Non-linear dynamic of singular long-period volcanic tremors observed at Mt. Asama

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On September 1, 2004, a middle-scale eruption occurred at Mt.Asama. Before the eruption, long-period volcanic earthquakes were observed with the broadband seismographs located at the summit of Mt.Asama since October 17, 2003. The signals are so feeble that we can hardly recognize them even at the second nearest station from the summit crater. On June 24, we observed three long-period tremors with singular waveforms, which occurred at 4:25, 11:30, and 20:30. These events were estimated to lie just beneath the vent with very shallow depth. In this paper, the dynamical structure and characteristics of these tremors are investigated by employing some reliable and robust techniques in the estimation of geometrical and dynamical parameters. We applied surrogate data analyses for statistical testing of non-linearity, too.

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 qualitatively similar dynamical attractor to the original in a relatively low-dimensional delay-coordinate space. The key questions are following. How can the minimum embedding dimension be determined for reconstructing the original dynamics? How do we select the delay time? An optimum time lag of delay-coordinate space is determined using high-order correlations up to sixth-order. A practical method for determining the minimum embedding dimension proposed by Cao has several advantages compared to other methods. It is more objective than others, it can distinguish deterministic signals from stochastic signals, and so on.

For the tremor occurred at 4:25, the optimum time lag of 7 steps and the minimum embedding dimension of 7 were obtained by employing these methods. We succeed in reconstructing the attractors of tremors using these dimension and time lag. Then, we calculated a correlation integral curve of the reconstructed attractor, founding a certain degree of scaling region with the correlation dimension of 2.35 plus minus 0.16. The optimum time lag and the minimum embedding dimension for the tremor at 11:30 were 20 steps and 7, respectively. However, we could not found a certain degree of scaling range in the correlation integral curve in this case. The optimum time lag of 9 steps and the minimum embedding dimension of 7 were obtained for the tremor at 20:30. In this case, a correlation integral curve of the reconstructed attractor, represents a certain degree of scaling region with the correlation dimension of 1.48 plus minus 0.17.

The surrogate data analysis is a kind of statistical hypothesis testing. In order to check an non-linearity of the tremor occurred at 4:25, we set several linearity null-hypotheses and applied the surrogate data analysis. This surrogate data analysis indicates that the null-hypotheses are rejected with the strong rejection level, suggesting there exists a deterministic non-linear dynamics in the tremor excitation which can be modeled with the system dimension ranging between 3 to 7.