Numerical Simulation of Seismic Wave Propagation and Strong Motions in 3D Heterogeneous Structure

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The Earth Simulator realized realistic 3D simulation of seismic wave propagations over a regional scale and relatively higher frequencies. In addition, a visualization tool for seismic 3D wavefield made it possible to directly understand the complex regional seismic wavefield imposed by heterogeneities in the crust and upper-mantle structure. We applied the parallel FDM code and visualization tools both are optimized for the Earth Simulator (Furumura and Chen, 2004) for modeling of seismic wave propagation from recent and historically damaging earthquakes, such as for the great 1923 Kanto earthquake (M7.9) and the 1983 Kushiro-Oki earthquake (M7.8), in order to understand the generation process of the strong ground motions in 3D heterogeneous structure. The good agreement in the simulations and observations in the feature of the seismic wavefield and pattern of intensities indicating that the computer simulation is already a suitable level to apply to investigate the pattern of ground motions expecting for future earthquake scenarios.

Keywords: Earthquake, Seismic Waves, Strong Ground Motions, Visualization

Introduction

The heterogeneities in the crust and upper mantle structure as well as the complex source rupture process have an important influence on regional seismic wavefield, particularly for high-frequency waves. Moreover small-scale heterogeneities such as for the sedimentary basin introduce significant amplification of ground motion, which lead to long ground shaking over several minutes in the population centers. In order to see seismic wave behavior imposed by such heterogeneous structures, a high-resolution computer simulation with including a deep plate structure as well as a shallow superficial structure is indispensable. The Earth Simulator made it possible to provide a realistic simulation of strong ground motions in 3D heterogeneous structure.

In this report we will show two examples of strong ground motion simulations with illuminated 3D seismic wavefield using a newly developed visualization techniques suitable for the Earth Simulator (Chen et al., 2003). The first example is for the ground motions from the 1983 Kushiro-oki earthquake (M7.8) which produced anomalous pattern of seismic intensity in wide area of northern Japan due the subduction of low-attenuative (high-Q) Pacific plate. The second example is the modeling of strong ground motions for the 1923 Kanto earthquake (M7.9) to show the amplification effect in low-velocity structure in the basin of Tokyo.

Anomalous intensity from deep plate earthquakes

The deep focus earthquakes, which occurred in the subduction of the Pacific Plate, always shows an anomalously extension of isoseismic contours from hypocenter to several hundred kilometers to south along the eastern seaboard (Pacific Sea side). On the other hand the intensity decays significantly to inland and along the western seaboard (Japan Sea side). Figure 1 illustrates a typical example of such anomalous intensity distribution for the 1983 Kushiro-oki earthquake. Such a large-scale anomalies is relating to the efficient propagation of high-frequency waves along the subducting Plate.

In order to understand the process to generate larger intensities along the subducting Pacific Plate, we have conducted high-frequency simulations of seismic waves wave propagation using 3D structural model of northern Japan. The 3D model is 820 km by 410 km by 300 km, which is discretized by a uniform grid size of 0.4 km by 0.4 km by 0.2 km. The 3D simulation of 31billion grid model took a memory of 0.5 Tbytes and wall-clock time of 2 hours using 128 node (1024 CPUs) of the Earth Simulator. We have conducted a set of simulations using different structural models, each include a part of the subduction zone model, in order to understand the contribution of each model that leads to the anomalous propagation and attenuation of high-frequency waves in the structure of the subduction zone.

In the first model we use a laterally heterogeneous crustal

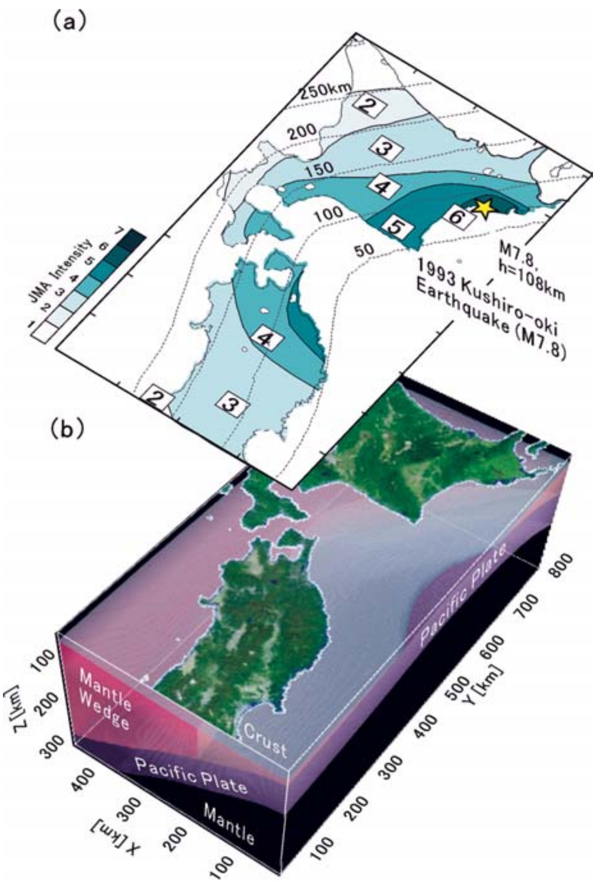

Fig. 1 (a) Intensity distribution of the 1993 Kushiro-oki (M7.8) earthquake, showing anomalous extension of seismic intensity from hypocenter to south for several hundred kilometers along the eastern seaboard. (b) 3D model of the subduction structure beneath northern Japan used in the simulation. The depth of the subducting plate is shown at the top.

structure, and excluding heterogeneities imposed by the subducting plate and the wedge of the mantle. The simulation result shows isoseismal pattern of seismic intensity above the hypocenter (Fig. 2a). By introducing the subducting plate of high-V and high-Q oceanic mantle, a clear extension of intensity contours from the hypocenter to south along the eastern seaboard appears (Fig. 2b). In addition, the incorporation of the low-V and high-attenuation mantle wedge significantly attenuates seismic waves propagating to inland and along the western seaboard of the Japan sea, and in consequence, the enhanced anomalies in the seismic intensity in Fig. 2c recovered the observation of the the 1993 Kushiro-oki earthquake (Fig. 1) well. The radiation of the seismic P and S waves from the deep earthquake, and efficient propagation in seismic wave along the plate and elimination in the amplitude in the mantle wedge is clearly confirmed in the snapshots of 3D wavefield shown in (Fig. 2).

Strong ground motions from the 1923 Kanto earthquake (M7.9)

The great 1923 Kanto earthquake was a typical inter-plate event by subduction of Philippine-sea plate beneath Kanto region. The earthquake caused significant damage around Tokyo, killing over 100,000 peoples. Amplification of ground motions in 3D basin structure should offer an important effect on the ground motions, so we have conducted numerical 3D simulation of seismic wave propagation using the structure of Kanto basin and source-slip model for the earthquake. The 3D basin structure for the Kanto basin are now available from the analysis of large data sets such as

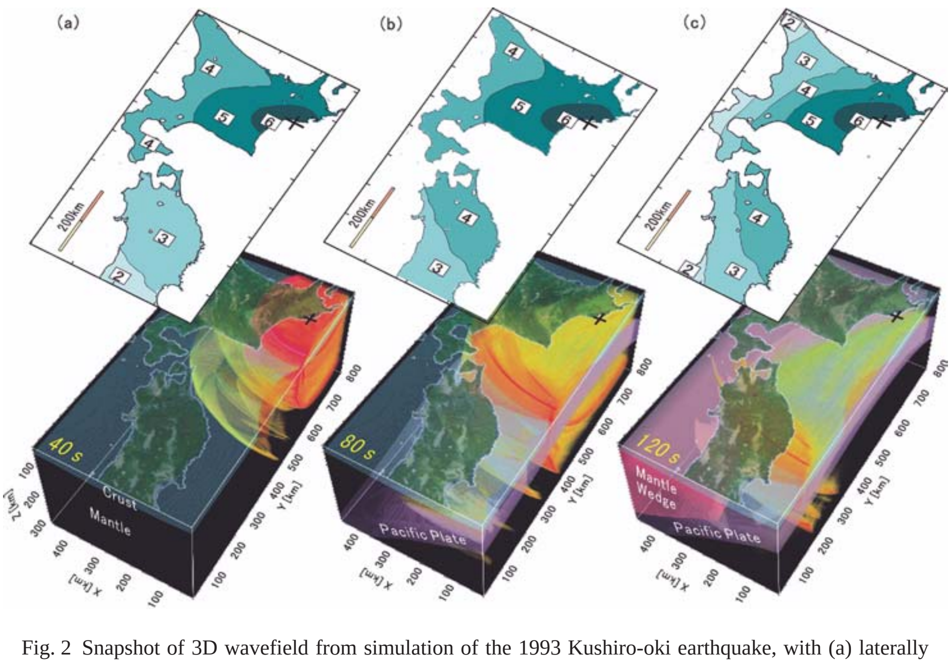

Fig. 2 Snapshot of 3D wavefield from simulation of the 1993 Kushiro-oki earthquake, with (a) laterally homogeneous crust, (b) the inclusion of the high-Q Pacific plate, and (c) the incorporation of a full subduction zone model including the high-Q plate and low-Q mantle wedge. The pattern of intensity from the subduction zone model agrees with observation (Fig. 1).

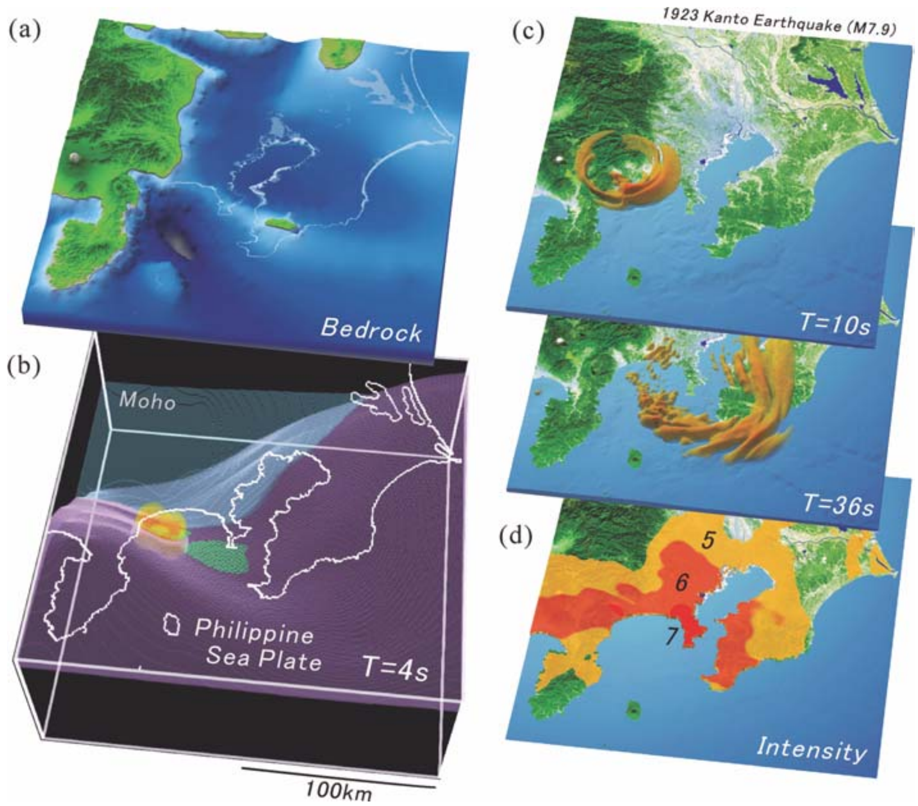

Fig. 3 Structural model of Kanto basin used in the 3D simulation of seismic wave propagation, showing (a) the configuration of sediment/bedrock interface and (b) structure of the Philippine-sea plate. (c) Snapshot of ground motion at 10s, 36s after fault rupture initiation, and (d) intensity distribution derived by the simulation.

based on reflection and refraction experiments, micro tremor and gravity data.

Figure 3 shows the snapshot of seismic wave propagation for the 1923 Kanto earthquake generated by the simulation and concurrent visualization on the Earth Simulator. In the snapshot the development of the strong ground motions radiating from two large slips (asperities) on the plate surface, propagating in heterogeneous structure imposed by subducting Philippine-sea plate, and dramatic amplification in soft sedimentary basin are clearly demonstrated. The simulation recovers large ground motions areas with intensity larger than 6 over larger area in the southern Kanto basin. The effect of deep basin structure in Tokyo cause significant amplification and extension of long-period ground motions. Such localized amplification effects due to low-velocity structure are clearly demonstrated by the Earth Simulator using a small mesh model (0.2 km), but it was not reproduced well with previous experiments using coarser mesh model (0.8-1.2 km).

Conclusion

The character of the regional wavefield is controlled by the radiation of the seismic source and the variations in the crust and upper-mantle structure along the propagation path. We have been able to show the complex regional seismic wavefield in Japan by large-scale simulation using the Earth Simulator. The example of strong motion simulation for the 1993 Kushiro-oki earthquake agrees very well with observations. Thus, we applied the current simulation model to understand the process of the strong motion generation during the 1923 Kanto earthquake.

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