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Non-linear dynamics of singular long-period long-lasting volcanic earthquakes observed at Mt. Asama

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On September 1, 2004, a middle-scale eruption occurred at Mt. Asama, Japan. Before the eruption, we had observed several kinds of singular events since October 2003. These singular events include long-period tremors and long-period volcanic earthquakes with long durations. Takeo (2007) revealed the non-linear dynamics of long-period tremors using an embedding method of time delays and a surrogate data analysis, and made clear that there existed a deterministic non-linear dynamics in the tremor excitation, which could be modeled with the system dimension between 3 to 7 (prospective dimension 3 or 4).
In this paper, we apply the embedding method of time delays to the long-period earthquakes and estimate geometrical and dynamical non-linear parameters of them to constrain the dynamics in the excitation. Embedding by the method of time delays has become the standard procedure in non-linear dynamical system analysis of a single time series. The first step for the nonlinear analysis of a single time series is to reconstruct a topologically equivalent attractor to the original in a relatively low-dimensional delay-coordinate space. The key questions are how the minimum embedding dimension can be determined for reconstructing the original dynamics, and how we select the delay time. We employed some reliable and robust techniques in the estimation of optimum delay time and minimum embedding dimension. Concretely speaking, we used higher-order correlations to select an optimum delay time (Albano et al., 1991). A practical method for determining minimum embedding dimension proposed by Cao (1997) was used in this paper. The waveforms of the long-period earthquakes were similar to each other, so we selected a typical event that occurred at 12:34 on June 12, 2004. We employed a FIR low-pass filter with a cut-off frequency of 1 Hz to omit high frequency component. The optimum time lag of 0.24 sec and the minimum embedding dimension of 7 were obtained by employing these methods. We succeed in reconstructing the attractor of the long-period earthquakes, and got a correlation integral curve of the reconstructed attractor, founding a scaling region over one decade with the correlation dimension of 2.04 plus minus 0.11. This result indicates that the source process of long-period earthquake could be modeled on a non-linear dynamics with a system dimension between 3 to 6, which is similar dimension range with the source process of long-period tremors. Another way of saying, the apparent waveform characteristics of long-period earthquakes and long-period tremors are quite different, however the both correlation dimensions calculated from the reconstructed attractors are almost same values.
Modifying a hydraulic control valve model with the system dimension of 4, we succeeded to simulate a long-period oscillation resembling with the long-period earthquakes and with the long-period tremors based on a same mathematical model. These two long-period oscillations are sharply distinguished by a discharge coefficient of vent. The remaining problem is how to excite seismic waves from the simulated valve oscillations.

Keywords: volcanic tremor, non-linear oscillation