinate system of Aki & Richards (2002), where x, y, and z are taken as north, east, and down, respectively. Due to the low-velocity accretionary prism and seawater, durations of surface waves were amplified and elongated. In particular, for M_{xy} = 1.0 (i.e. a pure strike-slip with strike angle of 0°, dip angle of 90°, and rake angle of 0°), Love waves on horizontal components were strong and long. We assumed six-element moment tensors for the CMT inversions, which includes five double couple and an isotropic moment tensors (e.g.

Kikuchi & Kanamori 1991).

In the CMT inversions, we basically used Green's functions at F-net stations within epicentral distances of 100–400 km from the initial epicentre. The initial epicentre was obtained from the F-net MT catalogue. In cases where earthquake $Mw < 4.5$, we selected a distance range of 100–350 km due to the signal-to-noise ratio of the observed waveforms for the analysed period. We visually checked the filtered displacement waveforms and discarded noisy ones. Centroid location and time of the analysed earthquake were determined using grid search inversion. Because the analysis period range was longer than the source durations of target earthquakes with $Mw = 4.3$–6.5, we did not estimate source durations of these events. A set of Green's functions at the source grids, which were located in a ± 0.4° region from the initial epicentre and were distributed at depths of 6–50 km, was selected for the grid search inversion.

The CMT inversions were conducted for each selected source grid every 1 s from three minutes before the origin minute as recorded in the F-net catalogue. We used a 200-s time window for each CMT inversion. During grid search CMT inversion, we did not allow time shifts between synthetic and observed seismograms. After CMT inversion at all of the selected source grids, we obtained seismic moments and focal mechanisms at all locations and times. To identify the optimal solution, we evaluated variance reductions (VRs) between the observed and synthetic displacement seismograms for periods of 25—100 s. The VR could then be evaluated using the following equation:

$$VR = \left[1 - \frac{\sum_{i=1}^{N_S} \int \left(u_i^{Obs.}(t) - u_i^{Syn.}(t)\right)^2 dt}{\sum_{i=1}^{N_S} \int \left(u_i^{Obs.}(t)\right)^2 dt}\right] \times 100\ [\%] \tag{1}$$

where N_S is the number of stations and $u_i^{Obs.}$ and $u_i^{Syn.}$ are the time-series of observed and synthetic displacements, respectively. If observed and synthetic seismograms are perfectly matched, VR is 100 %. The solution with the maximum VR was considered the optimal solution, providing the optimal centroid location, depth, time, focal mechanism, and seismic moment of each earthquake. In the case that the optimal solution was located at the edges of the initial source grids, we performed the CMT inversion again using Green's functions for a broader source grid dataset. In the cases of regions around the edges of all source grids (all crosses in Figure 2), such as southern Kyushu and eastern Izu, we could not extend the grid set and then the optimal solution was located at the grid edge. These events may include possibilities of some shifts outside the edges of the assumed source grids. Our grid search CMT inversion required approximately 15–20 minutes using a typical, single-core desktop machine.

3. Results

We obtained a total of 215 CMT solutions for moderate earthquakes that occurred between April 2004 and August 2019. We discarded the solutions with a maximum VR of less than 20%. Our 3D CMT catalogue is listed in Global CMT (GCMT) format in the Supplementary data (Table S1) and the CSV format full catalogue data is available from https://doi.org/10.5281/zenodo.3674161. The size distribution and magnitude-time diagram of our 3D CMT catalogue are shown in Figures S1 and S2. The estimated moment magnitudes were slightly changed from the original F-net catalogue. The VRs of earthquakes with small magnitudes tended to be low (Figure S2) due to the signal-to-noise ratio for the analysed period range. We also compared our results with the GCMT catalogue (Figure S1). Teleseismic CMT inversion is robust but our regional CMT catalogue contains more earthquakes, whose *Mw* values are less than about 5.

Figures 3 and 4 show examples of CMT solutions for the southeast off the Kii Peninsula earthquake (1 April 2016) and the Hyuga-nada earthquake (9 May 2019), respectively. In our previous study (Takemura *et al.* 2018a), the 2016 southeast off the Kii Peninsula earthquake was also analysed. The epicentre location and origin time were fixed in the previous study. We re-analysed this earthquake via full 3D CMT inversion, which estimates centroid location, depth, time, and moment tensor. The F-net MT solution of this earthquake was a high-angle (38°) reverse faulting mechanism (grey focal sphere in Figure 3). Its optimal solution is a *Mw* 5.9 low-angle (10°) thrust faulting at a depth of 10 km (Figure 3), where the plate boundary closely exists (e.g. Kamei et al., 2012; Park et al., 2010). The synthetic seismograms of the optimal solution corresponded well with the observations. The depth variation of VRs illustrated a clear peak around the optimal depth. The centroid depth of this earthquake was well constrained by our CMT inversion. Takemura *et al*. (2018a) numerically demonstrated that the low-velocity accretionary prism just above the seismic source—which controls long-period surface wave propagation—provides a better constraint on the centroid depth. They also demonstrated that the 3D oceanic plate has an important role for constraining focal mechanism (Figures 7 and 8 of Takemura *et al.* 2018a).

The centroid location was also close to that estimated by ocean-bottom seismometers deployed just above the source region (Nakano *et al.* 2018a, Wallace *et al.* 2016), while the GCMT solution was slightly (0.2°) shifted to the south (Figure S3). The CMT result was consistent with models estimated by offshore observations (Kubota *et al.* 2018, Nakano *et al.* 2018a, Wallace *et al.* 2016). Especially, by using travel times, tsunami, and afterslip records, Wallace *et al.* (2016) and Nakano *et al.* (2018a) concluded that this earthquake can be interpreted as an interplate earthquake. Our CMT solution based on 3D Green's functions and onshore seismograms also suggests this earthquake was considered as faulting on the plate boundary.

Figure 4 shows the results of the CMT inversion and waveform fitting for the Hyuga-nada earthquake on 9 May 2019. The F-net MT solution was also high-angle (33°) reverse faulting. The optimal CMT solution indicated a *Mw* 6.2 low-angle (16°) thrust mechanism. The dip angle from the CMT solution agreed well with that of the Philippine Sea Plate around this earthquake. The synthetic waveforms also corresponded well to observed ones. Although the optimal depth (26 km) was determined to be close to the upper surface of the Philippine Sea Plate (approximately 27 km), a high VR (> 80%) area was found within a wider depth range (16–32 km). Because the depth of this earthquake was deeper than the 2016 southeast off the Kii Peninsula earthquake, the effects of the low-velocity accretionary prism might not have been so strong. Thus, the depth resolution of the CMT solutions might not be good when compared to the case of the 2016 southeast off the Kii Peninsula earthquake. To constrain the hypocentre depth more sharply, additional data, such as shorter-period (~ 4 s) first-arrival *P*-wave waveforms, would need to be considered (e.g. Okamoto *et al.* 2018, Takemura *et al.* 2018a, Wang & Zhan 2020).

Figure 5 shows a comparison of the estimated focal mechanisms for the F-net and our 3D CMT catalogues. Our CMT solutions of onshore earthquakes were not significantly differed from those in the F-net catalogue. However, our CMT solutions differed to those based on 1D analysis. In particular, dip angles and centroid depths of offshore earthquakes—which are important for distinguishing interplate and intraslab earthquakes—were different. This was clearly illustrated in detailed comparisons of seismicity southeast off the Kii Peninsula and off the Hyuga-nada (Figures 6, 7, S4, and S5). The dip angles of offshore earthquakes that occurred outside of onshore seismic arrays were poorly estimated by the conventional 1D CMT inversion due to the lack of the 3D subducting oceanic plate and the accretionary prism (e.g. Takemura *et al.* 2018ab). The comparisons and error estimations of dip angles was illustrated in Figures 9 and 10. The comparison of spatial distributions of CMT solutions with the GCMT catalogue is also illustrated in Figure S3.

We focused our attention on seismicity southeast off the Kii Peninsula and the Hyuga-nada (local names are illustrated in Figure 1), where seismic activities are relatively high in the Nankai subduction zone. Figure 6 shows spatial distributions of the CMT solutions southeast off the Kii Peninsula. We also plotted shallow VLFEs in the catalogue of Takemura *et al.* (2019b) as grey focal spheres. Shallow VLFEs, which were characterised by low-angle thrust faulting, were concentrated near the trench. In the region with shallow VLFE active, low-angle thrust type CMT solution at depths of 5-10 km, which suggests seismic slip on the plate boundary, was not estimated. On the down-dip side of the shallow VLFE region, a low-angle thrust faulting mechanism was estimated at a depth near the plate boundary (along profile A in Figure 6). This earthquake is the 2016 southeast off the Kii Peninsula earthquake (Figure 3). Almost all of the other earthquakes plotted in Figure 6 are aftershocks of the 2004 *Mw* 7.5 intraslab earthquake that occurred on 5 September 2004 southeast off the Kii Peninsula. Our CMT solutions of these aftershocks were separately distributed at two depths within the oceanic crust and mantle (10–15 and 20–30 km depths). This separation corresponded well to the hypocentre depth distributions of the aftershocks of the *Mw* 7.5 earthquake as determined using ocean-bottom seismometers (e.g., Nakano *et al.* 2015, Sakai *et al.* 2005). On the other hand, almost all the centroid depths of the F-net solutions were concentrated within the accretionary prism, crust and oceanic crust (5–15 km depths; Figure S3). According to comparisons with the detail hypocentre distributions in this region, even for earthquakes near the trough axis, our CMT method provided better constraints for centroid depths, compared to the 1D F-net MT solutions.

Figure 7 shows the spatial distribution of CMT solutions around the Hyuga-nada region. Our CMT solutions characterised by low-angle thrust faulting mechanisms were distributed across the region with average slip rates of approximately 20–40 mm/yr as inferred from small repeating earthquakes (e.g., Yamashita *et al.* 2012). The optimal centroid depths of such thrust solutions were concentrated around the plate boundary (profiles B and C in Figure 7). The distribution of our CMT solutions was agreed with that derived from onshore and temporal offshore seismometers (Tahara *et al.* 2008). The 3D CMT solutions, especially for depths and low-angle thrust faulting mechanisms, corresponded to the areas of detected repeating earthquakes (Yamashita *et al.* 2012). Our 3D CMT also well worked in this region. The dip angles of the F-net MT solutions at depths around the plate boundary were slightly higher than those of the plate boundary, as shown in Figure S4. The centroid depths of the F-net catalogue were also slightly deeper than the depths of the plate boundary. These also might have been due to a lack of 3D geometry of the subducting oceanic plate in the 1D analysis.

To evaluate differences between 3D CMT and F-net MT solutions, we calculated correlation coefficients of *P*-wave radiation patterns (e.g., Helffrich 1997, Kuge & Kawakatsu 1993) between two catalogues. We also calculated differences of estimated centroid depths from corresponding F-net solutions. Figure 8 shows the spatial distribution of correlation coefficients of *P*-wave radiation patterns and depth differences between our CMT and F-net MT catalogues. The values of correlation coefficients of offshore earthquakes (enclosed by dashed lines in Figure 8a) were widely distributed. Centroid depths of offshore earthquakes were also different from those of the F-net catalogue. Other earthquakes, which occurred in onshore regions or had good station coverages, have good similarities and small depth differences. The rigidity of the 3D model complicatedly depends on the centroid location, and consequently depth shifts could cause shifts of moment magnitudes from the F-net catalogue (Figure S1).

The parameter of the dip angle is important for distinguishing earthquake types. In the Nankai subduction zone, because megathrust earthquakes have repeatedly occurred, seismicity of interplate earthquakes is important. We selected low-angle thrust faulting solutions at depths around the plate boundary from our 3D CMT catalogue. These selected events could be interpreted as seismic slips on the plate boundary. Figure 9 shows a comparison of dip angles between the Philippine Sea plate and suggestive interplate earthquakes from the 3D CMT catalogue. We also compared dip angles of corresponding earthquakes in the F-net MT and GCMT catalogues. Although dip angles of F-net catalogues were higher angles compared to the Philippine Sea plate, our CMT solutions well correlated with dip angles of the plate boundary. Those of the GCMT catalogue roughly corresponded to dip angles of the Philippine Sea plate, but our solutions showed better agreements. The teleseismic CMT solutions are generally robust but regional 3D CMT could provide better constraints of dip angles.

We also calculated the VRs between observed and synthetic displacement waveforms to discuss estimation errors of dip angles for offshore earthquakes. Synthetic displacement waveforms were calculated from 3D Green's functions, assuming double-couple point sources and fixing hypocentre locations and seismic moments. Figure 10 shows spatial distributions of VRs for the 2016 southeast off Kii Peninsula earthquake and the 2019 Hyuga-nada earthquake. Clear trade-offs between strike and rake angles appeared in the strike-rake plane (upper panels). We confirmed that higher VR values (> 75 %) only appeared in the regions with dip angles of 5-15° and 10-20° for both earthquakes. Thus, our 3D CMT provides constraints of dip angles with uncertainties of approximately ±5°.

4. Discussion

4.1. Slip behaviours on the plate boundary along the Nankai Trough

In order to discuss slip behaviour on the plate boundary, Figure 11 shows the spatial distribution of slow earthquakes and earthquakes with low-angle (< 25°) thrust faulting solutions at depths around the plate boundary along the Nankai Trough. The large coseismic slip area of the 1968 *Mw* 7.5 earthquake (Yagi *et al.* 1998) is indicated by the blue area in Figure 11. The cumulative deep SSE slips in each grid were determined by summing slip of each SSE in each catalogue (Nishimura *et al.* 2013, Takagi *et al.* 2016, 2019). We then evaluated the SSE slip rates by dividing the cumulative SSE slip at each grid by the analysis period of each catalogue. The SSE slip rate indicates the activity of deep slow earthquakes. We did not calculate SSE slip rates for shallow SSEs reported by Yokota & Ishikawa (2020) because the number of detected events was still too low at each region. For similar reasons, the long-term SSEs off the Kii Channel (Kobayashi 2014) and Tokai (Miyazaki *et al.* 2006) regions were also excluded from the SSE slip rate calculation. Thus, we plotted the fault configurations or large slip areas of long-term SSEs and shallow SSEs. We also plotted shallow LFTs (Yamashita *et al.* 2015) and shallow VLFEs (Takemura *et al.* 2019c) as indicators of shallow slow earthquake activity. The spatial distribution of slip-deficit rates from GNSS and GNSS-A observations by Noda et al. (2018), is plotted using blue contour lines in Figure 11.

At deeper depths (30–40 km), deep slow earthquakes were active, especially in areas with high SSE slip rates, but no interplate regular earthquakes were found. Although SSEs were not removed in the slip-deficit rate estimation of Noda et al. (2018)—except for long-term SSEs at the Bungo Channel—the regions with deep SSEs were characterised by low (20–40 mm/y) slip-deficit rates. At shallower depths (< 30 km) in the offshore region, regular earthquakes, slow earthquakes, and high (> 60 mm/y) slip-deficit zones were separated from each other. Similar separation of the repeating earthquakes, slow earthquakes, and large coseismic slip areas of megathrust earthquakes at shallower depths were observed in the regions of Tohoku (e.g., Nishikawa *et al.* 2019), Central Ecuador (e.g., Vaca *et al.* 2018) and Costa Rica (e.g., Dixon *et al.* 2014). In particular, Nishikawa et al. (2019) pointed out that slow earthquakes were complementarily distributed in the regions surrounding the large coseismic slip area of the 2011 *Mw* 9.0 Tohoku earthquake. Takemura *et al*. (2019c) pointed out that shallow, slow earthquakes cluster or migrate due to the existence of pore fluid in the transitional regions between high-strength and low-strength zones of the plate boundary. According to these previous studies and our observations, we suggest that the observed separation between slip behaviours on the plate boundary along the Nankai Trough are related to the heterogeneous distribution of effective strengths on the plate boundary, which is controlled by the frictional coefficient, pore fluid pressure, and normal stress.

4.2. Regional 3D CMT inversions for the *Mw* 7.2 and 7.5 earthquakes southeast off the Kii Peninsula

We conducted 3D CMT inversions of offshore earthquakes with *Mw* of 4.3–6.5. During the analysis period (April 2004 to August 2019), *Mw* 7.2 and 7.5 intraslab earthquakes occurred southeast off the Kii Peninsula on 5 September 2004. Because typical *Mw* 7 class earthquakes have rupture durations of 30–50 s and fault areas of 1000–5000 km^2 (e.g. Kanamori & Brodsky 2004), precise source parameter estimation for such earthquakes is difficult based on our assumptions of the CMT inversion. Despite these disadvantages, the rapid estimation of CMT solution for these large earthquakes is important for disaster mitigation, such as a CMT-based tsunami warning system. We, therefore, tested the our simple CMT inversion for the *Mw* 7.2 and 7.5 southeast off the Kii Peninsula earthquakes. Because amplitude saturation of F-net broadband seismometers occurs for regional large earthquakes, we used F-net strong motion seismometers, which have a large clip level and a similar frequency response to STS-2 seismometers for periods less than 100 s. We selected F-net stations with distances of 200–500 km from the initial epicentre, which were slightly farther than for the original CMT settings (100–400 km).

Figures 12 and 13 show the results of CMT inversions for the *Mw* 7.2 and 7.5 earthquakes southeast off the Kii Peninsula, respectively. Detailed estimated parameters are also listed in Table S2. Signal-to-noise ratios were enough high compared to smaller (*Mw* < 4.5) earthquakes in this study but the VRs were low compared to those of moderate earthquakes. The synthetic waveforms roughly corresponded to the observed ones (Figures 12b and 13b). Due to the assumptions of a point source and simple-source time function, detailed characteristics of the observed waveforms were not successfully reproduced. Furthermore, the high (> 66%) VR areas were wider than the CMT results for moderate earthquakes within the same region (Figure 3). The estimated deviatoric components were very similar to those in the GCMT catalogue, but, especially in the result of the *Mw* 7.2 earthquake, a large isotropic component appeared. Waveform fitting and large non-double couple components suggest the likely complexity of the rupture processes and the source extents for the *Mw* 7.2 and 7.5 earthquakes. Estimated moment magnitudes were slightly smaller than those of the GCMT catalogue as a result of analysed period and the deeper centroid depths. Our analysed period was not enough longer than rupture durations of *Mw* 7 earthquakes. However, the regional 3D CMT method provides better constraints of dips and depths for offshore earthquakes compared to 1D CMT systems (Figures 3, 4, 5, 6, and 9), and our 3D grid search required only 15-20 minutes. These points are good advantages for CMT-based tsunami prediction systems (e.g. Inazu *et al.* 2016, Reymond *et al.* 2012). To obtain more accurate solutions, the CMT method with various durations (e.g., Takemura *et al.* 2019b) or deconvolution method (e.g., Vallée *et al.* 2011) should be implemented. Such sophisticated methods require more time to obtain solutions.

We compared our CMT result for the *Mw* 7.2 earthquake with the finite-fault model (Okuwaki & Yagi 2018) conducted using teleseismic records based on Yagi & Fukahata (2011). Our horizontal centroid location was very close to an area with large (> 3 m) coseismic slips (Figure 14). The horizontal location of the dominant slip and centroid locations of the 3D CMT solution were shared. The centroid location was also agreed with that estimated by tsunami record (Satake *et al.* 2005). Thus, we think that the centroid location of the *Mw* 7.2 earthquake was well constrained by our 3D CMT method. The depths of such large coseismic slips in the finite fault model ranged from 9 to 18 km but the optimal centroid depth of the 3D CMT inversion was 26 km. The depth difference could be originated from the regional 3D heterogeneities (accretionary prism, bathymetry change, and subducting plate). According to the hypocentre determinations derived using ocean-bottom seismometers (Nakano *et al.* 2015, Sakai *et al.* 2005), the hypocentres of aftershocks due to the *Mw* 7.5 earthquake were distributed at depths of approximately 10–30 km. We also tested the centroid depth and large isotropic components by our 3D CMT inversion. By using simulated seismograms of the finite-fault model (Okuwaki & Yagi 2018) as observed seismograms, we conducted CMT inversion of the simulated *Mw* 7.2 intraslab earthquake (Figure S6). The centroid location and depth well corresponded to the large slip area of the finite-fault model. The large isotropic component was also estimated. Thus, large non-double couple components suggest the likely complexity of the rupture processes and the source extents for the finite-fault model of the *Mw* 7.2 earthquake. Based on the hypocentre distribution of aftershocks, the fault dimensions of the *Mw* 7.2 earthquake, and synthetic test, we considered that the extension of seismic slips at depths of approximately 26 km might be possible.

The detailed rupture processes of the *Mw* 7.2 and 7.5 earthquakes remain unclear. The regional seismic data and 3D Green's functions may provide additional constraints for large offshore earthquakes. The finite fault modelling based on the 3D Green's functions is an important but challenging issue that requires particular attention in future studies.

5. Conclusion

We conducted 3D CMT inversions of moderate earthquakes along the Nankai Trough using the regional 3D Green's function dataset. By comparing 3D CMT solutions with those in the F-net catalogue, large differences in focal mechanisms and centroid depths were found for offshore earthquakes. These differences could be caused by 3D offshore heterogeneities, such as the low-velocity accretionary prism and subducting Philippine Sea plate. Onshore MT inversion using a simple 1D Earth model could provide incorrect estimations due to offshore heterogeneities and station coverage. By introducing the effects of such 3D heterogeneities, the 3D CMT solutions for offshore earthquakes practically agreed with hypocentre distributions determined by ocean-bottom seismometers. Furthermore, our CMT method based on onshore seismograms provided better constrained focal mechanisms and centroid depths compared to the F-net MT catalogue. We also compared our CMT solutions with those of the GCMT catalogue. The teleseismic CMT solutions are generally robust but regional 3D CMT could provide better constraints of dip angles. The regional 3D CMT catalogue contains more earthquakes compared to the GCMT catalogue, where earthquakes with *Mw* > about 5 are only listed. To investigate detailed decade-scale seismicity in a certain region, CMT inversion incorporating regional 3D velocity model should be required.

Although no suggestive interplate earthquakes are listed in the 1D catalogue, some low-angle thrust faulting solutions at depths around the plate boundary were confirmed by our 3D CMT catalogue. These earthquakes could be interpreted as interplate earthquakes. By using our 3D CMT catalogue and previously published slow earthquake models, we illustrated the spatial distribution of slip behaviours on the plate boundary along the Nankai Trough. Regular interplate earthquakes and slow earthquakes occur within different segments on the plate boundary. These separated distributions might reflect the heterogeneous distribution of effective strength on the plate boundary. The gap zones, where no regular interplate and slow earthquakes occurred, were found in the Nankai, Tonankai, and Tokai regions. These were the regions with large (> 60 mm/y) slip-deficit rates, where the plate boundary can be strongly coupled.

The regional CMT inversion of earthquakes with *Mw* > 7 was generally difficult due to their fault size and the amplitude saturation of the broadband sensors. CMT inversions for the 2004 *Mw* 7.2 and 7.5 intraslab earthquakes southeast of the Kii Peninsula were performed using the regional broadband strong motion sensors of F-net. Although signal-to-noise ratios of the observed displacements were good enough, the waveform fittings of the *Mw* 7.2 and 7.5 intraslab earthquakes were not good compared to those of typical moderate earthquakes due to fault sizes and the rupture complexity. However, the centroid location was agreed with that estimated by tsunami record and focal mechanism could be constrained. These points and rapid focal mechanism estimation are good advantages for CMT-based tsunami warning systems.

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F-net waveform data and the F-net MT catalogue are available via the website of the National Research Institute for Earth Science and Disaster Resilience (https://doi.org/10.17598/NIED.0005). Bathymetric depth data was obtained from ETOPO1 (Amante & Eakins 2009). OpenSWPC software (Maeda *et al.* 2017) and the 3D model of Koketsu et al. (2012) were obtained from https://github.com/takuto-maeda/OpenSWPC and https://www.jishin.go.jp/evaluation/seismic_hazard_map/lpshm/12_choshuki_dat/, respectively. Generic Mapping Tools (Wessel *et al.* 2013) and Seismic Analysis Code (SAC; Helffrich *et al.* 2013) were used to make the figures and when conducting the signal processing work, respectively. The catalogue of slow earthquakes (Nishimura *et al.* 2013, Takagi *et al.* 2016, Yamashita *et al.* 2015) was downloaded from the Slow Earthquake Database website (Kano *et al.* 2018; http://www-solid.eps.s.u-tokyo.ac.jp/~sloweq/). Our CMT catalogue and CMT results of assumed source grids for each earthquake are available from https://doi.org/10.5281/zenodo.3674161. The FDM simulations of seismic wave propagation were conducted on the computer system of the Earthquake and Volcano Information Center at the Earthquake Research Institute, the University of Tokyo. This study was supported by the Japan Society for the Promotion of Science (JSPS) KAKENHI Grant Numbers 17K14382 under the Grant-in-Aid for Young Scientists (B) and 19H04626 in Scientific Research under Innovative Areas 'Science of Slow Earthquakes'. We also thank two anonymous reviewers and Editor Prof. J. Virieux for careful reviewing and constructive comments, which have helped to improve the manuscript.

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Figures

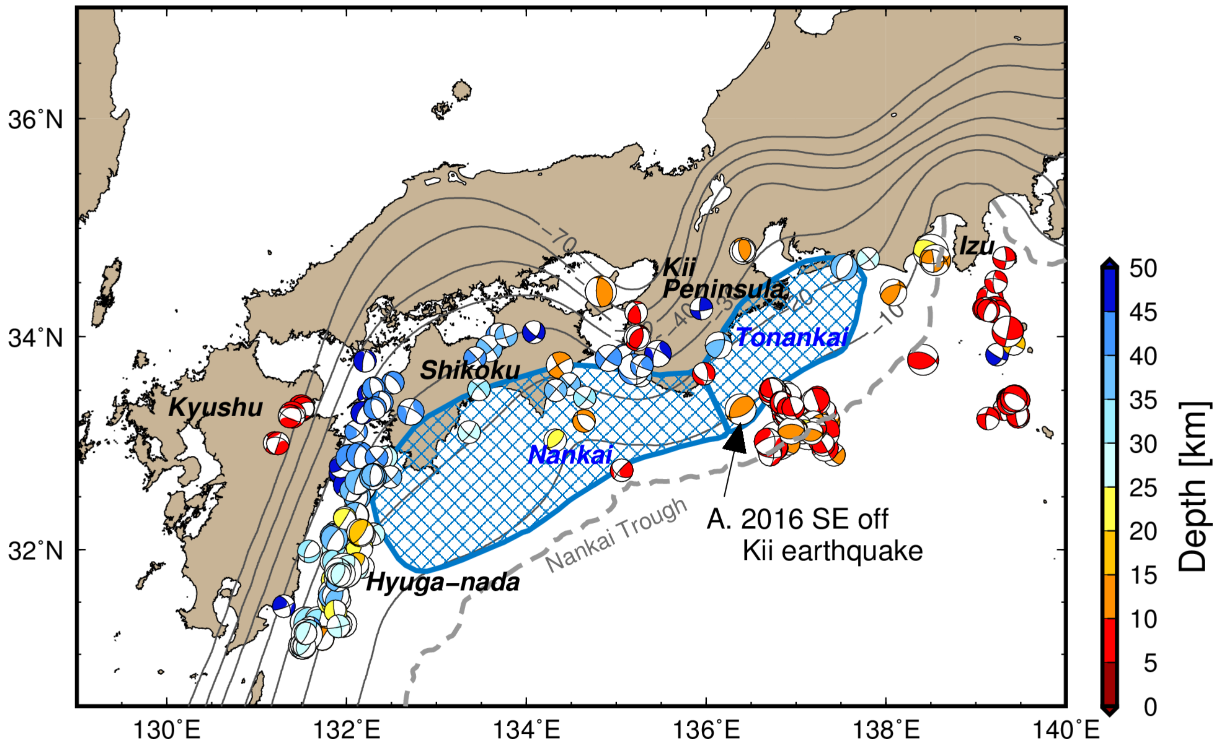

Figure 1. Map of the study region. The black contour lines are the iso-depth contour lines of the upper surface of the Philippine Sea Plate of Koketsu *et al.* (2012). Focal mechanisms are the moment tensor (MT) solutions of regular earthquakes with *Mw* of 4.3–6.5 in the F-net catalogue (Fukuyama *et al.* 1998, Kubo *et al.* 2002) that occurred in the area with latitudes less than 34.8°N, longitudes greater than 131°E, and at depths of less than 50 km. The plotted MT solutions range from April 2004 to August 2019. The blue hatched areas represent the expected source region of the Nankai and Tonankai earthquakes (Earthquake Research Committee, 2001, available at: http://www.jishin.go.jp/main/chousa/01sep_nankai/index.htm). The earthquake marked A is the *Mw* 5.8 southeast off Kii Peninsula earthquake that occurred on 1 April 2016.

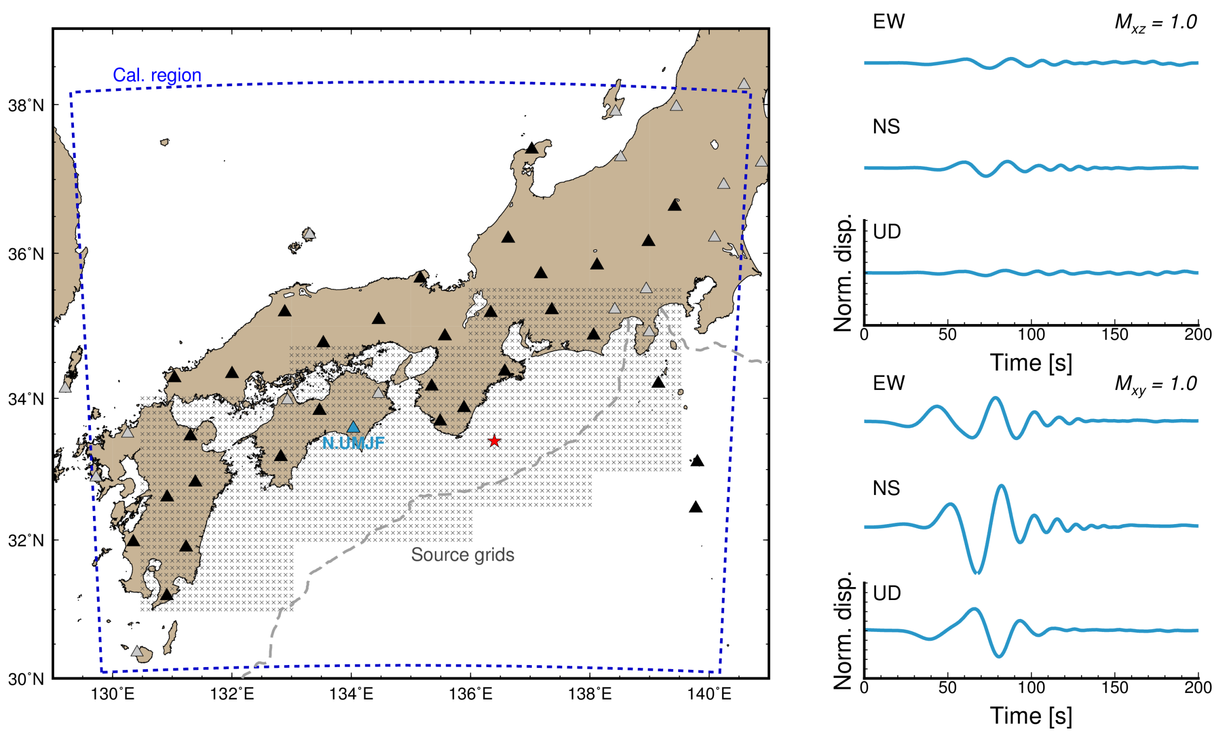

Figure 2. Calculation settings used in this study were the blue dashed line represents the horizontal coverage of the simulation model region. The triangles and crosses in the map denote the locations of the F-net stations and the assumed source grids, respectively. Green's functions from the source grids to the black-fill and blue-fill triangles were evaluated via reciprocal calculations using OpenSWPC code (Maeda *et al.* 2017). The right-hand panels show examples of filtered displacements of Green's functions from a certain hypocentre (red star, at a depth of 10 km) to the N.UMJF station (blue triangle), whose epicentral distance is 263 km. The filter passed band ranged from 25 to 100 s.

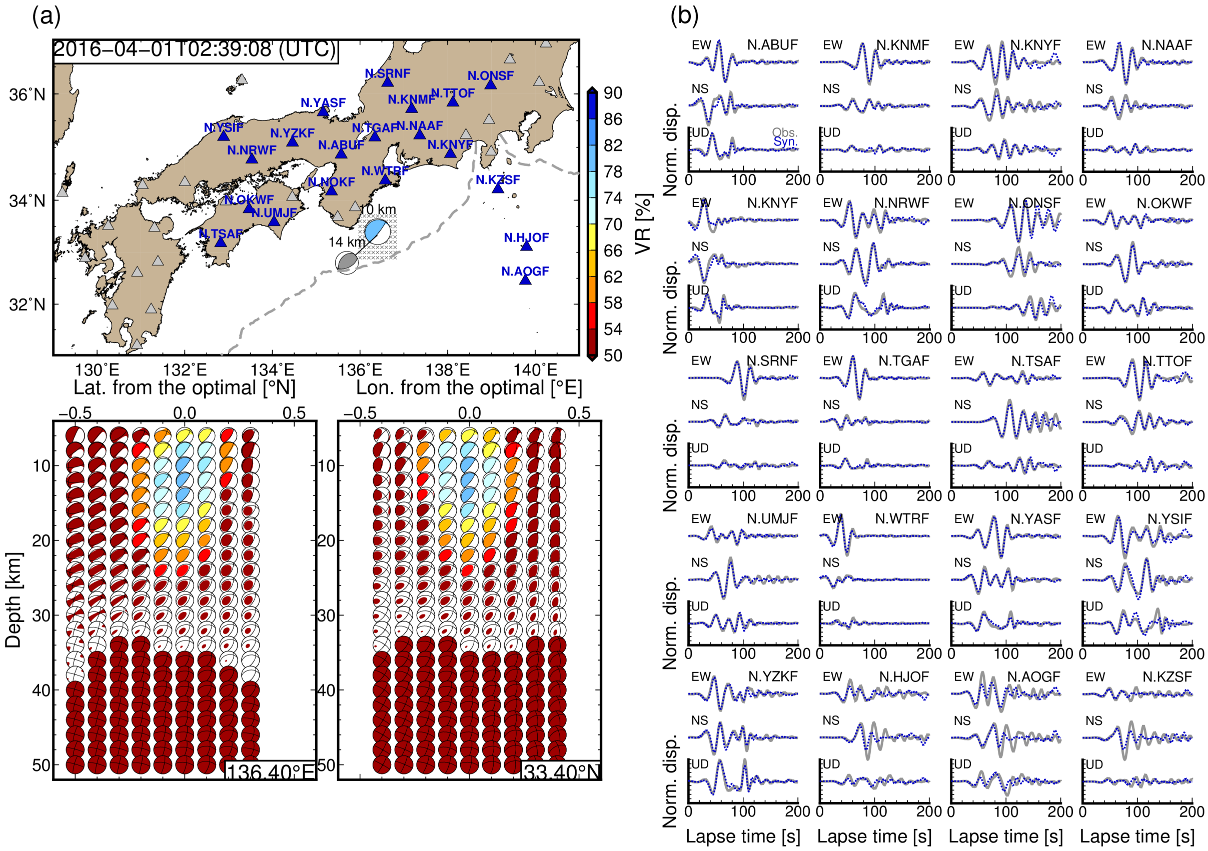

Figure 3. CMT results for the southeast off Kii Peninsula earthquake that occurred on 1 April 2016. (a) Locations of the optimal solutions, used stations, and depth variations of optimal solutions at each source grid. Colours of the focal mechanisms reflect values of variance reduction between observed and synthetic displacements for 25–100 s periods. The numbers above the optimal solutions in (a) are the optimal centroid depths. The grey focal mechanism in (a) is the F-net MT solution of this earthquake. (b) Comparisons of observed and synthetic displacements for 25–100 s periods. Grey solid and blue dotted lines are the observed and synthetic seismograms, respectively. Synthetic seismograms were evaluated by assuming the optimal solution. Amplitudes at each station were normalised by the maximum amplitude of both observed and synthetic three-component displacement waveforms. Detailed source parameters are listed in Table S1.

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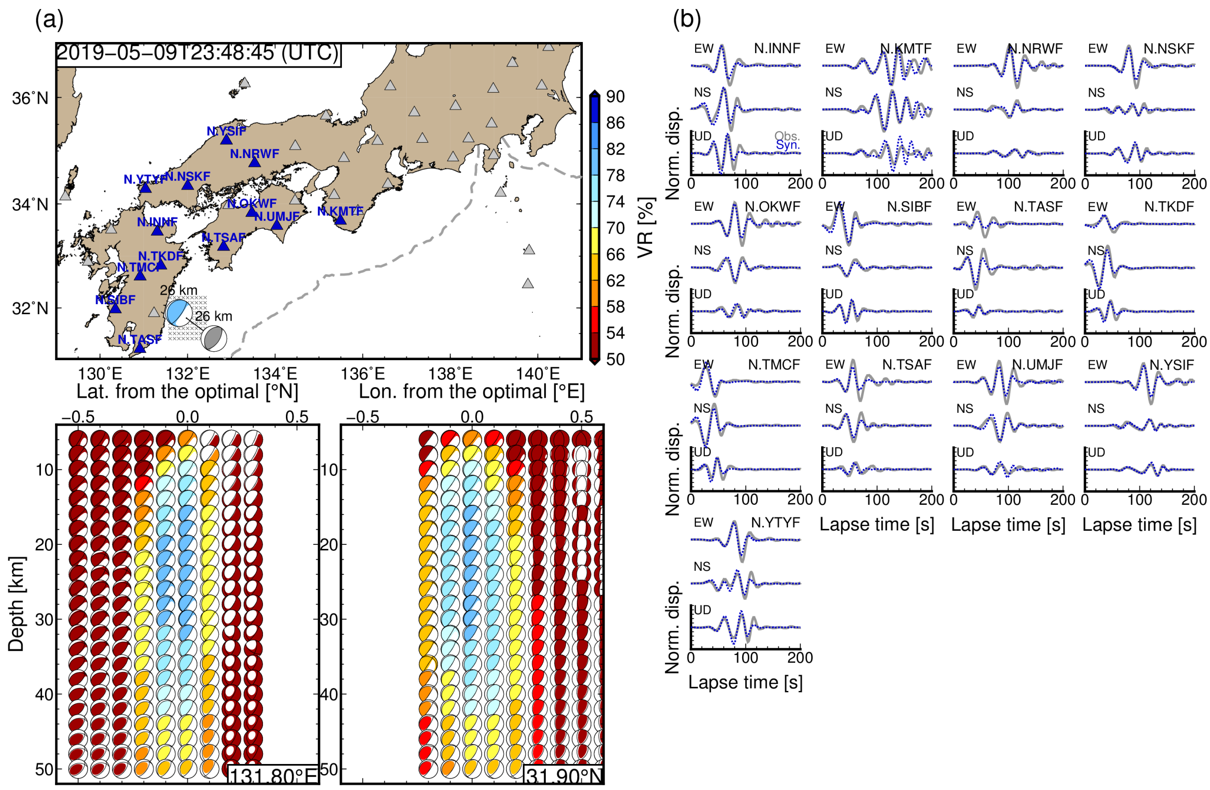

Figure 4. CMT results for the Hyuga-nada earthquake that occurred on 9 May 2019. (a) Locations of the optimal solutions, used stations, and depth variations of optimal solutions at each source grid. Colours of the focal mechanisms reflect values of variance reduction between observed and synthetic displacements for 25–100 s periods. The numbers above the optimal solutions in (a) are the optimal centroid depths. The grey focal mechanism in (a) is the F-net MT solution of this earthquake. (b) Comparisons of observed and synthetic displacements for 25–100 s periods. Grey solid and blue dotted lines are the observed and synthetic seismograms, respectively. Synthetic seismograms were evaluated by assuming the optimal solution. Amplitudes at each station were normalised by the maximum amplitude of both observed and synthetic three-component displacement waveforms. Detailed source parameters are listed in Table S1.

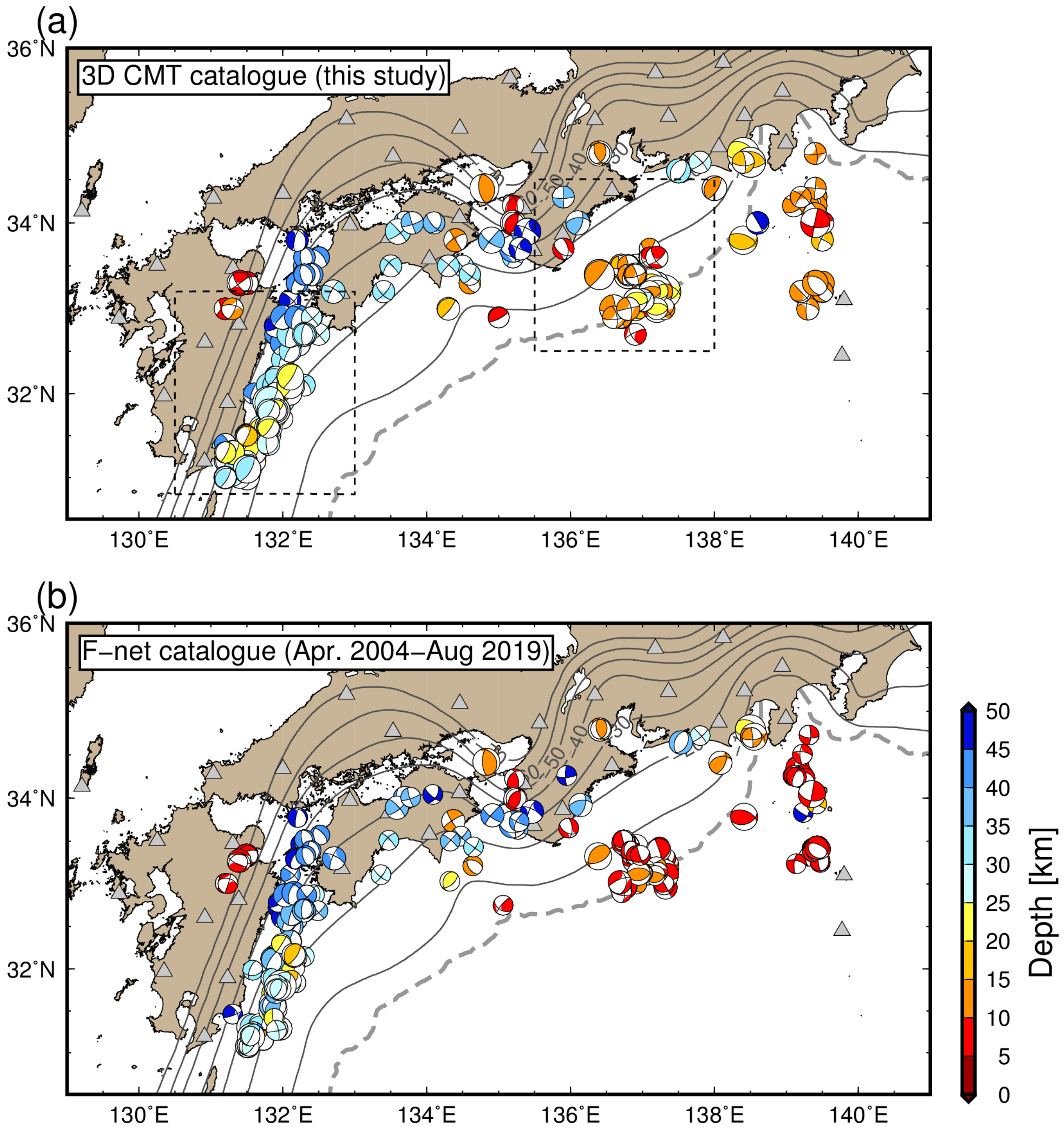

Figure 5. Comparisons of estimated CMT solutions between the (a) 3D CMT and (b) F-net MT catalogues. Colours of focal mechanisms represent the centroid depths of each solution. Detailed source parameters of our 3D CMT solutions are listed in Table S1. The regions enclosed by the dashed lines in (a) are enlarged in Figures 6 and 7.

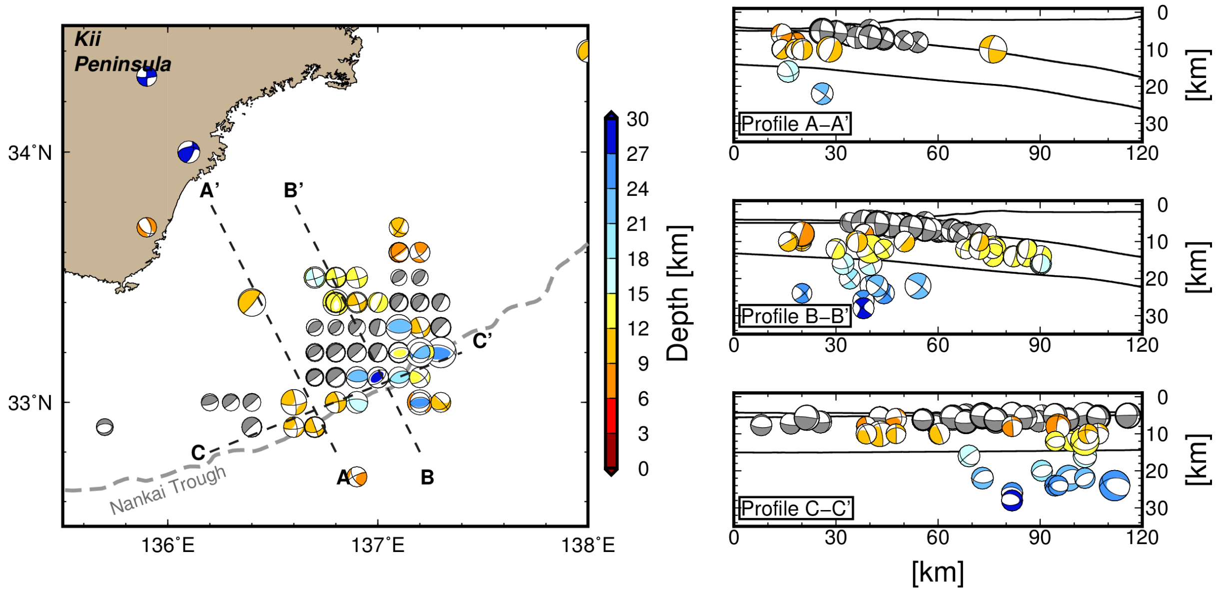

Figure 6. Spatial distribution of the CMT solutions southeast of the Kii Peninsula. Coloured focal mechanisms are our CMT solutions. Grey focal mechanisms are the CMT solutions of shallow VLFEs (Takemura, Shunsuke, Matsuzawa, *et al.* 2019). The right-hand panels show cross-sections along profiles A-A’, B-B’ and C-C’. The bathymetry of ETOPO1 (Amante & Eakins 2009), the upper surface, and oceanic Moho of the Philippine Sea Plate (Koketsu *et al.* 2012) along each profile are plotted in the right-hand panels.

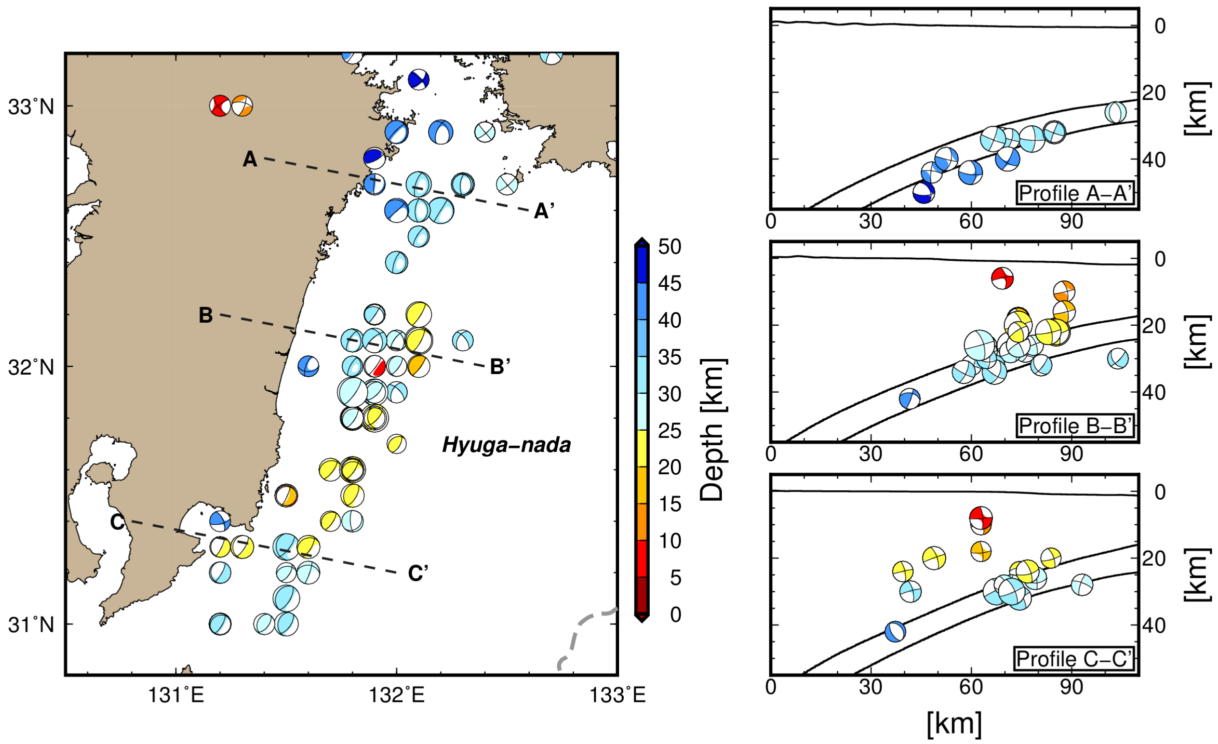

Figure 7. CMT results for the Hyuga-nada region. Coloured focal mechanisms are our CMT solutions. The right-hand panels show cross-sections along profiles A-A’, B-B’ and C-C’.

The bathymetry of ETOPO1 (Amante & Eakins 2009), the upper surface, and oceanic Moho of the Philippine Sea Plate (Koketsu *et al.* 2012) along each profile are plotted in the right-hand panels.

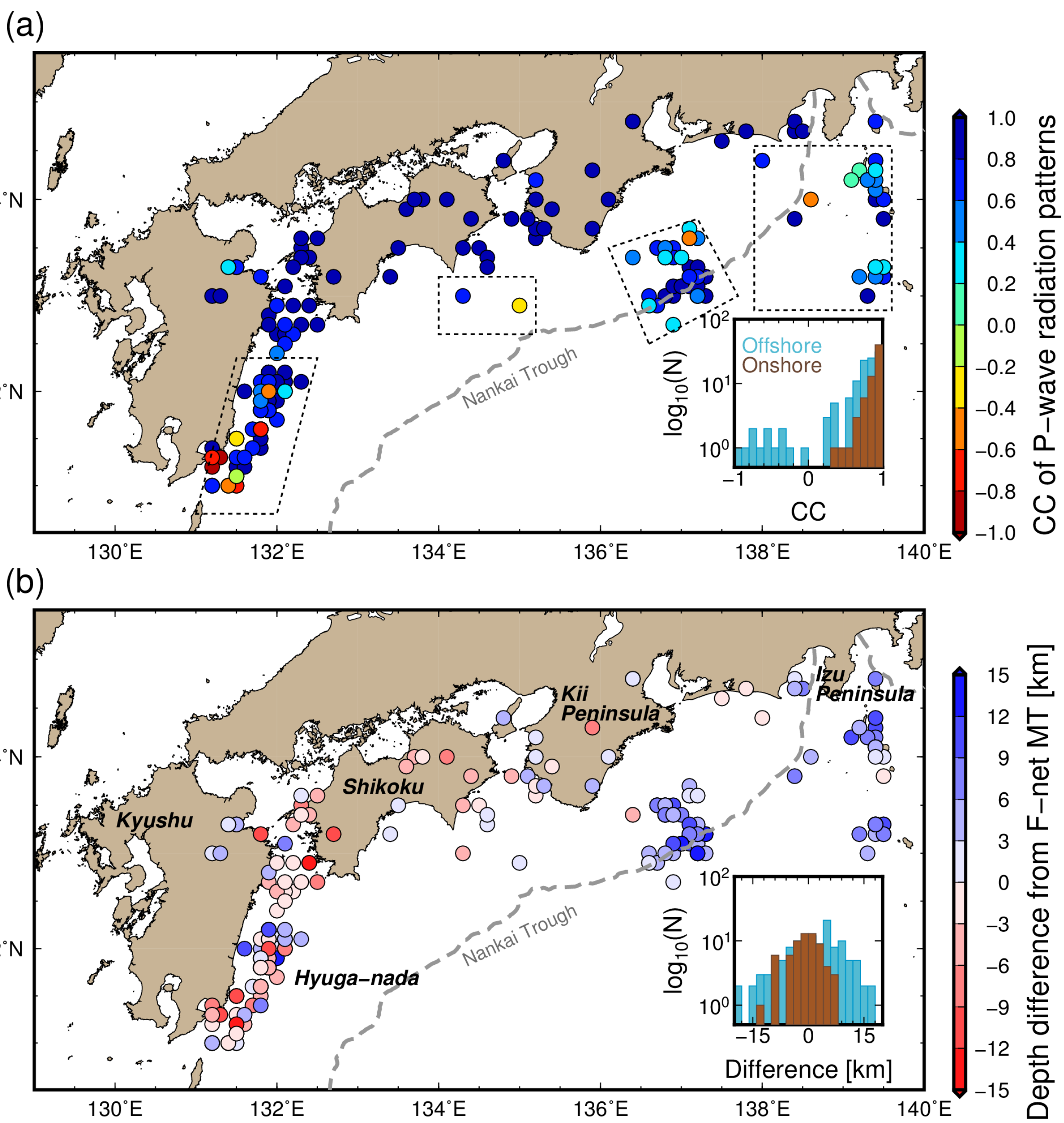

Figure 8. Spatial distributions of (a) correlation coefficients (CCs) of *P*-wave radiation patterns between 3D CMT and F-net solutions and (b) depth differences of 3D CMT solutions from the F-net catalogue. Lower right panels in (a) and (b) show histograms of CCs and differences, respectively. Offshore earthquakes are defined as earthquakes that occurred within regions closed by dotted lines in (a).

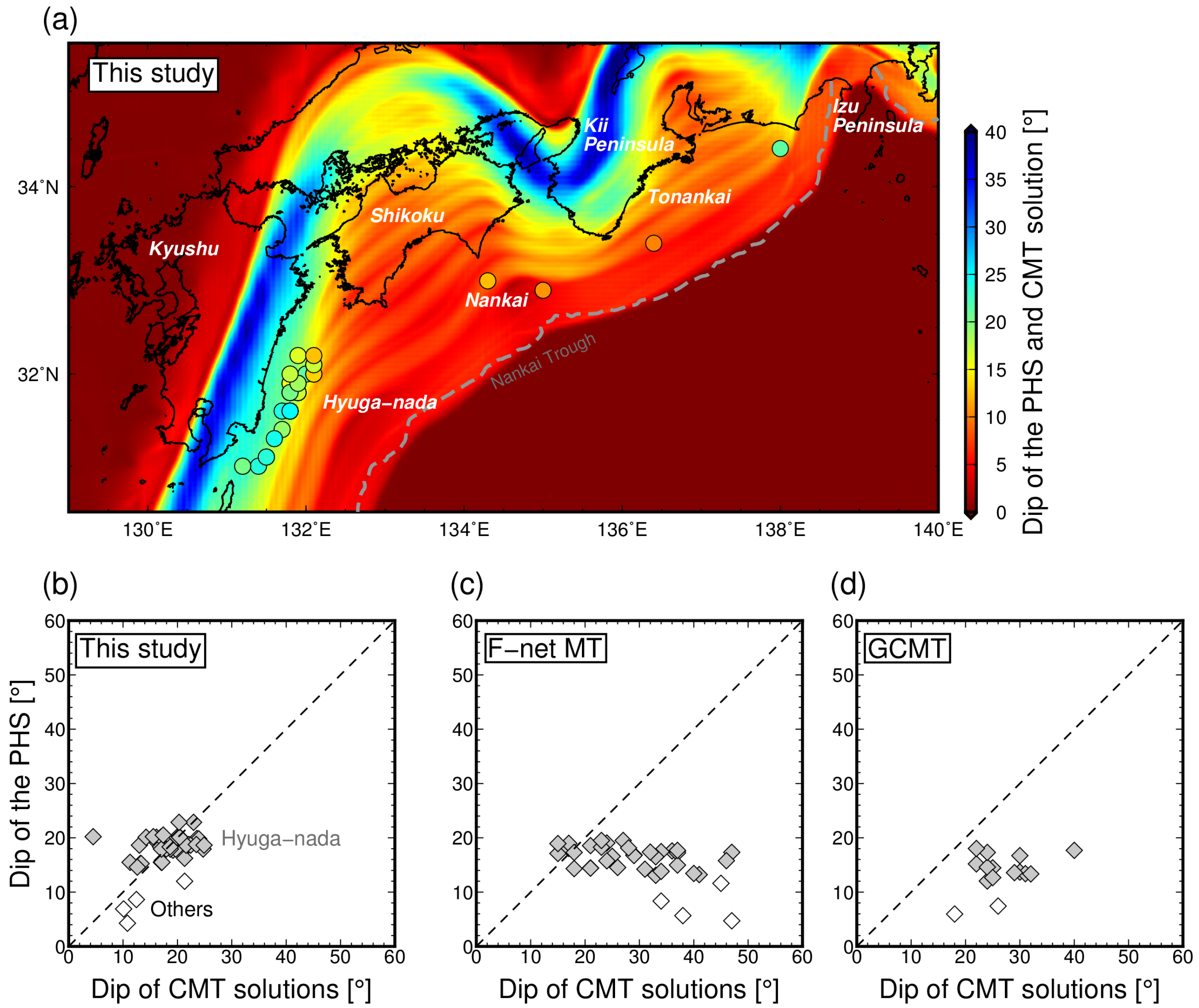

Figure 9. Comparisons of dip angles between the Philippine Sea plate (PHS) and CMT solutions for suggestive interplate earthquakes. (a) Map of the region, comparisons of dip angles of the Philippine Sea plate with (b) CMT solutions of this study and (c) F-net MT solutions. The background colour in (a) is representing spatial distribution of dip angles of the Philippine Sea plate. The coloured circles denote dip angles of CMT solutions in this study. We compared dip angles between the Philippine Sea plate and (c) F-net MT and (d) GCMT solutions of corresponding earthquakes.

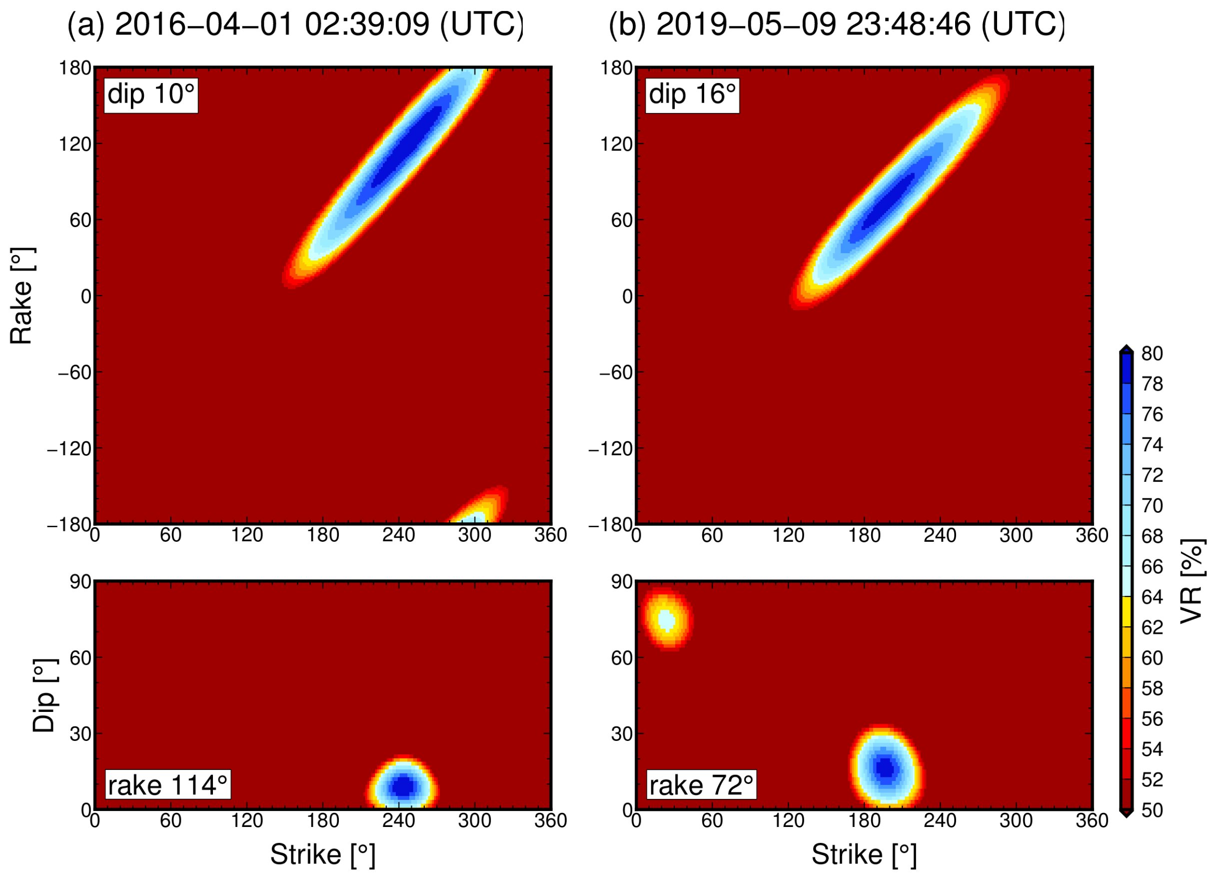

Figure 10. Distributions of variance reductions (VR) in the strike-rake and strike-dip planes for (a) the southeast off Kii Peninsula earthquake on 1 April 2016 and (b) the Hyuga-nada earthquake on 9 May 2019. In synthetics of displacement seismograms with various strike, dip, and rake, we assumed pure double-couple point sources and fixed hypocenter locations and seismic moments from CMT results (Figures 3 and 4).

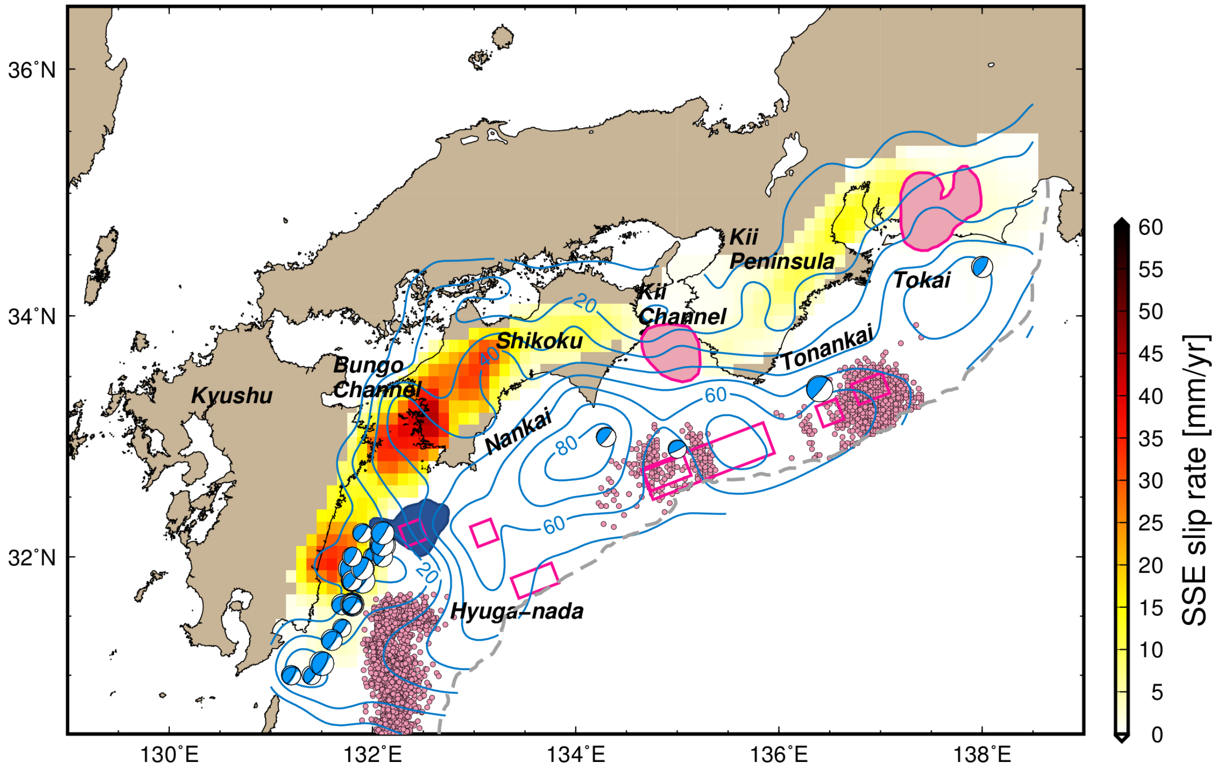

Figure 11. Spatial distribution of slip behaviours on the plate boundary along the Nankai Trough. Plotted focal mechanisms are low-angle thrust faulting solutions at depths around the plate boundary. The coseismic slip area of the 1968 *Mw* 7.5 Hyuga-nada earthquake (Yagi *et al.* 1998) is shaded in dark blue. SSE slip rates were evaluated from the combined SSE catalogues (Nishimura *et al.* 2013, Takagi *et al.* 2016, 2019). The pink circles indicate the epicentres of the shallow LFTs of the Hyuga-nada and the shallow VLFEs in the Tonankai region referred from Yamashita et al. (2015) and Takemura, Noda, et al. (2019). The pink shaded areas and pink rectangles indicate the large slip areas of long-term SSEs (Kobayashi 2014, Miyazaki *et al.* 2006) and shallow SSEs (Yokota & Ishikawa 2020), respectively. The blue contour lines indicate the slip-deficit rates [mm/yr] on the plate boundary by Noda *et al.* (2018)

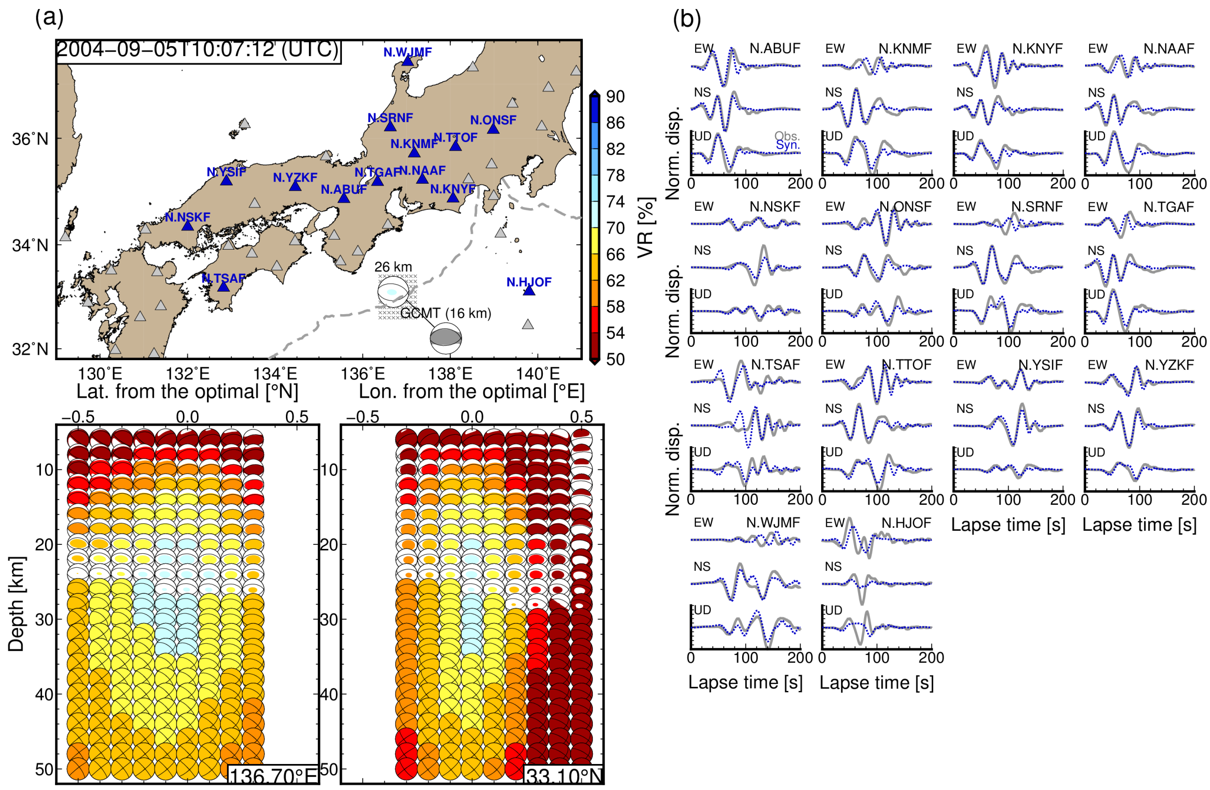

Figure 12. CMT results for the *Mw* 7.2 southeast off the Kii Peninsula earthquake that occurred on 5 September 2004. Grey focal mechanisms are the solutions of the F-net MT and GCMT catalogues. (a) Locations of the optimal solutions, used stations, and depth variations of optimal solutions at each source grid. Colours of the focal mechanisms reflect values of variance reduction between observed and synthetic displacements for 25–100 s periods. The numbers above the optimal solutions in (a) are the optimal centroid depths. The grey focal mechanism in (a) is the F-net MT solution of this earthquake; (b) Comparisons of observed and synthetic displacements for 25–100 s periods. Grey solid and blue dotted lines are the observed and synthetic seismograms, respectively. Synthetic seismograms were evaluated by assuming the optimal solution. Amplitudes at each station were normalised by the maximum amplitude of both observed and synthetic three-component displacement waveforms. Detailed source parameters are listed in Table S2.

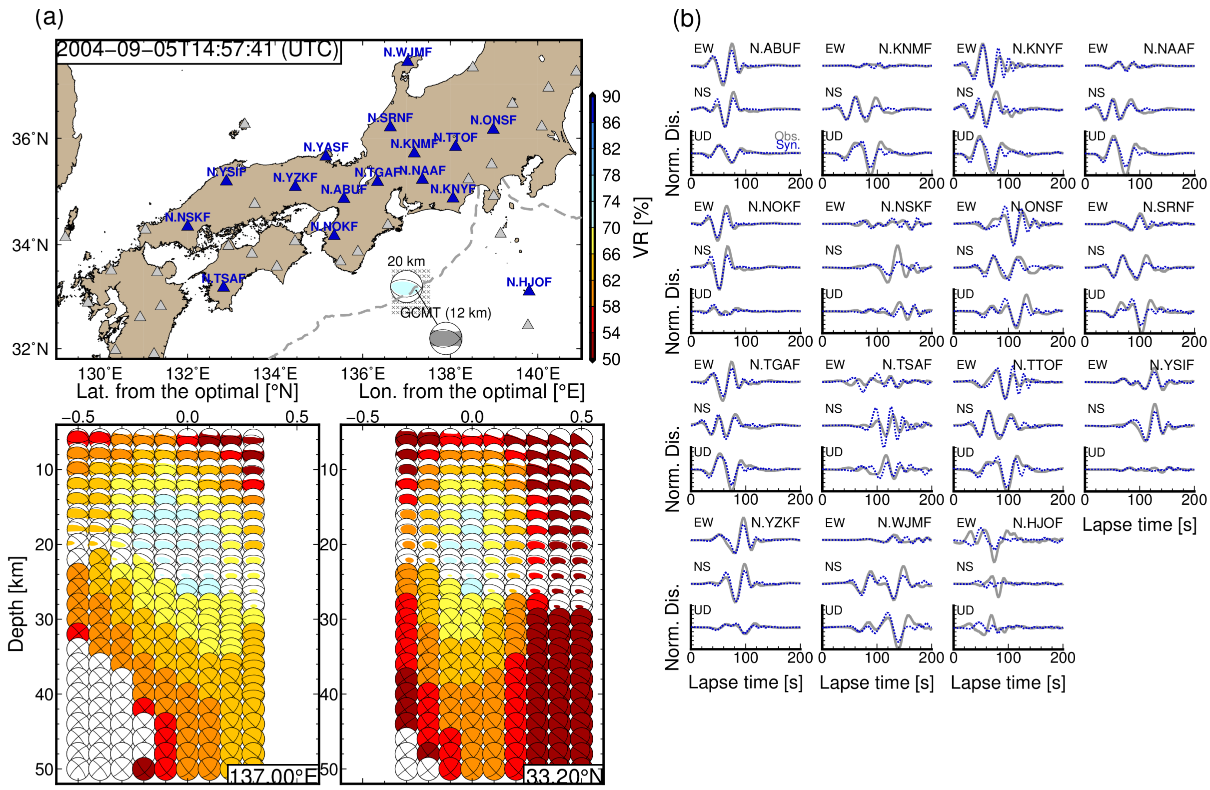

Figure 13. CMT results for the *Mw* 7.5 southeast off the Kii Peninsula earthquake that occurred on 5 September 2004. (a) Locations of the optimal solutions, used stations, and depth variations of optimal solutions at each source grid. Colours of the focal mechanisms reflect values of variance reduction between observed and synthetic displacements for 25–100 s periods. The numbers above the optimal solutions in (a) are the optimal centroid depths. The grey focal mechanism in (a) is the F-net MT solution of this earthquake; (b) Comparisons of observed and synthetic displacements for 25–100 s periods. Grey solid and blue dotted lines are the observed and synthetic seismograms, respectively. Synthetic seismograms were evaluated by assuming the optimal solution. Amplitudes at each station were normalised by the maximum amplitude of both observed and synthetic three-component displacement waveforms. Detailed source parameters are listed in Table S2.

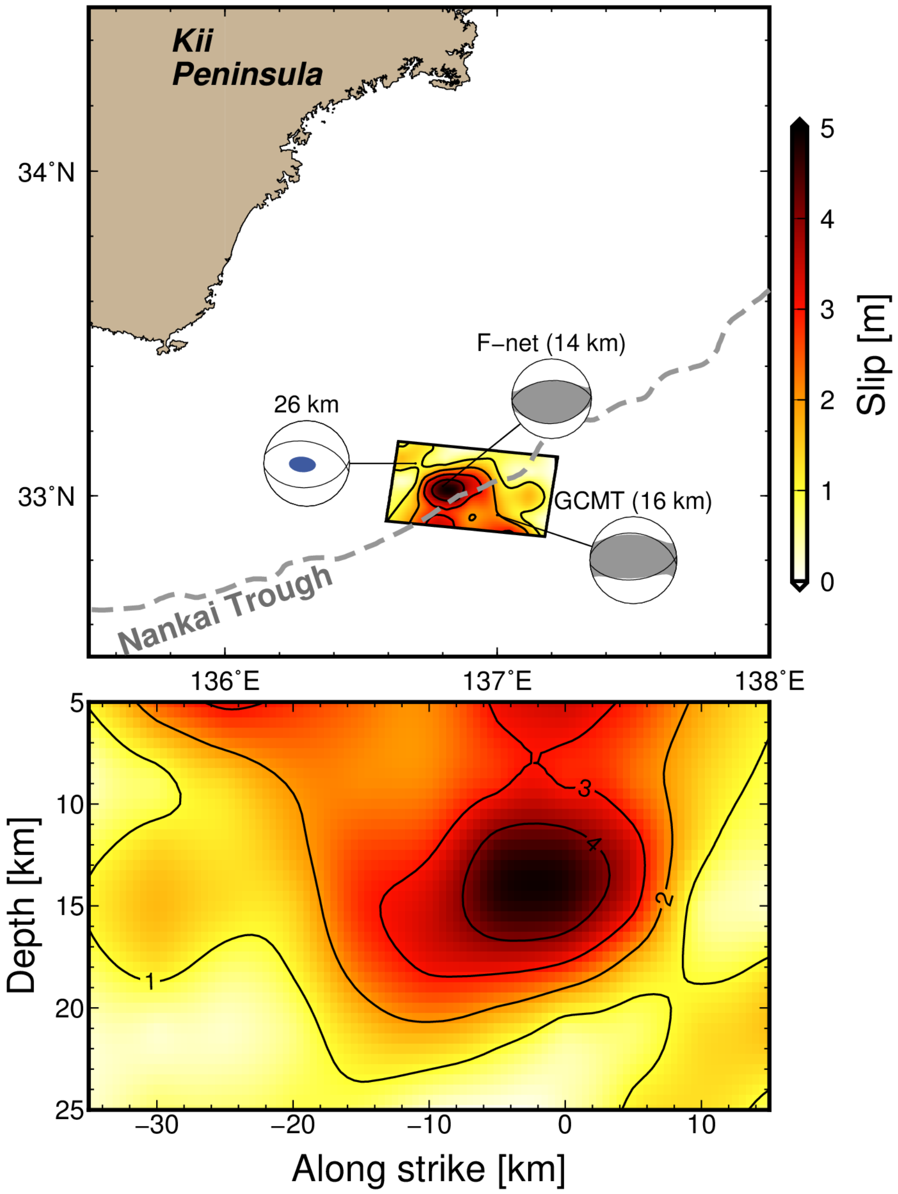

Figure 14. Comparison of the CMT results for the *Mw* 7.2 southeast off the Kii Peninsula earthquake and other CMT catalogues (Ekström *et al.* 2012, Fukuyama *et al.* 1998, Kubo *et al.* 2002) and finite fault modelling (Okuwaki & Yagi 2018) solutions. The bottom panel is the slip distribution of the finite fault model in the strike-depth plane.

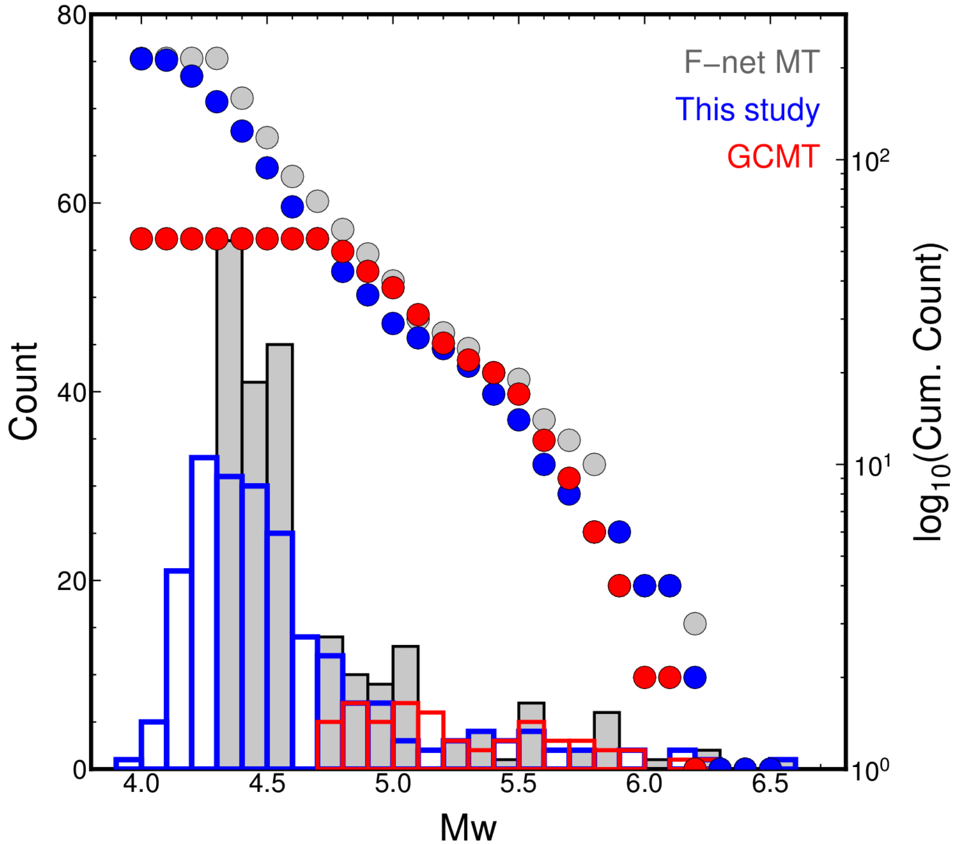

Figure S1. Size distribution of our 3D CMT catalogue (blue), the F-net catalogue (grey), and the GCMT catalogue (red). The selected criteria of the F-net and GCMT catalogue is same as in Figure 1.

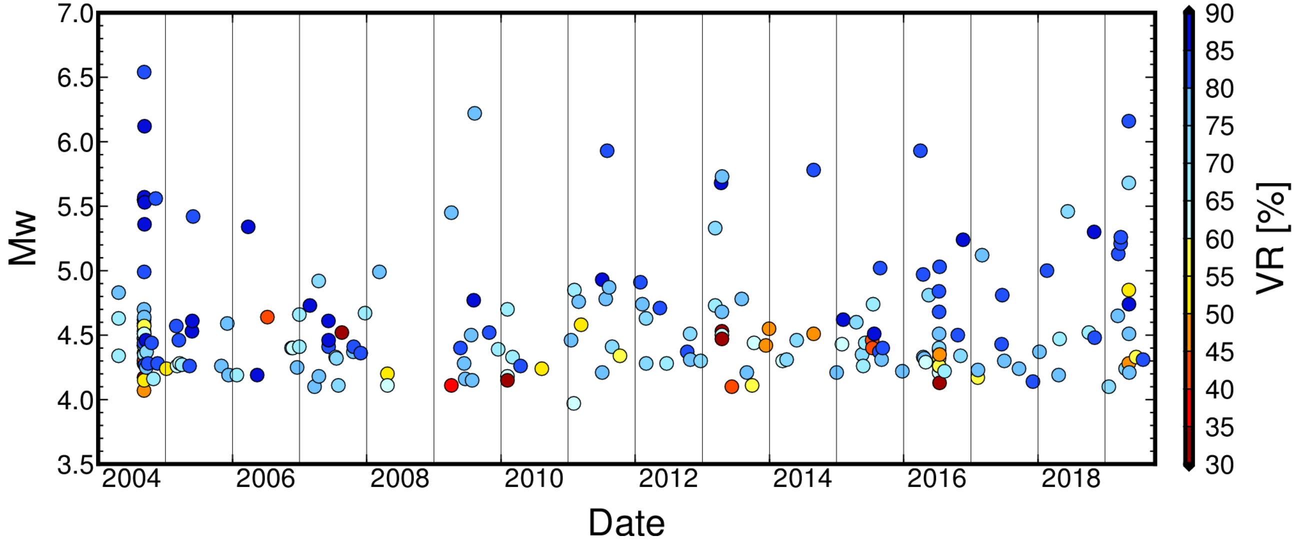

Figure S2. Magnitude-time diagram of our 3D CMT catalogue.

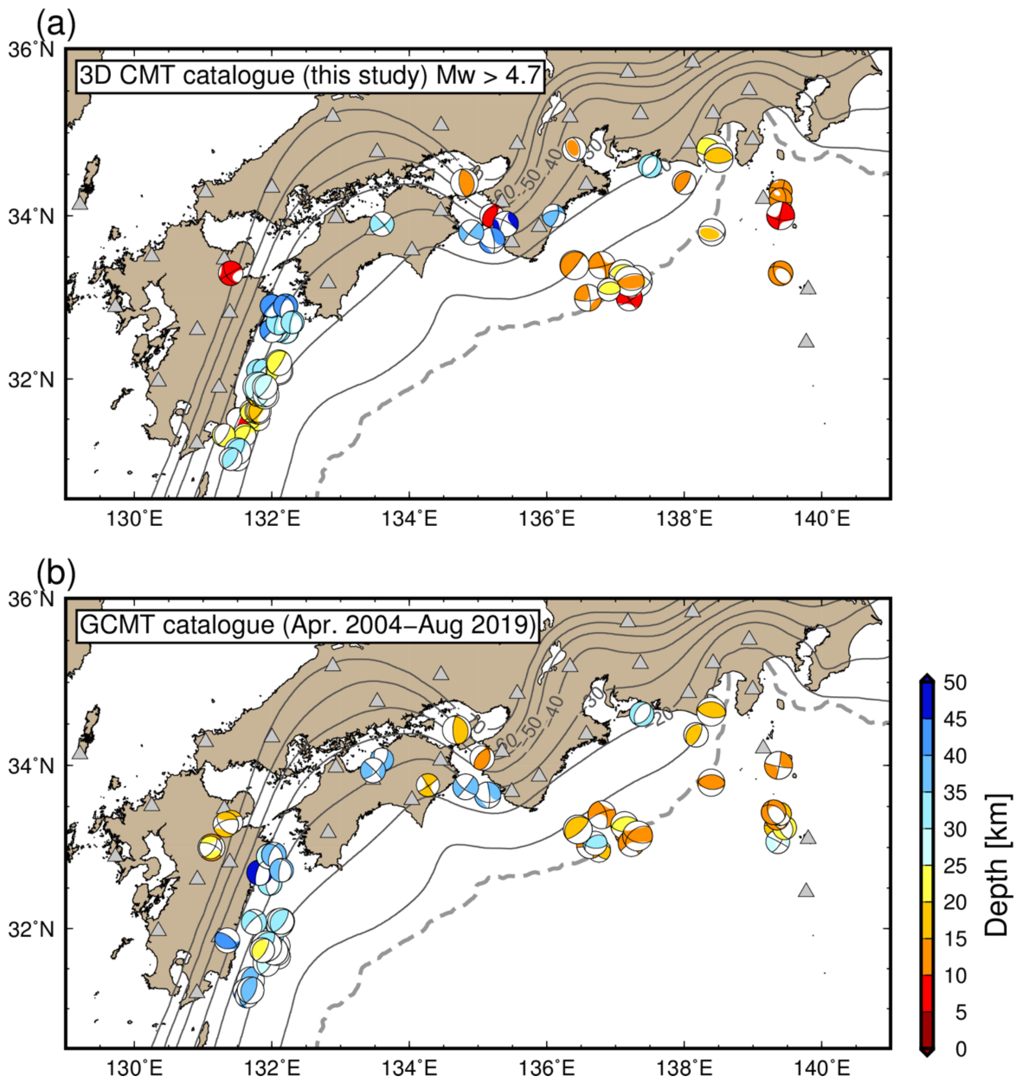

Figure S3. Similar as Figure 5 but for comparison with the GCMT catalogue. The *Mw* of plotted earthquakes in our 3D CMT catalogue is larger than 4.7, which is the lower limit of the GCMT catalogue (see Figure S1).

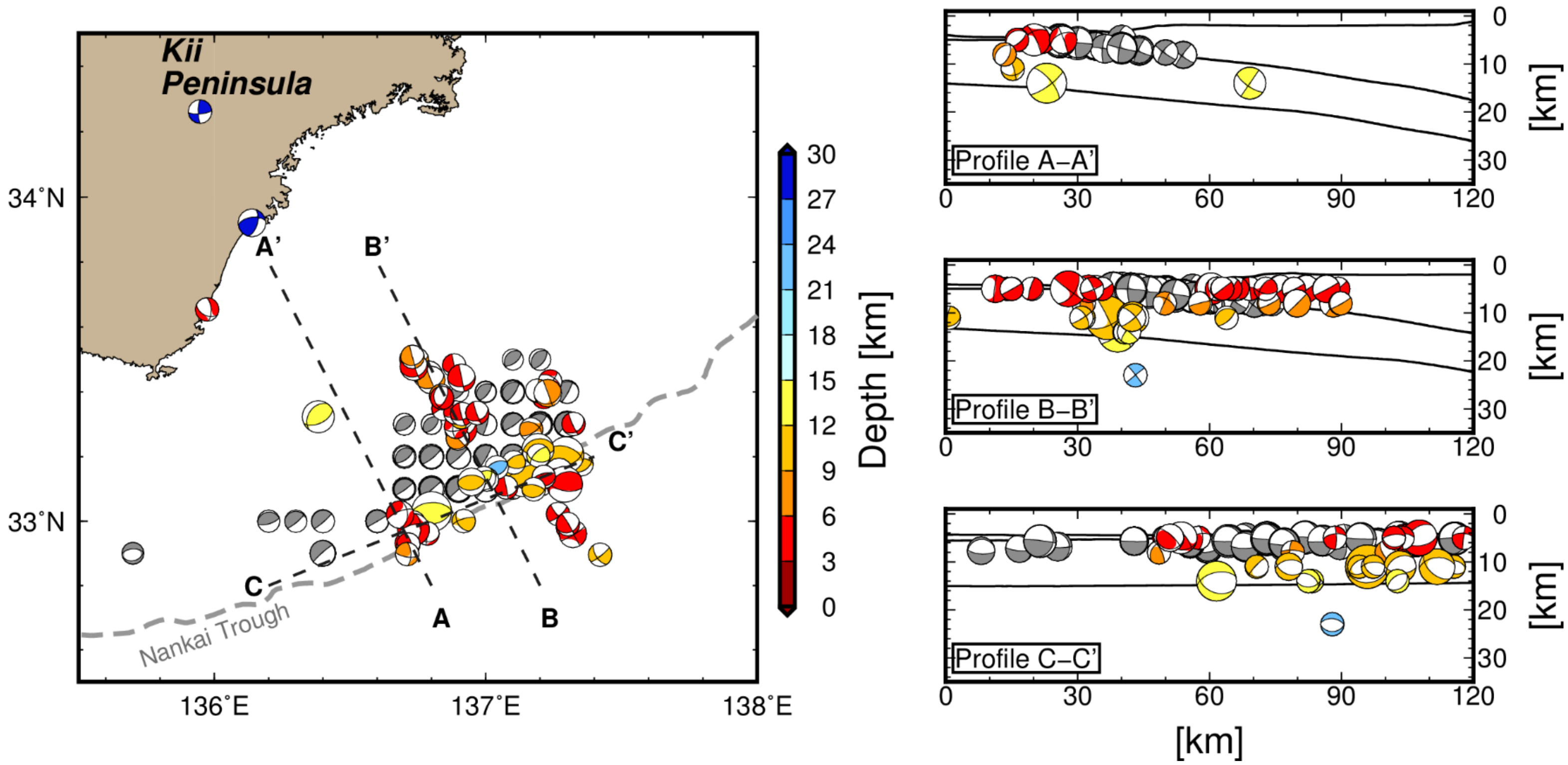

Figure S4. Spatial distribution of CMT solutions southeast of the Kii Peninsula. Coloured focal mechanisms are referenced from the F-net MT catalogue. Grey focal mechanisms are the CMT solutions of shallow VLFEs (Takemura, Matsuzawa et al., 2019). Right-hand panels show cross-sections along profiles of A, B and C. The bathymetry of ETOPO1 (Amante & Eakins, 2009), the upper surface, and the oceanic Moho of the Philippine Sea Plate (Koketsu et al., 2012) along each profile are plotted in the right-hand panels.

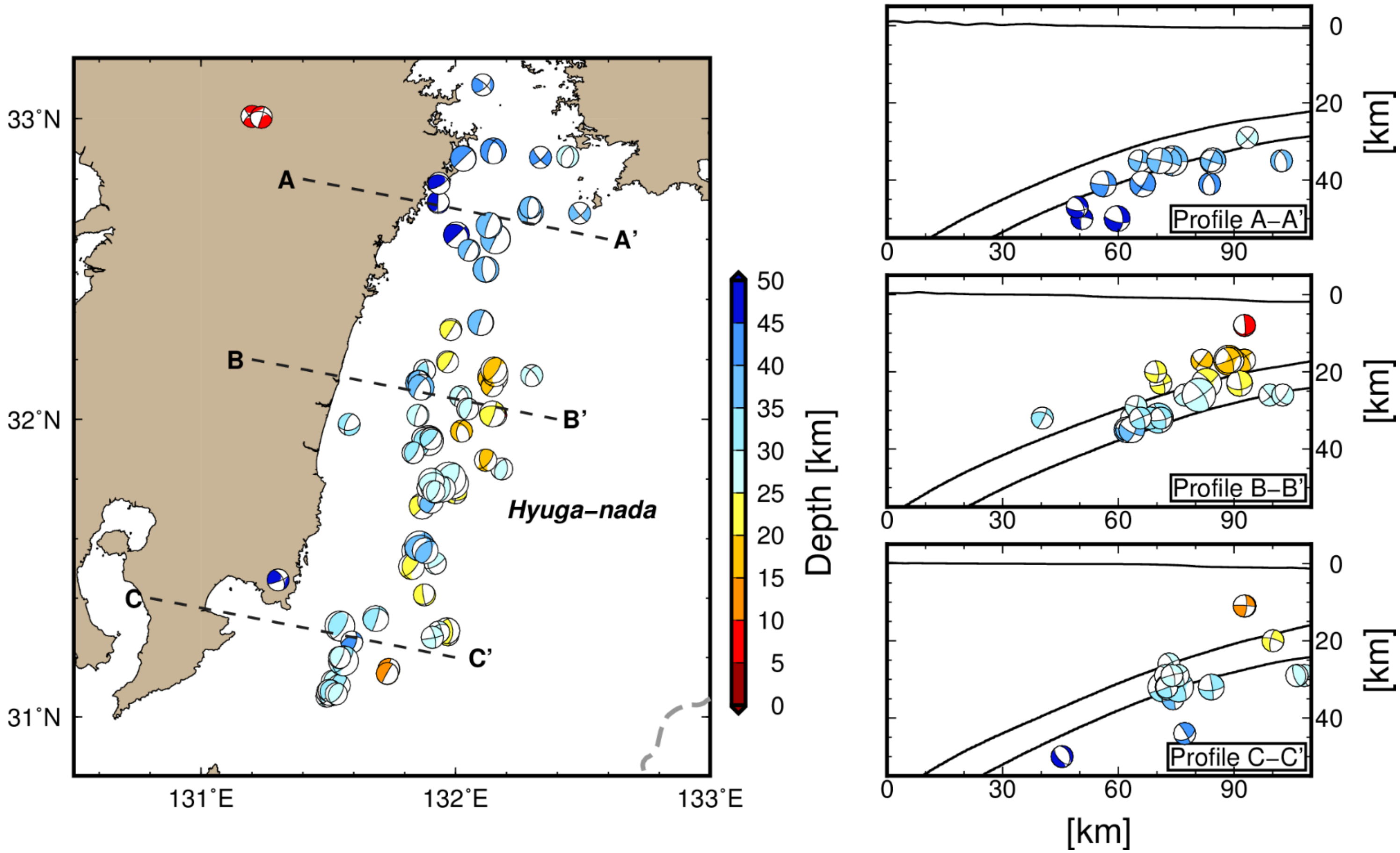

Figure S5. CMT results for the Hyuga-nada region.

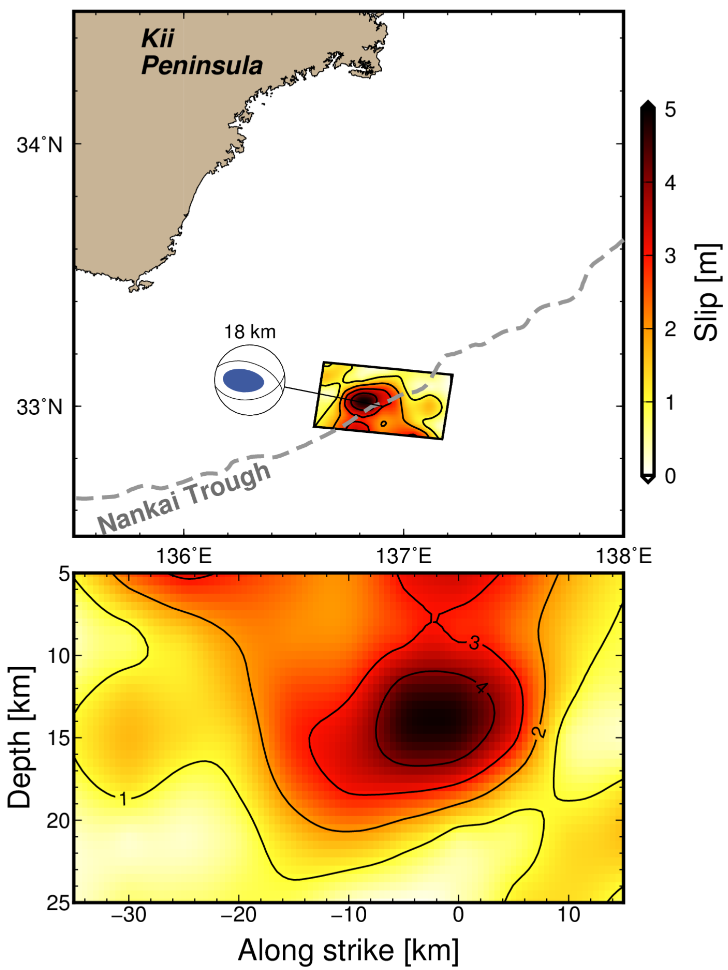

Figure S6. Comparison of the CMT results for the simulated *Mw* 7.2 southeast off the Kii Peninsula earthquake using the finite fault modelling (Okuwaki & Yagi 2018) solutions. In this CMT inversion, simulated seismograms using the finite fault modelling (Okuwaki & Yagi 2018) solution were used as observed seismograms. The bottom panel is the slip distribution of the finite fault model in the strike-depth plane.

Table S1. CMT solutions for all analysed moderate earthquakes.

Centroid time (UTC)	Lon.	Lat.	Depth [km]	M_{rr}	$M_{\theta\theta}$	$M_{\phi\phi}$	$M_{r\theta}$	$M_{r\phi}$	$M_{\theta\phi}$	Exp.	Mw	VR [%]
2004-04-21T07:26:30	132.3	33.5	38	-1.5100	-1.8500	2.9000	-2.4800	-1.2300	1.3700	22	4.34	67.45
2004-04-21T21:10:41	131.8	31.6	20	0.9760	0.2520	-0.3590	0.5200	0.6680	-0.2540	23	4.64	68.22
2004-04-21T21:20:52	131.8	31.5	24	1.9100	0.5570	-1.1000	0.7080	1.1300	-0.8800	23	4.84	78.46
2004-09-06T14:31:02	136.8	33.4	12	0.6040	-0.8920	1.5300	0.5790	0.5210	2.1800	24	5.55	82.86
2004-09-06T16:48:42	137.1	33.1	20	8.9900	-7.9500	0.5620	-0.1920	-2.1800	-2.2800	22	4.57	35.87
2004-09-06T17:59:37	136.9	33.5	14	0.0678	-0.5330	0.4660	0.0528	0.2790	0.9020	23	4.62	71.96
2004-09-06T20:06:48	137.1	33.6	8	1.5300	3.1600	-1.0500	2.1700	1.7800	-0.2500	22	4.32	65.56
2004-09-06T20:45:39	137.2	33.0	10	-0.3520	-2.4200	1.0300	-1.0300	-0.1840	1.0200	22	4.18	34.71
2004-09-06T22:49:05	136.8	33.4	14	-0.1690	-0.7280	0.9130	-0.4740	0.9630	0.8910	22	4.07	46.53
2004-09-06T22:59:28	136.8	33.5	12	0.5830	-2.8800	4.0400	-0.5310	1.2600	3.9300	22	4.42	77.34
2004-09-06T23:28:52	136.8	33.5	14	0.9900	-2.3300	3.3500	-1.0300	1.7300	2.6700	22	4.37	61.55
2004-09-07T00:35:45	137.0	33.1	8	0.7790	-2.0700	2.3900	-0.3200	3.3300	3.4900	22	4.42	66.03
2004-09-07T00:46:48	136.8	33.5	14	1.3300	-3.6700	5.5700	-1.6400	3.1700	4.4600	22	4.52	74.39
2004-09-07T00:54:35	136.7	33.5	16	-0.1140	-7.2000	6.7400	-1.2300	2.3000	6.3300	22	4.59	80.49
2004-09-07T01:10:05	136.8	33.4	14	0.5490	-3.1200	3.9500	-2.0500	3.9300	3.2200	22	4.48	77.42
2004-09-07T02:20:32	137.3	33.2	24	5.9200	-6.1500	0.2230	-1.5100	0.6320	-1.4300	22	4.47	76.12
2004-09-07T03:11:57	136.9	33.0	16	0.8740	-0.9970	0.2930	-0.7250	-0.0274	0.7540	23	4.70	78.61
2004-09-07T04:29:18	137.1	33.2	24	4.9000	-10.1000	0.6640	1.9100	-0.0017	-0.7360	22	4.54	68.2
2004-09-07T04:39:47	137.2	33.1	12	0.8410	-6.4300	2.4600	-0.1140	3.1000	0.3390	22	4.44	81.55
2004-09-07T04:59:32	136.6	32.9	8	0.7040	-1.2800	1.3200	1.2200	-0.9690	2.5300	22	4.28	59.12
2004-09-07T10:45:29	136.7	33.5	14	-0.0107	-0.7450	0.9020	-0.1830	0.3450	0.6880	23	4.64	78.17

2004-09-07T11:23:37	136.7	32.9	6	0.8930	0.5190	0.5580	4.0400	7.3800	3.1600	22	4.57	56.97
2004-09-07T14:02:48	136.7	33.5	16	-0.0584	-0.6920	0.8610	-0.2420	0.1940	1.2300	22	4.05	59.38
2004-09-07T17:29:41	137.3	33.2	24	4.3300	-11.2000	-0.4320	-1.4100	1.4000	-0.0673	25	6.56	81.44
2004-09-08T00:10:04	137.2	33.2	16	2.3000	-3.5800	-1.0400	-2.2200	-0.1920	-0.9520	23	5.00	82.86
2004-09-08T00:17:50	137.1	33.7	10	1.1100	2.1200	-1.0100	0.9700	0.8070	0.5910	22	4.17	51.85
2004-09-08T04:58:53	137.2	33.3	10	0.9130	-2.9700	5.0100	-0.3630	4.9100	3.5000	22	4.51	63.08
2004-09-08T05:56:30	137.0	33.4	12	-0.2580	-0.0829	3.1500	-1.0700	-2.4800	1.6200	22	4.32	42.47
2004-09-08T11:20:24	136.9	32.7	6	0.3250	-2.3400	2.6100	-1.2600	-2.5700	1.8700	22	4.35	67.83
2004-09-08T12:36:23	137.1	33.3	22	2.3700	-2.9700	-0.1930	0.9000	-0.2030	-0.1730	24	5.57	85.05
2004-09-08T15:02:14	137.1	33.6	8	1.2300	1.2300	-0.2840	1.6900	0.7740	0.0002	22	4.17	57.56
2004-09-09T08:40:10	137.2	33.0	8	0.1450	-1.4000	0.9040	-0.4990	0.2190	0.5310	24	5.36	85.86
2004-09-09T08:58:27	137.2	33.2	12	1.1200	-2.3800	0.2500	-0.3270	-0.3450	-0.2470	25	6.13	89.29
2004-09-10T20:05:57	136.6	33.0	10	0.0795	-0.4280	0.5350	0.4930	0.9040	2.1700	24	5.53	86.87
2004-09-12T03:05:58	136.7	32.9	10	0.2740	-1.3400	1.6600	-0.5860	2.0400	1.9200	22	4.27	83.36
2004-09-17T12:56:28	136.6	32.9	10	-0.5720	-0.4840	1.1900	2.8500	3.2900	4.2700	22	4.46	87.03
2004-09-18T18:48:38	136.8	33.5	12	0.1220	-0.6940	1.9900	0.1600	0.4740	2.5600	22	4.25	77.3
2004-09-20T14:17:51	137.2	33.6	8	0.4310	2.9600	-4.2100	2.2000	-0.4970	-1.3700	22	4.37	74.09
2004-09-28T09:37:43	137.3	33.0	10	0.4440	-1.9900	1.1600	-2.1800	1.1900	1.3100	22	4.28	83
2004-10-03T17:00:20	136.8	33.4	12	-0.2920	0.5230	3.2200	0.4630	0.2370	0.1240	22	4.18	71.88
2004-10-17T16:05:41	137.2	33.2	22	3.7600	-5.3300	1.0000	-1.2900	-2.6500	-1.9000	22	4.44	82.04
2004-10-28T06:27:30	135.2	33.6	34	-0.3740	-1.6700	2.2300	0.0469	-0.4460	-0.8680	22	4.16	69.66
2004-11-09T09:07:27	138.4	33.8	16	1.2800	-3.5400	-0.4050	-1.0100	0.6480	0.3660	24	5.58	82.93
2004-11-19T14:46:27	137.1	33.2	12	1.5700	-4.6800	-0.8920	-0.7280	-0.4220	-0.4780	22	4.31	80.91
2005-01-06T08:49:12	139.3	34.2	8	2.6600	-1.8000	3.3200	0.0929	0.5320	0.6500	22	4.29	53.42

2005-03-01T15:59:45	136.9	33.4	12	3.8000	-3.0200	7.6100	3.1300	1.8900	6.0700	22	4.59	84.06
2005-03-05T23:58:49	131.2	31.4	42	1.2400	-1.6700	1.4600	0.8400	1.2300	2.0300	22	4.26	64.99
2005-03-15T04:49:31	137.0	33.1	28	5.8700	-4.6000	-0.8160	-2.4000	-0.0550	-2.0400	22	4.46	82.27
2005-03-19T20:34:09	137.2	33.0	24	2.4000	-4.1300	0.0492	-0.3670	0.0348	-0.3640	22	4.29	64.7
2005-04-01T18:41:48	131.4	31.0	32	3.0500	-0.1300	-0.8730	1.1700	1.8200	-1.0400	22	4.28	68.09
2005-05-12T13:22:50	132.0	32.1	28	-0.6250	-0.0351	3.6100	1.3700	1.5400	0.5930	22	4.28	82.71
2005-05-26T05:31:29	132.3	33.4	46	-3.2300	-4.4200	7.2800	3.3400	2.2300	-1.7300	22	4.53	85.27
2005-05-27T12:17:18	133.7	34.0	36	-0.3810	-0.4810	1.0700	-0.4680	-0.3470	0.0844	23	4.61	89.65
2005-05-31T20:04:14	131.5	31.3	30	1.6900	0.7830	-0.3400	0.9510	0.8890	-0.3210	24	5.45	81
2005-11-01T21:47:34	135.1	33.8	46	-0.9580	0.6550	0.6100	-2.2700	-1.4100	1.1500	22	4.26	78.44
2005-12-03T19:39:01	137.0	33.1	26	8.7900	-8.7000	-4.0800	0.1430	0.8020	-3.3100	22	4.59	77.63
2005-12-03T20:01:21	137.0	33.1	28	4.3900	-7.3300	-4.8500	1.1900	1.4600	-4.1800	22	4.55	73.32
2005-12-11T03:32:08	132.0	32.0	26	1.5500	0.0063	-1.2300	1.2500	1.4500	-0.4200	22	4.19	76.16
2006-01-25T06:36:46	131.7	31.4	20	1.9700	-0.0443	-0.3050	1.0000	1.6100	-0.7570	22	4.20	67.21
2006-03-27T20:50:25	132.2	32.6	34	0.5430	0.3400	0.7660	0.6620	1.1100	-0.0280	24	5.38	86.62
2006-05-15T10:42:10	135.2	34.2	6	0.7870	0.3760	-3.2700	-0.0809	0.6340	-0.7800	22	4.21	86.19
2006-07-10T02:48:05	139.4	34.3	14	1.2700	0.2770	1.6400	-0.0862	0.1950	-0.8850	23	4.76	40.87
2006-11-18T10:08:35	132.0	31.9	32	-1.9100	-1.7900	5.5000	2.4100	-0.5070	-1.1900	22	4.41	75.13
2006-11-26T00:39:44	132.1	32.0	10	4.2400	0.7990	0.0740	2.6200	3.5400	-0.3240	22	4.42	60.13
2006-11-25T12:28:49	131.6	32.0	42	-0.3890	2.3300	0.9110	-0.1350	1.8300	1.9100	22	4.27	79.22
2006-11-25T11:49:31	139.4	34.2	12	0.4630	0.9330	1.4500	-0.6150	0.1020	-0.9650	23	4.75	67.16
2006-11-25T12:42:10	139.3	34.2	12	-1.7800	4.1300	2.8200	1.4000	-0.4390	-3.8400	22	4.43	69
2007-02-26T05:41:21	136.9	33.1	22	1.4000	-1.4700	-0.0424	0.6020	-0.2340	-0.1850	23	4.73	85.6
2007-03-24T01:20:52	136.9	33.4	10	0.2360	-0.7510	1.2100	0.2090	0.6620	1.3500	22	4.11	76.6

2007-04-15T21:19:28	136.4	34.8	14	1.9000	-1.1000	-3.3000	0.5050	0.7610	1.2400	23	4.94	71.68
2007-04-16T03:34:44	136.4	34.8	12	1.6900	0.0968	-2.4300	0.8840	-0.5490	0.1330	22	4.18	77.15
2007-04-26T18:02:54	133.6	33.9	34	0.5410	-3.3800	3.2000	-0.3530	0.9470	0.6560	23	4.96	88.57
2007-06-07T08:42:48	131.5	33.3	10	0.1110	1.2900	-0.4550	0.0837	0.3930	-0.2780	23	4.62	87.28
2007-06-08T02:22:14	131.5	33.3	8	0.6900	7.2800	-1.1500	0.3940	2.2100	-1.7100	22	4.45	84.5
2007-06-08T05:50:38	131.5	33.3	8	-0.3410	7.7300	-1.9500	-0.8060	2.8100	-1.6300	22	4.48	85.79
2007-07-17T02:24:17	135.9	34.3	38	0.1960	0.6830	0.2060	0.1410	-0.7580	-3.9000	22	4.34	61.32
2007-07-21T02:15:24	139.4	34.8	12	1.9700	0.9580	-0.2440	-1.0400	-1.0800	-3.2600	22	4.33	71.52
2007-07-31T19:22:39	131.9	32.2	26	1.9500	0.6120	-1.1400	-0.2330	0.8090	-0.4540	22	4.12	70.23
2007-08-19T19:21:54	138.6	34.0	50	0.5570	3.9900	-0.2680	3.3500	-6.0000	-2.0200	22	4.52	31.48
2007-10-21T11:09:26	131.9	32.2	28	2.3700	-0.8360	-0.5320	2.1100	3.3000	-1.3300	22	4.37	76.79
2007-10-22T18:35:59	139.1	34.2	14	6.5700	-0.7260	6.6900	-1.5000	2.5700	0.6990	22	4.51	83.03
2007-11-30T05:17:47	131.9	32.7	44	0.8450	-0.0984	2.3800	0.5950	4.0000	1.1800	22	4.37	83.26
2007-12-23T11:49:05	131.6	31.2	26	0.7680	-0.0350	0.6130	0.2310	1.0000	-0.6550	23	4.70	69.39
2008-03-10T19:44:30	131.8	31.8	18	3.1300	0.0972	-0.2790	1.7700	2.7100	-0.8190	23	5.00	75.47
2008-04-23T03:07:19	131.4	31.0	28	0.3990	-1.4000	-0.4010	-1.2200	-1.0600	-1.7300	22	4.21	54.25
2008-04-23T03:26:10	131.5	31.0	24	1.0200	-0.4460	0.8440	-1.0300	-0.8560	-0.9920	22	4.13	62.9
2009-04-06T03:36:27	131.9	31.9	26	1.6000	0.3630	-0.2710	0.9720	1.2800	-0.3600	24	5.47	78.17
2009-04-06T03:53:17	131.8	31.9	28	1.3600	0.3350	0.5540	0.9970	1.3700	0.4610	22	4.14	37.31
2009-05-26T05:26:20	137.8	34.7	28	0.4350	-4.6400	4.5700	-0.1080	1.6200	0.7650	22	4.40	82.58
2009-06-15T04:17:53	132.1	33.1	50	1.0400	-1.9200	3.5000	-0.3130	1.8300	0.0194	22	4.29	78.16
2009-06-20T13:22:17	135.0	32.9	6	0.9780	-0.4630	-0.0802	1.8300	0.9460	-0.3280	22	4.16	76.56
2009-07-23T08:51:00	134.3	33.0	16	2.0000	-2.1600	-1.5300	3.9200	5.1600	-1.5800	22	4.50	77.36
2009-07-28T14:30:54	131.8	32.0	32	0.3260	1.3800	2.5300	0.8300	1.4600	0.5420	22	4.22	77.51

2009-08-05T21:51:13	132.1	32.6	34	-0.6180	0.4690	2.1400	0.0996	1.1400	0.0227	23	4.80	85.05
2009-08-11T14:07:08	138.4	34.8	22	2.3400	-1.9500	0.5600	1.0700	0.7670	0.9580	25	6.22	79.55
2009-10-29T11:37:08	132.0	32.4	32	0.3630	4.3700	8.6200	2.2600	5.8200	0.9270	22	4.58	80.96
2009-12-16T23:12:50	133.4	33.2	30	0.7220	-3.7400	4.2200	-2.6800	-0.1910	-0.0985	22	4.39	69.81
2010-02-05T02:41:58	131.5	31.5	10	-2.2300	-0.2730	-0.3570	-0.9350	-1.8500	0.0247	22	4.21	61.72
2010-02-05T05:30:08	131.5	31.5	8	-0.7890	-0.1860	-0.3460	-0.5180	-1.2800	0.0114	23	4.72	65.27
2010-02-05T05:35:21	131.5	31.1	28	-0.5990	-0.2270	-1.4200	-0.5510	-1.7100	-0.9070	22	4.17	33.1
2010-03-05T15:49:55	139.5	33.8	16	-0.1790	-2.5100	3.7300	0.6980	-0.0789	-2.2300	22	4.33	69.12
2010-04-17T14:34:55	132.5	33.6	40	-2.3500	0.7910	2.2700	1.3300	-0.9060	-1.1100	22	4.26	84.9
2010-04-18T06:24:06	132.4	32.9	32	-2.1800	0.6880	3.2000	0.4310	-0.2830	0.8580	22	4.25	51.64
2011-01-17T05:33:22	133.8	34.0	36	-0.1260	-3.5100	3.7600	-0.6940	0.9810	4.8400	22	4.46	78.87
2011-02-01T11:32:24	132.0	31.7	22	0.8540	-0.3790	-0.5040	0.2120	0.5490	-0.6000	22	3.97	62.9
2011-02-05T03:11:23	131.5	31.0	32	2.7500	0.1790	-1.0300	0.9620	0.8370	-0.6420	23	4.87	68.85
2011-02-28T18:04:33	131.8	32.1	34	-0.4780	0.4270	2.0200	0.7020	0.9010	0.3580	23	4.79	78.53
2011-03-13T07:11:01	136.8	33.0	10	0.5130	-0.8780	6.0500	3.2200	1.0900	8.0300	22	4.59	52.28
2011-07-06T04:18:41	135.2	34.0	8	2.8800	-0.1930	-1.9900	-0.0750	1.2100	-1.4300	23	4.93	86.46
2011-07-06T04:34:53	135.2	34.0	8	2.2300	-0.3010	-1.8600	0.1840	1.1000	-1.1500	22	4.21	75.28
2011-07-25T08:32:11	136.1	34.0	38	1.2500	-0.6200	-0.0724	-0.4360	0.8300	-1.3200	23	4.79	78.51
2011-08-02T08:58:12	138.5	34.7	18	8.7200	-8.3200	-0.4010	4.6400	0.4010	0.2340	24	5.93	81.6
2011-08-12T13:37:45	138	34.4	10	1.7300	-0.5450	-1.1900	1.0100	1.5400	-0.7180	23	4.87	76.42
2011-08-28T18:52:02	131.2	31.0	30	5.5100	-0.3220	0.3930	1.8000	3.4000	-1.3800	22	4.44	70.95
2011-10-11T04:19:27	134.1	34.0	38	-1.8000	-0.9610	3.3900	-2.5100	1.3900	-0.4370	22	4.34	55.4
2012-01-30T12:18:20	132.0	32.6	44	0.6040	-0.4710	1.1500	2.0800	1.8100	-0.2870	23	4.91	84.49
2012-02-09T21:55:14	131.6	31.3	24	1.5200	-0.1100	0.0839	0.5160	1.1200	-0.6240	23	4.76	77.61

2012-02-29T10:23:01	131.9	31.8	18	0.9930	0.2130	-0.2410	0.5610	0.6860	-0.2020	23	4.65	70.72
2012-03-01T04:33:32	131.8	31.6	18	1.6200	0.6990	-0.7530	1.1600	2.8400	0.0018	22	4.28	72.98
2012-05-14T21:36:43	131.7	31.6	24	1.2300	-0.2870	0.0972	0.5740	0.9540	-0.5520	23	4.72	82.78
2012-06-20T12:35:32	132.3	32.1	30	-1.6900	-1.1000	3.3300	1.7200	-0.7720	-0.2970	22	4.28	68.9
2012-10-10T14:49:33	132.5	32.7	26	-0.1940	-4.5100	4.0800	-0.5900	0.4700	0.8570	22	4.37	80.93
2012-10-26T10:54:13	131.9	31.9	28	6.9100	-0.5030	-2.2800	3.7600	3.0000	-2.4500	22	4.52	74.92
2012-10-27T13:44:35	133.5	33.5	32	0.2950	-2.8700	3.2900	2.0400	-0.4650	-0.1490	22	4.32	78.78
2012-12-23T00:15:28	132.3	33.6	44	-2.2800	1.1800	3.8100	0.0741	1.6400	-0.4460	22	4.31	74.72
2013-03-12T03:34:51	131.8	31.6	22	1.0500	0.2970	-0.4430	0.5970	0.7460	-0.2560	24	5.34	74.59
2013-03-12T03:59:44	131.8	31.6	18	1.5200	0.3480	-0.3950	0.8020	0.9360	-0.2940	23	4.75	68.12
2013-04-13T14:33:17	134.8	34.4	14	3.2300	-0.0934	-4.0200	0.1170	-1.9900	0.7870	24	5.68	86.62
2013-04-17T19:15:22	139.4	34.1	12	3.3400	0.5930	-5.9100	-3.6200	0.7030	-4.9700	22	4.53	26.36
2013-04-17T20:13:57	139.5	34.0	6	2.5100	4.8900	-1.6900	1.3000	-0.0078	-6.0300	22	4.51	62.63
2013-04-17T20:16:18	139.4	34.1	10	-1.5600	3.7900	-2.3900	-1.1400	-1.6500	-4.9700	22	4.47	32.05
2013-04-17T21:22:12	139.4	34.1	10	0.0273	0.8930	-0.6150	-0.3640	-0.2790	-0.9960	23	4.68	75.46
2013-04-18T02:57:36	139.4	34.0	8	0.9590	-1.0200	2.1000	-0.2260	-2.0000	-4.3200	24	5.74	78.29
2013-06-10T19:11:01	139.4	33.2	10	1.8000	0.4650	1.0300	-1.5100	0.7290	0.1010	22	4.17	41.52
2013-08-03T18:56:13	137.5	34.6	32	-1.4300	0.9170	1.7500	-0.2710	-0.2480	0.7870	23	4.79	78.63
2013-08-18T17:00:59	139.4	33.3	12	0.1380	0.1800	0.4230	-0.1540	0.4480	-1.2100	23	4.69	74.86
2013-08-31T02:32:24	135.9	33.7	8	-1.4700	0.3350	2.0900	-0.1970	-0.5020	-1.8300	22	4.21	76.14
2013-09-28T13:37:47	131.5	31.2	28	1.7700	-0.7440	0.0424	0.1470	1.0500	-0.7720	22	4.12	58.21
2013-10-09T05:45:21	131.9	31.8	20	4.5900	0.5480	-1.4400	3.0400	3.6200	-1.4600	22	4.45	62.64
2013-12-12T20:25:13	131.2	31.2	30	-2.0100	0.9670	2.8600	-2.6700	-3.8600	-0.0001	22	4.42	48.1
2013-12-29T19:17:49	139.5	33.3	50	-0.8930	1.2000	3.9800	-3.3700	1.6700	-6.9600	22	4.55	48.6

2014-03-13T16:35:53	131.4	31.0	26	4.0700	0.1290	-1.5800	1.0800	0.8840	-1.5900	22	4.32	63.2
2014-04-04T09:46:42	132.1	32.5	34	0.6020	2.1100	3.9100	1.7600	2.7200	0.7310	22	4.37	74.38
2014-05-29T18:17:59	139.4	33.3	14	-5.2900	3.4200	3.5200	1.5200	-0.5440	-3.0200	22	4.46	72.95
2014-08-29T13:14:35	132.1	32.1	22	2.7700	-1.0100	-0.6080	2.3900	4.5000	-1.8200	24	5.78	82.64
2014-08-29T13:32:03	132.1	32.1	22	3.0400	-0.5990	-0.9730	4.1700	5.2600	-1.7000	22	4.51	45.04
2015-01-02T10:14:06	131.9	32.1	32	0.7340	1.1600	1.9300	0.4440	2.4600	0.1780	22	4.25	79.54
2015-01-31T01:45:54	131.8	31.8	18	4.8100	1.2500	-1.4400	2.9100	3.5800	-0.6980	22	4.45	64
2015-02-06T19:25:10	134.4	33.8	10	0.1400	0.9420	-0.9130	-0.1330	0.2550	-0.4570	23	4.62	85.96
2015-04-19T03:34:54	132.1	32.0	16	0.6220	-0.0366	-0.1890	0.5430	0.7160	-0.1400	23	4.61	70.71
2015-05-20T00:13:18	139.4	34.4	14	1.3100	1.0700	2.6300	-0.0486	0.0517	-4.1800	22	4.38	70.38
2015-05-26T10:35:21	131.9	31.8	22	2.5200	0.0556	-1.5400	1.5700	1.5700	-0.6770	22	4.26	65.76
2015-06-07T01:28:12	139.3	33.0	10	-1.9700	-0.5750	2.1800	0.7020	2.7700	-4.5800	22	4.44	69
2015-07-14T00:52:34	131.8	31.4	28	-1.8300	-0.5050	4.9800	-0.2720	4.7100	1.8100	22	4.47	42.29
2015-07-16T01:18:46	139.2	33.2	12	2.7700	0.3240	4.2400	-2.7500	3.6600	-0.3660	22	4.44	44.73
2015-07-19T11:13:42	131.3	31.3	20	-1.3000	-0.0173	0.6100	-0.8220	-0.9840	0.1300	23	4.74	67.6
2015-07-25T02:53:33	132.4	33.4	40	-4.5800	1.2200	7.4000	0.3360	4.3800	-0.2900	22	4.52	86.6
2015-08-22T01:54:34	132.2	33.3	44	-2.5300	1.6200	4.2100	1.6500	2.2500	1.1500	22	4.38	81.54
2015-08-26T16:51:35	131.9	32.1	34	-1.3000	-0.4380	3.9000	2.4100	1.4700	1.3700	23	5.02	82.74
2015-09-03T01:07:46	134.6	33.3	12	-2.8600	1.7300	1.2900	-0.5470	1.9300	-1.7600	22	4.31	76.71
2015-09-09T05:22:38	138.4	34.7	18	1.2900	-0.4620	0.3680	1.2300	2.2300	4.1400	22	4.40	81.52
2015-12-25T20:20:35	134.5	33.5	32	0.0457	-2.4100	2.6200	-0.6620	0.5150	0.1980	22	4.22	77.08
2016-04-01T20:39:08	136.4	33.4	10	3.7900	-1.4100	-0.6440	5.7600	7.4300	-1.5500	24	5.93	80.84
2016-04-16T16:11:36	131.4	33.3	6	1.5300	4.1900	-1.1700	1.5600	1.1500	-1.4700	23	5.01	83.35
2016-04-16T23:03:55	131.2	33.0	6	0.8010	3.7800	-3.2200	0.3090	1.3600	-1.0300	22	4.33	70.96

2016-04-22T08:20:36	134.3	33.5	30	-0.2900	-3.1100	4.2500	0.4440	0.2300	-0.3540	22	4.32	76.54
2016-04-30T00:09:33	131.4	33.3	6	0.4920	3.7800	-2.2400	1.0300	0.4920	-1.0100	22	4.29	63.2
2016-05-17T02:50:19	131.8	31.8	18	1.7900	0.2350	-0.2700	1.0200	1.3700	-0.3590	23	4.82	73.74
2016-07-12T00:22:00	139.4	33.3	14	-0.5700	1.7900	2.4600	0.6470	0.9710	-1.1000	23	4.89	80.29
2016-07-12T01:58:33	139.4	33.3	14	-2.9800	2.9000	3.2300	1.9700	1.2100	-1.9900	22	4.39	76.06
2016-07-12T02:33:01	139.5	33.2	10	-2.3100	2.5100	2.1900	1.7600	1.0200	-1.7900	22	4.33	58.82
2016-07-12T02:39:39	139.4	33.3	14	-0.5620	2.1100	2.6900	1.2300	0.6250	-1.4000	22	4.26	61.52
2016-07-12T04:31:10	139.4	33.3	14	-1.7100	1.9700	2.7800	1.0100	0.9590	-1.3800	22	4.28	70.48
2016-07-12T14:54:19	139.5	33.3	14	-1.2000	0.3680	0.7810	0.4930	-0.1700	-0.6490	23	4.68	80.11
2016-07-12T15:56:51	139.4	33.3	12	-3.5400	0.9930	3.5400	2.2700	-1.0900	-2.4300	22	4.40	73.1
2016-07-12T16:34:01	139.4	33.3	12	-2.5500	6.2000	5.5900	2.0900	2.5600	-4.3500	22	4.54	75.36
2016-07-13T15:24:51	139.5	33.2	12	-1.1500	2.8200	2.5200	1.0000	0.6950	-1.7300	22	4.30	57.3
2016-07-14T20:05:55	139.4	33.3	14	1.2900	2.5400	2.9600	0.8120	1.1500	-1.1000	22	4.29	20.44
2016-07-14T20:07:06	139.4	33.3	14	-1.0800	3.6400	4.3000	1.5800	1.4800	-2.2600	22	4.41	49.93
2016-07-14T20:17:26	139.4	33.3	12	-2.8500	3.1000	3.0200	1.4000	1.1700	-2.2100	23	5.05	80.29
2016-08-11T01:25:56	131.8	31.8	18	2.0200	0.0648	-0.0248	1.2900	1.9600	-0.4920	22	4.23	69.61
2016-10-22T12:33:44	131.9	32.8	50	3.7400	-4.4500	0.0375	4.7300	3.1400	-0.5440	22	4.50	83.13
2016-11-06T01:57:32	131.9	31.8	18	3.9600	0.6410	-0.3670	1.9800	2.6500	-0.6890	22	4.36	73.58
2016-11-19T20:48:00	135.4	33.9	48	-4.8700	-5.3000	6.4500	2.7200	-0.4450	-5.7800	23	5.25	87.65
2017-02-08T01:21:50	131.5	31.5	18	-1.4600	0.3990	-0.5350	-0.5660	-1.9700	0.0394	22	4.18	56.09
2017-02-08T12:19:26	134.6	33.4	32	0.0980	-2.2400	2.6200	-1.0400	0.3670	-0.7230	22	4.23	77.81
2017-03-03T08:53:42	132.1	32.7	34	-0.4610	2.3400	7.3400	1.5100	4.2700	0.7860	23	5.17	79.75
2017-06-17T07:39:50	131.8	31.9	26	4.4700	0.4820	-1.6800	2.9400	3.2200	-1.3000	22	4.44	80.08
2017-06-21T08:27:39	132.0	32.9	40	0.2360	0.5780	1.3100	1.2700	1.3700	0.6920	23	4.83	81.36

2017-07-02T09:58:21	131.3	33	10	-1.6700	1.9300	-1.3400	0.0344	-1.3000	2.6200	22	4.30	79.73
2017-09-20T03:33:07	132.3	33.4	40	-2.0300	0.9110	2.7200	0.0234	1.3100	-0.8110	22	4.24	78.71
2017-12-05T01:54:11	131.9	32.2	30	0.7080	-0.7160	1.0100	0.7960	1.6400	-0.2400	22	4.15	80.68
2018-01-09T14:51:52	131.8	33.2	40	-0.8680	-4.0500	-0.2880	1.4800	2.8800	-1.4000	22	4.37	29.96
2018-02-19T12:31:36	132.2	32.9	40	-2.4600	-0.1980	3.8100	1.7600	1.4800	-0.2860	23	5.00	84.71
2018-04-23T14:49:36	139.2	34.3	10	4.6400	1.4400	5.3800	0.9050	0.2380	-0.7390	22	4.41	77.28
2018-04-28T22:27:33	131.9	32.0	6	-4.4100	-1.9800	0.1830	-3.7800	-4.5300	0.0852	22	4.49	68.74
2018-06-12T13:54:20	131.5	31.1	30	2.0100	0.1340	-0.5320	0.6840	1.1400	-0.5430	24	5.48	74.03
2018-10-05T02:20:52	131.2	31.0	30	8.6400	-0.6640	0.1650	2.2500	4.7300	-2.2400	22	4.55	68.18
2018-11-03T01:53:53	135.2	33.7	40	-0.4100	0.0548	0.4150	0.2260	-0.6330	-0.8110	24	5.30	89.27
2018-11-05T17:19:13	135.3	33.7	46	-0.9130	-4.3300	4.4300	2.1900	-1.7500	-4.0400	22	4.48	81.7
2019-01-22T08:17:07	132.4	32.9	28	0.0827	-1.7100	1.7500	-0.2720	0.2710	0.3020	22	4.10	74.62
2019-03-12T00:37:48	132.7	33.2	34	-0.3650	-0.8620	1.0900	0.3180	0.2010	-0.5390	23	4.66	79.17
2019-03-13T22:48:46	134.9	33.8	38	0.2280	-6.3100	5.0700	-0.8290	-1.8600	-1.6400	23	5.13	84.24
2019-03-27T18:11:22	132.1	32.1	22	3.7800	-1.4500	-1.7600	3.2600	6.4300	-2.7900	23	5.21	83.68
2019-03-28T00:38:03	132.1	32.2	22	4.5800	-0.4790	-1.9300	4.6800	7.6100	-2.3900	23	5.26	84.47
2019-04-23T16:49:49	131.2	31.3	24	-1.8200	0.0989	0.5650	-1.2600	-2.2800	-0.0562	22	4.24	73.07
2019-05-10T16:43:23	131.9	31.8	20	3.2900	0.2030	-0.9640	2.1500	2.7900	-0.7340	24	5.69	73.07
2019-05-10T17:48:45	131.8	31.9	26	1.4000	0.1140	-0.5820	1.1400	1.5300	-0.4370	25	6.17	80.1
2019-05-10T18:07:36	131.9	31.8	26	2.5400	0.4640	-1.4000	0.9410	0.9770	-0.1030	23	4.86	50.82
2019-05-10T22:53:52	131.9	31.8	22	2.7100	1.2700	-1.6300	2.0200	1.1000	-0.8500	22	4.29	47.78
2019-05-11T05:40:37	131.8	31.8	28	4.2100	-2.7500	-2.5600	2.6500	5.0600	-2.0400	22	4.51	77.56
2019-05-11T17:59:38	132.3	32.7	32	-0.2330	0.2990	1.4400	0.3300	1.3200	-0.1170	23	4.76	87.79
2019-05-13T00:07:41	132.3	32.7	32	-0.9350	0.6150	2.5100	0.2610	1.9400	-0.0225	22	4.23	77.08

2019-06-19T20:35:44	131.2	31	32	3.8600	-0.1390	0.3560	1.2000	2.9300	-0.7980	22	4.35	58.62
2019-07-27T11:11:46	131.8	31.6	24	2.7700	-0.5160	0.8590	1.4300	2.5800	-1.4700	22	4.33	80.01
2004-04-21T07:26:30	132.3	33.5	38	-1.5100	-1.8500	2.9000	-2.4800	-1.2300	1.3700	22	4.34	67.45

Table S2. CMT solutions for the *Mw* 7.2 and 7.5 earthquakes.

Centroid time (UTC)	Lon.	Lat.	Depth [km]	M_{rr}	$M_{\theta\theta}$	$M_{\phi\phi}$	$M_{r\theta}$	$M_{r\phi}$	$M_{\theta\phi}$	Exp.	Mw	VR [%]
2004-09-05T 10:07:12	136.7	33.1	26	0.4435	-7.6109	-2.2143	-0.331	0.4022	0.3545	26	7.10	71.76
2004-09-05T 14:57:43	137.0	33.2	20	0.6117	-1.3773	-0.0418	-0.3787	0.1300	0.1093	27	7.31	71.83