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Reconstruction of 2D seismic wavefield from Long-Period Seismogram and Short-Period Seismogram Envelope by Seismic Gradiometry applied to the Hi-net Array

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The high-sensitive seismograph network (Hi-net) operated by National Research Institute for Earth Science and Disaster Prevention (NIED) has about 800 stations with average separation of 20 km all over the Japanese archipelago. Although it is equipped with short-period seismometers, we also can observe long-period seismic wave up to 100 s in periods for significantly large earthquakes. In this case, we may treat long-period seismic waves as a 2D wavefield with station separations shorter than wavelength rather than individual traces at stations. In this study, we attempt to reconstruct 2D wavefield and obtain its propagation properties from seismic gradiometry (SG) method.

The SG estimates the wave amplitude and its spatial derivative coefficients from discrete station record by the Taylor series approximation with an inverse problem. By using spatial derivatives in horizontal directions, we can obtain properties of propagating wave packet such as the arrival direction, slowness, geometrical spreading and radiation pattern. In addition, by using spatial derivatives together with free-surface boundary condition, we may decompose the vector elastic 2D wavefield estimated by the SG into divergence and rotation components.

First, we applied the seismic gradiometry to a synthetic long-period (20-50 s) seismogram dataset computed by numerical simulation in realistic 3D medium at the Hi-net station layout as a feasibility test. We confirmed that the wave amplitude and its spatial derivatives are very well reproduced with average correlation coefficients higher than 0.99 in this period range. Applications to a real large earthquakes show that the amplitude and phase of the wavefield are well reconstructed with additional information of arrival direction and its slowness. The reconstructed wavefield contained a clear contrast in slowness between body and surface waves, regional non-great-circle-path wave propagation which may be attributed to scattering. Slowness/arrival directions together with divergence/rotation decomposition will be useful for pursuing constituents of observed wavefield in inhomogeneous medium.

In contrast, short-period waves are quite incoherent at stations mostly due to wave significant wave scattering. However, their envelope shapes resemble at neighbor stations. Therefore, we may be able to extract seismic wave energy propagation by seismogram envelope analysis. Based on this idea, we applied the same method to the time-integration of seismogram envelope to estimate its spatial derivatives. Together with seismogram envelope, we succeeded in reconstructing 2D envelope field and in estimating its arrival direction as well as long-period waveforms, without using phase information of seismic waves.

Our results show that the seismic gradiometry suits the Hi-net to extract wave propagation characteristics both at long and short periods. This method is appealing that it can estimate waves at homogeneous grid to monitor seismic wave as a wavefield. It is promising to obtain phase velocity variation from direct waves, and to understand scattering and/or attenuation from coda envelopes, by applying the seismic gradiometry to Hi-net.