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Improvement of earthquake early warning system using the extrapolation of wavefield with apparent velocity and direction

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The present early warning system in Japan utilizes the epicenter information preliminary estimated by P-wave arrival times at stations near an event. The present system is still not effective in the following cases, for example, (a) more than one earthquakes occur nearly simultaneously, (b) a deep event whose wave front propagates in a different manner from shallow ones, particularly with very high apparent velocity on the surface, and (c) a large event (M>8) whose finite fault area cannot be neglected. In order to deal with non-circular wave front expansion of these cases, we propose a new approach based on the extrapolation of the early observed wave field alone without determining an epicenter. The idea is similar to the migration method of exploration seismology. The conventional migration method utilizes the wave field on a given wavefront (e.g., Kirchhoff integral migration). In the early warning system, on the other hand, we can obtain the speed and direction of wave field expansion over the surface. Based on the standard representation theorem with a Green's function, we extrapolate wave field outwards or in the future with not only the observed waveform but also its spatial derivative (normal for the wavefront). This enhances the resolution and reliability in the extrapolated wave field in comparison with the conventional approach with the waveform only.

For the extrapolation of wave fields accurately and reliably, we need a reliable Green function in each case. Since the actual wave propagation of P or S waves is very complex or sensitive to details of 3-D velocity structure between a source to each target point on the surface, we shall consider it in a two dimensional manner only focusing on the practical use of the early warning system, that is, a wavefront propagates on the surface with an apparent velocity of P-wave. These apparent velocities vary for events of various depths in different regions. The velocity of shallow events in Hokkaido is about 7.1km/s while that in Nagano prefecture of central Honshuu island is about 5.5km/s. The velocity strongly depends on focal depth: 7.1km/s for the depth of 10km, and 8.9km/s for the depth 100km. The velocity also varies as a function of epicentral distance, particularly for a deep event. We make a table of apparent velocities in different depths, regions and epicenters so that we can pick up an appropriate Green function (apparent velocity) for the wave field extrapolation when an event takes place. We also explain how to estimate the apparent velocity and propagation direction with several early observed wave forms. One key to apply the wavefield extrapolation in the warning system is the good correlation among the seismograms that are observed early as input data. Nevertheless, correlations are generally poor in high-frequency (about 1Hz) seismograms recorded in Japan such as Hi-net data. To enhance the correlation of P waveforms among adjacent stations, we need to correct the site response of each station promptly. Using both shallow and deep events, we first estimated site effect as a function of frequency for Hi-net stations in Hokkaido. We used a rock site station (ONPH) as a reference station for site correction terms for other stations.

For deep earthquakes, a region of anomalous seismic intensity is seen in the Pacific Ocean side of Japan called 'abnormal seismic intensity' , due to a subducting Pacific plate of high velocity and small attenuation. For the earthquake of 590 km deep beneath Vladivostok on 18 February 2010, we examined the direction of P waves propagating in Japan. The apparent velocity is highly anisotropic: fast along the islands but slow perpendicular to them. It is about 7.5km/s in the Souya district in the north of Hokkaido while about 13km/s in the Hidaka district in the south. In our extrapolation scheme, we can model the amplification of wavesin terms of abnormal seismic intensity.

Keywords: earthquake early warning system, extrapolation of seismic wave field, migration, apparent velocity, site effect, abnormal seismic intensity