S051-007 Room: C102 Time: May 27 15:15-15:30

Deep low-frequency earthquakes beneath the Japan arc - nonlinear stationarity and causality analyses for time series -

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Recently, deep low-frequency earthquakes lying near the Moho discontinuity and in the lower crust have been observed not only beneath the volcanic front but also away from the volcanic front. These events are characterized by anomalously low predominant frequencies, and, sometimes, by large and long tailing coda parts of S-wave. Comparing the seismic waves of the deep low-frequency events and of the deep earthquakes whose incident angles of seismic waves have almost same to each other, the coda waves are not caused by the crustal sturcture beneath the stations. Therefore, these waves represent the time evolution of the deep low-frequency event's source process directly.

In this paper, we applied a nonlinear time series analysis to reveal the characteristics of the time evolution. This analysis is composed of two parts: the test for stationarity of time series and the test of causality among time series to investigate the non-linear structure lying behind the complex time series. Both tests are based upon the fluctuation-dissipation theorem. The time series X(n) can be written by KM2O-Langevin equation whose coefficient matrix function is the KM2O-Langevin matrix. Based on the correlation matrix function (R) of X, we can calculate a unique system of KM2O-Langevin matrix which satisfies the fluctuation-dissipation theorem. Employing these relations, we can test the stationary property of the time series X. When the time series has the stationary property, we can construct a nonlinear prediction formula suggesting a difference equation of the dynamic source process.

Here, we apply the test of the stationary property and the causal-value analysis using 19 numbers of nonlinear transformations. The main results are summarized as follows. 1) The major parts of the coda waves of the deep low-frequency earthquakes show the stationary property. 2) The causal values for the linear transformation and the nonlinear transformations with odd orders are relatively higher than those for the nonlinear transformations with even orders. This result suggests that the source process of the deep low-frequency earthquakes should not excite only a fundamental mode wave and its even-order higher modes waves.