Real-time source imaging based on data assimilation of observed seismic records and reverse-time wave propagation calculation

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The recent development of high-density strong-motion network and high-performance computers have realized real-time forecasting of strong motions based on assimilation of observation and simulation. Hoshiba & Aoki (2005) has developed a novel method for instantaneously forecasting shaking intensity based on assimilation on observation wave propagation calculation using radiative transfer theory. Furumura, Maeda & Oba (2019) extended this with 3-D FDM simulation for forecasting of long-period ground motions, and is further extended by Oba, Furumura & Maeda (2020) using Green's function for instantaneous forecasting.

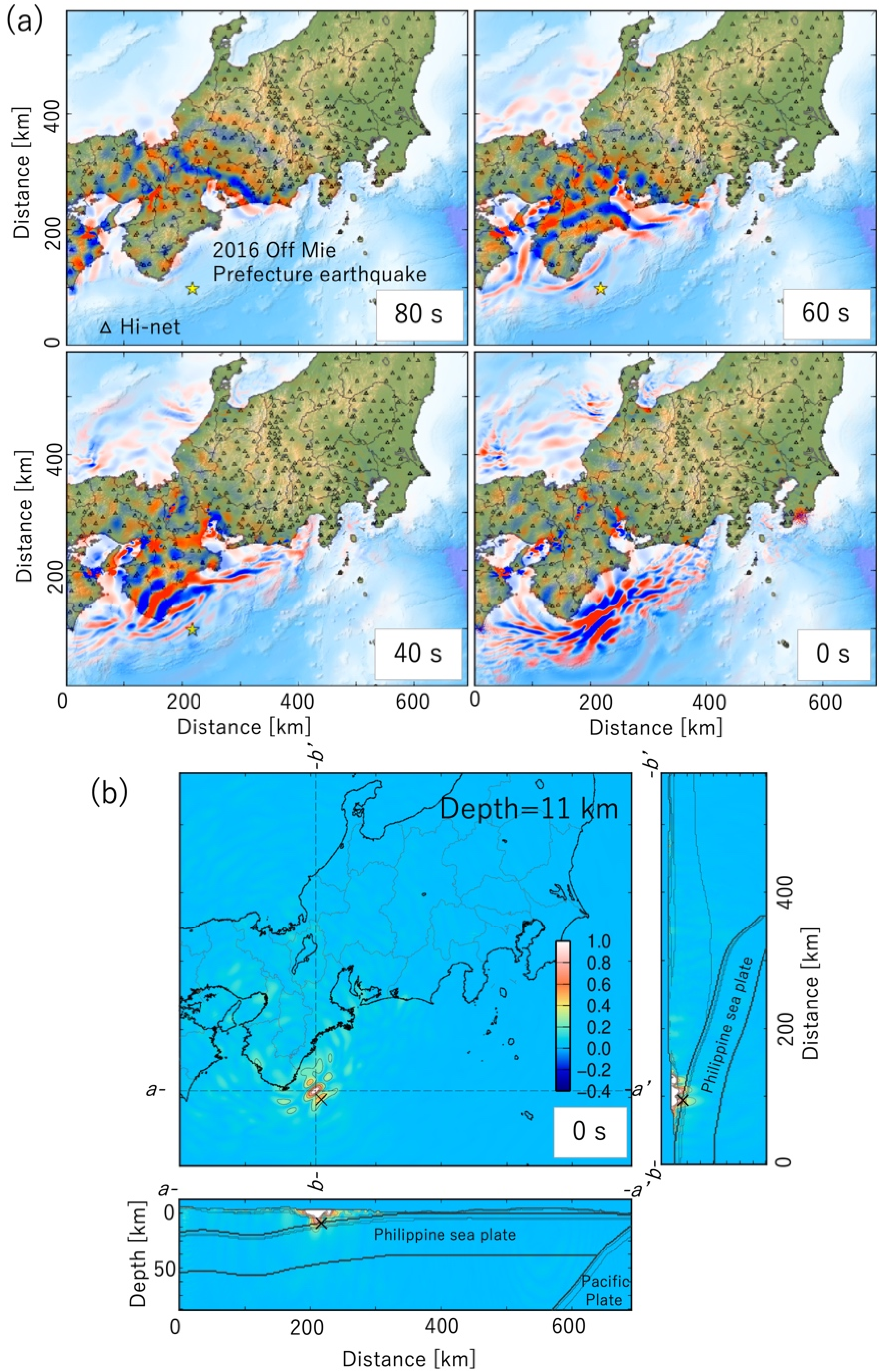
Though these methods do not require source parameters to the forecast, but assimilated wavefield has a wealth of information on the spatiotemporal development of seismic fields. Thus, it is expected to utilize not only to forecast but also to obtain sources processes.

In this study we attempted to apply the data assimilation technique for imaging seismic source by simulating wave propagatio retrospectively to the earthquake origin time with the time reversed while assimilating the calculation results and observation data. Due to the spatiotemporal symmetry of the equation of motion, the process of returning seismic waves from the observation stations to the epicenter can be reproduced by reversing the time step of the FDM modeling. Such reverse-time simulation has been succeeded in the source imaging of moderately large earthquakes (McMechan et al., 1985; Kremers et al., 2011), tremors (Larmat et al., 2009; Solano et al., 2017), and also applied to the estimation of slip distribution of megathrust earthquake (Larmat et al., 2006). In these studies, the simulation were usually used 1-D structure model, and no data assimilation is performed between the calculation and the observation. We attempted more efficient source imaging by data assimilation of observed and 3-D wavefield, in consideration of coarse seismic stations and the imperfection of the subsurface structure model used for simulation.

The Off Mie Prefecture earthquake on Apr. 1, 2016 (Mw5.8) occurred in the hypothetical source area of the Nankai Trough earthquake, so there was great concern about its effect on the megathrust earthquake. However, the sourve depth was not able to determine immediately due to the offshore earthquake and the strong heterogeneity of the subduction zone structure.

We tried a source imaging to estimate hypocenter, especially its depth using Hi-net records from 415 stations. The waveforms were broadened by applying an instrument response correction filter of Maeda et al. (2011). The reverse-time simulation was performed by 3-D FDM using the JIVSM (Koketsu et al., 2012) structural model. We applied the optimal interpolation data assimilation technique and parameters (weights) were calculated assuming 10 km correlation distance between observed wavefield, and the error of the observation and the calculation was the same level.

Fig.(a) shows a snapshot of the wevefield ofn the surface at 80, 60, 40, and 0 sec. from the earthquake origin time obtained by the reverse-time calculation. As the time elapsed, seismic waves radiated from each observation station propagated back toward the epicenter, and at the earthquake origin time, the seismic waves converge near the epicenter. Large signal was converged at a depth of 11 km near the top of the plate, and 4 km northwest of the Japan Meteorological Agency epicenter (marked by x in Fig. b). Large signal was also appeared in the sedimentary layer (accretionary prism) above it. Fig. b shows the converged wavefield in vertical and horizontal (11 km depth) sections. The large amplitude correspond to the hypocenter and the place where the surface wave was generated. On the other hand, in conventional source imaging without data assimilation, the convergence of seismic waves was insufficient to appear many virtual images around the hypocenter.


(a)
Distance [km]
2016 Off Mie
Prefecture earthquake
△ Hi-net
80 s
60 s
40 s
0 s
(b)
Depth=11 km
a-
a'
-b'
b-
-a'
Philippine sea plate
Pacific
Plate
Depth [km]
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
0 s