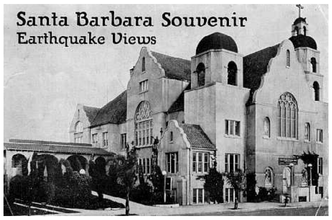

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BROADBAND GROUND MOTION SIMULATION FOR GREAT INTERPLATE EARTHQUAKES WITH MULTI-SCALE HETEROGENEOUS SOURCE MODELING

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ABSTRACT

Broadband ground motions are estimated in the Kanto sedimentary basin for anticipated great interplate earthquakes along surrounding plate boundaries. Possible scenarios of the great earthquakes along the Sagami Trough are modeled combining characteristic properties of the source area and adequate variation in source parameters so as to evaluate possible ground motion variation due to a next Kanto earthquake. South to the rupture area of the 2011 off the Pacific coast of Tohoku earthquake along the Japan Trench, we consider a possible M8 earthquake. Ground motions for these earthquake scenarios are computed with 3D FDM for lower frequency range and a stochastic Green's function method for higher frequency range. In addition, the response of the alluvium and diluvium layers is computed with the equivalent linear method. A comparison of ground motion distributions in the Kanto basin from the various earthquake scenarios suggests that source parameters which largely change the ground motion level in a wide area, first, the average stress drop, and, second, hypocenter location. The 1923 Taisho Kanto earthquake gives a ground motion distribution close to the severest among all those generated by the earthquake scenarios considered in this study. The Off Boso Peninsula earthquake scenarios do not yield high intensity on the land, similar or less compared to the observed intensity for the 1987 Chiba-ken Toho-oki earthquake (M6.7).

INTRODUCTION

Two oceanic plates are subducting beneath the Kanto Basin; the Philippine Sea Plate is subducting at the Sagami trough beneath the North American Plate from the south, and the Pacific Plate is subducting at the Japan trench beneath the Philippine Sea Plate and the North American Plate from the east. Both of the subduction zones can be source areas of interplate earthquakes.

The Kanto earthquake is a M8 class, interplate earthquakes occurring on the upper surface of the subducting Philippine Sea Plate along the Sagami Trough. The source area is located beneath the Kanto region at a depth ~30km making the Kanto earthquake rather shallow and potentially destructive earthquake. Historically, two Kanto earthquakes are known, the 1923 Taisho Kanto earthquake and the 1703 Genroku Kanto earthquake. The 1923 Taisho Kanto earthquake caused tremendous damage including 105,385 fatalities and 297,387 building collapses. A similar destructive earthquake is considered likely to occur in the reasonably near future since the estimated recurrence period is about 200 years from the interval between the latest two events.

The Off Boso Peninsula earthquake is a M8 class, interplate earthquake we anticipate to occur on the upper surface of the subducting Pacific Plate far off Boso Peninsula. In this region, no M8-class earthquake but some earthquakes with magnitude less than M7.5 are observed since Meiji era (1868~). However, from historical record, an M8-class earthquake in 1677 is suggested (Usami, 2003). This region is south next to the source area of the 2011 off the Pacific coast of Tohoku earthquake (M9.0), and there, the shear stress on the plate boundary is expected to have increased by the earthquake.

In this study, we predict the ground motion and its variance due to the anticipated Kanto and Off Boso earthquakes by ground motion simulations with various earthquake scenarios involving adequate variation of source parameters. We consider that earthquakes occurring repeatedly in a certain source area share some inherent characteristics closely related to its tectonic setting, but at the same time show certain variation substantial for nonlinear process in complex system. Therefore, for the anticipated Kanto earthquakes, we assume that the asperity distribution of the 1923 Taisho Kanto earthquake estimated by the waveform inversions is the inherent characteristics and that the other source parameters (e.g., stress drop, rupture velocity, etc) are variable. For the anticipated Off Boso Peninsula earthquakes, as no information indicating its asperity distribution is available, we construct earthquake scenarios borrowing the asperity distribution of the Taisho Kanto earthquake. In order for the broadband ground motion simulation due to the mega earthquakes, we follow the broadband source modeling method by Sekiguchi et al. (2008) and Sekiguchi and Yoshimi (2011). Sekiguchi and Yoshimi (2011) succeeded in reconstruction of the broadband ground motion due to the 1923 Taisho Kanto earthquake by introducing multi-scale heterogeneity to an inverted source model.

EARTHQUAKE SCENARIOS

Scenarios for the Kanto Earthquakes

A bunch of source scenarios are constructed fixing the area of the asperities based on the source model of the 1923 Taisho Kanto earthquake (Sato et al., 2005), considering possible combination of their activation, and varying the source parameters within a certain ranges supported by stochastic analysis of source properties.

The area for the Kanto earthquakes includes 1) the source area of the Taisho Kanto earthquake, which also ruptured during the Genroku earthquake (fault A), 2) to the southeast of the fault A, beneath the southern tip of the Boso Peninsula, which ruptured during the Genroku earthquake but not ruptured during the Taisho Kanto earthquake (fault B), and 3) to the east of fault B, far off Boso Peninsula (fault C) (Fig.1). The fault A is modeled following Sato et al. (2005) and the fault B following Shishikura et al.(2004). The fault C which is indicated from tsunami data (e.g., Matsuda et al., 1974; Shishikura et al., 2004) is omitted in this study because its contribution to the ground motion on land is relatively very small compared to those of the faults A and B.

On these fault planes, inherent asperities are assumed; two on the fault A (a1 and a2), one on the fault B (b) (Fig.1). Asperities a1 and a2 in this study are based on Sato et al. (2005) but two asperities are common among the source models of this earthquake (Wald and Sommerville, 1995; Kobayashi and Koketsu, 2005; Sato et al., 2005). Only the average slip amount is estimated for the fault B. We borrow a part of the asperity a2 and modify the total slip amount and slip direction to construct asperity b.

The variable source parameters we set are the average stress drop (“average” means “the average on the fault”), the average rupture velocity (“average” means “the average on the fault”), the hypocenter location, and multi-scale heterogeneities.

Variation range of the average stress drop is based on the empirical relation between magnitude and the rupture area. Murotani et al. (2008) compiled inverted source models of interplate earthquakes to find a scaling relation between magnitude and the rupture area. As the coefficient of this scaling relation involves the average stress drop, we can transfer the derived scaling relation and its variance to the average of the average stress drop and its variance. In this study, we make source scenarios with the average stress drop of average and average +- 1 SD (standard deviation) of the interplate earthquakes, values estimated for the Taisho Kanto earthquake and for the Genroku Kanto earthquake (for the fault B) (Table. 1). Note that the average stress drop on the fault B for the Genroku earthquake derived by Shishikura et al. (2004) is extremely large compared to the average +1 SD of the interplate earthquakes by Murotani et al. (2008).

For the average rupture velocity, Yamada et al. (2007) derived the average and SD to be respectively 0.694Vs and 0.078Vs based on the compilation by Miyakoshi and Petukhin (2005), although the compilation was done for intraplate earthquakes. We set the S-wave velocity at the source area as 3.7km/s. In this study, we make source scenarios with the average rupture velocity of average and average +- 1 SD (standard deviation), and the value derived for Taisho Kanto earthquake (Table. 1).

About the hypocenter position, there is no reliable data to locate hypocenters of the future Kanto earthquakes other than the hypocenter of the Taisho Kanto earthquake. Therefore, we set hypocenters considering their influence on the ground motion distribution. We selected a point in the eastern part of the fault A, on the southeast of the asperity a2, as a hypocenter that may cause the largest forward directivity effects to the land area.

In order for broadband ground motion predictions, we construct earthquake scenarios following Sekiguchi and Yoshimi (2011). First we prepare an initial source model by changing the above-mentioned source parameters of the inversion source model (Sato et al., 2005). Then, multi-scale heterogeneity is introduced in both the slip distribution and the rupture velocity distribution of the initial source model randomly to realize the empirical source features of the k-2 spectrum of slip distribution (Mai and Beroza, 2002) and the fluctuations of rupture velocity on a fault (Miyakoshi and Petukhin, 2005). Slip velocity time functions are calculated following Nakamura and Miyatake (2000) for each point on the fault considering the spatially variable slip, stress drop and rise time.

Fig. 1 illustrates the fault and asperity model and several of the earthquake scenarios. Fault planes are curved and at 1km below the upper surface of the Philippine Sea Plate. The strike and dip angles are corrected to match the local inclination of the subducting plate, and the slip direction is also corrected so that the projection of a slip vector on to the earth surface does not change.

Table.1 Variation ranges given to source parameters

source area			average rupture velocity	
a1 + a2 (Taisho EQ case)			Taisho EQ case	3.0 km/s
a1 + a2 + b (Genroku EQ case)			average + 1 SD	2.9 km/s
a2 + b			average	2.6 km/s
a1			average – 1 SD	2.3 km/s
a2				
b			hypocenter	
			west (Taisho EQ case)	
average stress drop			East	
fault B during Genroku EQ	24 MPa			
fault A during Taisho EQ	2.8 MPa		multi-scale heterogeneity	
average + 1 SD	2.6 MPa		slip	
average	1.4 MPa		rupture velocity	
average – 1 SD	0.67 MPa			

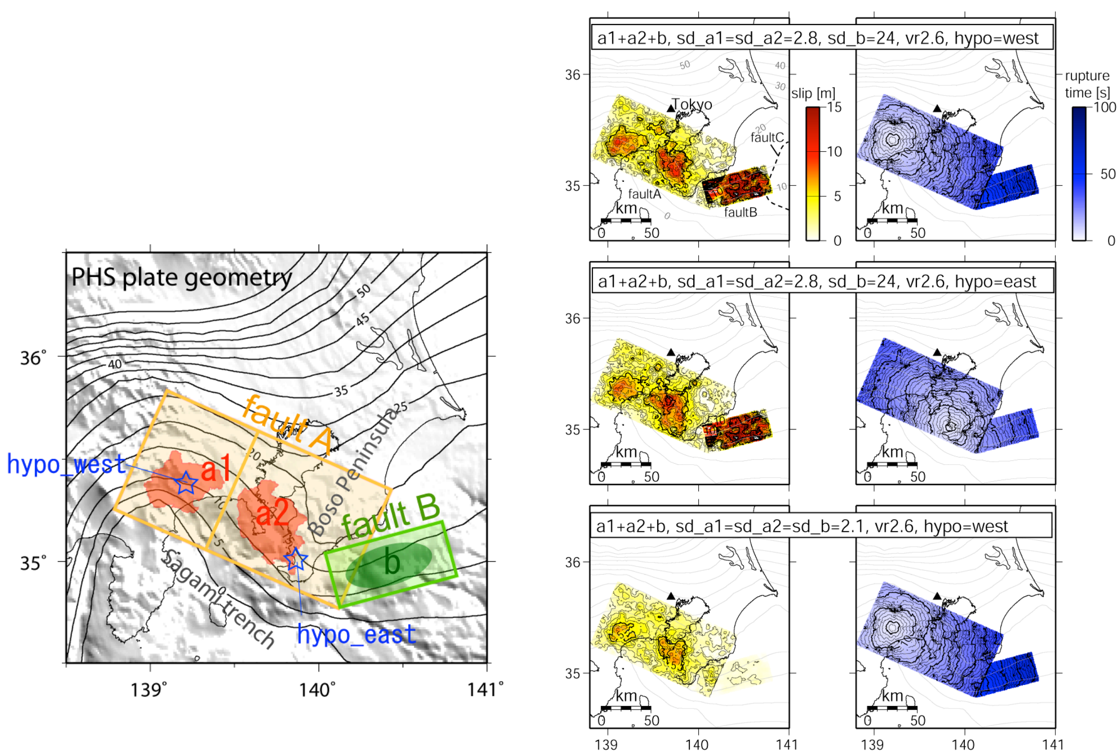

Fig. 1. The fault and asperity model of the Kanto earthquakes and several of the earthquake scenarios. The slip distribution (middle) and the rise time distribution (right) of earthquake scenarios are shown. The selected values of source parameters are listed at the upper part of each. Contours show the depth to the upper surface of the subducting Philippine Sea Plate.

Scenarios for the Off Boso Earthquakes

Neither information about exact rupture area or asperity distribution about former events nor any indication related to is available for Off Boso Peninsula earthquake. The magnitude of the 1677 earthquake estimated in this region is M8, similar magnitude to that of the 1923 Taisho Kanto earthquake. Therefore, we use the inversion model of the Taisho Kanto earthquake (Sato et al, 2005) as the base model. Here, we assume two scenarios. One is located at shallow part on the plate boundary and has the rupture propagation just like the Taisho Kanto earthquake respect to the slip distribution. The other is located at the deepest within the depth range of the remarkable slip of the 2011 off the Pacific coast of Tohoku earthquake (i.e., closest to the land) and the hypocenter is located so that the forward directivity effects on the land become largest.

GROUND MOTION COMPUTATION

The ground motions are computed with a four-step hybrid technique. We first calculate low-frequency ground motions at the engineering basement with a 3D finite difference method (Pitarka, 1999). A 3D velocity structure model is assumed combining Kanto sedimentary basin structure model (CDMC, 2004), Philippine Sea plate slab geometry based on Ishida (1992), Sato et al. (2005), Toda et al. (2008) and Uchida et al.(2009), Pacific plate slab geometry based on Ishida (1992) and Noguchi (1998), and Moho discontinuity model (Ryoki, 1999). The sedimentary structure to the east of 141E is modeled using gravity anomaly distribution. We then calculate higher-frequency ground motions at the engineering basement using a stochastic Green's function method modified after Onishi and Horike (2000), and combine the lower- and higher-frequency motions using a matched filter. We finally calculate ground motions at the surface by computing the response of the alluvium-diluvium layers with the equivalent linear method (DYNEQ: Yoshida and Suetomi, 1996) to the combined motions at the engineering basement.

PREDICTED GROUND MOTIONS

The Kanto Earthquakes

The distributions of peak ground velocity (PGV) and JMA seismic intensity computed for several scenarios are shown in Fig.2 and the comparisons of the PGV and the seismic intensities when varying the source parameters at selected points are illustrated in Fig.3. The source parameter whose variation gives rise to the largest variation of ground motion is the average stress drop. The average + 1SD of stress drop is twice as large as the average and causes almost twice amplitudes of ground motion. The variation of rupture area matters when comparing earthquakes with and without the fault A. However, activation of the fault B affects on a small area in the southeastern part of the Boso Peninsula. The relocation of the hypocenter causes large difference in PGV distributions in some areas like to the northwest of the fault, but the influence is not remarkable in the seismic intensity distributions. On the other hands, the variation of the average rupture velocity causes small differences of the ground motions. This indicates that the forward directivity effects are not significant in wide area for low-angle thrust faults, and that in the area just over the source fault, high frequency radiation from the shallow slip just below is dominant.

We found that the 1923 Taisho Kanto earthquake gives a ground motion distribution close to the severest among all those generated by the earthquake scenarios considered in this study though the largest rupture area and a hypocenter in the east gives the severest distribution. For the strongest scenarios, intense ground motions with PGV exceeding 50 cm/s are obtained in the area above the fault plane. Above the southern, or shallow, portion of the fault plane, PGV reaches 200-250 cm/s on the surface.

The Off Boso Peninsula Earthquakes

The scenario deeper and closer to the land, Boso-f2, generates larger seismic intensity and PGV than the other. PGV is several tens cm/s or more over the Boso Peninsula and reaches 50 cm/s in the southeast part of the peninsula. But either of the two scenarios does not give high intensity on the land. Comparing with the observed intensity for the 1987 Chiba-ken Toho-oki earthquake (M6.7), an intra-slab earthquake at about 60 km depth beneath the Pacific coast of Boso Peninsula, intensity V area is similar or less considering the sparseness of the observation point in 1987 (Fig.4).

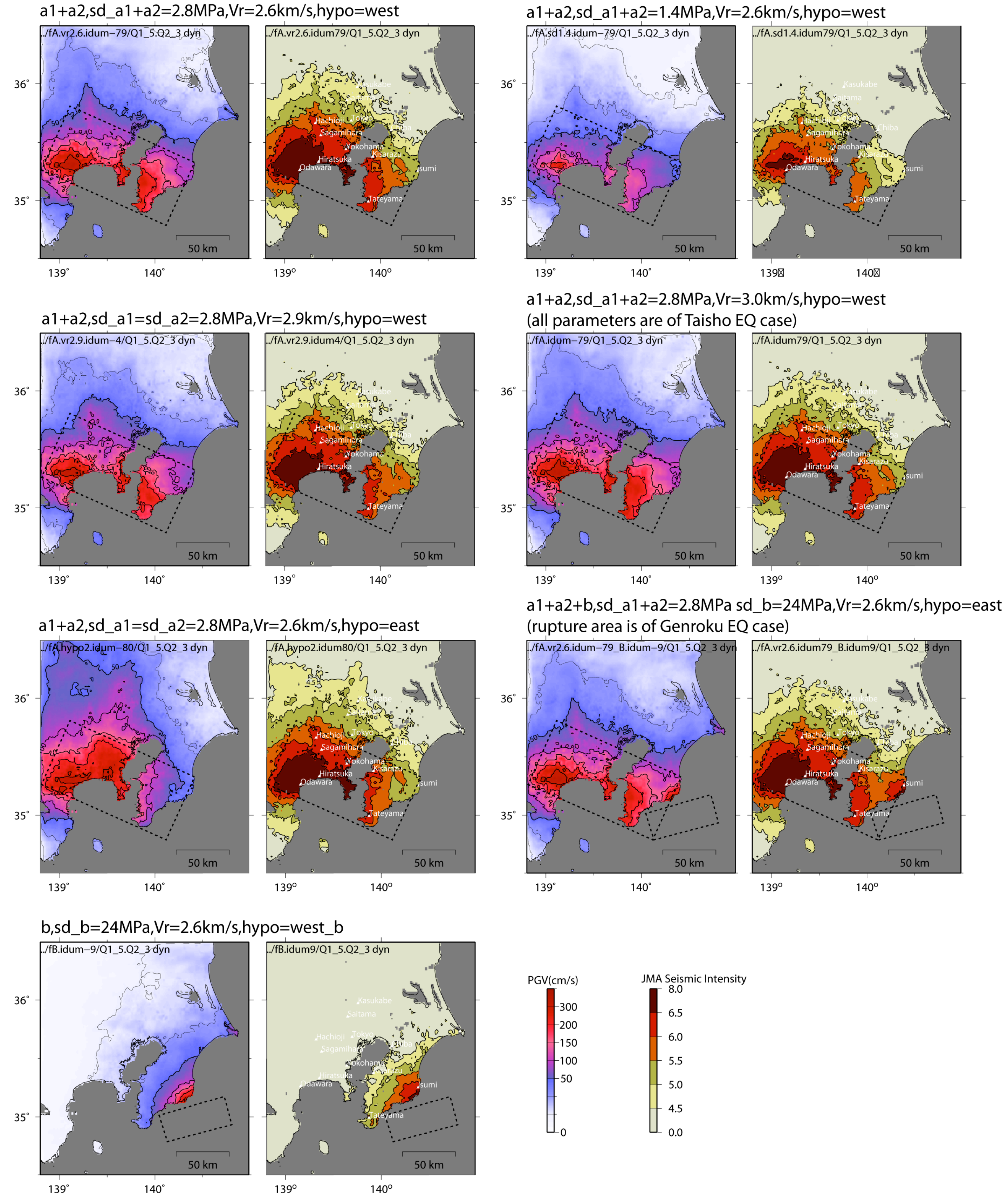

Fig. 2. Predicted ground motion distributions for the anticipated Kanto earthquakes.

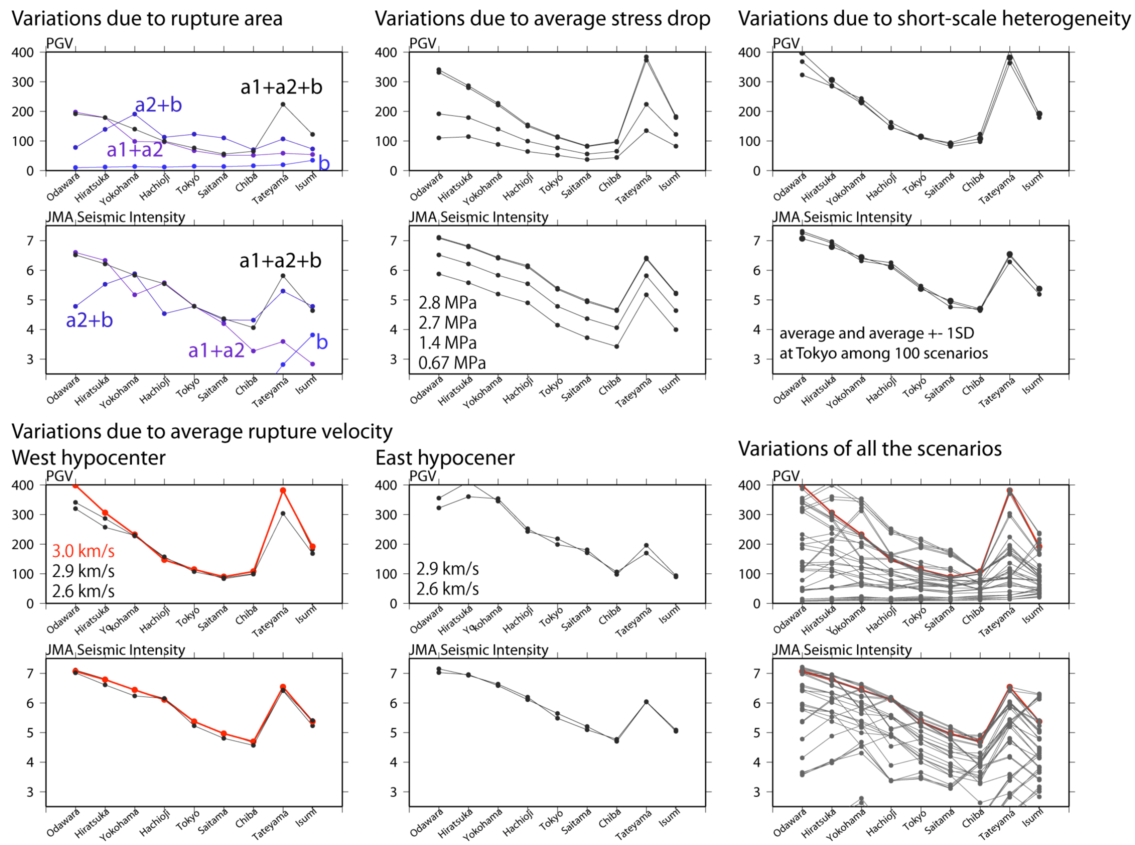

Fig. 3. Variations of PGV and seismic intensity for anticipated Kanto earthquakes at selected sites due to variation of source parameters.

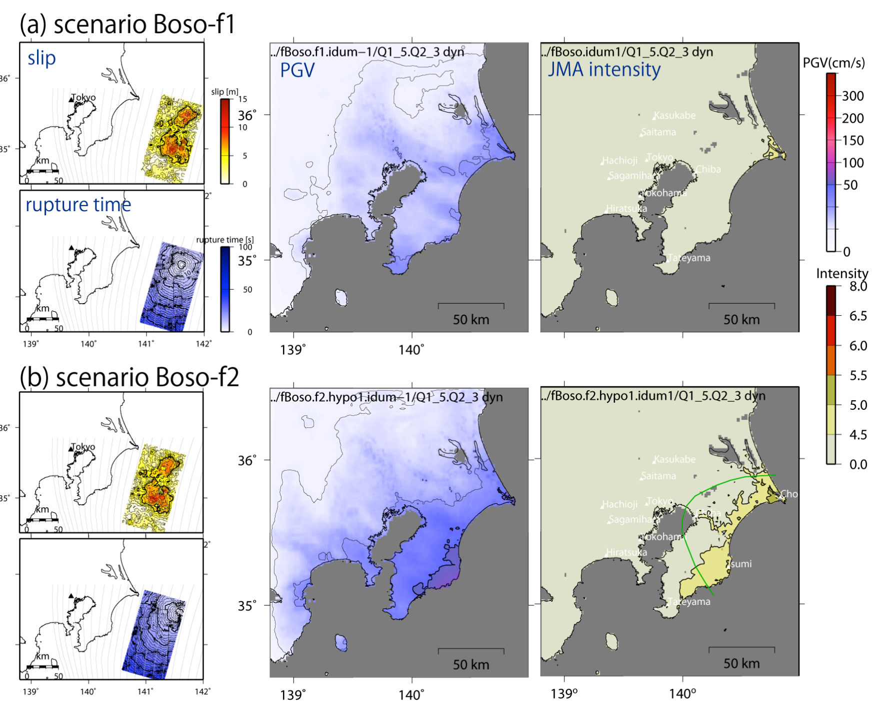

Fig. 4. Earthquake scenarios and predicted ground motion distributions for anticipated the Off Boso Peninsula earthquakes. (a) multi-scale heterogeneous distribution of slip and rupture time for the earthquake scenario Boso-f1 (left), PGV distribution (middle) and JMA seismic intensity (right) due to the scenario. (b) The same as (a) but for the scenario Boso-f2. The Green line on the seismic intensity distribution shows the area of intensity V (larger than 4.5 and smaller than 5.5) due to the 1987 Chiba-ken Toho-oki earthquake (Usami, 2003).

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