High-performance computing for understanding seismic sources

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Slip inversion using seismic waveform data has become a popular method to investigate the source process of large earthquakes. This is fundamental information to understand physical process related to earthquake rupture and to assess the possibility of future earthquakes. However, the results usually include large errors, which is mainly due to the limitation of our ability to compute seismic wave field between the source and stations. There are actually two problems: the lack of information about underground structure and technical difficulty to solve elasto-dynamic equations in complex structures. The latter can be tackled with state-of-art high-performance computing.

In practical data analyses of earthquake rupture process, the availability of data is limited to avoid the source of large model errors. We often assume, without guarantee, that near-field strong-motion records are well approximated by 1-D layered structures, and that PREM and the ray theory are sufficient for teleseismic data in the hypocentral distance range from 30° to 100°. Data between 2° and 30° were not used, usually. These data are plenty and have sufficient signal-to-noise ratio, but the wave propagation is complex and information about structure is insufficient in this intermediate range.

A breakthrough to this problem might be provided by the combination of high-performance computing and high-resolution structural information. Several studies have attempted to compute seismic wave fields with complex structural information. Tsuboi et al. (2016) calculated seismic waves up to 1.2 s, using a global 3D heterogeneous model. Ichimura et al. (2016) computed deformation of a space of about 3000 km, with a realistic underground structure around Japan, and suggested that similar computation for seismic field is also possible. Seismic waveforms using realistic Earth structure will become popular in near future.

Although seismic wave field in global heterogeneous Earth is currently too expensive, significant improvement is expected just by introducing realistic shape of subducting slab and seafloor topography. The shape of subducting slab is clearly resolved around Japan. However, in some subduction zones, the uncertainty of hypocenter locations is too large to image slab shape. Near-filed seismic stations are rare, though many stations are available in the intermediate range. In such a region, theoretical waveforms calculated considering slab and see-floor topography may be useful.

In medium scale, and in a well-studied region with dense observation networks, like Japan, more detailed study including a complex underground structure may be meaningful. It would be helpful to know how the result of seismic tomography and receiver function analyses improve the resolution of the seismic source imaging. Starting from the low-frequency limit, i.e. static deformation, we will be able to model complete seismic wave field around Japan, which will reduce the uncertainty of seismic source models.

Very informative, but challenging data for seismic source imaging are the records of ocean bottom seismograms, which have been installed in many places around Japan. In addition to complexity due to seafloor topography and water layer, appropriate modeling of thick sediment layers is necessary to explain complicated observed seismograms. This was a realistic problem when an earthquake of Mw 6.5 occurred in the Kumano-Nada region on April 4, 2016. Because of our inability to model seismic waves in this region, we could not distinguish whether the earthquake was inter- or intra-plate earthquake, immediately after the earthquake. In this region, active tectonic tremors and slow slip events were observed by DONET1, and underground structure is relatively well-known. If accurate theoretical waves are available using high-performance computing, these are helpful for studying both large disastrous earthquakes and

diverse slow earthquakes.

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