Estimation of the mantle structure with mutiple ScS phases by time-domain analysis

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In comparison of seismic waveform records or different parts of one record, researchers usually use a spectral approach with FFT, that is, records are compared in the frequency domain. Frequency-domain analyses are developed for stationary time serieses, but non-stationary wavelets with a finite record length are processed commonly in seismology. The Wiener filter is one of data processing schemes invented for such non-stationary signals, comparing two records directly in the time domain.

This study employs the Wiener filter approach to estimate the average seismic mantle structure with multiple ScS phases of a large deep earthquake in the west off Ogasawara Islands on 30 May 2015. We compared the results obtained by the time-domain Wiener-filter approach with those by a conventional spectral analysis in the frequency domain. We used seismograms recorded by F-net stations in the south of Japan islands, rotating them to obtain transverse component records for ScS and its related phases.

Each target wavelet (e.g., ScS and ScS2) in seismograms was recorded in a time window of 100-200 sec in our case. To exclude signals of other phases, we need to compare such data of a short record length. If we obtain the Fourier spectra of seismic waveform records and then compare them, any procedures to smooth the original waveform records are required, particularly to “taper” both ends of records. Such a procedure distorts the records, particularly amplitudes in a low frequency range although their phase information appears to be robust. As a result, the estimation of attenuation factors or Q values is degraded because of the use of amplitude spectra.

As an alternative approach, we considered one waveform record as an input time series and the other as an output one, and they are connected by a filter, which corresponds to a Wiener filter. The design of such a Wiener filter is based on a manner of least squares in errors. If the length of a least-square filter or the number of filter coefficients gets large, the error in the fit of the outcome of the input and the output becomes small. Nevertheless, a very long filter turns to be very unstable, usually with rapidly oscillatory characteristics. We found an optimal filter length based on the AIC (Akaike Information Criterion) parameter that indicates the trade-off between the size of errors and the number of filter parameters. The Wiener filter obtained in the above manner is then analyzed by the Fourier transform, which provided us with very reliable amplitude and phase differences between input and output time serieses (e.g., ScS and ScS2 phases) in a very wide frequency range. With the deep earthquake in the west off Ogasawara Islands, Q values at F-net stations in Japan along the Pacific Ocean were obtained to be 150 to 500 in a period range from 0.5 to 20 sec. Detail variations among stations, that is, fine lateral heterogeneous mantle Q structures can be discussed.

The present approach may be particularly useful with more than two waveform data similar to each other, when a cross correlation coefficient is utilized. With the use of a Wiener filter, we may detect a very small difference among waveforms in the study of temporal changes in seismograms.

Keywords: multiple ScS phases, velocity and attenuation structure of the mantle, time-domain analysis of seismic waveforms